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Research and Analysis of the Digital Economy to Facilitate Enterprise Innovation

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Abstract

Based on the characteristic fact that the digital economy is vigorously developed nowadays, the impact of digital economy development on corporate innovation activities is empirically tested in multiple dimensions. It is found that the development of digital economy helps to enhance the total number of patent applications and total number of patents granted by enterprises, and this finding still holds after robustness tests such as instrumental variables and quasi-natural experiments. And the breakdown of different types of patents reveals that digital economy development in general has a stronger promotion effect on invention patents. The heterogeneity test results found that, in terms of regional heterogeneity, digital economic development has a stronger innovation incentive effect on enterprises in the central and western regions compared to enterprises in the eastern regions; in terms of ownership heterogeneity, digital economic development has a stronger innovation incentive effect on state-owned enterprises compared to non-state-owned enterprises; in terms of new enterprise vs. incumbent enterprise heterogeneity, compared to new enterprises without invention patent application experience, digital economic development has a stronger innovation incentive effect on incumbent firms with experience in patent application for inventions have stronger innovation incentives. The study on the expansion of innovation activities found that, in terms of R&D, the impact of digital economy development on the R&D side of enterprises has an asymmetric effect of insignificant extensive margin and significant intensive margin; in terms of innovation structure, digital economy development significantly increases the proportion of invention patents, which helps to improve the innovation structure of enterprises and stimulate the propensity of enterprises to substantive innovation; in terms of innovation quality, digital economy development helps to achieve the improvement of both innovation quantity and innovation quality of enterprises. In terms of innovation quality, the development of digital economy helps to improve both quantity and quality of innovation; in terms of cooperative innovation behavior, the development of digital economy helps to stimulate enterprises to cooperate and innovate, especially the cooperation between industry, university and research.

Keywords

Digital Economy; Enterprise Innovation; Innovation Activity; Binary Margin; Industry-University Research.

1. Introduction

Successful innovation depends on the development and integration of new knowledge in the innovation process, part of which will be transmitted to the firm from external sources (CassimanandVeugelers, 2002). In the context of the new development landscape, the digital economy is continuously generating and aggregating various innovation factors, accelerating the diffusion of external knowledge and technology, and further exerting a significant influence on corporate innovation activities. Big data has overturned the traditional mode of thinking,

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and there are no longer unrelated but complex intrinsic connections between massive amounts of data (Li, F., 2019). In recent years, the digital economy is becoming a key force in restructuring global factor resources, reshaping the global economic structure, and changing the global competitive landscape.On October 18, 2021, General Secretary Xi Jinping pointed out during the 34th collective study of the Political Bureau of the CPC Central Committee that it is necessary to promote the integration of the digital economy and the real economy, grasp the direction of digitization, networking, and intelligence, promote the manufacturing, service, and agricultural We should make use of new Internet technologies to transform traditional industries in all aspects and chains, improve total factor productivity, and give full play to the amplification, superposition and multiplication of digital technologies for economic development. According to the data of "Digital China Development Report (2020)", the value added of China's digital economy core industries will reach 7.8% of GDP in 2020, becoming an important force to promote high-quality economic development. In this regard, based on the fact that the digital economy is being developed vigorously, this paper is dedicated to exploring the impact of digital economy development on enterprise innovation activities from multiple dimensions, in order to provide theoretical explanation and empirical support for the digital economy to promote high-quality economic development from the perspective of technological innovation, which has important practical guidance and policy inspiration significance.

Existing digital economy-related studies focus more on research perspectives on scale measurement, high-quality economic development, global investment, and employment structure (Zhan Xiaoning and Ouyang Yongfu, 2018; Xu Xianchun and Zhang Meihui, 2020; Chen Jianwei and Su Lifeng, 2021), and generally lack the exploration of enterprise innovation. A few related studies only focus on the impact of digital economy development on the number of enterprise patents and green technology innovation (Hu, Shan and Yu, Yongze, 2022; Wang, Fengzheng et al., 2022), ignoring the impact of digital economy on enterprise innovation structure, innovation quality, and cooperative innovation. In view of this, based on the original literature, this paper attempts to explore the innovation incentive role of digital economy development from the perspective of multidimensional innovation activities. Specifically, based on constructing and measuring the indicators of digital economy development level, this paper selects the interaction term of the number of fixed telephones per 100 people in 1984 and the number of mobile Internet users nationwide in the previous year as the instrumental variable of digital economy development level based on the data of A-share listed companies in China's Shanghai and Shenzhen markets from 2011-2018, and overcomes the endogeneity of innovation output, innovation structure, innovation quality, R&D binary margin and cooperative innovation dimensions, the impact of digital economy development on enterprise innovation activities is empirically tested, thus laying a factual foundation and empirical support for promoting digital economy development.

The marginal contribution of this paper may be reflected in the following three aspects, first, literature. Current digital economy-related studies have more often focused their research perspectives on scale measurement, high-quality economic development, global investment, and employment structure, and there is still a lack of research on the dimension of enterprise innovation. This paper attempts to explore the innovation incentive role of digital economy development from the perspective of multidimensional innovation activities, which helps to provide an important supplement to the research related to digital economy and enterprise innovation. Second, the research perspective aspect. Unlike existing studies that focus only on a single dimension of enterprise innovation, this paper explores innovation output, innovation structure, innovation quality, R&D binary margin and cooperative innovation to examine the impact of digital economy on enterprise innovation in a more integrated and comprehensive way, which not only helps to provide a new research perspective and test criteria for assessing the impact of digital economy development on enterprise innovation activities, but also helps

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to enrich the understanding of the community on the It not only helps to provide a new research perspective and test criteria for assessing the impact of digital economy development on enterprise innovation activities, but also helps to enrich the understanding of the innovation incentive effect of digital economy development. Third, the significance of revelation. On the one hand, this paper reveals the positive effect of digital economy development on the innovation activities of local enterprises, which provides empirical support for the national and regional levels to accelerate the construction of digital economy; on the other hand, this paper suggests that digital economy development may be a new engine and new power for the central and western regions to achieve "overtaking". On the other hand, this paper suggests that digital economy development may be a new engine and a new driving force for the central and western regions to achieve "overtaking", and that the digital economy helps to improve the allocation efficiency of resources and the supply of innovation factors, which may have a greater driving effect on state-owned enterprises. The conclusions have important implications for weakening the problem of uncoordinated and insufficient regional economic development and improving the efficiency of state-owned enterprises.

2. Literature Review and Research Hypothesis

2.1. Digital Economy Related Research Compendium

With the digital economy gradually changing people's life style and business model, more and more scholars have started to pay attention to the digital economy, and the existing research on digital economy mainly includes two main lines. The first is the measurement of digital economy indicators and development status. Xu Xianchun and Zhang Meihui (2020) systematically constructed a digital economy indicator system by refining the connotation and formative elements of digital economy, including the indicators of value added and total output of digital economy. On the one hand, there is still a gap between the value added of China's digital economy and that of the United States, but the average annual growth rate of China's digital economy in recent years is significantly higher than that of the United States, and it is in a state of continuous catching up. On the other hand, China's digital economy is playing an important role in driving economic growth, and its average annual real growth rate of value added is significantly higher than the average annual real growth rate of GDP. Second, the digital economy indicators are measured at the provincial level. Using provincial-level data, Liu Jun et al. (2020) measured digital economy development level indicators in three aspects: information development, Internet development and digital transaction development, and found that China's digital economy has obvious unbalanced and insufficient development problems, and there is a large "rich-poor gap" and "Matthew effect" in the development of provincial digital economy. There is a large "rich-poor gap" and "Matthew effect" in the development of provincial digital economy, and there is a large difference in the level of digital economy development between the eastern region and the central and western regions. Wang Binyan et al. (2018) also found that there are spatially divergent characteristics of China's digital economy development through indicator measurement, and pointed out that the digital economy development is particularly prominent in the eastern region and urban cluster areas. Third, the digital economy indicators are measured at the regional level. Zhao Tao et al. (2020) 69-70 derived a comprehensive digital economy index at the city level from two dimensions of Internet development and digital inclusive finance, using principal component analysis of segmented indicators, and empirically tested the impact of China's digital economy development on high-quality economic development. In addition, some enterprises and research institutions have also released digital economy development indices. Second, the impact of the digital economy era on economic activities. A large number of scholars discuss the impact of digital economy on the high-quality economic development, and Li Hui (2019)

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argues that big data promotes high-quality economic development through three dimensions: improving efficiency at the macro level, promoting industrial structure upgrading at the meso level, and achieving business model innovation at the micro level. Li (2019) argues that the rapid development of new-generation information technology has not only changed the structure of economic growth dynamics and driven the transformation of industrial structure, but also improved the quality of economic growth dynamics. Li and Li (2020) believe that the essence of digital economy is "dematerialization". In the era of digital economy, virtual factors such as data and knowledge gradually become important resources for enterprises to compete for, and become another important factor of production after capital and labor (Jiao and Yong, 2020). Wei-Ling (2020), based on Marxist political economy, argues that data are intelligently processed means of production and do not have exclusive characteristics. The digital economy can alleviate the double pressure of rising labor costs as well as resources and environment by improving total factor productivity, and thus promote high-quality economic development. Some scholars also focus on the impact of the digital economy on economic activities such as business survival, residential household income, and global investment; Song (2017) and Zhang Xun et al. (2019) find that digital financial development helps drive farmers' entrepreneurial behavior and boosts the income of rural low-income groups, thus reducing the urban-rural income gap. Ren, Yingwei et al. (2021) argue that digital transformation of micro and small enterprises can enhance firm viability through productivity increase and organizational restructuring. Zhan and Ouyang (2018) argue that the development of digital economy has led to a new stage of enterprise internationalization, and the level of regional digital economy development has gradually become an important determinant of capital flows and multinational enterprises' location selection.

2.2. Theoretical Analysis and Research Hypothesis

The mechanism of action of the development of the digital economy that affects the innovation of enterprises includes the following four parts.

First, the external environment exerts pressure mechanism. The digital economy has intensified market competition, which not only makes the rapid growth of new firms possible, but also exposes the market position of incumbent firms to the possibility of being disrupted (Dang, Lin et al., 2021). Unlike in the past, in the era of digital economy, new expectations and requirements for the supply and demand of products and technologies have been put forward. Relying on the digital development environment, enterprises that fail to follow the trend of digital economy development and continuously carry out technological innovation and lean production will find it difficult to maintain and improve their market competitiveness, resulting in a passive state in the fierce market competition, and may even be eliminated eventually. Therefore, the pressure of digital development environment may force enterprises to carry out technological innovation. Second, the platform effect mechanism. The development of digital economy has given rise to a large number of public innovation platforms, which play an important role as platform effect mechanism in driving innovation of technology enterprises. A large number of public innovation platforms can not only precisely match resources for enterprises and make up for the defects of individual enterprise innovation limited by factors such as enterprise scale and production factors, but also help promote the clustering and diffusion of resources and technologies and reduce enterprise innovation risks by using the paths provided by the platforms (He Yumei, 2021). Third, the mechanism of technology spillover effect. In the era of digital economy, the construction of efficient network infrastructure creates a convenient channel for knowledge and technology spillover, and enterprises can realize knowledge and technology spillover effects through information networks to make up for the shortcomings of the lack of knowledge of a single enterprise. At the same time, the development of digital economy also breaks down the barriers for

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innovation cooperation, which helps reduce the transaction costs of industry-university-research cooperation and promotes technical cooperation between enterprises and universities and research institutes (Hu, Shan and Yu, Yongze, 2022). In the process of industry-university-research cooperation, knowledge spillover can be realized more effectively, especially for tacit knowledge, thus promoting complementary advantages and accelerating enterprise innovation (Caloghirouetal., 2021; Xuetal., 2021). Fourth, factor-driven effect mechanism. In the final analysis, enterprise innovation cannot be separated from the supply of production factors. In terms of financial support, any kind of substantial innovation, especially breakthrough innovation, requires long-term and substantial financial support and human capital investment (Hsuetal., 2014), and financing constraints become a key element that restricts the innovation of enterprises, especially private enterprises (J. Zhang et al., 2012). On the one hand, the development of digital economy can reduce the transaction cost and operation cost of enterprises, and alleviate the problem of capital constraint of enterprises through the way of "cost cutting". The emergence of big data and artificial intelligence not only reduces the search cost of enterprises and enables the rapid matching of supply and demand between the two sides of the transaction, but also helps to bring into play the economies of scale and form the "long tail theory" in the most effective way. Unlike the traditional industrial economy, the economies of scale in the digital economy have shifted from the supply side to the demand side, which helps to reduce the transaction and management costs of enterprises (Jiang Xiao Juan, 2017; Pei Changhong et al., 2018). On the other hand, the development of enterprise digital economy helps to reduce business risks and improve the availability of enterprise financing, alleviating the problem of enterprise capital constraints by means of "open source". The emergence of sharing economy platforms has promoted the trading of excess capacity and the use of idle equipment (Zhao, Chen-Yu et al., 2021), which reduces business risks by reducing management and maintenance costs and improving resource allocation efficiency, thus increasing the inflow of funds to science and technology enterprises and weakening their financial constraints. Moreover, the development of digital economy can also help reduce the information asymmetry between banks and enterprises, enabling financial institutions and external investors to access enterprise information more conveniently and effectively assess the operating conditions and solvency of enterprises, thus enhancing the availability of financing for enterprises (Hu, Shan and Yu, 2022). Therefore, the development of digital economy can help science and innovation enterprises to obtain R&D financial support and accumulate R&D capital through both "cost-cutting" and "cost-cutting" channels. In terms of human capital, innovation drive is essentially talent drive, and ultimately, scientific and technological talents are the most fundamental executors and backbone of enterprise innovation. In the era of digital economy, on the one hand, information flow and data availability provide data and knowledge basis for human capital accumulation and regional innovation and entrepreneurship (Qiu Zixun and Zhou Yahong, 2021); on the other hand, the development of digital economy has continuously realized the substitution of low-end labor force and increased the demand for highly qualified and specialized technical talents (Sun Zhao and Hou Yulin, 2019). Regions and universities also continue to strengthen the cultivation and introduction of big data talents, and the influx of a large number of highly qualified and specialized technical talents has laid the talent foundation for enterprise technology innovation. In terms of data elements, in the era of digital economy, virtual elements such as data and knowledge gradually become important resources that enterprises compete to obtain, becoming another important factor of production after capital and labor (Jiao, Y., 2020). Big data has overturned the traditional mode of thinking, and there are no longer unrelated but complex intrinsic connections between massive amounts of data (Li-Hui, 2019). At the same time, innovation resource acquisition no longer relies solely on the innovation subject itself, but is the result of network interaction with other innovation subjects and the external

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environment (Zhang Xinwei, 2019). The development of the digital economy has accelerated the circulation and dissemination of data elements, enhanced the availability of advanced technologies and data, and shortened the spatial distance between enterprises and external technologies and knowledge. This not only helps to promote the spillover effect of external technology and knowledge, but also helps enterprises to better utilize external technology and knowledge for innovation, which provides better conditions and foundation for enterprise innovation. Based on the above analysis, this paper puts forward the following hypotheses:

Hypothesis 1:The development of digital economy helps to improve the innovation performance of enterprises.

3. Econometric Model and Data Description

3.1. Econometric Model Construction

To examine the impact of digital economy development on firms' innovation activities, the following benchmark regression model is developed.

$$Innovation_{it} = \beta_0 + \beta_1 + DigitalEco_{it} + \emptyset Control_{it} + \sigma_j + \gamma_k + \varepsilon_{it} \quad (1)$$

where the subscripts i, j, k and t correspond to firm, province, industry and year, respectively. The explanatory variable Innovation is the innovation output of enterprises, which is measured by the logarithm of the number of patent applications plus one (Patent_ap) and the logarithm of the number of patents granted plus one (Patent_au) with reference to the existing research practice, and the impact of digital economy development on the number of different types of patent applications and grants is also examined in this paper. The main explanatory variable (DigitalEco) is the level of digital economy development variable, which is mainly measured by using principal component analysis, specifically borrowed from Zhao Tao et al. (2020).Control is the set of control variables, including enterprise age (age), financial leverage (leverage), enterprise size (size), profitability (ROA), and cash flow level (cash). In addition, the model incorporates industry, province, and time fixed effects to mitigate the disturbance of potential industry and province characteristics with macroeconomic factors on the estimation results. ε is a random disturbance term to portray other non-specific factors. This paper focuses on the coefficient estimates and direction of the main explanatory variable (DigitalEco), which aims to portray the impact of the digital economy on firms' innovation activities.

3.2. Endogenous Processing

The sources of endogeneity mainly include omitted variables, measurement errors, and explanatory and explained variables being causal to each other in three aspects, specifically in the research design of this paper, which are manifested in the following three aspects:First, the interference of macro-level policy and characteristic factors may be omitted in the research design, such as industrial policies at industry and province levels, industry competition level, regional development level, market size, degree of openness to the outside world, etc. characteristic factors may affect firms' innovation activities, and if these factors are not controlling for these factors, it may be difficult to identify the net effect of digital economy development affecting enterprise innovation. For this reason, province-years fixed effects as well as industry-years fixed effects are included in the regressions to alleviate the endogeneity problem caused by omitted variables. Second, the measurement error of the main explanatory variable, digital economy development level (DigitalEco), is addressed by mainly considering a more micro perspective and adopting the indicator of the degree of digital transformation of enterprises to replace the original explanatory variable. Third, there may be a reciprocal causal relationship between digital economy development and enterprise innovation output, and

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enterprise innovation is influenced by digital economy development, while regional digital economy development cannot be separated from technological innovation. For this reason, both instrumental variable method and quasi-natural experiment are used for endogeneity treatment to exclude endogeneity interference and more robustly assess the impact of digital economy development on enterprise innovation. Among them, the instrumental variables are mainly referred to the design ideas of Qunhui Huang et al. (2019) and Nunn and Qian (2014), while the quasi-natural experiment mainly considers the exogenous shock of the "Broadband China" pilot.

3.3. Descriptive Statistics of Data Sources

In this paper, we select the data of A-share listed companies in Shanghai and Shenzhen markets of China from 2011-2018 as the base sample, and follow the research convention to exclude ST and PT abnormal samples, financial and insurance samples, samples with missing main variables and samples without any patent applications during the sample period. And the continuous variables were subjected to extreme tailing in the 1% and 99% quartiles. The underlying data were obtained from the Guotaian enterprise database and Patentics patent intelligent search and analysis platform. The underlying data used in the digital economy development level measurement were obtained from the China City Statistical Yearbook and the China Digital Financial Inclusion Index compiled by Guo Feng et al. (2020). The definitions of the main variables and descriptive statistics results, from which it can be found that the average number of non-invention patent applications and the average number of granted patents remain almost the same, while the average number of granted invention patents is much lower than the average number of applications, which fully reflects the basic feature that under the current patent system, utility model and design patents are granted upon application, while invention patents need to undergo strict substantive examination before being granted, and a considerable This fully reflects that under the current patent system, utility model and design patents are granted upon application, while invention patents are subject to strict substantive examination before granting.

4. Results and Analysis of the Empirical Study

4.1. How the Digital Economy Affects Business Innovation Output

The model estimation results for the digital economy affecting firms' innovation output control for firm characteristics variables and industry, province and year fixed effects in each column. Observing the estimation results in columns (1) to (3), the patent application dimension, when the explanatory variable is the total number of patent applications (Patent_ap), the coefficient estimate of the digital economy development level variable (DigitalEco) is 0. 043, which is significant at the 1% level of significance, which indicates that the digital economy development level constructed in this paper is positively related to the innovation output of listed companies, supporting hypothesis The coefficient estimate of the digital economy development level variable (DigitalEco) is 0.045 when the explanatory variable is the number of invention patent applications (Invent_ap), which is significant at the 1% level of significance, while the coefficient estimate of the digital economy development level variable (DigitalEco) is 0.045 when the explanatory variable is the number of non-invention patent applications (Noninv_ap), which is significant at the 1% level of significance. DigitalEco) has a coefficient estimate of 0.029, which is significant at the 1% level of significance. It can be found that digital economy development not only helps to enhance the number of non-invent patent applications of enterprises, but also helps to enhance the number of invention patent applications of enterprises, and has a stronger contribution to the number of invention patent applications in general. Observing the estimation results in columns (4) to (6), the patent grant dimension, the coefficient estimates of the digital economy development level variable (DigitalEco) are

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significantly positive at the 1% significance level in all three regressions, and this result further supports hypothesis 1.

4.2. Heterogeneity Analysis

4.2.1. Regional Heterogeneity

Considering the large differences in location conditions, resource endowments, and factor supply and access among regions in China, the development of digital economy may also have heterogeneous effects on enterprise innovation in different regions. To this end, with reference to existing research practices, this paper divides enterprises into two groups according to their locations: enterprises in the eastern region and enterprises in the central and western regions, and introduces a dummy variable for enterprises in the eastern region (East) and an interaction term between digital economy development and the dummy variable for enterprises in the eastern region (DigitalEco×East) on the basis of the benchmark model (1). The regression results show that the interaction term (DigitalEco×East) between digital economic development and the dummy variable of enterprises in the eastern region is significantly negative at different significance levels in both the enterprise patent application dimension and the enterprise patent grant dimension, and especially in the invention patent application and grant dimension, the effect of this difference in effect is more The effect of this difference is particularly significant in the invention patent application and grant dimension. It indicates that in terms of patent output, the digital economy development has a stronger incentive effect on the innovation of enterprises in the central and western regions compared to the eastern regions. The possible reason is that, compared with the eastern regions, enterprises in the central and western regions are relatively deficient in terms of resource acquisition, especially in terms of knowledge and technology resources, so the digital economy development may have a greater driving effect on enterprises in these regions. A typical example is the establishment of the national-level big data pilot zone in Guizhou, which has not only brought the advantages of industrial clustering, but also facilitated the learning of knowledge and technology, which has played an important role in driving local innovation development. It should be noted that the above results only reflect regional heterogeneity effects, and the digital economy also has a significant and important innovation-driving role for the eastern region.

4.2.2. Ownership Heterogeneity

Based on the special differences between SOEs and non-SOEs, there may be differences in the effects of digital economy development on both. Although SOEs enjoy unique resource advantages and policy tilts, the investment efficiency of SOEs has long been widely questioned, and their investment efficiency is much lower than that of private enterprises (Yang, R. D., 2015). Therefore, how to improve the investment efficiency of SOEs and achieve sustained endogenous growth has been a major problem facing SOE reform. Whether the development of digital economy can become a new grasp to improve the innovation vitality and investment efficiency of SOEs has become a major proposition widely concerned by the society. To this end, this paper introduces the SOE dummy variable (Soe) and the interaction term between digital economy development and SOE dummy variable (DigitalEco×Soe) on the basis of the benchmark model (1). The regression results of the impact of digital economy development on innovation activities of enterprises with different ownership indicate that the interaction term of digital economy development and the dummy variable of state-owned enterprises (DigitalEco×Soe) is significantly positive at least at the 1% significance level, both in the enterprise patent application dimension and in the enterprise patent grant dimension. It indicates that in terms of patent output, digital economy development has a stronger innovation incentive effect on SOEs compared to non-SOEs. The possible reason is that the main constraint on innovation in non-SOEs is financing constraints, while the constraints on innovation in SOEs may lie more in resource allocation and access to innovation factors. The

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digital economy helps to improve the allocation efficiency of resources and the supply of knowledge and innovation factors, and thus may have a greater driving effect on SOEs. It should be noted that the above results only reflect the heterogeneous influence of ownership, and the digital economy also has a significant and important innovation-driving effect on non-SOEs.

4.3. Further Expansion of Innovative Activities

The above empirical findings show that the development of the digital economy significantly increases the innovation output of regional enterprises, as manifested by the increasing number of patent applications and patents granted. Further, this part attempts to analyze in depth the impact of digital economy development on enterprise innovation activities from multiple perspectives, including the R&D end of enterprise innovation activities, innovation structure, innovation quality and cooperative innovation behavior, in order to enrich the community's understanding of the relationship between digital economy and enterprise innovation activities.

The results of the above-mentioned benchmark study found that the development of digital economy helps to increase the number of invention and non-invention patent applications and grants of enterprises, but how the development of digital economy affects the innovation structure of enterprises needs to be further tested. Existing scholars emphasize that the utility model patent system is a transitional policy for technological learning and innovation accumulation, with the stage applicability of economic and technological development (Mao Hao et al., 2018). The fundamental reason for the country's initial use of the utility model patent system was to protect small inventions and creations with short cycles and easy imitation, but the basic characteristics of lenient examination, short cycles, and low cost have gradually made this type of utility model patent a particularly preferred invention method for enterprises, especially under the stimulation of China's science and technology innovation policy, some enterprises have distorted motives for applying for utility model patents and are more focus on catering to policy needs and obtaining policy incentives to engage in patent application activities (Li, W.-J. and Zheng, Manni, 2016; Zhang, J. and Zheng, W.-P., 2018). The regression results of the impact of digital economic development on the innovation structure of enterprises show that the coefficient estimates of digital economic development (DigitalEco) are significantly positive at least at the 5% significance level, regardless of whether the explanatory variable is the share of the number of invention patent applications or the share of the number of invention patents granted, which indicates that digital economic development significantly increases the share of invention patents of enterprises and helps improve the innovation structure and stimulate enterprises. This indicates that digital economy development significantly increases the share of invention patents of enterprises, which helps to improve the innovation structure of enterprises and stimulate their propensity to substantive innovation.

Can the development of digital economy, which accelerates the circulation and dissemination of data elements, further promote the direct interface between industry, academia and research? As a typical model of cooperative innovation, industry-university-research collaborative innovation is a new exploration of the interaction between scientific and technological progress and industrial innovation, which is in essence the cross-organizational transfer of knowledge and learning management (Bonaccorsi and Piccaluga, 1994; He, Yubing, 2012). To this end, this paper further examines the impact of digital economy development on enterprises' cooperative innovation behavior. Specifically, according to the definition of cooperative innovation, this paper measures the cooperative innovation variables by the number of patents cooperatively applied by enterprises in the current year, and the number of patents cooperatively applied by enterprises with universities and research institutions in the current year to measure the industry-university-research cooperative innovation variables. It can be found that the

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coefficient estimates of digital economic development (DigitalEco) are significantly positive at least at the 1% significance level for the cooperative R&D innovation dimension, regardless of whether the explanatory variable is the total number of cooperative patent applications (Coop_all) or the number of cooperative invention patent applications (Coop_inv); for the industry-university-research cooperation dimension, regardless of whether the explanatory variable is the total number of cooperative patent applications (IUR_all) or the number of cooperative patent applications (IUR_inv) The coefficient estimates of DigitalEco are also significantly positive regardless of whether the explanatory variable is the total number of patent applications (IUR_all) or the number of invention patent applications (IUR_inv). In summary, the digital economy development helps to stimulate enterprises to cooperate and innovate, especially the innovation behavior of industry-university-research cooperation.

5. Key Research Findings and Policy Implications

Based on the data of A-share listed companies in China's Shanghai and Shenzhen markets from 2011 to 2018, this paper empirically tests the impact of digital economy development on enterprises' innovation activities in multiple dimensions on the basis of overcoming endogeneity, thus laying a factual foundation and empirical support for promoting digital economy development. The empirical results show that:First, the development of digital economy helps to increase the total number of patent applications and the total number of patents granted by enterprises, and the breakdown of different types of patents reveals that the development of digital economy helps to increase not only the number of non-invention patent applications and grants, but also the number of invention patent applications and grants by enterprises, but the overall promotion effect on invention patents is stronger. This conclusion still holds after robustness tests such as the introduction of instrumental variables and quasi-natural experiments. Second, the impact of digital economy development on enterprise innovation is richly heterogeneous, in terms of regional heterogeneity, compared with enterprises in the east, digital economy development has a stronger innovation incentive effect on enterprises in the central and western regions; in terms of ownership heterogeneity, compared with non-state-owned enterprises, digital economy development has a stronger innovation incentive effect on state-owned enterprises; in terms of new and incumbent enterprises heterogeneity, compared with new enterprises without invention patent In terms of heterogeneity between new and incumbent firms, digital economic development has a stronger innovation incentive effect on incumbent firms with patent application experience than new firms without patent application experience. Thirdly, further extension of the study reveals that there is an asymmetric effect of digital economy development on the R&D side of enterprises with insignificant extensive margin and significant intensive margin, and its main effect is to increase the R&D investment of enterprises, which is not significant to enhance the R&D propensity of enterprises. In terms of enterprise innovation structure, digital economy development significantly increases the proportion of invention patents, which helps to improve enterprise innovation structure and stimulate enterprises' tendency of substantive innovation; in terms of enterprise innovation quality, digital economy development helps to realize the double improvement of enterprise innovation quantity and innovation quality; in terms of cooperative innovation behavior, digital economy development helps to stimulate enterprise cooperative innovation, especially industry-university-research cooperative innovation.

In addition to providing empirical evidence that digital economy development affects firms' innovation activities, based on the above findings, this paper also has the following policy implications: First, digital economy development not only helps to encourage firms to increase R&D investment and realize the double improvement of firms' innovation quantity and

innovation quality, but also helps to improve firms' innovation structure, stimulate firms' propensity to substantive innovation, and stimulate firms' cooperative innovation behavior between industry, academia and research. . Therefore, it is of great importance and far-reaching significance for the national and regional levels to attach great importance to the construction of the digital economy, and to increase investment in the Internet and big data industries, to realize "two-wheel drive" in both digital industrialization and industrial digitization, to jointly promote the healthy development of the digital economy, and to continuously expand and play the innovation advantages of the digital economy development. The advantages of incentives for digital economy development. Secondly, empirical studies have found that digital economy development has a stronger innovation incentive effect on enterprises in the central and western regions compared with those in the eastern regions. Therefore, from the perspective of enterprise innovation, digital economy development may be a new engine and a new driving force for science and technology innovation and economic development in the central and western regions to achieve "overtaking", which is better reflected in the process of digital economy development in Guizhou. Moreover, promoting the construction of digital economy in the central and western regions may play an important role in weakening the problem of unbalanced and insufficient regional development and promoting common prosperity. Therefore, it is particularly urgent and important to build a digital economy highland in the central and western regions according to local conditions and differentiation. Third, the constraints on innovation of SOEs may lie more in resource allocation and access to knowledge innovation factors, and empirical studies have found that digital economy development has a stronger innovation incentive effect on SOEs compared with non-SOEs. Therefore, the construction of regional digital economy should be accelerated to fully unleash the contribution of digital economy to enhance the innovation vitality and investment efficiency of SOEs, so as to improve the efficiency of SOEs.

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