Journal of Innovation & Knowledge 10 (2025) 100697

Contents lists available at ScienceDirect

Journal of Innovation & Knowledge

journal homepage: www.elsevier.com/locate/jik

# Innovation capacity in urban agglomerations: The role of digital finance

Kai Tang, Xiaopei Cai, Haijie Wang *

*Business School, Zhengzhou University, 100 Science Road, Zhengzhou, Henan 450001, China*

ARTICLE INFO

*JEL classification:*
O11
R10
G10

*Keywords:*
Urban agglomeration
Innovation capacity
Digital finance
Mediating effect
Economic policy uncertainty

ABSTRACT

Using panel data of 196 cities in 19 urban agglomerations in China from 2012 to 2021, this study analyzes the impact of digital finance on the innovation capacity of urban agglomerations and the underlying mechanisms. The level of digital finance development is measured using Peking University's Digital Financial Inclusion Index. Meanwhile, by manually sorting the relevant evaluation indicators in CSSCI journal papers, creating frequency statistics, and combining the total and average indices, innovation capacity is measured from five aspects: innovation resources, knowledge creation, innovation performance, innovation environment, and innovation collaboration. The results show that digital finance promotes the innovation capacity of urban agglomerations. This effect is stronger for small-scale, highly marketized, and polycentric urban agglomerations. Mechanism analysis shows that, first, via the agglomeration of innovation capital, digital finance provides financial support for improving the innovation capacity of urban agglomerations. Second, by improving entrepreneurial activity, digital finance promotes the formation of an innovation ecosystem. Third, by enhancing credit resource allocation, digital finance encourages more innovation funds to flow into innovative enterprises and promotes innovation capacity in urban agglomerations. Finally, economic policy uncertainty plays an "inverted N-type," nonlinear moderating role in the relationship between digital finance and innovation capacity. In summary, by introducing digital finance as a key variable into urban agglomeration innovation research, this study expands the theory of financial and regional innovation systems. Next, demonstrating the heterogeneous impact of digital finance on different types of urban agglomerations, the findings can serve as a benchmark against which urban agglomerations can be compared to develop differentiated digital finance development strategies. Finally, the insights can inspire managers to re-examine the complex influence of economic policy uncertainty in the innovation process, which may help them make sound economic decisions.

## Introduction

Improving the innovation capacity of urban agglomerations is crucial for ensuring steady and long-term economic development in China. China has introduced several policies to improve the creative and coordinated development of urban agglomerations. For example, in the Central Plains Urban Agglomeration Development Plan (2016), it proposed building the "innovation and entrepreneurship pilot zone in the Central and Western regions." The Chengdu-Chongqing Urban Agglomeration Development Plan (2016) emphasizes the creation of a "Chengdu-Chongqing Urban Agglomeration Innovation Community." Another proposal in the Development Plan for Urban Agglomeration in the Middle Reaches of the Yangtze River (2022) is to "build a scientific and technological innovation highland with core competitiveness". These policies have provided significant support for improving the innovation capacity of urban agglomerations. However, a gap remains between the innovation level of urban agglomerations in China and the global average. This may be due to problems such as poor flow of innovation factors, difficulty in gathering innovation resources, and imperfect collaborative innovation mechanisms among urban agglomerations. As such, understanding ways to further enhance the innovation capacity of urban agglomerations is crucial to achieve high-quality regional economic development.

Digital finance can be one such factor for enhancing innovation capacity, ushering in rapid development in China. Technologies such as artificial intelligence, big data, cloud computing, and blockchain have accelerated the generation, collection, processing, and sharing of data (Manyika et al., 2016). The framework of traditional finance based on "credit" has gradually changed to one based on "data," transforming the business model of traditional financial institutions (Li et al., 2020). Indeed, digital finance is developing rapidly in China. According to the 2018 Global Fintech 100 jointly released by KPMG and H2 Ventures,

* Corresponding author.
*E-mail address:* zzusxy123@163.com (H. Wang).

https://doi.org/10.1016/j.jik.2025.100697
Received 8 November 2024; Accepted 14 March 2025
Available online 21 March 2025

Chinese fintech companies make up three-fifths of the "Leading 50" list. Among them, Ant Financial, JD Finance, and Baidu are ranked among the top five. The development and scale of digital finance in the 19 Chinese urban agglomerations has also been excellent. Digital financial services such as mobile payments, online banking, and digital currency pilots have been widely. According to the "China Digital Financial Inclusion Development Report (2024)," as of June 2024, the outstanding loan balance of banking financial institutions for small and micro enterprises reached 78 trillion yuan, while the penetration rate of mobile payments was the highest in the world at 86%. However, digital finance in urban agglomerations in China is characterized by differences and convergence (Sun, et al., 2021; Li et al., 2020). On the one hand, the overall development level of digital finance is high in the east and low in the west. Specifically, the development of digital finance in the eastern urban agglomerations (such as the Yangtze River Delta and Pearl River Delta city clusters) is significantly ahead of that in the central and western regions. Meanwhile, the development level of the central urban agglomerations (such as the Central Plains and Guanzhong Plain city clusters) is better than that of the western urban agglomerations (e.g., the as Lanzhou-Xining and Hubao Eyu city clusters). On the other hand, these differences between regions are gradually narrowing and exhibiting spatial convergence.

The rapid development of digital finance has opened up a new path for improving innovation capacity and advancing high-quality economic development in urban agglomerations. Compared to traditional finance, digital finance has many advantages such as low cost, high efficiency, omni-directionality, stronger customer reach ability, and geographical penetration (Gomber et al., 2017). Meanwhile, compared with other investment avenues, innovation projects have large investments, high risk, long cycles, and large uncertainty. As such, continuous and stable funding is particularly important for innovation activities (Dasgupta & Stiglitz, 1980). Digital finance can provide "convenient, efficient, sustainable and all-round" financial services to more economic entities, thereby providing the necessary financial support for innovative activities (Lin & Ma, 2022). However, the digital financial market and transmission mechanisms in China are not perfect. Further, the coverage of financial services is insufficient, and their development is unbalanced and insufficient (Li et al., 2020; Hasan et al., 2022). These problems make it difficult for to fully leverage digital finance and improve the innovation capacity of urban agglomerations.

Addressing these gaps, we analyze the impact of digital finance on the innovation capacity of urban agglomerations and the underlying mechanisms. Specifically, we posit the following research questions: What will be impact of the overall acceleration of digital financial development on the innovation capacity of urban agglomerations in China? What are the rules and characteristics? What are the underlying mechanisms? Will there be heterogenous impacts of digital finance on the innovation capacity? Answering these above questions not only deepens or understanding of the leading role of digital finance in improving the innovation capacity of urban agglomerations, but also provides rigorous evidence for the formulation and implementation of relevant supporting policies.

## Literature review

### *Connotation and evaluation measure of innovation capacity*

Numerous studies have examined national, regional, and other innovative capabilities. Cooke (2001) believed that regional innovation capacity is a type of integration capacity produced by the effective integration of innovation elements in the cooperation of innovation subjects. Furman et al. (2002) argued that the core of national innovation capacity is not limited to the level of innovation output, but more focused on the whole innovation process. Hu and Mathews (2008) held the view that national innovation capacity is closely related to innovation resources and is the power source for a country's economic performance. The China Regional Innovation Capacity Report (2019) stated that regional innovation capacity refers to a region's capacity to transform new knowledge into new products, processes, and services. Different perspectives on innovation capacity lead to different definitions, but its essence remains the same. Essentially, innovation capacity is the balance accumulated through past innovation activities. Innovation input, resources, output, the environment, and so on play important roles in the formation and promotion of innovation capacity.

To evaluate innovation capacity, we need a set of better indicators. At present, extensive research has been conducted on the evaluation measure of innovation capacity. However, there are differences in evaluation indicators. Many scholars advocate the use of multiple indicators to comprehensively evaluate innovation capacity. For example, the China Regional Innovation Capacity Report (2019) measured regional innovation capacity from four perspectives: knowledge creation, knowledge acquisition, enterprise innovation, and innovation environment. Hu et al. (2019) discussed regional innovation capacity from the two aspects of technology and systems, and measure regional institutional innovation capacity from seven aspects. The National Innovation Index Report (2015) constructed a national innovation capacity index system based on five pillars of innovation resources, knowledge creation, enterprise innovation, innovation performance, and innovation environment. Despite their differing methodologies, studies mostly believe that innovation capacity is a comprehensive measure that needs to be analyzed from many aspects. However, many scholars use a single index to reflect regional innovation capacity. One of the most commonly used ones is the number of patents (for example,. granted, patent applications, invention patents, and the number of invention patent applications) (Hamidi et al., 2019; Zhang et al. 2023; Geng et al., 2023; He et al., 2020). Another commonly used method is R&D funding, and its intensity (for example. R&D expenditures, number of high-tech employees, and enterprises' R&D expenditures) (Shen et al., 2020; Liu et al., 2023).

### *The effect of digital finance*

Digital finance, supported by digital technologies such as big data and inclusive features, can reduce barriers to financial services, significantly expand the scope of financial services, and positively affect all aspects of the economy and society (Hui et al., 2023).

First, digital finance plays an important role in easing the financing constraints. Using digital technology, valuable information can be mined from big data and applied to corporate financing, which is significant for easing financing constraints, improving financial inclusion, and developing the real economy (Sarma & Pais, 2011; Kapoor, 2014). Specifically, digital finance expands the scope of loans through digital financial models, such as peer-to-peer lending and crowdfunding, reduces the difficulty of obtaining financial services, and improves the convenience and availability of loans (Bollaert et al., 2021; Aziz & Naima, 2021).

Second, digital financing promotes consumption and employment. On the one hand, digital finance promotes the development of online credit, making it possible to match the supply side's financial demands (Pierrakis & Collins, 2013). Simultaneously, the easing of liquidity constraints and reduction in financial service transaction costs will improve the ability and efficiency of household consumption payments and transfers (Li et al., 2020). On the other hand, digital finance has significantly boosted sustainable employment by empowering small, medium, and micro enterprises (MSMEs), providing them with broader and more effective financial support (Geng & He, 2021).

Third, digital finance plays a positive role in improving the level of industrial structure and quality of innovation. Through digital technology, each demand end of the industrial chain can be accurately matched to promote the rational allocation of resources and industrial structure upgrading (Wang & Wang, 2021). Next, studies show that digital finance can positively affect innovation quality (Li et al., 2023). Digital finance

can overcome the geographical and spatial limitations of traditional financial channels and compensate for the shortcomings of traditional finance (Cao et al., 2021; Pal et al., 2021), effectively improve the efficiency of the connection between capital supply and demand (Calantone et al., 2002), and provide financial support for innovative and entrepreneurial activities.

*Underlying mechanisms*

Most studies have demonstrated the positive effect of digital finance on innovation capacity, and the underlying mechanisms at the macro and micro levels.

First, studies reveal the theoretical mechanism by which new models, such as digital finance, affect economic innovation behavior at the macro level. Digital finance can significantly promote the innovation quality or performance of a city or region (Hui et al, 2023; Li et al., 2023). This promotion effect is mainly achieved by improving the allocation of credit resources, promoting consumer consumption, upgrading the industrial structure (Li & Li, 2022), and increasing regional R&D investment (Shao & Chen, 2023). In addition, traditional financial supply (Li et al., 2023), financial agglomeration, and environmental regulation (Shao & Chen, 2023), etc., play important roles. Further, digital finance can have heterogenous impacts on regional innovation capacity from the aspects of business attraction degree (Li et al., 2023), geographical location (Yang et al., 2022), and regional hierarchy (core areas and non-core areas) (Sun & You, 2023).

Second, studies are also exploring the impact of digital finance on the innovation activities of micro-economic entities at the micro level. In terms of the mechanism, digital transformation, government subsidies (Jiang et al.2022), external bank competition (Xiong et al., 2023), easing financing constraints, financing costs, etc., have mediated the influence of digital finance on the innovation capacity of enterprises. Some particular important aspects are digital transformation and easing financing constraints. Digital finance broadens innovative financing channels for enterprises (Li et al., 2022; Xiong et al., 2023), lays a solid financial foundation for enterprises' digital transformation, and helps them quickly achieve digital transformation. Additionally, fiscal constraints, the shareholding of the largest shareholder, and the asset-liability ratio (Jiang et al., 2022) can play a moderating role in this process.

*The impact of economic policy uncertainty on innovation*

Economic policy uncertainty refers to uncertainty related to whether, when, and how the government will change the current economic policies (Gulen & Ion, 2016). It negatively affects macroeconomic development and micro-enterprise behavior. At the macro level, the rise of economic policy uncertainty not only intensifies the fluctuation of key macroeconomic variables of output and employment but also affects the economic cycle and hinders economic recovery (Fernández-Villaverde et al., 2015; Pastor & Veronesi, 2012; Baker et al., 2016). At the micro level, economic policy uncertainty affects microenterprises' economic activities. Economic policy uncertainties changes the cost of business activities and inhibits enterprises' investment activities. This inhibitory effect may be related to factors such as financial constraints, degree of competition among firms, and industry characteristics (Julio & Yook, 2012; Gulen & Ion, 2016; Kang et al., 2014).

However, innovation is an important link and a fundamental driving force of economic activities. Yet, few studies have explored the impact of economic policy uncertainty on innovation. Owing to the differences in adjustment cost characteristics, economic policy uncertainty has different impacts depending on the types of business activities (especially R&D activities) (Bloom, 2007; Gu et al., 2018). The few studies on the impact of economic policy uncertainty on innovation present two opposing views. Some scholars believe that economic policy uncertainty positively affects scientific and technological innovation activities, leading to an increase in enterprises' R&D levels and promoting innovation (Atanassov et al., 2024; Marcus, 1981). Other scholars hold the opposite view, arguing that economic policy uncertainty causes enterprises to delay R&D investment decisions, damaging the driving force of a country's economic innovation and hindering innovation, especially in industries with high R&D intensity and politically connected enterprises (Bhattacharya et al., 2017; Wang et al., 2017). Therefore, understanding the complex mechanisms of policy uncertainty in the innovation process is important.

*Summary and study contributions*

Extant studies provide useful guidance for exploring the relationship between digital finance and innovation. However, there are still research deficiencies. (1) In terms of research objects, owing to the dispersion and disorder of data, the literature mainly studies innovation capacity based on provinces, cities, or single urban agglomerations. Few studies have focused on the 19 urban agglomerations in China. (2) Regarding the evaluation index system, although there have been few studies on the innovation capacity of urban agglomerations, most are based on research on regional innovation capacity in terms of definition and measurement. Few focus on the urban agglomeration. Urban agglomeration innovation is quite different from urban, regional, and enterprise innovations. An urban agglomeration is a unique spatial form that transcends administrative divisions, and has different scales and functions (Tang et al., 2024). It has its own internal development and change laws, and should not be confused with the city or provincial level. Therefore, it is necessary to establish a unique evaluation index system for the UA innovation capacity of urban agglomeration. (3) Few studies consider the mediating factors of innovation capital agglomeration, entrepreneurial activity, credit resource allocation, and moderating moderating effect of economic policy uncertainty. While studies considered these factors, they have not focused on these factors' mechanism roles.

Our contributions to the literature are fourfold. (1) In terms of research objects, this study focuses on 196 cities in 19 urban agglomerations in China to explore the impact of digital finance on the innovation capacity of urban agglomerations. This broader selection can reveal the nuances of digital finance's impact on innovation capacity at the urban agglomeration level from a comprehensive, macro perspective. (2) To construct the innovation capacity index system of urban agglomerations, the evaluation indicators have been sorted related to the innovation capacity of urban agglomerations in CSSCI journal papers from 2012 to 2022, and frequency statistics have been conducted. Finally, we create an indicator system for the innovation capacity of urban agglomerations, which includes 25 indicators from five dimensions: innovation resources, knowledge creation, innovation performance, innovation environment, and innovation collaboration. This index system provides a more accurate and comprehensive measurement tool for examining the urban agglomeration innovation capacity and improving innovation capacity evaluation. (3) Third, we provide evidence on three mechanisms mediating the main effect: innovation capital agglomeration, entrepreneurial activity, and credit resource allocation. Simultaneously, this study explores the moderating effect of economic policy uncertainty. Revealing these internal action paths provides a theoretical basis for understanding how digital finance promotes innovation in urban agglomerations and improves the theoretical understanding of the impact mechanism of digital finance on regional innovation. (4) Finally, we examine the heterogeneous impact of digital finance on the innovation capacity of urban agglomerations from three perspectives: scale, marketization level, and spatial structure. This analysis helps us to better understand the effects of digital finance in different contexts and can provide a scientific basis for formulating regional innovation policies according to local conditions. (5) Finally, our findings can hold relevance for other countries or regions, despite its focus on urban agglomerations in China. As an important spatial carrier

of economic development on a global scale, any urban agglomeration faces similar innovation challenges and opportunities. Other countries or regions can learn from the methods and conclusions of this study, combined with their actual conditions, to explore local digital finance and urban agglomeration innovation development paths.

## Theoretical background and hypotheses development

### *Digital finance and urban agglomeration innovation capacity*

Finance is an important part of the innovation and entrepreneurship environment. Financial institutions' decision to finance MSMEs directly affects the development of innovation and entrepreneurship activities (Hoskisson et al., 2000; Ahlstrom & Bruton, 2010). Many studies shows that the degree of friendliness of a country's or region's financial system toward innovative banks affects the extent of entrepreneurial activity in a country or region (Welter & Smallbone, 2011; Lim et al., 2010). Digital finance is the product of a combination of financial services and digital technology, such as mobile payments, digital insurance, Internet credit, and so on (Gomber et al., 2017), and provides inclusive and accurate financial services as its core attribute (Teng & Ma, 2020). Innovative activities are characterized by high risk, long cycles, and high input, and require the support of large and stable cash flows (Wang, 2022). The universality, low cost, and intelligence of digital finance make it feasible to optimize its development of digital finance to promote the improvement of regional innovation capacity.

Studies provide different definitions of innovation capacity from various perspectives. Cooke (2001) believed that innovation capacity is a type of integration capacity. Furman et al. (2002) believed that the core of innovation capacity should focus on the innovation process. Hu and Mathews (2008) attached great importance to the role of innovation resources in terms of innovation capacity. According to this definition of innovation capacity, this study holds that innovation capacity is a complex concept. Innovation resources, knowledge creation, innovation output, and innovation environment are important components of a country's or region's innovation capacity. As an urban complex formed by the combination of multiple spatial entities, the innovation capacity of an urban agglomeration can be defined as "the ability of an urban agglomeration to rely on its internal and external innovation environment, use the innovation resources within the group for knowledge creation, and form innovative performance through the collaborative innovation of various entities within the group".

As a new form of finance, digital finance has significantly compensated for the shortcomings of traditional finance. It provides portable financial support for MSMEs in urban agglomerations and plays a direct role in promoting their innovation capacity of urban agglomerations.

On the one hand, digital finance can effectively overcome many restrictions on traditional financial services and compensate for the shortcomings of traditional financial services. Technological innovation activities have a long investment cycle, large capital investment, high risk, and often face serious financing constraints (Nie et al., 2021). However, the shortcomings of traditional financial services make it difficult to provide sufficient and effective financial support for innovation activities. Innovation activities are mainly reflected in the narrow financial coverage, resource mismatch, and financing discrimination. Traditional financial institutions are often reluctant to serve remote and poor people (De Aghion & Morduch, 2005). Simultaneously, it is difficult for traditional financial intermediaries to alleviate the information asymmetry between supply and demand, and resource mismatches (Stiglitz & Weiss, 1981; Li et al., 2023). As a new financial model, digital inclusive finance applies digital technology and other financial technologies to the field of inclusive finance (Hasan et al., 2020). This effectively compensates for the shortcomings of traditional financial services, promotes the improvement of service efficiency and quality of financial institutions (Yang et al., 2022), and encourages innovation and entrepreneurship activities in urban agglomerations.

On the other hand, digital finance can provide portable financial support for MSMEs in urban agglomerations, thus stimulating their innovation vitality and internal motivation. As the most active and potential innovation subjects in urban agglomerations, MSMEs are excluded from the traditional financial system owing to many restrictions (Lin et al., 2022). MSMEs' external financing is limited by imperfect information disclosure mechanisms, non-standard financial statements, and poor management abilities (John Mathis & Cavinato, 2010; Xie et al., 2018; Booyens, 2011). This makes it difficult for traditional financial institutions to judge their integrity and economy (Yang & Zhang, 2020; Faherty & Stephens, 2016), and provide effective and appropriate financial services. The "inclusive" concept and "grassroots" characteristics of digital finance (Durai & Stella, 2019) coincide with the characteristics of innovative financing needs of MSMEs. Digital financing lowers the cost and threshold of financial services, increases MSMEs' capital source channels, and stimulates their innovation impetus to promote the innovation capacity of urban agglomerations. Therefore, we propose the following hypothesis:

**Hypothesis 1**. Digital finance can improve the innovation capacity of urban agglomeration.

### *Digital finance, innovation capital agglomeration, and urban agglomeration innovation capacity*

Next, we argue that digital finance promotes innovation capital agglomeration, thus improving the innovation capacity of urban agglomerations.

On the one hand, digital finance is conducive for promoting innovative capital agglomeration in urban agglomerations. Digital finance, as a new financial model driven by the advancement of digital technology, is characterized by wide accessibility and high efficiency (Hasan et al., 2022). This has the potential to influence the allocation of financial resources and information flows, enhancing the agglomeration and circulation of funds within urban agglomerations. Through electronic payments, blockchain, and other technologies, digital finance can quickly realize cross-regional transfer and clearing of funds, and promote a more efficient concentration of funds into innovation (Rao et al., 2022). Meanwhile, digital finance promotes the formation of fin-tech ecosystems in urban agglomerations. Digital technology upgrades can promote greater financial resource flow between underdeveloped and developed regions, enhance capital spillover and resource radiation, promote financial industry agglomeration, and ensure financial stability (Risman et al., 2021). Through cooperation among innovation subjects, innovation funds gather and flow in urban agglomerations, forming a benign capital cycle and innovation ecology, and effectively promoting the capital agglomeration of urban agglomerations.

On the other hand, innovation capital agglomeration has injected vitality into improving the innovation capacity in urban agglomerations. Many studies confirm that economic agglomeration can produce various spillover effects and economies of scale (Martin & Ottaviano, 2001; Rosenthal & Strange, 2006). The agglomerated innovation capital can be directly invested in scientific research, technological innovation, transformation of scientific and technological achievements, and other innovative activities (Mention, 2012). Innovation capital agglomeration provides the necessary financial support and guarantees to improve the innovation capacity of urban agglomerations. Meanwhile, the concentration of innovation funds is conducive to promoting high-tech industry agglomeration, promoting the technological upgrading and industrial structure optimization of key industries within the urban agglomeration, and enhancing the innovation level of urban agglomerations (Xu & Jiao, 2021). Thus, we hypothesize:

**Hypothesis 2**. Digital financing can improve the innovation capacity of urban agglomerations by enhancing the innovative capital agglomeration.

*Digital finance, entrepreneurial activity, and urban agglomeration innovation capacity*

Next, we argue that digital finance promotes the innovation capacity of urban agglomerations by improving entrepreneurial activity. Financial development can promote entrepreneurial activities by easing liquidity constraints of entrepreneurs (Bianchi, 2010), while financial constraints affect the level and scale of entrepreneurship (Hurst & Lusardi, 2004). On the supply side, digital finance lowers the threshold for entrepreneurs to obtain funds by providing diversified financing channels and tools (Wang, 2022; Qin et al., 2022), making "mass entrepreneurship and innovation" possible. Simultaneously, the increasing technological revolution in finance and banking, and the increasing efficiency and creativity of digital finance are driving the prosperity of the financial sector (Alkhwaldi et al., 2022), greatly reducing the operating costs of financial services (Ketterer, 2017). The reduction in costs encourages enterprises to realize product and service innovation with more abundant funds (Luo, 2022). From the demand side, digital financial technologies can help entrepreneurs better understand and respond to market changes and business risks (Wang, 2022). Entrepreneurs can better understand market needs in a modern and innovative way, quickly adjust business strategies to meet diverse customer wishes, and enhance market adaptability and competitive advantage (Chen et al., 2019; Singh & Del Giudice, 2019).

The improvement in entrepreneurial activity further injects vitality into improving the innovation capacity of urban agglomerations. First, it can improve the dissemination of innovative knowledge and technology. Regions with high levels of entrepreneurial activity tend to become hubs for knowledge and technology exchange. Entrepreneurs share and exchange innovative ideas here. Expertise in different fields can gather and interact (Amaghouss & Ibourk, 2013; Szirmai et al., 2011), thereby promoting the cross-border integration of urban agglomeration innovation. The second aspect is the formation and expansion of innovative ecosystems. Entrepreneurship plays an important role in innovation activities (Acs & Audretsch, 2005; Veeraraghavan, 2009; Szirmai et al., 2011). An increase in entrepreneurial activity contributes to the cultivation and development of entrepreneurship, thus forming a more active and diversified innovation ecosystem in urban agglomerations (Zahra & Nambisan, 2011; Nambisan & Baron, 2013; Beliaeva et al., 2020). This promotes the generation and development of innovation capacity in urban agglomerations (Zahra & Nambisan, 2011). Therefore, we propose the following hypothesis:

**Hypothesis 3**. Digital finance can improve the innovation capacity of urban agglomerations by promoting entrepreneurial activity.

*Digital finance, credit resource allocation, and urban agglomeration innovation capacity*

First, we argue that digital finance improves the innovation capacity of urban agglomerations by improving the allocation of credit resources. First, the development of digital finance can improve information transparency and market efficiency. The relevant literature on resource allocation shows that a reasonable allocation of financial resources can guide the optimal allocation of social resources and improve the efficiency of resource utilization (Wang et al., 2022). Improving the efficiency of financial institutions can improve the efficiency of resource allocation (Jie et al., 2021). Digital finance is a new business model that combines finance and digital technology (Huang & Huang, 2018), which can more accurately assess borrowers' credit risk and reduce information asymmetry (Kong et al., 2022). This promotes financial resources to flow more effectively to borrowers who really need them. Second, there has been an improvement in the coverage and efficiency of financial services. Faced with challenges such as information asymmetry and financing difficulties, MSMEs have significant demand for credit financing. Digital financial technology can overcome the geographical limitations and high operating costs of traditional financial institutions (Yang et al., 2022; Ketterer, 2017). By providing online financing channels, financing difficulties can be reduced (Guo et al., 2023) to expand financial services to more areas and groups within urban agglomerations and improve the balanced allocation of credit resources (Hasan et al., 2020).

Meanwhile, the improvements in the allocation of credit resources improve the innovation capacity of urban agglomerations. As the most extensive external financing channel, bank credit plays a crucial role in upgrading enterprises' investment and innovation activities (Hall, 2002; Atanassov, 2016; Chiu & Lee; 2020), especially in countries in transition with inadequate capital markets. Firms without access to bank credit tend to be less productive (Cao & Leung, 2020). Improved credit resources imply that more money can flow into innovative enterprises and projects. In urban agglomerations, with sufficient credit resource support, innovative enterprises can more easily obtain startup and expansion funds to increase investment in R&D and undertake innovative activities (Shi et al., 2019). Simultaneously, through a better allocation of credit resources, enterprises in a group can be more actively involved in market competition (Dell'Ariccia & Marquez, 2004). Improvements in market competitiveness are also an important embodiment of the enhanced innovation capacity of urban agglomerations. Hence, we hypothesize the following:

**Hypothesis 4**. Digital finance helps improve the allocation of credit resources, thereby promoting the innovation capacity of urban agglomerations.

*Moderating effect: economic policy uncertainty*

Under the influence of many factors, different economic policy factors lead to uncertainties (Al-Thaqeb & Algharabali, 2019; Baker et al., 2016). The first is the diversity of policy adjustments. To meet the needs of the economic development, different cities have formulated and implemented diverse economic policies (Siegel et al., 1995). These policies include industrial development, fiscal taxation and financial supervision. The diversity of policies makes it difficult for enterprises and markets to accurately predict the direction of future policies (Abel, 1983; Baker & Bloom, 2013), thus creating uncertainty in economic policy. The second is the complexity of the policy objectives. Each city's economic policies tend to have multiple objectives that may be interrelated and mutually restrictive (Bhattacharya et al., 2017). Moreover, cities have different priorities in achieving these goals at different times. This makes it difficult for enterprises and the market to grasp the specific direction and focus of policies, and further aggravates the uncertainty of economic policies (Turner, 2012; Bekaert et al., 2013; Atanassov et al., 2024). The third factor is the difference in policy implementation. Although different cities have similar economic policies, their implementation processes may differ. This is because each city has different administrative efficiencies, local interests, and regulatory capacities. These differences make it difficult for enterprises to accurately judge the actual effect and impact of policies (Bloom, 2009; Balcilar et al., 2016), thus increasing the uncertainty of economic policy.

To regulate the market economy and improve the efficiency of resource allocation, the government promotes economic development by adjusting economic policies. Repeated updates of economic development policies can increase the policy uncertainty of the external environment (Gulen & Ion, 2016; He & Shen, 2021). Economic policy uncertainty is an important environmental factor influencing the impact of digital finance with the innovation capacity of urban agglomerations (Wang et al., 2024). Due to the complexity of the economic system and behavior of market agents, economic policy uncertainty may have different impacts, resulting in a dynamic trade-off between risk aversion, innovation incentives, and survival pressure.

First, when economic policy uncertainty is low, the innovation decisions of firms and urban agglomerations are typically based on stable

policy expectations. On the one hand, based on real options theory, market agents tend to be risk-averse by postponing risky investments under low uncertainty (Myers, 1977). Under low uncertainty, market players tend to rely on existing policy dividends and deterministic paths. Enterprises choose to delay investments to wait for more information, and have little incentive to invest in high-risk, long-cycle innovations. This leads to difficulties in fully transforming digital economic resources (e.g., data elements and digital technologies) into innovation capabilities, thus generating negative shock effects. On the other hand, institutional theory emphasizes that path dependence may be reinforced when institutions are stable (North, 1990). A stable policy environment may encourage urban agglomerations and firms to entrench their established business models and technological routes, thereby inhibiting disruptive innovation. For example, firms may be more inclined to optimize their existing digital technology applications rather than breakthrough R&D.

Second, when economic policy uncertainty rises to a moderate level, its inhibitory effect on innovation capacity diminishes or even turns into a positive incentive. On the one hand, when economic policy uncertainty rises to a moderate level, it pushes back the innovation mechanism. Schumpeter's theory of innovation emphasizes creative destruction as the driving force of economic progress (Schumpeter & Swedberg, 2021). Policy volatility forces firms to innovate to cope with market risks and enhance their market power (Tajaddini & Gholipour, 2021; Peng et al., 2023; Geng et al., 2023). For example, in response to potential policy adjustments (e.g., increased data regulation), firms may accelerate the development of compliant technologies or explore new markets. On the other hand, based on dynamic capabilities theory, uncertainty motivates urban agglomerations to reorganize their resources to cope with environmental changes (Teece et al., 1997). Uncertainty forces an accelerated flow of factors (capital, talent, and technology) within urban agglomerations (Cheng & Masron, 2023), promoting the optimal allocation of innovation resources and facilitating cross-regional collaborative innovation (Lin & Ma, 2022). For example, local governments may attract firms and talent to the digital economy through differentiated policies that form innovation networks.

Third, when economic policy uncertainty exceeds another threshold, its negative impact once again dominates. On the one hand, according to the expected return theory, frequent policy fluctuations make it difficult for market players to accurately judge future market demand, cost changes, etc., and the expected return on investment and innovation becomes highly unstable (Ilmanen, 2022), inhibiting long-term R&D investment. For example, uncertainty regarding the direction of digital tax policy may discourage firms from investing in big data. On the other hand, according to the theory of market failure, excessive policy uncertainty can undermine the normal operation of the market mechanism (Nair & Howlett, 2020; Stiglitz, 1989). This can lead to distorted market signals, ineffective functioning of the price mechanisms, and serious distortions in resource allocation. For example, funds in the financial market may flow to safe assets in large quantities. Digital economy enterprises may then find it difficult to obtain sufficient financial support, and talent will be lost due to market instability, thus negatively affecting the innovation capacity of urban agglomerations. Based on the above analysis, Hypothesis 5 is proposed.

**Hypothesis 5**. Economic policy uncertainty has an "inverted N-type" nonlinear moderating effect on the impact of digital finance on the innovation capacity of urban agglomerations.

Fig. 1 outlines the theoretical framework with our hypotheses.

This study advances extant theory and knowledge. (1) Regarding the direct relationship between digital finance and the innovation capacity of urban agglomerations, previous studies have mostly focused on innovation in provincial, municipal, or single urban agglomerations. This study considers many urban agglomerations and systematically analyzes the impact of digital finance on their innovation capacity. (2) This study proposes three mechanisms mediating the main effect: innovation capital agglomeration, entrepreneurial activity, and credit resource allocation. Compared with extant studies which consider a single or small number of perspectives, this study provides a more in-depth and systematic theoretical explanation, enriching the theoretical framework of the impact mechanism. (3) Regarding the moderating effect of economic policy uncertainty, most studies argue that economic policy uncertainty hinders innovation. Meanwhile, this study paints a more complex picture, challenging the conventional wisdom and promoting an in-depth discussion of the innovation-promoting role of digital finance in complex policy environments.

## Methodology

### *Definition of urban agglomeration*

An urban agglomeration refers to an urban complex with a relatively compact space and close economic connections (Yu et al., 2019; Yu et al., 2020). With the acceleration of the construction of urban agglomerations and metropolitan areas in China, the country has established the pattern of "19+2" urban agglomerations. Considering data availability and development planning of various urban agglomerations, we select 196 cities in 19 urban agglomerations defined in the "13th Five-Year Plan" as the research sample[1]. The regional definitions of specific urban agglomerations and relevant documents are provided in the Appendix.

### *Variable selection*

Our dependent variable is the innovation capacity of urban agglomerations (*Inn*). It refers to the capacity of an urban agglomeration to rely on innovation environment to transform innovation inputs into social productivity, and to promote knowledge creation through the synergy of industry, academia and research within the cluster, ultimately leading to the formation of innovation output. In recent years, scholars have conducted extensive research on the indicators of regional innovation capacity. However, to our knowledge, no unified and comprehensive index system exists for evaluating the innovation capacity of urban agglomerations. Therefore, this study manually collects the literature related to the innovation capacity of urban agglomerations from CSSCI journal papers from 2012 to 2022. Among them are authoritative Chinese economic journals such as Economic Research, Industrial Economics of China, Quantitative and Technical Economics Research, and Economic Management. While selecting empirical literature on the innovation capacity of urban agglomerations, we exclude irrelevant literature[2]. Through manual sorting, we finally select 108 papers on the measurement indicators of innovation capacity of urban agglomerations and obtain 183 variables to measure innovation capacity of urban agglomerations.

Among the papers that use comprehensive indicators to measure innovation capacity, the highest number of papers (11) use the three broad levels of "innovation input," "innovation output," and

[1] The relevant data of some cities (such as Hengshui, Xiantao, Qianjiang, Tianmen, Jiyuan, Yuncheng, Xingtai, Handan, and Danzhou) are not disclosed in the "China Urban Statistical Yearbook", or there are many years of data missing. Therefore, cities with poor data availability are eliminated, yielding 196 cities in 19 urban agglomerations. According to the relevant data of China Statistical Yearbook 2022 and China Urban Statistical Yearbook 2022, the total regional GDP of the 196 cities accounts for about 72% of the GNP. Thus, our sample has relatively reasonable coverage and representativeness.

[2] Among the irrelevant papers removed from this study, the first are purely theoretical studies on the innovation capacity of urban agglomeration. The second are studies on urban innovation but which use enterprise data rather than regional data to analyze technological innovation problems. The third are studies which use regional data to analyze the innovation capacity of urban agglomerations, but do not use quantitative methods for empirical analysis.

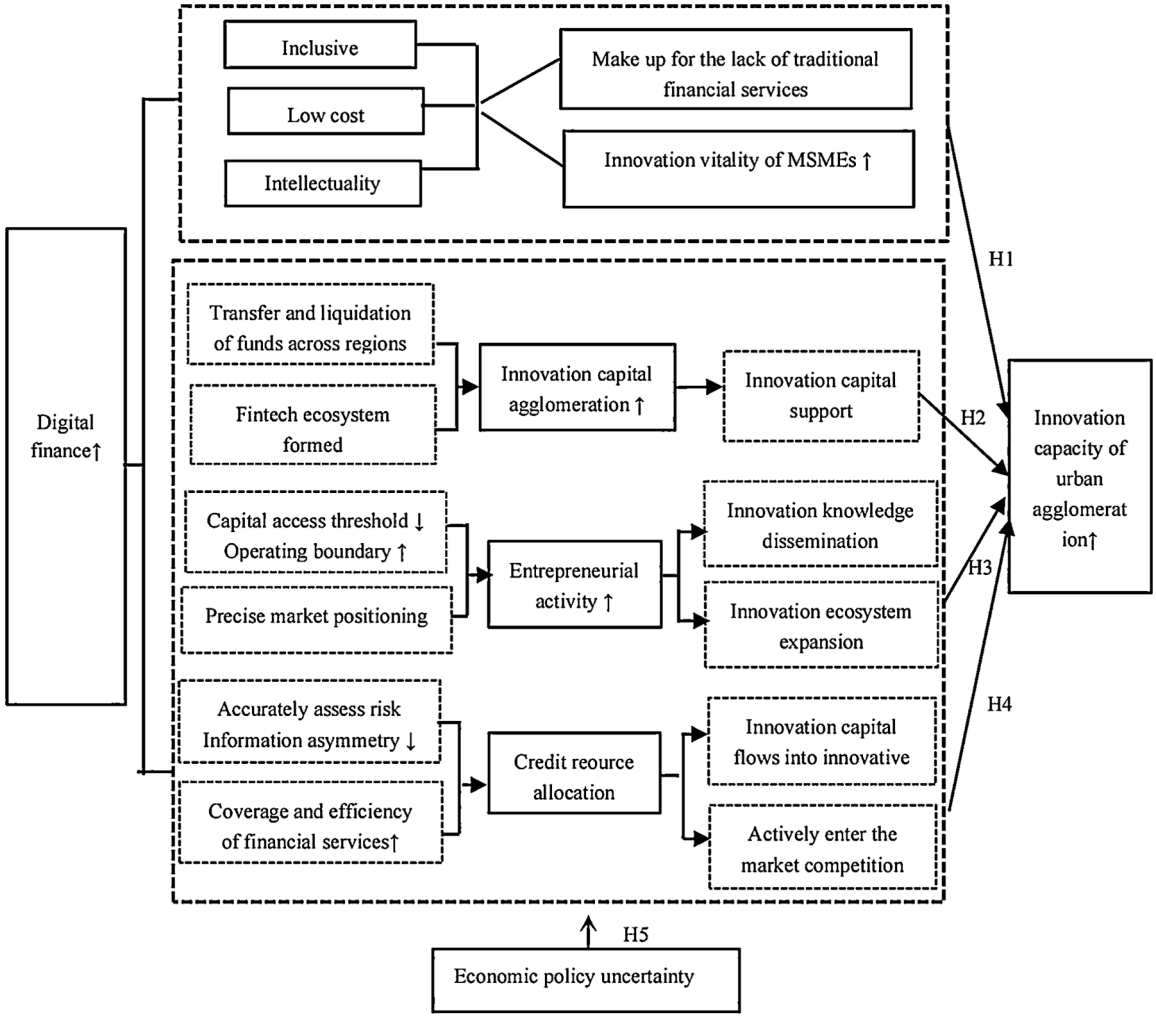


**Fig. 1.** Theoretical framework and research hypotheses.

"innovation environment". Therefore, the 183 variables collected are classified according to these three levels. This yields 47 variables of innovation input, 45 variables of innovation output, and 29 variables of innovation environment. The innovation input variables have been used a total of 81 times, innovation output variables have been used 107 times, and innovation environment variables have been used 45 times. However, considering that it is impossible to include all the variables into the econometric model in the following analysis, this study preliminarily screens the above measurement factors as follows: the selection criteria for the innovation input variables were used seven or more times, and for the innovation output and innovation environment variables were used four or more times. Combined with the availability of data, the main indicators and usage frequencies of the innovation capacity of Chinese urban agglomerations selected from the 108 papers are shown in the Appendix.

Next, we compare authoritative domestic and foreign reports[3] on the innovation capacity of urban agglomerations. Most reports construct an index system of regional innovation capacity from the perspectives of "innovation resources," "knowledge creation," "enterprise innovation," "innovation performance" and "innovation environment." Innovation resources reflect the input intensity and supply capacity of regional innovation factors, as well as the degree of improvement in innovation infrastructure. Knowledge creation reflects the output capacity of regional scientific research inputs, and the ability of knowledge dissemination and spillover. Enterprise innovation is primarily used to reflect the intensity, efficiency, and level of innovation activities at the micro-enterprise level. Innovation performance reflects the effects and influence of regional innovation. The innovation environment reflects the external hardware and software environment on which regional innovation activities depend. This index system can more comprehensively reflect the innovation capacity of urban agglomeration. Therefore, based on the main indicators of the innovation capacity of urban agglomerations obtained using the frequency statistics method, we classify and reorganize them according to four levels: "innovation resources," "knowledge creation," "innovation performance," and "innovation environment"[4]. We also add an index of "innovation synergy"[5].

In addition, market openness, as an important factor affecting the innovation activities of a country or region, is usually measured by

[3] The authoritative reports above include the National Innovation Index Report (2016-2017), China Regional Innovation Capacity Evaluation Report (2016), China Metropolitan Area Development Report (2018), etc.

[4] Since the object of this study is the macro level of urban agglomeration, the micro-level index of "enterprise innovation" is excluded.

[5] The index of "innovation synergy" is added because the cultivation of synergy plays a very important role in the innovation capacity of urban agglomerations. Urban agglomerations are agglomerations of cities or even provinces, linked by industrial and economic ties between cities. The innovation capacity of urban agglomerations should consider the extent of coordinated development among cities.

indicators such as trade openness (Fankem & Oumarou, 2020; Fröidh & Nelldal, 2015; González & Ferencz, 2018). On the one hand, market openness attracts external resources such as capital and labor, which affect innovation resources. On the other hand, it also affect the innovation environment by promoting competition and increasing market diversity. However, according to Can et al. (2017) and Huang et al. (2016), most studies divide market openness into innovation resources. To avoid duplication, we divide the indicators related to market openness (number of foreign-invested enterprises and amount of foreign capital utilized in the year) into innovation resources. Similarly, international exchanges reflect the exchanges and interactions between countries or regions in politics, economy, culture, science, and technology. In economic terms, it can be measured by indicators such as trade and investment (Wang & Bu, 2019; Wang & Zhang, 2021). International exchanges play an important role in the acquisition, integration, and utilization of innovative resources. They also help spread knowledge and transfer technology, create a good innovation environment, and provide strong support for regional innovation and development. However, to avoid duplication, we refer to existing studies (Guanghu, 2015; Peng et al., 2023) and divide the relevant indicators of international exchanges (number of foreign-invested enterprises and amount of foreign capital actually utilized in the year) into innovation resources.

In summary, this study constructs an innovation capacity index system for urban agglomerations from five dimensions: innovation resources, knowledge creation, innovation performance, innovation environment, and innovation collaboration. Finally, we get 25 secondary indicators, with 5 indicators for each dimension. Next, we use the entropy weight method to determine the index weight of urban agglomeration innovation capacity. Notice that factors such as the development stage, jurisdictional area, and scale of different urban agglomerations should be considered. If we simply use the aggregate index value, there is no comparability among national, regional, and regional urban agglomerations. Similarly, simply using the mean values cannot reflect the scale and agglomeration effects of urban agglomerations. Hence, we consider both aggregate and mean values for the indices. Specifically, among the 25 indicators used here, 11 are use aggregate values, while the remaining 14 indicators use mean values. Table 1 summarizes the index system.

Next, our independent variable is digital finance (*Difi*), measured using the Peking University digital financial inclusion index of China (PKU-DFIIC). The digital financial index is constructed from three aspects: coverage breadth (*Breadth*), usage depth (*Depth*), and digitization level (*Digi*). The specific measurement method of this indicator can be found in Peking University Digital Financial Inclusion Index (2011–2018). We use the arithmetic average of the digital financial inclusion index and its sub-indicators to obtain the digital financial level of urban agglomeration.

Many other factors affect the innovation capacities of urban agglomerations. To ensure the accuracy and reliability of the empirical results, the following control variables are selected based on Tao et al. (2022) and Li et al. (2023). ① Opening-up degree (*Open*): It is expressed by the arithmetic mean of the logarithm of the amount of foreign capital actually utilized in the year in the year as a share of GDP. A higher degree of openness to the outside world often creates more opportunities for international cooperation and introduction of advanced technologies. This may improve the ability of urban agglomerations to obtain external resources, and promote innovation and efficiency (Cheung & Ping, 2004; Lu et al., 2017; Zhang, 2017). ② Urbanization rate (*Ur*): It is measured by the arithmetic mean of the logarithm of urban population as a share of the resident population at the end of the year. A higher level of urbanization may lead to a narrowing of the wealth gap and improved infrastructure. Simultaneously, it may promote the optimal allocation of resources and population agglomeration, thus promoting innovation (Andersson et al., 2009; Chen et al., 2020). ③ Human capital (*Hum*): It is measured by the arithmetic mean of the logarithm of the population with a general college degree or higher as a percentage of the city's resident population. Human capital is an engine of economic development and innovation. Human capital stock can enhance a country's or region's ability to develop local technological innovation and disseminate knowledge (World Development Report, 1998), thus providing intellectual support for innovation activities (Nelson & Phelps, 1966; Danquah & Amankwah-Amoah; 2017). ④ Fixed asset investment (*Fai*): This is the arithmetic mean of the logarithmic value of total urban fixed asset investment. Investment in fixed assets reflects the strength of economic development and the foundation of industrial development in a region. Investment in fixed assets is conducive to increasing employment, improving the production efficiency and profitability of enterprises, promoting industrial structure upgrading, and positivley affects economic vitality and innovation capacity (Olatunji & Adegbite, 2014; Eriotis et al., 2002). ⑤ Transportation level (*Trans*): It is measured by the arithmetic mean of the logarithm of the road freight volume. Improvements in transportation infrastructure affect the efficiency of resource circulation within and between urban agglomerations. Good transportation conditions can promote the flow of innovation factors, increase innovation opportunities, narrow regional innovation gaps, and

**Table 1**
Innovation capacity index.

| Target layer | Indicator level | Calculation method | Weight (%) |
|---|---|---|---|
| Innovation resources (18.94%) | Share of fiscal expenditure on science and technology in local fiscal expenditure | Mean | 0.69 |
| | Ratio of education expenditure to local financial expenditure | Mean | 3.79 |
| | Number of personnel engaged in scientific research, technical services, and geological exploration | Total | 4.51 |
| | Number of foreign-invested enterprises | Total | 10.83 |
| | Amount of foreign capital actually utilized in the year | Total | 2.55 |
| Knowledge creation (16.88%) | Number of general higher education institutions | Total | 2.20 |
| | Number of full-time teachers in general higher education institutions | Total | 2.36 |
| | Number of students enrolled in general higher education institutions | Total | 2.55 |
| | Number of published papers | Total | 4.38 |
| | Patent applications | Total | 8.51 |
| Innovation performance (27.60%) | Technology market turnover | Total | 10.03 |
| | Number of well-known trademarks | Total | 4.49 |
| | Number of patents granted | Total | 8.89 |
| | Turnover of scientific and technological achievements per 10,000 people | Mean | 8.93 |
| | Green coverage rate | Mean | 0.24 |
| Innovation environment (31.24%) | Gross regional product per capita | Mean | 1.94 |
| | Proportion of output value of tertiary industry in GDP | Mean | 1.79 |
| | Number of books in public libraries per 100 people | Mean | 5.48 |
| | Internet users per 10,000 people | Mean | 4.62 |
| | Postal and telecommunications revenue | Total up | 4.08 |
| Innovation collaboration (5.34%) | Urbanization level | Total up | 1.69 |
| | Coupling degree of science and technology and economy | Mean | 1.98 |
| | Economic gap | Mean | 0.69 |
| | Innovation input gap | Mean | 1.76 |
| | Human capital gap | Mean | 1.02 |

positively affect regional innovation (Garrison & Souleyrette, 1996; Bian et al., 2019). ⑥ Unemployment level (*Unemploy*): This is represented by the arithmetic mean of the logarithm of registered unemployed persons in urban areas. The unemployment rate reflects the employment situation and economic vitality of the region. A high unemployment rate may lead to brain drain and decreased consumption power, which in turn adversely affects innovation input and atmosphere, and thus, regional innovation (Stiglitz, 2014; Majewska & Rawińska, 2018).

We adopt three mediating variables: ① Innovation capital agglomeration (*Cap*): It is measured as the proportion of urban agglomeration R&D expenditure to national R&D expenditure. ② Entrepreneurial activity (*Ent*): It is measured as the arithmetic average of the number of new businesses per 100 people in a city. ③ Credit resource allocation (*Credit*): The regional credit constraint is measured by the traditional financial development level index of each city to reflect the regional credit resource allocation. The higher the level of traditional financial development in urban agglomerations, the better the credit resource allocation. This implies that enterprises in urban agglomerations face fewer credit constraints.

Finally, we use economic policy uncertainty (*Uncertain*) as the moderating variable. It is measured using the Economic Policy Uncertainty index compiled by Baker et al. (2016). Since this index is a monthly indicator, we take the arithmetic average of the economic policy uncertainty index to obtain the annual index and divide it by 100 for empirical estimation. The higher the index, the higher the uncertainty of economic policy in the current year.

### *Model construction*

This study uses panel data from 19 urban agglomerations in China from 2012 to 2021. Panel data refer to data obtained by repeated measurements of the same group of individuals over a period and have been widely used by scholars in various studies (Bai et al., 2024; Li et al., 2023; Hui et al., 2023; Ren et al., 2023; Cheng et al., 2024). This study uses data from multiple urban agglomerations at multiple time points. The level of digital finance in each urban agglomeration changes with time. Further, its impact on innovation capacity can also change. From a spatial perspective, the level of digital finance in different urban agglomerations is different. Additionally, its impact on innovation capacity can also be different. The panel data model can simultaneously consider the influence of individual differences and time changes. We use the following empirical specification:

$$Inn_{it} = \alpha_0 + \alpha_1 Difi_{it+}\alpha_i Control_{it} + \lambda_i + \omega_t + \mu_{it} \quad (1)$$

where $Difi_{it}$ is digital finance; $Inn_{it}$ is the innovation capacity of urban agglomeration; $i$ represents the 19 urban agglomerations in China; $t$ represents time (*year*); $Control_{it}$ is a series of control variables that include opening-up degree (*Open*), urbanization rate (*Ur*), human capital (*Hum*), fixed asset investment (*Fai*), transportation level (*Trans*), and unemployment level (*Unemploy*); $\lambda_i$ is the urban agglomeration-fixed effect; $\omega_t$ is the year-fixed effect; and $\mu_{it}$ is the random error term.

Next, we consider three mediating variables: innovative capital agglomeration, entrepreneurial activity, and credit resource allocation. We use the following specification to test the mediating effects:

$$Med_{it} = \beta_0 + \beta_1 Difi_{it} + \beta_i Control_{it} + \mu_{it} \quad (2)$$

where $Med_{it}$ represents the mediating variables, including innovation capital agglomeration (*Cap*), entrepreneurial activity (*Ent*), and credit resource allocation (*Credit*). First, innovation capital agglomeration (*Cap*) is measured by the ratio of urban agglomeration R&D expenditure to national R&D expenditure. Second, entrepreneurial activity (*Ent*) is measured as the arithmetic average of the number of new businesses per 100 people in a city. Third, as an inverse proxy for credit resource allocation, regional credit constraint is measured using the traditional financial development level index of each city (*Credit*). The higher the level of traditional financial development in urban agglomerations, the better the credit resource allocation and the fewer credit constraints enterprises face to innovate.

Next, we examine whether economic policy uncertainty has a nonlinear moderating effect on the relationship between digital finance and innovation capacity, as it is an important environmental factor affecting the digital economy and regional innovation (Zhou et al., 2023; Xu, 2020; He et al., 2020; Nguyen & Nguyen, 2023; Cheng & Masron, 2023). We construct the following nonlinear moderating model. First, based on model (1), the squared term of economic policy uncertainty ($Uncertain_t^2$) and its cross-multiplier with digital finance ($Difi_{it}$*$Uncertain_t^2$) are added to construct model (3). This model is used to test whether there is a "U-type" or "inverted U-type" nonlinear moderation effect of economic policy uncertainty. Then, the cubic term of economic policy uncertainty ($Uncertain_t^3$) and its cross-multiplier with digital finance ($Difi_{it}$*$Uncertain_t^3$) are added to model (3), yielding model (4) which examines whether there is an "N-type" or "inverse N-type" nonlinear moderating effect of economic policy uncertainty.

$$Inn_{it} = \alpha_0 + \alpha_1 Difi_{it} + \alpha_2 Uncertain_t + \alpha_3 Uncertain_t{}^2 + \alpha_4 Difi_{it} * Uncertain_t + \alpha_5 Difi_{it} * Uncertain_t{}^2 + \alpha_i Control_{it} + \lambda_i + \omega_t + \mu_{it} \quad (3)$$

$$Inn_{it} = \alpha_0 + \alpha_1 Difi_{it} + \alpha_2 Uncertain_t + \alpha_3 Uncertain_t{}^2 + \alpha_4 Uncertain_t{}^3 + \alpha_5 Difi_{it} * Uncertain_t + \alpha_6 Difi_{it} * Uncertain_t{}^2 + \alpha_7 Difi_{it} * Uncertain_t{}^3 + \alpha_i Control_{it} + \lambda_i + \omega_t + \mu_{it} \quad (4)$$

where $Uncertain_t$ indicates economic policy uncertainty and is measured using the Economic Policy Uncertainty index compiled by Baker et al. (2016). If the coefficients of $Difi_{it}$*$Uncertain_t^2$ and $Difi_{it}$*$Uncertain_t^3$ in the model are significantly non-zero, this indicates that economic policy uncertainty has a nonlinear moderating effect in the influence of digital finance on the innovation capacity of urban agglomerations.

### *Data sources and descriptive statistics*

Based on the availability of data, consistency of statistical caliber, and integrity of data samples, we exclude cities with missing data in the urban agglomeration. Finally, we select panel data of 196 cities in 19 urban agglomerations in China from 2008 to 2021. Basic data are obtained from the China City Statistical Yearbook. We use the PKU-DFIIC to measure digital finance development levels. Data such as the turnover of scientific and technological achievements, turnover of the technology market, and number of well-known trademarks are collected from the CSMAR and WIND databases, the National Bureau of Statistics, and local statistics bureaus. The number of patent applications for each city in the past year comes from the "China Patent Database" of the State Intellectual Property Office of the People's Republic of China. Economic policy uncertainty comes from Baker et al. (2016). The descriptive statistics of the variables are presented in Table 2.

The mean value of innovation capacity (*Inn*) of urban agglomerations is 0.15, the minimum value is 0.03, and the maximum value is 0.73. Thus, the innovation capacity of urban agglomerations exhibits

**Table 2**
Descriptive statistics.

| Variable type | Variable name | Variable abbreviation | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|---|---|
| Dependent variable | Innovation capacity of urban agglomeration | *Inn* | 209 | 0.1489 | 0.1291 | 0.0264 | 0.7281 |
| Independent variable | Digital finance | *Difi* | 209 | 0.4912 | 0.2100 | 0.0568 | 0.8854 |
| Mediating variables | Innovation capital agglomeration | *Cap* | 209 | 0.0526 | 0.0547 | 0.0039 | 0.2291 |
| | Entrepreneurial activity | *Ent* | 209 | 1.4859 | 0.8877 | 0.4430 | 5.4256 |
| | Credit resource allocation | *Credit* | 209 | 1.2023 | 0.3582 | 0.5324 | 2.2738 |
| Moderating variable | Economic policy uncertainty | *Uncertain* | 209 | 2.2001 | 1.7200 | 0.2285 | 4.6584 |
| Control variables | Opening-up degree | *Open* | 209 | 0.0022 | 0.0016 | 0.0000 | 0.0080 |
| | Urbanization rate | *Ur* | 209 | 0.6014 | 0.1228 | 0.3836 | 0.9881 |
| | Human capital | *Hum* | 209 | 2.4092 | 0.7516 | 1.1236 | 4.8436 |
| | Fixed asset investment | *Fai* | 209 | 16.4567 | 0.8145 | 11.9609 | 18.2332 |
| | Transportation level | *Trans* | 209 | 9.1950 | 0.4455 | 7.4060 | 10.4359 |
| | Unemployment level | *Unemploy* | 209 | 9.8042 | 0.4858 | 8.5134 | 10.7299 |

**Table 3**
Benchmark results.

| Variable | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *Difi* | 1.193*** | 1.067*** | | | |
| | (0.161) | (0.170) | | | |
| *Difi1* | | | 0.288 | | |
| | | | (0.191) | | |
| *Difi2* | | | | 0.526*** | |
| | | | | (0.111) | |
| *Difi3* | | | | | 0.406*** |
| | | | | | (0.071) |
| *Open* | | 2.824 | 1.922 | 4.555** | 6.234*** |
| | | (2.159) | (2.520) | (2.269) | (2.254) |
| *Ur* | | −0.089 | −0.147 | −0.087 | −0.181* |
| | | (0.103) | (0.113) | (0.107) | (0.104) |
| *Hum* | | −0.024*** | −0.028*** | −0.026*** | −0.028*** |
| | | (0.008) | (0.009) | (0.008) | (0.008) |
| *Fai* | | −0.001 | 0.005 | 0.002 | −0.000 |
| | | (0.004) | (0.005) | (0.005) | (0.004) |
| *Trans* | | 0.004 | 0.016 | 0.009 | 0.016* |
| | | (0.010) | (0.010) | (0.010) | (0.009) |
| Unemploy | | −0.034*** | −0.047*** | −0.034*** | −0.031*** |
| | | (0.010) | (0.011) | (0.010) | (0.010) |
| Constant | −0.019 | 0.395*** | 0.421*** | 0.340** | 0.356** |
| | (0.017) | (0.136) | (0.150) | (0.143) | (0.138) |
| Urban agglomeration | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes |
| Obs | 209 | 209 | 209 | 209 | 209 |
| R-squared | 0.670 | 0.701 | 0.638 | 0.675 | 0.692 |

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

substantial differences. Similarly, the level of digital finance development differs, with an average value of digital finance (*Difi*) being 0.49, the minimum value is 0.06, and the maximum value is 0.89. In addition, control variables, such as the degree of openness to the outside world (*Open*), urbanization (*Ur*), human capital (*Hum*), fixed asset investment (*Fai*), transportation level (*Trans*), and unemployment level (*Unemploy*) vary considerably across urban agglomerations.

## Empirical results

### *Benchmark regression results*

Table 3 reports the benchmark regression results for digital finance on the innovation capacity of urban agglomerations. The Hausman test is a statistical tool commonly used in empirical research to select fixed- and random-effects models (Bai et al., 2024). The Hausman test result shows that the p-value is 0.000, and the fixed-effects model should be used. The fixed effects model can effectively deal with individual differences, allowing us to accurately assess the impact of digital finance on the innovation capacity of urban agglomerations while controlling for their inherent characteristics. Column (1) shows the regression results without control variables. Digital finance has a significant positive impact on the innovation capacity of urban agglomerations (coefficient = 1.205; passes the significance level test at the 1% level). Column (2) adds the control variables to the regression model. Again, the main effect holds (coefficient = 1.064; passes the significance level test of 1%), supporting Hypothesis 1. At its core, digital finance involves providing inclusive and accurate financial services (Teng & Ma, 2020) by applying digital technology and other fintech technologies (Hasan et al., 2020). It can effectively overcome many restrictions on traditional financial services, promote the service efficiency and quality improvement of financial institutions (Yang et al., 2022), and encourage innovative and entrepreneurial activities. Meanwhile, the characteristics of "inclusiveness" and the "grassroots" of digital finance (Durai & Stella, 2019) coincide with the innovative financing needs of MSMSEs. The development of digital finance lowers the cost and threshold of financial services, and increases the sources of capital for MSMEs. With artificial intelligence, big data, and other digital technologies, digital finance can speed up the approval process, reduce the financing costs of MSMEs, and ensure the smooth progress of innovation activities.

The Digital Finance Index comprises three sub-indicators: coverage, depth of use, and digitization level. The results in columns (3)–(5) of Table 5 show the impact of the three dimensions on the innovation capacity of urban agglomerations. The depth of use of digital finance has the greatest and most significant impact on the innovation capacity (coefficient = 0.526; passes the significance test at the 1% level).

Digitization level also has a significant positive impact on the innovation capacity (coefficient = 0.046; passes the significance test at the 1% level). Although the regression coefficient of digital financial coverage breadth on the innovation capacity of urban agglomerations is positive, it does not pass the significance test. Thus, the main effect is mainly driven by the depth of use of digital finance and digitization level. Although the coverage of digital finance can expand the beneficiary groups of financial services so that more groups can reach it, its direct correlation with the improvement of innovation capacity of urban agglomeration is weak (Nie et al., 2021). The breadth of coverage does not guarantee the quality and depth of service. Innovative activities are uncertain and require significant capital, long-term investments, and professional risk assessment. Therefore, the quality and depth of service are more critical to innovation activities. High-quality financial services can accurately assess risks and rationally allocate resources (Tao et al., 2022; Xie et al., 2018), whereas in-depth services can provide customized solutions that are critical elements for stimulating innovation vitality and improving the innovation capacity of urban agglomerations.

*Robustness test and endogenous problem handling*

To ensure the accuracy of the conclusions, five robustness tests are conducted: replacing the dependent variable, replacing the independent variable, adjusting the research sample, adjusting the sample interval, and mitigating the influence of outliers. First, we replace the dependent variables. The Urban Innovation Index published by Kou and Liu (2017) has been widely adopted by scholars as a measure of urban innovation capacity. Therefore, we use this index as a proxy variable for the innovation capacity of urban agglomerations. The results shown in Column (1) of Table 4 are consistent with the benchmark results. Second, we use the "text mining method" to construct the Internet finance index as a substitute variable for digital finance. The regression results in Column (2) of Table 4 are consistent with the main results. Third, we adjust the research sample by excluding urban agglomerations with fewer than three cities, such as the north slope of Tianshan Mountain, central Guizhou Urban agglomeration, and central Yunnan Urban agglomeration. This is because the number of cities in China's urban agglomerations differ, which may affect the accuracy of the estimation results. Column (3) of Table 4 shows the results, which is qualitatively similar to the main results. Next, to avoid the excessive policy confusion effect caused by an excessively long sample interval, this study shortens the sample interval and selects the samples from 2013 to 2021. The results in Column (4) of Table 4 are consistent with the main results. Finally, to avoid the influence of possible outliers given the large differences between the maximum and minimum values for each variable, we winsorize the 0.5% and 1% outliers of the dependent, independent, and control variables. The results in Columns (5) and (6) of Table 4 yield the same conclusions as the benchmark results. Thus, our main conclusions hold under these robustness tests.

Next, we address endogeneity concerns. First, we lag the core explanatory and control variables by one and two periods to mitigate reverse causality between digital finance and the innovation capacity of urban agglomerations (Wooldridge, 2010). The results shown in Columns (1) and (2) of Table 5, respectively, are consistent with the main conclusions. Next, we employ the instrumental variable approach. Geographical location is an exogenous variable that is separate from the economic system. Referring to Nunn and Qian (2014), the average distance between prefecture-level cities and ports in urban agglomerations is used as an instrumental variable for digital finance. Considering that the research sample consists of balanced panel data and selected instrumental variable has cross-sectional data, it cannot meet the requirements of the panel data regression model. Therefore, the selected instrumental variable is interacted with the number of Internet broadband users at the national level in the current period, which is used as the instrumental variable for digital finance. The regression results shown in Columns (3) and (4) of Table 5 reveal that in the first-stage regression, the instrumental variable coefficient is significantly negative. The Wald F statistic is 85.37, which is much higher than 10, and the LM statistic is 64.56 (p=0.000). Thus, there is no weak variable problem in the selected instrumental variables and the over-recognition constraint is effective. Column (4) presents the second-stage regression results. After considering possible endogeneity problems, the influence

**Table 5**
Endogeneity test results.

| Variable | Independent variable lag processing | | Instrumental variable method | |
|---|---|---|---|---|
| | (1) | (2) | (3) First-stage regression | (4) Second-stage regression |
| Difi | | | | 1.102*** |
| | | | | (0.462) |
| L.Difi | 1.087*** | | | |
| | (0.181) | | | |
| L2.Difi | | 1.058*** | | |
| | | (0.197) | | |
| TRI | | | −0.001*** | |
| | | | (0.000) | |
| _Cons | 0.514*** | 0.614*** | −0.188*** | −0.624*** |
| | (0.150) | (0.169) | (0.049) | (0.258) |
| Control | Yes | Yes | Yes | Yes |
| Urban agglomeration | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes |
| obs | 190 | 171 | 209 | 209 |
| R2 | 0.710 | 0.692 | 0.992 | 0.571 |
| C-D Wald F statistic | | | 85.369 | 85.369 |
| A- canon LM statistic | | | 64.559 | 64.559 |
| 10% max IV size | | | 16.380 | 16.380 |

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

**Table 4**
Robustness test results.

| Variable | (1) Replacing the dependent variable | (2) Replacing the independent variable | (3) Adjusting the research sample | (4) Adjusting sample interval | (5) 0.5% Tailing treatment | (6) 1% Tailing treatment |
|---|---|---|---|---|---|---|
| *Difi* | 6.285*** | 0.124* | 1.117*** | 1.049*** | 0.984*** | 0.837*** |
| | (0.895) | (0.071) | (0.183) | (0.177) | (0.162) | (0.153) |
| Constant | 1.684** | 0.439*** | 0.593** | 0.038 | 0.386*** | 0.353*** |
| | (0.716) | (0.150) | (0.234) | (0.143) | (0.133) | (0.129) |
| Control | Yes | Yes | Yes | Yes | Yes | Yes |
| Urban agglomeration | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| obs | 209 | 209 | 176 | 171 | 209 | 209 |
| R-squared | 0.965 | 0.567 | 0.668 | 0.688 | 0.709 | 0.660 |

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

**Table 6**
Heterogeneity analysis results.

| Variable | (1) Small-scale | (2) Large-scale | (3) High marketization | (4) Low marketization | (5) Polycentric | (6) Monocentric |
|---|---|---|---|---|---|---|
| Difi | 0.741*** | 1.097* | 1.367*** | 0.118 | 1.670*** | 0.548** |
| | (0.130) | (0.545) | (0.266) | (0.157) | (0.238) | (0.255) |
| _Cons | 0.169* | 1.841* | −0.439 | 0.123 | 0.241 | 0.328* |
| | (0.091) | (1.054) | (0.279) | (0.142) | (0.275) | (0.191) |
| Control | Yes | Yes | Yes | Yes | Yes | Yes |
| Urban agglomeration | Yes | Yes | Yes | Yes | Yes | Yes |
| Year | Yes | Yes | Yes | Yes | Yes | Yes |
| Obs | 159 | 50 | 108 | 101 | 99 | 110 |
| R-squared | 0.721 | 0.921 | 0.749 | 0.656 | 0.766 | 0.773 |

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

coefficient of digital finance on the innovation capacity of urban agglomerations is still significantly positive.

*Heterogeneity analysis*

First, we perform heterogeneity analysis by urban agglomeration size. We consider the average sum of the registered populations of urban agglomerations as the measure of size. We define urban agglomerations that are greater than the average population as "large-scale urban agglomerations" and those that are less than the average as "small-scale urban agglomerations." The regression results are shown in Columns (1) and (2) of Table 6, respectively. Digital finance has a significant positive promoting effect on the innovation capacity of both large- and small-scale urban agglomerations, with stronger effects for the latter. These differences may be because of the difference in the access to financial resources. Small-scale urban agglomerations lack financial resources and traditional financial coverage, making it difficult for innovative MSMEs to obtain sufficient funds through traditional financial channels. Digital finance can overcome these geographical limitations, use big data to accurately match the supply and demand of funds, quickly provide funds for innovative subjects, and provide timely assistance to technology start-ups. By contrast, large-scale urban agglomerations are rich in financial resources, and innovative firms have more access to capital and are less dependent on digital finance. The second factor is the innovation cost. Digital finance reduces transaction costs and information asymmetry. This can particularly help in small-scale urban agglomerations, helping enterprises and talent reduce costs, such as those related financing and research. While large-scale urban agglomerations have also benefited, the promotion of innovation through digital finance has been relatively limited owing to complex economic structures and dispersed effect of cost reductions. The third factor is policy flexibility. Small urban agglomerations are relatively simple in terms of their administrative hierarchy because of their small geographical scope. Policymakers can capture information more keenly in the face of market changes and innovation needs. When digital finance brings new development opportunities and innovation needs, smaller agglomerations can react quickly and introduce policies to support the integration of digital finance and innovation to adjust the policy direction in a timely manner. In contrast, large-scale urban agglomerations have complex administrative systems, where policymaking needs to consider the interests of many parties, and the decision-making process is complicated. Therefore, it is difficult to adjust policies quickly to market changes, resulting in a slower response in the use of digital finance to drive innovation.

Next, we perform the heterogeneity analysis considering the marketization levels in urban agglomerations. We separate the sample into high and low marketization level urban agglomerations depending on whether they are above or below the mean marketization level, respectively. The regression results are shown in columns (3) and (4) of Table 6, respectively. Digital finance has a significant effect on the innovation capacity of urban agglomerations with high marketization levels (coefficient = 1.37; passes the significance test at the 1% level). However, it has no significant effect on the innovation capacity of urban agglomerations with low marketization levels. These differences may drive by the following three factors: The first is innovation demand and response. In urban agglomerations with high marketization levels, enterprises are highly competitive and have a strong demand for innovation to survive and develop. Simultaneously, consumer demand for innovative products and services is also stronger. Enterprises and financial institutions in high marketization urban agglomerations have flexible decision-making mechanisms. Digital finance can help them capture these demands and respond precisely to the innovation needs. By contrast, there is insufficient market competition within low-marketization urban agglomerations. Enterprises have insufficient incentives to innovate, with relatively little and singular demand for innovation. Bound by traditional thinking and institutions, the decision-making process is cumbersome and the response to innovation demand is slow. Even if digital finance can support innovation, it is difficult to find sufficient high-quality innovation projects or face obstacles in the process of effectively stimulating innovation. The second factor is the efficiency of resource allocation. In high marketization, urban agglomerations have well-developed market mechanisms such as price signals, competition mechanisms, and the free flow of factors. With the help of big data, artificial intelligence, and other technologies, digital finance can more accurately assess the potential and risks of innovative projects, precisely allocate innovative resources to the most valuable innovative fields, and improve the efficiency of resource utilization. However, in urban agglomerations with low marketization levels, the market mechanism is flawed, and price signals are distorted. It is difficult for digital finance to accurately judge the value of innovative projects, which may lead to the allocation of resources to inefficient or non-innovative areas. Moreover, factors such as local protectionism and industry monopolies are more common in such urban agglomerations, restricting the free flow of resources and development of innovative activities. The third factor is the innovation ecosystem. Urban agglomerations with high marketization levels have abundant innovation factors, such as universities, research institutions, and scientific and technological intermediary service institutions, with close synergy and cooperation among these factors. As an important link, digital finance can promote the deep integration of industry, academia, and research, provide comprehensive financial support for innovation, accelerate the transformation and application of innovation results, and improve the innovation ecosystem. Low marketization urban agglomerations often lack high-quality innovation resources, and effective communication and collaboration among the elements in the innovation ecosystem. Without a good foundation in the innovation ecology, it is difficult for digital finance to promote innovation.

Next, we analyze the heterogeneity by the spatial structure of urban agglomerations A reasonable spatial structure provides the platform for regional economic development and optimizing the spatial allocation of resources (He et al., 2021). The advantages and disadvantages of single and multiple centers have been debated in academic circles. To investigate the heterogeneity impacts of digital finance on the innovation

capacity of urban agglomerations with different spatial structures, this study classifies 19 urban agglomerations in China into monocentric and polycentric urban agglomerations based on the sequencing scale method[6]. The innovation advantage of polycentric urban agglomerations may come from their internal synergy networks rather than simple spatial structural differences. Hence, it is necessary to control for innovation synergies. This study uses the variance in the per capita innovation capacity of cities within an urban agglomeration to measure the degree of innovation synergy. When the variance is large, it indicates a large gap in innovation capacity between cities and a large obstacle to synergistic development. The regression results are shown in Columns (5) and (6) of Table 6. According to the $Difi_{it}$ regression coefficient and significance, digital finance has a significantly positive promoting effect on the innovation capacity of urban agglomerations with polycentric and monocentric spatial structures. However, the value of $Difi_{it}$ regression coefficient in polycentric urban agglomeration (1.68) is larger than that in monocentric urban agglomeration (0.52). This is because of, first, diversified innovation needs. Polycentric urban agglomerations typically exhibit distinctive industrial characteristics. The industrial structure of each center varies greatly and covers multiple fields, which makes innovation demand more diversified in terms of type, scale, and level. Simultaneously, innovation subjects in polycentric urban agglomerations are diverse and have significant differences in demand. By relying on big data, artificial intelligence, and other technologies, digital finance can accurately identify the needs of each center and provide customized services. By contrast, the industrial structure of monocentric urban agglomerations is relatively homogeneous, focusing on the development of leading industries in core cities. Further, the demand for innovation is concentrated in specific fields. The concentration of innovation subjects in core cities limits the diversity and flexibility of digital financial services. T he second aspect is the promotion of collaborative innovation. There is a strong complementarity of resources, technologies, and talent among cities in polycentric urban agglomerations. Digital financing can facilitate the integration of factor flows and promote cross-regional innovation cooperation. Meanwhile, multi-center urban agglomerations are easy for forming complex innovation networks. Here, innovation subjects can conveniently communicate and cooperate through digital finance to build innovation alliances and accelerate the transformation of innovation outputs into commercial products or services. In contrast, monocentric urban agglomerations exhibit a core-edge structure. Innovation is concentrated in the core city, whereas peripheral cities have a relatively secondary position in innovation. Collaborative innovation is more about the radiation of innovation from core cities to neighboring cities, making it difficult to form an comprehensive, multilevel, and collaborative innovation. Digital finance mainly supports the diffusion of innovations from the core cities to the periphery, and its role in promoting inter-city collaborative innovation is relatively limited.

The third factor is risk diversification and response. Polycentric urban agglomerations have diversified economic structures to reduce innovation risks. Digital finance can diversify investments, invest funds in innovative projects in different centers and industries, and balance risks and returns. Simultaneously, central cities can share information and experience to provide backup solutions for innovation. Monocentric urban agglomerations are dependent on core cities for innovation, where risks are concentrated. In the event of a major risk to the core city, the innovation capacity is severely affected. In this case, it is difficult for digital finance to diversify risks through internal diversification, and innovation activities may come to a standstill or regress.

[6] The monocentric urban agglomerations include the Central Plains urban agglomerations, the middle reaches of the Yangtze River, Guanzhong urban agglomeration, north slope of Tianshan Urban agglomeration, Chengdu-Chongqing urban agglomeration, Beijing-Tianjin-Hebei urban agglomeration, Lanzhou Xining urban agglomeration, Beibu Gulf urban agglomeration, the Jinzhong urban agglomeration, and the central Yunnan urban agglomeration. Polycentric urban agglomerations include Yangtze River Delta, Pearl River Delta urban agglomeration, Shandong Peninsula urban agglomeration, Ningxia Yanhuang urban agglomeration, Hubao Eyu urban agglomeration, West Strait urban agglomeration, Harbin-Chang urban agglomeration, central and southern Liaoning urban agglomeration, and central Guizhou urban agglomeration.

*Mechanism analysis*

Based on Model (2), this study explores the mediating roles of different factors in the relationship between digital finance and the innovation capacity of urban agglomerations. The regression results are presented in Table 7.

First, we consider innovation capital agglomeration. The results in Column (1) of Table 7 show that the development of digital finance significantly promotes the agglomeration of innovative capital in urban agglomerations (coefficient = 0.11, passing the significance test at the 1% level). Studies have confirmed the positive relationship between innovation capital agglomeration and innovation capacity. Yu (2011) used the spatial panel measurement method to study the relationship between innovation factor agglomeration, government support, and technological innovation efficiency. The author found a clear spatial correlation between the efficiency of scientific and technological (S&T) innovation in China. Further, the agglomeration of innovation factors positively affects enterprises' S&T innovation efficiency. Fang and Xie (2012) focused on 31 provinces in China to explore the impact of the spatial distribution of innovation factors on regional innovation outputs. The authors found that R&D expenditure has a positive correlation with the number of patents granted. Yu et al. (2023) found that the agglomeration of innovation factors, characterized by knowledge and technology, has a significant positive impact on innovation efficiency. The flow of innovative talent and capital between regions is conducive to the spatial spillover of knowledge. Further, the positive spillover effect of regional innovation capital is greater than that of innovation talent. Therefore, digital finance can promote the innovation capacity of urban agglomerations through the innovation-capital agglomeration effect. Additionally, digital finance has the potential to affect the allocation of financial resources and information flows, enhancing the agglomeration and circulation of funds in urban agglomerations. Simultaneously, digital finance promotes the formation of fintech ecosystems in urban agglomerates, promoting the agglomeration of the financial industry and ensuring financial stability (Risman et al., 2021). Innovation funds gather and flow into urban agglomerations through cooperation among the innovation participants. Moreover, the concentration of innovation funds provides the necessary financial support and guarantees for improving innovation capacity. It is helpful for promoting high-tech industrial agglomeration, technology upgrading, and industrial structure optimization in key industries within urban agglomerations (Xu & Jiao, 2021), thereby improving the innovation level of urban agglomerations.

**Table 7**
Benchmark mechanism analysis results.

| Variable | (1) *Cap* | (2) *Ent* | (3) *Credit* |
|---|---|---|---|
| Difi | 0.107*** | 10.516*** | −2.211** |
| | (0.032) | (1.678) | (1.053) |
| _Cons | 0.044* | 1.788 | 3.623*** |
| | (0.026) | (1.342) | (0.842) |
| Control | Yes | Yes | Yes |
| Urban agglomeration | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| obs | 209 | 209 | 209 |
| R2 | 0.257 | 0.819 | 0.680 |

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

The second mechanism we consider is entrepreneurial activity. The results in Column (2) of Table 7 show that digital finance has a significant positive impact on entrepreneurial activity (coefficient = 10.52, passing the significance test at the 1% level). Improvements in entrepreneurial activity are conducive to providing the vitality for innovation in urban agglomerations. This finding has been supported by several scholars. Entrepreneurial activity plays an important role in promoting high-quality development and innovation capacity enhancement such as industrial upgrading (Wei & Jiajia, 2019), job creation (Glaeser et al., 2015), and structural transformation (Noseleit, 2013), thereby greatly contributing to the improvement of innovation capacity. Equal opportunities for entrepreneurship can increase entrepreneurial activity, and promote inclusive growth and innovative development in China (Xun et al., 2020). Hence, digital finance can promote the innovation capacity of urban agglomerations by improving entrepreneurial activities. By providing diversified financing channels and tools, digital finance lowers the threshold for entrepreneurs to obtain funds (Wang, 2022; Qin et al., 2022), thereby promoting "mass entrepreneurship and innovation". Simultaneously, the efficiency and creativity of digital finance can be improved (Alkhwaldi et al., 2022), which can help reduce the operating cost of financial services (Ketterer, 2017), thus encouraging enterprises to realize product and service innovation with more abundant funding (Luo, 2022). From the demand side, digital financial technology can help entrepreneurs better understand and meet market needs by quickly adjusting their business strategies and product designs. Furthermore, the increase in entrepreneurial activity promotes the exchange and dissemination of knowledge and technology. The professional knowledge in different fields can gather and influence each other (Amaghouss & Ibourk, 2013; Szirmai et al., 2011), thereby promoting the cross-border integration of urban agglomeration innovation.

The third mechanism is credit resource allocation. The results in Column (3) of Table 7 show that digital finance has a significant negative impact on credit constraints (coefficient = -2.21, passing the significance test at the 5% level). Thus, digital finance can help alleviate credit constraints and improve the allocation of credit resources. Improvements in the allocation of credit resources can help innovative enterprises obtain innovation funds and promote innovative activities in urban agglomerations. Studies have confirmed the positive relationship between credit resource allocation and innovation capacity improvement. Impullitti (2022) proposed a new mechanism that uncovers the link between credit access and productivity growth, finding that increased credit constraints lead to reduced firm innovation. Hlioui et al. (2022) argued that cheaper access to credit facilitates financing, leading to more competition in product markets. This, in turn, promotes stronger choice, innovation, and growth. Zhenjie (2016) held the view that the credit market's function of facilitating financing and resource allocation can, to a certain extent, improve the efficiency of credit resource allocation and thus enhance the impetus for technological innovation of Chinese enterprises. The development of digital finance is conducive for improving information transparency and market efficiency, guiding the optimal allocation of social resources, improving resource utilization efficiency (Wang et al., 2022), and avoiding resource waste and credit discrimination. Meanwhile, digital finance reduces financing difficulties by providing online financing channels (Guo et al., 2023) expands financial services to more regions and groups within urban agglomerations, and improves the balanced allocation of credit resources. In turn, improved allocation of credit resources means that more funds can flow into better innovative enterprises and projects, which can be used to develop new technologies, products, and services. Intra-group firms can also more actively participate in market competition (Dell'Ariccia & Marquez, 2004).

Next, we test the robustness of the mechanism analysis results by employing substitute variables. First, we substitute the innovation capital agglomeration variable (*cap**). Originally, we use proportion of urban agglomeration R&D expenditure to national R&D expenditure as the proxy for innovation capital agglomeration. This proxy highlights the relative importance of urban agglomeration R&D expenditures in the national economy. However, the uneven distribution of R&D resources within urban agglomerations may be overlooked. Moreover, the ratio is significantly influenced by the size of urban agglomerations (such as population size and economic aggregates, etc.) (Reynolds et al., 2005; Shanshan et al., 2024). Therefore, this study selects R&D expenditure per 10,000 people as a substitute variable.

Next, we substitute the entrepreneurial activity variable (*Ent**). Existing methods for measuring innovation activity include population, labor market, and ecological research methods (Zeng & Wen, 2021; Shanshan et al., 2024). Our original measure of entrepreneurial activity is the number of new businesses per 100 people. This uses the regional population as the standardized base. It reflects the degree of individual residents' participation in entrepreneurship in urban agglomerations, demonstrating the popularity of entrepreneurial activities and vitality among the population. As an alternative, we use the number of employees as the standardized base for the number of newly registered enterprises. It reflects the proportion of the labor force participating in entrepreneurship and the dynamic change in employment structure; thus, it can appropriatley reflect entrepreneurial activity.

We then substitute the credit resource allocation variable. The positive effect of credit input on the real economy can be reflection of the efficient state of credit capital allocation (Peng et al., 2018). Hence, this study selects the ratio of economic output to credit input (added value of the secondary industry/balance of deposits and loans) as a substitute variable. This index reflects whether credit resources are effectively allocated to areas that produce higher outputs.

Table 8 lists the regression results after replacing the mediating variables. The regression coefficients of innovation capital concentration (*Cap**), entrepreneurial activity (*Ent**) and credit resource allocation (*Credit**) are significantly positive (coefficients are 0.33, 0.42 and 0.79, respectively, which pass the statistical significance test of 5%, 1% and 1% respectively). These results are consistent with the benchmark mechanism analysis results.

### *Nonlinear moderating effect analysis*

Economic policy uncertainty is an important environmental factor affecting the digital economy and regional innovation (Zhou et al., 2023; Nguyen & Nguyen, 2023). Due to the complexity of the economic system and behavior of market agents, economic policy uncertainty may have a nonlinear impact on the influence of the digital economy on the innovation capacity of urban agglomerations. Table 9 presents the empirical results for the nonlinear moderating effect of economic policy uncertainty on the impact of digital finance on innovative capacity. Column (1) shows the regression results of Model (3), which introduces only the squared term of economic policy uncertainty with the digital finance cross-multiplier ($Difi_{it}*Uncertain_t^2$). The coefficients of $Difi_{it}*Uncertain_t$ and $Difi_{it}*Uncertain_t^2$ are not significant at the 10% significance level. Column (2) introduces the cross-multiplier of the cubic term of

**Table 8**
Robustness test results for the mechanism analysis.

| Variable | (1) *Cap** | (2) *Ent** | (3) *Credit** |
|---|---|---|---|
| Difi | 0.326** | 0.420*** | 0.794*** |
| | (0.157) | (0.150) | (0.235) |
| _Cons | 0.233* | −0.006 | −0.327* |
| | (0.126) | (0.120) | (0.188) |
| Control | Yes | Yes | Yes |
| Urban agglomeration | Yes | Yes | Yes |
| Year | Yes | Yes | Yes |
| obs | 209 | 209 | 209 |
| R2 | 0.641 | 0.786 | 0.755 |

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively; robust standard errors are in parentheses.

**Table 9**
Moderating effect of economic policy uncertainty.

| Variable | (1)<br>*inn* | (2)<br>*inn* |
|---|---|---|
| Difi | 0.468* | 0.649** |
| | (0.243) | (0.255) |
| Difi*Uncertain | 0.057 | −0.686* |
| | (0.123) | (0.370) |
| Difi*Uncertain$^2$ | 0.015 | 0.388** |
| | (0.024) | (0.177) |
| Difi*Uncertain$^3$ | | −0.049** |
| | | (0.023) |
| _Cons | 0.624*** | 2.175** |
| | (0.219) | (0.900) |
| Control | Yes | Yes |
| Urban agglomeration | Yes | Yes |
| Year | Yes | Yes |
| obs | 209 | 209 |
| R2 | 0.734 | 0.741 |

economic policy uncertainty with digital finance ($Difi_{it}$*$Uncertain_t^3$) based on Model (3). The coefficients of $Difi_{it}$*$Uncertain_t$, $Difi_{it}$*$Uncertain_t^2$ and $Difi_{it}$*$Uncertain_t^3$ are -0.686, 0.388 and -0.049, respectively, and are significant at the 10%, 5%, and 5% levels, respectively. Thus, economic policy uncertainty exerts an "N-type" nonlinear moderating effect. According to the extreme value solution method, further calculations show that the first and second thresholds in model (4) are 0.049 and 4.173, respectively. Thus, first, when the economic policy uncertainty index is less than 1.123, the facilitating effect of digital finance on the innovation capacity of urban agglomerations shrinks with an increase in economic policy uncertainty. This is because when economic policy uncertainty is low, firms' innovation decisions are usually based on stable policy expectations and have a greater tendency to be risk averse (Tajaddini & Gholipour, 2021; Peng et al., 2023; Geng et al., 2023). Simultaneously, it may prompt market players to solidify established business models and technological routes, reinforce path dependency, and inhibit the exploration of disruptive innovations (Teece, Pisano, & Shuen, 1997). Second, when the economic policy uncertainty index is between 1.123 and 4.173, the facilitating effect increases with increasing economic policy uncertainty. This is because when economic policy uncertainty rises to a moderate level, it catalyzes innovation mechanisms. It also prompts urban agglomerations to reorganize their resources to cope with environmental changes (Cheng & Masron, 2023), promote the optimal allocation of innovation resources, and facilitate cross-regional collaborative innovation (Lin & Ma, 2022). Third, when the economic policy uncertainty index exceeds 4.173, economic policy uncertainty re-suppresses the contribution of digital finance to the innovation capacity of urban agglomerations. This is because frequent policy fluctuations make it difficult for market players to accurately judge future market demand, cost changes, etc., and the expected returns on investment and innovation become highly unstable (Ilmanen, 2022). This in turn inhibits long-term R&D investment. Meanwhile, excessive policy uncertainty can undermine the normal operation of the market mechanism, leading to market failure and serious distortions in resource allocation.

## Conclusion

### *Main conclusions*

Digital finance, as a new financial model, is booming and has become a new engine for the high-quality development of regional economies and improving innovation capacity. Based on the panel data of 196 prefecture-level cities in 19 urban agglomerations in China from 2008 to 2021, this study explores the impact of digital finance on the innovation capacity of urban agglomerations and the underlying mechanisms. The conclusions are summarized below.

First, digital finance has a significant positive impact on the innovation capacity of urban agglomerations. The comprehensive index of digital finance, depth of use, and digitization level all play significant positive roles, whereas the breadth of coverage has no significant effect. For innovative activities, the quality and depth of digital financial services are more critical. Meanwhile, the breadth of coverage may be less correlated with innovation capacity and is merely a quantitative expansion. It does not ensure the quality and depth of service. Therefore, the positive effect of digital finance on innovation capacity is mainly driven by the depth of its use and degree of digital financial services. Moreover, the main conclusions hold under various robustness and endogeneity tests.

Second, heterogeneity analysis shows that digital finance plays a more significant role in the innovation capacity of small-scale, highly marketized, and polycentric urban agglomerations. First, small-scale urban agglomerations have relatively limited financial resources. Here, innovation costs are low and policy flexibility is relatively high. Digital finance can help them overcome regional restrictions, accurately match the supply and demand of funds, and provide timely assistance to technology start-ups, thus having a stronger positive impact on innovation capacity. Second, urban agglomerations with high marketization levels have a free flow of factors and fierce competition among enterprises. This create a better innovation ecosystem and greater innovation demand. Digital finance can allow these urban agglomerations to efficiently allocate resources, guiding capital to areas with high innovation efficiency. This can strengthen the effect of digital finance on innovation capacity. Third, polycentric urban agglomerations have diversified innovation needs and close cooperation among centers, which is conducive to risk diversification and response. Digital finance can help diversify investment, provide customized services, and invest funds in innovation projects in different centers and industries.

Next, mechanism analysis shows that the main effect is driven by the agglomeration of innovation capital, improved entrepreneurial activity, and enhanced credit resource allocation. First, digital finance contributes to the cross-regional transfer and liquidation of funds, thus creating the innovation capital agglomeration and providing the required financing for improving the innovation capacity of urban agglomerations. Second, digital finance lowers the capital access threshold and improves the accuracy of market positioning for the demand side, thus enhancing entrepreneurial activity. Third, digital finance helps reduce information asymmetry and improves the efficiency of financial services, thereby enhancing credit resource allocation and directing more innovation funds to innovative enterprises.

Lastly, economic policy uncertainty plays an "inverted N-type", nonlinear moderating role in the relationship between digital finance and innovation capacity. Due to the complexity of the economic system and behavior of market agents, economic policy uncertainty may have different impacts at different levels, resulting in a dynamic trade-off between risk aversion, the incentive to innovate, and pressure to survive. When economic policy uncertainty is low, firms tend to be risk averse and path dependent, inhibiting the exploration of disruptive innovations. When economic policy uncertainty rises to a moderate level, it pushes innovation and resource reorganization. Here, its inhibitory effect on innovation capacity diminishes or even turns into a positive incentive. Finally, when economic policy uncertainty overcomes a threshold, it undermines the normal functioning of the market mechanisms. Then, the expected return on investment and innovation by market participants is highly volatile, with its negative impact dominating again.

### *Theoretical and practical contributions*

Theoretically, first, this study advances the theory of the relationship between finance and innovation. Extant research has mostly focused on the provincial, municipal, and enterprise levels in China. For example, Li et al. (2023) and Li and Li (2022) analyzed the impact of digital finance

on urban innovation from the perspective of cities. Nie (2021) and Hui et al. (2023) conducted spatial econometric analyses of the impact of digital finance on regional green innovation efficiency from a provincial perspective. Teng and Ma (2020) and Zhang et al. (2023) analyzed the impact of digital finance on enterprise innovation from the micro-perspective of enterprises. Differing from extant studies, this study focuses on the spatial unit of urban agglomerations. As complex urban agglomerations span administrative regions, their innovative activities involve specific factors such as resource flow and collaboration among cities. This study sheds light on the underlying mechanisms through which digital finance promotes the innovation capacity of urban agglomerations and improves the theoretical framework of financial innovation from the micro to macro level.

Second, this study deepens the theory of regional innovation systems. Many studies have explored the factors that influence regional innovation capacity, including urbanization (Andersson, et al., 2009), industrial structure and financial development level (Feng et al., 2023), transportation infrastructure (Bian et al., 2019), and foreign direct investment (Cheung & Ping, 2004). This study introduces digital finance as a key variable in the urban agglomeration innovation research. It clarifies the core position of digital finance in the construction of the innovation ecosystem in urban agglomerations and its heterogeneity in different types of urban agglomerations, thus providing new empirical evidence for the theory of differentiated regional development.

Third, this study expands the theory of economic policy uncertainty. Many studies argue that economic policy uncertainty negatively affect macroeconomic and microenterprise activities (Fernández-Villaverde et al., 2015; Baker et al., 2016; Julio & Yook, 2012; Gulen & Ion, 2016). Meanwhile, a few scholars believe that economic policy uncertainty positively affects scientific and technological innovation activities (Atanassov et al., 2024; Marcus, 1981). However, most scholars believe that economic policy uncertainty causes enterprises to delay their R&D investment decisions, which damages the driving force of a country's economic innovation and hinders innovation, particularly in industries with high R&D intensity and politically connected enterprises (Bhattacharya et al., 2017; Wang et al., 2017; Hao et al., 2016). Therefore, understanding the complex mechanisms of policy uncertainty in the innovation process is crucial. This study finds that economic policy uncertainty plays an "inverted N-type" nonlinear moderating role in the relationship between digital finance and innovation capacity of urban agglomeration. This challenges the traditional understanding of this relationship, opening up a new research direction for the theory of economic policy uncertainty and urging scholars to re-examine the complex mechanism of policy uncertainty in the innovation process.

Practically, first, this study provides a rigorous, empirically tested foundation for promoting sustainable economic development. This study finds that digital finance promotes the concentration and effective allocation of innovative capital. Enhancing entrepreneurial activities can give birth to more innovative enterprises with sustainable development concepts. Hence, the government should optimize the allocation of innovation capital, guide capital to towards innovative projects with sustainable development potential, and focus on supporting green technology and the circular economy. Next, stakeholders should build a digital financial service platform, integrate enterprise innovation project information and capital supply information, use big data to achieve accurate matching, improve innovation capital allocation efficiency, and promote the sustainable development of innovative enterprises.

Second, efforts should focus on enhancing regional innovation capacity. Digital finance has different effects on the innovation capacity of urban agglomerations with different characteristics. Thus, through reasonable guidance and the development of digital finance, the innovation capacity of different urban agglomerations can be effectively improved. Based on the comparative advantages of different urban agglomerations, the government should formulate targeted digital financial development strategies. It should also strengthen the integration of digital finance and the innovation ecology. Next, a cooperation mechanism between digital finance and scientific research institutions and universities should be established, including a joint innovation fund to support industry-university-research cooperation projects, and enhance the overall innovation capacity of the region.

Third, this study provides a theoretical basis for promoting the coordinated development of economy and society. This study finds that digital finance can help overcome the geographical and scale limitations of traditional financial services, and provide innovation opportunities and financial support for MSMEs and underdeveloped areas in urban agglomerations. Therefore, the government should expand the coverage of digital financial services, increase investments in the construction of digital financial infrastructure in less-developed areas, and improve the availability of digital financial services. Finally, it should encourage digital financial institutions to develop financial products suitable for MSMEs and vulnerable groups, provide them with innovation opportunities and financial support, and narrow regional economic gaps, thereby promoting coordinated economic and social development.

### *Policy implications*

First, the government should accelerate the layout of digital finance in China, increase the construction of the digital financial infrastructure, and promote the innovative development of urban agglomerations empowered by digital finance. On the one hand, the government should increase the construction of information infrastructure, and focus on removing digital barriers and information "islands." Next, it should remove obstacles to the development of digital finance and lay a solid foundation for the innovation-driven development of urban agglomerations. Simultaneously, it should strengthen the integration of the new generation of information technology and the financial industry. The digital transformation of traditional financial institutions should be accelerated through the application of financial technology, while a good investment environment for improving the innovation capacity of urban agglomerations should be created. On the other hand, effective measures should be established, such as establishing a financial technology innovation fund and providing tax incentives, to encourage the financial industry to undertake digital transformation. The government should support the research and application of digital financial technology, and strengthen the service functions of digital finance in the real economy. It is also necessary to build a diversified talent training mechanism, particularly to strengthen the training and introduction of financial technology talent. Next, policymakers should strengthen the construction of scientific and technological innovation R&D teams and cultivate professionals with digital financial skills.

Second, policymakers should consider the comparative advantages of each urban agglomeration and formulate appropriate digital financial development strategies. Large-scale urban agglomerations are rich in resources, solid industrial bases, and innovation factors. However, there may also be problems, such as the uneven distribution of digital financial resources and difficulty in regional coordination. Therefore, here, digital finance development should focus on optimizing resource allocation and strengthening collaboration. On the one hand, a regional digital financial development fund should be established to guide the flow of resources to vulnerable areas. Financial institutions should be encouraged to set up branches in neighboring cities to expand service coverage and optimize resource allocation. On the other hand, a cross-regional coordination mechanism must be established, such as a digital finance and innovation collaborative development committee with the participation of various cities, to jointly formulate regional development plans and policies. Meanwhile, a unified digital financial business standard and innovation evaluation system can be developed to promote data sharing, business interoperability, and the mutual recognition of innovation results among cities, thereby guiding the collaborative improvement of regional innovation capabilities.

Meanwhile, the digital infrastructure of small-scale urban agglomerations is imperfect, and there is a shortage of professional talent and

financial funds. Here, it is important to strengthen the construction of digital financial infrastructure, ensure stable network coverage and data communication, reduce the cost of digital financial services, and improve the accessibility of financial services. Next, policymakers should inculcate talent by introducing preferential policies, such as providing housing subsidies, children's education concessions, and research start-up funds, to attract outstanding talent and innovative teams from other places. Further, in the policy implementation process, small-scale urban agglomerations may face financial and resource constraints. Therefore, efforts should focus on optimizing the structure of fiscal expenditure, cut unnecessary administrative expenses and investment in low-efficiency projects, and reorient funds to key areas, such as digital financial infrastructure construction and innovative enterprise support. Next, these cities should expand diversified financing channels, actively adopt the public-private partnership model, and attract private capital to participate in the construction of the digital financial infrastructure. Finally, small cities should apply for special support funds from the provincial or national governments.

Additionally, urban agglomerations with high marketization degree have relatively better market mechanisms, greater competition, and strong demand for innovation. Here, leading role of the market should be leveraged and efficient market mechanisms should be used to encourage financial institutions to increase R&D investment in digital finance. They should explore the use of artificial intelligence to optimize risk assessment models and accurately serve innovative enterprises. Next, efforts should focus on expanding business boundaries and developing supply chain financial derivative services for emerging industries to meet the diversified needs of innovation entities. However, high marketization urban agglomerations may face challenges such as excessive market competition and difficult supervision. Therefore, it is necessary to promote the establishment of self-regulatory organizations, such as digital financial industry associations to guide enterprises and financial institutions to compete in an orderly manner and avoid excess competition. A dynamic regulatory mechanism adapted to the development of digital finance should be established, and technologies such as big data and artificial intelligence should be used to improve regulatory efficiency and precision.

Meanwhile, the market mechanism of low-marketization urban agglomerations needs to be improved, as their resource allocation efficiency is relatively low. Here, efforts should cultivate market players, support the development of financial institutions, help innovative enterprises grow, and solve their financing problems through products such as "innovation loan". Next, these agglomerations should formulate and improve the rules for the access, operation, and supervision of the digital financial market, and create a fair and transparent market environment. They should clarify the establishment conditions, business scope, and compliance requirements of digital financial institutions to ensure the orderly operation of the market. In addition, a low level of marketization implies insufficient competition. financial institutions in low marketization urban agglomerations may find it difficult to innovate digital financial products to meet the diversified financing needs of innovative enterprises because of their weak innovation impetus. Therefore, the government should introduce incentive policies, such as tax breaks and financial subsidies, to support innovative digital financial products developed by financial institutions.

In addition, the central city of monocentric urban agglomerations has prominent advantages. The leading role of central cities should be strengthened by improving the scale effect and dispersion ability of digital financial services, building a digital financial innovation highland with central cities as the core, and attracting innovative enterprises, talent, and capital. Simultaneously, the government should formulate a unified urban agglomeration digital finance and innovation-coordinated development plan where the functional position of each city is defined. Core cities should focus on cutting-edge digital financial technology research and high-tech personnel training. Peripheral cities should develop specific digital finance application scenarios based on their industrial bases, such as tourism and green finance. However, the monocentric urban agglomerations may face problems such as excessive concentration of resources and the siphon effect. Therefore, financial institutions should be encouraged to establish branches in peripheral cities through policy guidance and financial support. Further, advanced digital financial technologies and service models should be exported to the periphery to support the construction of digital financial infrastructure.

Finally, polycentric urban agglomerations have different functional positioning and diverse innovation needs. Such urban agglomerations should strengthen resource integration and cross-border collaboration, remove regional restrictions, and promote the coordinated development of digital financial services. Meanwhile, digital financial functions such as convenient payments and efficient financing should be used to promote the flow and sharing of cross-regional innovation factors, and meet the diversified innovation needs of different centers. In addition, digital financial institutions should be guided to provide customized services according to the characteristics of each center and promote regional collaborative innovation. However, owing to the difficulty of unifying standards, multiple central cities may operate independently in the development of digital finance and coordination is difficult. In addition, vicious competition between central cities may influence the effect of digital finance in promoting innovation. Therefore, establishing a cross-city digital financial coordination body is necessary. Efforts should focus on strengthening communication and exchanges among central cities, establishing the concept of "win-win," jointly building regional digital financial brands, and promoting the sharing of innovative resources.

Third, all urban agglomerations should work on mitigating economic policy uncertainty. The first set of actions should be at the governmental level. Governments should avoid drastic policy fluctuations and steer uncertainty into the "facilitative zone" through incremental reforms. Incremental reforms can adopt a phased and regionally piloted strategy to promote the integration of digital finance with the innovation capacity of urban agglomerations. For example, when implementing policies on digital financial innovation, representative cities can take the lead in launching pilot projects, including the introduction of innovative financial products and exploration of digital financial service models. After the pilots have gained successful experience, the policy can be gradually extended to other cities to achieve a smooth transition and effective implementation. Simultaneously, a scientific mechanism for policy evaluation and regulation must be established. Various indicators and tools should be comprehensively utilized to strengthen the monitoring, evaluation, and regulation of economic policy uncertainty. On the one hand, big data technology should be used to collect various types of policy documents, news reports, and other unstructured data, and extract key information through natural language processing technology. Combined with traditional macroeconomic indicators (e.g., interest rate fluctuations and exchange rate changes), econometric models can be used to quantitatively assess economic policy uncertainty, and construct a comprehensive set of economic policy uncertainty indicator systems. On the other hand, based on the assessment results, policy tools should be flexibly utilized for precise regulation. When uncertainty is too high, its impact on the market can be reduced by strengthening policy communication and stabilizing market expectations. When uncertainty is low, which is not conducive for stimulating market innovation and vitality, some moderately challenging policy measures can be introduced at the right time to guide uncertainty back to the "promotion zone."

Further, policy analysis reports should be released regularly to help enterprises better understand the policy trends. The government should integrate internal resources and establish a special policy analysis group that includes economists and policy-research experts. These reports can be released through various platforms such as official government websites and government press conferences to ensure that enterprises can easily and quickly obtain information. For example, some US government departments (such as the Federal Reserve and the Department

of Commerce) regularly release various economic policy analysis reports to provide decision-making references for enterprises and the market. This practice has achieved good results in practice.

In addition, policymakers should formulate flexible and targeted guidance policies for industries and enterprises that are greatly affected by policy uncertainty, such as providing tax incentives and fiscal subsidies. On the one hand, they should formulate differentiated tax incentives. For innovative enterprises, additional deductions for R&D expenses and tax relief could be increased. For example, a preferential corporate income tax rate of 15% for qualified high-tech enterprises, compared to the 25% tax rate for general enterprises, reduces the burden on enterprises and helps them respond better to economic policy uncertainties. On the other hand, in terms of financial subsidies, a special innovation support fund can be set up. Direct subsidies should be given to enterprises that are greatly affected by policy uncertainty but have innovative potential. For example, some European Union countries have established an SME Innovation Fund to provide financial support for MSMEs' innovation projects through government funding.

In addition, the above guidance policies should be formulated based on different types and characteristics of urban agglomerations. For example, in large-scale urban agglomerations, policies should focus on the construction of innovation platforms and development of cutting-edge technologies by large enterprises. For small-scale urban agglomerations, policies should focus on reducing the burden on enterprises, and improving their survival and developmental abilities. For high marketization urban agglomerations, tax incentives and financial subsidy policies should focus on guiding market resources into innovation and play a leading role in the market. The low marketization of urban agglomerations should optimize the market environment through policy guidance. Finally, they can increase investment in infrastructure and public services, and provide tax incentives to newly established innovative enterprises.

The second set of actions are at the enterprise level. Enterprises in urban agglomerations must enhance their sensitivity to economic policy uncertainty and strengthen their internal risk management systems. By establishing a dedicated policy research team or cooperating with professional consulting institutions, enterprises can thoroughly analyze the potential impact of policy changes on their innovation activities and formulate countermeasures in advance. For example, when a certain policy adjustment is predicted to affect corporate financing, diversified financing channels should be expanded to reduce the dependence on a single financing method. Meanwhile, enterprises should actively use the diversified financing tools provided by digital finance, such as supply chain finance and intellectual property pledge financing, to enhance their financing capabilities in an environment of policy uncertainty and ensure the capital needs of innovative activities.

### *Limitations and future research directions*

First, the data range is limited. On the one hand, although the sample involves 196 cities in 19 urban agglomerations, it fails to include all cities owing to a lack of data. On the other hand, missing data may lead to a sample selection bias, which can easily occur in the analysis of the regional characteristics of urban agglomerations (such as the comparison of eastern and western urban agglomerations). The development level of the eastern urban agglomerations is relatively high, exhibiting a high degree of digitalization; therefore, the availability of data may be relatively good in these regions. However, western urban agglomerations may face more difficulties in data collection and statistics. This difference in data availability may cause us to underestimate or overestimate the role of some influencing factors when analyzing the relationship between digital finance and innovation capacity in eastern and western urban agglomerations, making it difficult to compare them. Moreover, the sample covers only China; therefore, it may not be fully representative of the general characteristics of global urban agglomerations. Future research should address these data dimensions. The first step is to extend the time series. Earlier and future data should be collected to analyze the long-term innovation effects of digital finance on innovation. The second is to expand the data source channels and supplement missing city data. The third is to expand the geographical scope to global urban agglomerations.

Second, there are potential biases in the measurement indicators of the innovation capacity of urban agglomerations. Although we have attempted to build a relatively comprehensive innovation capacity indicator system, there may still be missing variables. For example, some factors are difficult to quantify, while some variables are difficult to obtain owing to data limitations. These missing variables may have led to a bias in the estimates. In the future, the overall index should be improved. Multiple government departments and institutions should collaborate to establish a unified innovation capacity indicator system.

Third, this study considers three mechanisms driving the main effect: innovation capital agglomeration, entrepreneurial activity, and credit resource allocation. As such, it may ignore other potentially important factors such as the depth of industry-university research cooperation and innovative cultural dissemination. While expanding the mechanisms dimension to enrich the understanding of how digital finance influences the innovation capacity of urban agglomerations is necessary, certain other mechanisms need more careful consideration. For instance, "industry-university-research cooperation" demands substantial financial and institutional support. Given the varying development levels among urban agglomerations, the difficulty of implementing such measures in different contexts has not been evaluated. Future research should consider these implementation challenges, and explore more feasible and adaptable strategies for different urban agglomerations.

## Funding

This work was supported by Henan Provincial University Philosophy and Social Science Innovation Talent Support Program [Grant Numbers: 2024-CXRC-13] and Key Project of National Social Science Fund "Research on Technology security Strategy of China's manufacturing industry chain under the new development pattern Key project of National Social Science Fund"[Grant Numbers: 21AZD109].

## CRediT authorship contribution statement

**Kai Tang:** Methodology, Data curation, Conceptualization. **Xiaopei Cai:** Writing – original draft, Software, Investigation. **Haijie Wang:** Writing – review & editing, Visualization, Formal analysis.

## Appendix

**Table A.1**
Research category.

| Urban agglomeration | Cities in the agglomeration | Related document |
|---|---|---|
| Beijing-Tianjin-Hebei urban agglomeration | Beijing, Tianjin, Shijiazhuang, Baoding, Langfang, Zhangjiakou, Qinhuangdao, Chengde, Xingtai, Handan, Cangzhou, and Tangshan | Outline of the Coordinated Development Plan for the Beijing-Tianjin-Hebei Region (2015) |
| Yangtze River Delta urban agglomeration | Shanghai, Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, Taizhou, Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Zhoushan, Taizhou, Yancheng, Jinhua, Hefei, Wuhu, Ma 'anshan, Tongling, Anqing, Chuzhou, Chizhou, and Xuancheng | Outline of Regional Integrated Development Plan for the Yangtze River Delta (2019) |
| Pearl River Delta urban agglomeration | Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Zhaoqing, Huizhou, Dongguan, and Zhongshan | Outline of the Reform and Development Plan for the Pearl River Delta Region (2008–2020) |
| Shandong peninsula urban agglomeration | Jinan, Qingdao, Yantai, Weihai, Dongying, Zibo, Weifang, and Rizhao | Shandong Peninsula City Agglomeration Development Plan (2006–2030) |
| Urban agglomeration on the west coast of the Strait | Fuzhou, Xiamen, Quanzhou, Putian, Zhangzhou, and Ningde | Coordinated Development Plan for Urban Agglomeration on the West Coast of the Taiwan Straits (2009) |
| Middle reaches of Yangtze River urban agglomeration | Wuhan, Huangshi, Yichang, Xiangyang, Ezhou, Jingmen, Xiaogan, Jingzhou, Huanggang, Xianning, Changsha, Zhuzhou, Xiangtan, Hengyang, Yueyang, Changde, Yiyang, Loudi, Nanchang, Jingdezhen, Pingxiang, Jiujiang, Xinyu, Yingtan, Ji 'an, Yichun, Fuzhou, and Shangrao | Development Plan for Urban Agglomeration in the Middle Reaches of the Yangtze River (2015) |
| Central plains urban agglomeration | Zhengzhou, Kaifeng, Luoyang, Nanyang, Anyang, Shangqiu, Xinxiang, Pingdingshan, Xuchang, Jiaozuo, Zhoukou, Xinyang, Zhumadian, Hebi, Puyang, Luohe, Sanmenxia, Changzhi, Jincheng, Liaocheng, Heze, Huaibei, Bengbu, Suzhou, Fuyang, and Bozhou | Central Plains Urban Agglomeration Planning (2016) |
| Jinzhong urban agglomeration | Taiyuan, Jinzhong, Luliang, Xinzhou, and Yangquan | High-quality Development Plan for Central Shanxi Urban Agglomeration (2022–2035) |
| Chengyu urban agglomeration | Chongqing, Chengdu, Zigong, Luzhou, Deyang, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Guang'an,Ziyang, Mianyang, Dazhou, and Ya'an | Chengdu-chongqing Urban Agglomeration Development Plan (2016) |
| Guanzhong plain urban agglomeration | Xi 'an, Shangluo, Tianshui, Xianyang, Yuncheng, Linfen, Weinan, Baoji, Qingyang, and Pingliang | Guanzhong Plain Urban Agglomeration Development Plan (2018) |
| Beibu Gulf urban agglomeration | Nanning, Beihai, Qinzhou, Fangchenggang, Yulin, Chongzuo, Haikou, Zhanjiang, Maoming, and Yangjiang | Beibu Gulf Urban Agglomeration Development Plan (2017) |
| Tianshan north slope urban agglomeration | Urumqi and Karamay | Plan for the Development of Urban Agglomeration on the North Slope of Tianshan Mountain (2017–2030) |
| Hubao Eyu urban agglomeration | Hohhot, Baotou, Ordos, and Yulin | Hubao Urban Agglomeration Development Plan (2018) |
| Ningxia along the yellow urban agglomeration | Yinchuan, Shizuishan, Wuzhong, and Zhongwei | Ningxia Along the Yellow City Belt Development Plan (2019) |
| Lanzhou - Xining urban agglomeration | Lanzhou, Baiyin, Dingxi, and Haidong | Lanzhou - Xining Urban Agglomeration Development Plan (2018) |
| Central Yunnan urban agglomeration | Kunming, Qujing, and Yuxi | Planning for Urban Agglomeration in Central Yunnan (2009–2030) |
| Central Guizhou urban agglomeration | Guiyang, Zunyi, Bijie, and Anshun | Central Guizhou Urban Agglomeration Development Plan (2017) |
| Harbour-Yangtze urban agglomeration | Changchun, Jilin, Siping, Liaoyuan, Songyuan, Harbin, Qiqihar, Daqing, Mudanjiang, and Suihua | Development Plan for Harbin and Changsha Urban Agglomeration s (2016) |
| Central and southern Liaoning urban agglomeration | Shenyang, Dalian, Fushun, Anshan, Benxi, Yingkou, Panjin, Tieling, and Liaoyang | Central and Southern Liaoning Urban Agglomeration Development Plan (2018) |

**Table A.2**
Main index of innovation capacity of urban agglomeration in 108 papers.

| Target layer | Indicator level | Frequency | Quantity proportion (%) |
|---|---|---|---|
| Innovation input | Ratio of education expenditure to local financial expenditure | 8 | 3.86 |
| | Share of fiscal expenditure on science and technology in local fiscal expenditure | 13 | 6.28 |
| | Number of personnel engaged in scientific research, technical services and geological exploration | 7 | 3.38 |
| | Number of foreign-invested enterprises | 7 | 3.38 |
| | Amount of foreign capital actually utilized in the year | 7 | 3.38 |
| | Number of general higher education institutions | 9 | 4.35 |
| | Number of full-time teachers in general higher education institutions | 7 | 3.38 |
| | Number of students enrolled in general higher education institutions | 13 | 6.28 |
| Innovation output | Number of published papers | 7 | 3.38 |
| | Patent applications | 22 | 10.63 |
| | Technology market turnover | 4 | 1.93 |
| | Number of well-known trademarks | 4 | 1.93 |
| | Number of patents granted | 48 | 23.19 |
| | Turnover of scientific and technological achievements per 10,000 people | 4 | 1.93 |
| Innovation basic environment | Green coverage rate | 4 | 1.93 |

(*continued on next page*)

**Table A.2** (*continued*)

| Target layer | Indicator level | Frequency | Quantity proportion (%) |
|---|---|---|---|
| | Gross regional product per capita | 11 | 5.31 |
| | Proportion of output value of tertiary industry in GDP | 4 | 1.93 |
| | Number of books in public libraries per 100 people | 11 | 5.31 |
| | Internet users per 10,000 people | 11 | 5.31 |
| | Postal and telecommunications revenue | 6 | 2.90 |

## References


Abel, A. B. (1983). Optimal investment under uncertainty. *The American Economic Review, 73*(1), 228–233. https://www.jstor.org/stable/1803942.

Acs, Z. J., & Audretsch, D. B. (2005). Entrepreneurship, innovation and technological change. *Foundations and Trends® in Entrepreneurship, 1*(4), 149–195. https://doi.org/10.1561/0300000004

Ahlstrom, D., & Bruton, G. D. (2010). Rapid institutional shifts and the co–evolution of entrepreneurial firms in transition economies. *Entrepreneurship Theory and Practice, 34*(3), 531–554. https://doi.org/10.1111/j.1540-6520.2010.00373.x

Alkhwaldi, A. F., Alharasis, E. E., Shehadeh, M., Abu-AlSondos, I. A., Oudat, M. S., & Bani Atta, A. A. (2022). Towards an understanding of FinTech users' adoption: Intention and e-loyalty post-COVID-19 from a developing country perspective. *Sustainability, 14*(19), 12616. https://doi.org/10.3390/su141912616

Al-Thaqeb, S. A., & Algharabali, B. G. (2019). Economic policy uncertainty: A literature review. *The Journal of Economic Asymmetries, 20*, e00133. https://doi.org/10.1016/j.jeca.2019.e00133

Amaghouss, J., & Ibourk, A. (2013). Entrepreneurial activities, innovation and economic growth: The role of cyclical factors evidence from OECD countries for the period 2001-2009. *International Business Research, 6*(1), 153–162. https://doi.org/10.5539/ibr.v6n1p153

Andersson, R., Quigley, J. M., & Wilhelmsson, M. (2009). Urbanization, productivity, and innovation: Evidence from investment in higher education. *Journal of Urban Economics, 66*(1), 2–15. https://doi.org/10.1016/j.jue.2009.02.004

Atanassov, J. (2016). Arm's length financing and innovation: Evidence from publicly traded firms. *Management Science, 62*(1), 128–155. https://doi.org/10.1287/mnsc.2014.2097

Atanassov, J., Julio, B., & Leng, T. (2024). The bright side of political uncertainty: The case of R&D. *The Review of Financial Studies*, hhae023. https://doi.org/10.1093/rfs/hhae023

Aziz, A., & Naima, U. (2021). Rethinking digital financial inclusion: Evidence from Bangladesh. *Technology in Society, 64*, Article 101509. https://doi.org/10.1016/j.techsoc.2020.101509

Bai, K., Shen, Z., Zhou, S., Su, Z., Yang, R., & Song, M. (2024). How does digitalization promote productivity growth in China? *Journal of Innovation & Knowledge, 9*(4), Article 100586. https://doi.org/10.1016/j.jik.2024.100586

Baker, S. R., & Bloom, N. (2013). Does uncertainty reduce growth? Using disasters as natural experiments (No. w19475). *National Bureau of Economic Research*. https://doi.org/10.3386/w19475

Baker, S. R., Bloom, N., & Davis, S. J. (2016). Measuring economic policy uncertainty. *The Quarterly Journal of Economics, 131*(4), 1593–1636. https://doi.org/10.1093/qje/qjw024

Balcilar, M., Gupta, R., & Segnon, M. (2016). The role of economic policy uncertainty in predicting US recessions: A mixed-frequency Markov-switching vector autoregressive approach. *Economics, 10*(1), Article 20160027. https://doi.org/10.5018/economics-ejournal.ja.2016-27

Bekaert, G., Hoerova, M., & Duca, M. L. (2013). Risk, uncertainty and monetary policy. *Journal of Monetary Economics, 60*(7), 771–788. https://doi.org/10.1016/j.jmoneco.2013.06.003

Beliaeva, T., Ferasso, M., Kraus, S., & Damke, E. J. (2020). Dynamics of digital entrepreneurship and the innovation ecosystem: A multilevel perspective. *International Journal of Entrepreneurial Behavior & Research, 26*(2), 266–284. https://doi.org/10.1108/IJEBR-06-2019-0397

Bhattacharya, U., Hsu, P. H., Tian, X., & Xu, Y. (2017). What affects innovation more: Policy or policy uncertainty? *Journal of Financial and Quantitative Analysis, 52*(5), 1869–1901. https://doi.org/10.1017/S0022109017000540

Bianchi, M. (2010). Credit constraints, entrepreneurial talent, and economic development. *Small Business Economics, 34*, 93–104. https://doi.org/10.1007/s11187-009-9197-3

Bian, Y. C., Wu, L. H., & Bai, J. H. (2019). Does high-speed rail improve regional innovation in China. *Journal of Financial Research, 6*, 132–149.

Bloom, N. (2007). Uncertainty and the dynamics of R&D. *American Economic Review, 97*(2), 250–255. https://doi.org/10.1257/aer.97.2.250

Bloom, N. (2009). The impact of uncertainty shocks. *Econometrica, 77*(3), 623–685. https://doi.org/10.3982/ECTA6248

Bollaert, H., Lopez-de-Silanes, F., & Schwienbacher, A. (2021). Fintech and access to finance. *Journal of Corporate Finance, 68*, Article 101941. https://doi.org/10.1016/j.jcorpfin.2021.101941

Booyens, I. (2011). Are small, medium-and micro-sized enterprises engines of innovation? The reality in South Africa. *Science and Public Policy, 38*(1), 67–78. https://doi.org/10.3152/030234211×12834251302445

Calantone, R. J., Cavusgil, S. T., & Zhao, Y. (2002). Learning orientation, firm innovation capability, and firm performance. *Industrial Marketing Management, 31*(6), 515–524. https://doi.org/10.1016/S0019-8501(01)00203-6

Can, Z., Gang, Z., & Xianzhong, C. (2017). Chinese inter-city innovation networks structure and city innovation capability. *Geographical Research, 36*(7), 1297–1308. https://doi.org/10.11821/dlyj201707009

Cao, S., & Leung, D. (2020). Credit constraints and productivity of SMEs: Evidence from Canada. *Economic Modelling, 88*, 163–180. https://doi.org/10.1016/j.econmod.2019.09.018

Cao, S., Nie, L., Sun, H., Sun, W., & Taghizadeh-Hesary, F. (2021). Digital finance, green technological innovation and energy-environmental performance: Evidence from China's regional economies. *Journal of Cleaner Production, 327*, Article 129458. https://doi.org/10.1016/j.jclepro.2021.129458

Chen, X., Liu, C., & Li, S. (2019). The role of supply chain finance in improving the competitive advantage of online retailing enterprises. *Electronic Commerce Research and Applications, 33*, 100821. https://doi.org/10.1016/j.elerap.2018.100821

Cheng, C., Gao, Q., Ju, K., & Ma, Y. (2024). How digital skills affect farmers' agricultural entrepreneurship? An explanation from factor availability. *Journal of Innovation & Knowledge, 9*(2), Article 100477. https://doi.org/10.1016/j.jik.2024.100477

Cheng, Z., & Masron, T. A. (2023). Economic policy uncertainty and corporate digital transformation: Evidence from China. *Applied Economics, 55*(40), 4625–4641. https://doi.org/10.1080/00036846.2022.2130148

Chen, J., Wang, L., & Li, Y. (2020). Natural resources, urbanization and regional innovation capabilities. *Resources Policy, 66*, Article 101643. https://doi.org/10.1016/j.resourpol.2020.101643

Chiu, Y. B., & Lee, C. C. (2020). Effects of financial development on energy consumption: The role of country risks. *Energy Economics, 90*, Article 104833. https://doi.org/10.1016/j.eneco.2020.104833

Cooke, P. (2001). From technopoles to regional innovation systems: The evolution of localised technology development policy. *Canadian Journal of Regional Science, 24*(1), 21–40.

Danquah, M., & Amankwah-Amoah, J. (2017). Assessing the relationships between human capital, innovation and technology adoption: Evidence from sub-Saharan Africa. *Technological Forecasting and Social Change, 122*, 24–33. https://doi.org/10.1016/j.techfore.2017.04.021

Dasgupta, P., & Stiglitz, J. (1980). Industrial structure and the nature of innovative activity. *The Economic Journal, 90*(358), 266–293. https://doi.org/10.2307/2231788

De Aghion, B. A., & Morduch, J. (2005). *The economics of microfinance*. MIT Press.

Dell'Ariccia, G., & Marquez, R. (2004). Information and bank credit allocation. *Journal of Financial Economics, 72*(1), 185–214. https://doi.org/10.1016/S0304-405X(03)00210-1

Durai, T., & Stella, G. (2019). Digital finance and its impact on financial inclusion. *Journal of Emerging Technologies and Innovative Research, 6*(1), 122–127. https://www.researchgate.net/publication/330933079.

Eriotis, N. P., Frangouli, Z., & Ventoura-Neokosmides, Z. (2002). Profit margin and capital structure: An empirical relationship. *Journal of Applied Business Research, 18*(2).

Faherty, U., & Stephens, S. (2016). Innovation in micro enterprises: Reality or fiction? *Journal of Small Business and Enterprise Development, 23*(2), 349–362. https://doi.org/10.1108/JSBED-11-2013-0176

Fang, Y., & Xie, M. (2012). The effect of innovation elements agglomeration on regional innovation output: Based on Chinese provinces and cities's ESDA-GWR analysis. *Economic Geography, 32*, 8–14.

Fankem, G., & Oumarou, M. (2020). Trade openness and economic growth in Sub-Saharan Africa: Evidence from new trade openness indicator. *Economics Bulletin, 40*(4), 2920–2931.

Feng, Y., Meng, M., & Li, G. (2023). Impact of digital finance on the asset allocation of small-and medium-sized enterprises in China: Mediating role of financing constraints. *Journal of Innovation & Knowledge, 8*(3), Article 100405. https://doi.org/10.1016/j.jik.2023.100405

Fernández-Villaverde, J., Guerrón-Quintana, P., Kuester, K., & Rubio-Ramírez, J. (2015). Fiscal volatility shocks and economic activity. *American Economic Review, 105*(11), 3352–3384. https://doi.org/10.1257/aer.20121236

Fröidh, O., & Nelldal, B. L. (2015). The impact of market opening on the supply of interregional train services. *Journal of Transport Geography, 46*, 189–200. https://doi.org/10.1016/j.jtrangeo.2015.06.017

Furman, J. L., Porter, M. E., & Stern, S. (2002). The determinants of national innovative capacity. *Research Policy, 31*(6), 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4

Garrison, W. L., & Souleyrette, R. R., II (1996). Transportation, innovation, and development: The companion innovation hypothesis. *Logistics and Transportation Review, 32*(1), 5. https://doi.org/10.3868/s060-015-022-0015-6

Geng, Y., Zheng, Z., & Ma, Y. (2023). Digitization, perception of policy uncertainty, and corporate green innovation: A study from China. *Economic Analysis and Policy, 80*, 544–557. https://doi.org/10.1016/j.eap.2023.09.006
Geng, Z., & He, G. (2021). Digital financial inclusion and sustainable employment: Evidence from countries along the belt and road. *Borsa Istanbul Review, 21*(3), 307–316. https://doi.org/10.1016/j.bir.2021.04.004
Cheung, K. Y., & Ping, L. (2004). Spillover effects of FDI on innovation in China: Evidence from the provincial data. *China Economic Review, 15*(1), 25–44. https://doi.org/10.1016/S1043-951X(03)00027-0
Glaeser, E. L., Kerr, S. P., & Kerr, W. R. (2015). Entrepreneurship and urban growth: An empirical assessment with historical mines. *Review of Economics and Statistics, 97*(2), 498–520. https://doi.org/10.1162/REST_a_00456
Gomber, P., Koch, J. A., & Siering, M. (2017). Digital finance and FinTech: Current research and future research directions. *Journal of Business Economics, 87*, 537–580. https://doi.org/10.1007/s11573-017-0852-x
Gu, X. M., Chen, Y. M., & Pan, S. Y. (2018). Economic policy uncertainty and innovation: Evidence from listed companies in China. *Economic Research Journal, 53*(2), 109–123.
Guanghu, Q. I. N. (2015). Research on the evaluation of comprehensively innovative capacity in the industrial transfer demonstration area of the cities along the Yangtze River based on the series catastrophe theory. *Science and Technology Management Research, 16*, 83–93.
Gulen, H., & Ion, M. (2016). Policy uncertainty and corporate investment. *The Review of Financial Studies, 29*(3), 523–564. https://doi.org/10.1093/rfs/hhv050
Guo, B., Feng, Y., & Lin, J. (2023). Digital inclusive finance and digital transformation of enterprises. *Finance Research Letters, 57*, Article 104270. https://doi.org/10.1016/j.frl.2023.104270
Hall, B. H. (2002). The financing of research and development. *Oxford Review of Economic Policy, 18*(1), 35–51.
Hamidi, S., Zandiatashbar, A., & Bonakdar, A. (2019). The relationship between regional compactness and regional innovation capacity (RIC): Empirical evidence from a national study. *Technological Forecasting and Social Change, 142*, 394–402. https://doi.org/10.1016/j.techfore.2018.07.026
Hao, L., Houser, D., Mao, L., & Villeval, M. C. (2016). Migrations, risks, and uncertainty: A field experiment in China. *Journal of Economic Behavior & Organization, 131*, 126–140. https://doi.org/10.1016/j.jebo.2016.08.008
Hasan, M. M., Yajuan, L., & Khan, S. (2022). Promoting China's inclusive finance through digital financial services. *Global Business Review, 23*(4), 984–1006. https://doi.org/10.1177/0972150919895348
Hasan, M. M., Yajuan, L., & Mahmud, A. (2020). Regional development of China's inclusive finance through financial technology. *Sage Open, 10*(1). https://doi.org/10.1177/2158244019901252, 2158244019901252.
He, F., Ma, Y., & Zhang, X. (2020). How does economic policy uncertainty affect corporate innovation?–Evidence from China listed companies. *International Review of Economics & Finance, 67*, 225–239. https://doi.org/10.1016/j.iref.2020.01.006
He, L., Tao, J. G., Meng, P., Chen, D., Yan, M., & Vasa, L. (2021). Analysis of socio-economic spatial structure of urban agglomeration in China based on spatial gradient and clustering. *Oeconomia Copernicana, 12*(3), 789–819.
He, G., & Shen, L. (2021). Whether digital financial inclusion can improve capital misallocation or not: A study based on the moderating effect of economic policy uncertainty. *Discrete Dynamics in Nature and Society, 2021*(1), Article 4912836. https://doi.org/10.1155/2021/4912836
Hlioui, Z., Gabsi, M., & Omri, A. (2022). Informal competition effect on SMEs' innovation: Do credit constraints matter? Evidence from Eastern European countries. *Sustainability, 14*(21), 13874. https://doi.org/10.3390/su142113874
Hoskisson, R. E., Eden, L., Lau, C. M., & Wright, M. (2000). Strategy in emerging economies. *Academy of Management Journal, 43*(3), 249–267. https://doi.org/10.5465/1556394
Hu, M. C., & Mathews, J. A. (2008). China's national innovative capacity. *Research Policy, 37*(9), 1465–1479. https://doi.org/10.1016/j.respol.2008.07.003
Hu, S., Liu, S., Li, D., & Lin, Y. (2019). How does regional innovation capacity affect the green growth performance? Empirical evidence from China. *Sustainability, 11*(18), 5084. https://doi.org/10.3390/su11185084
Huang, K. E., Wu, J. H., Lu, S. Y., & Lin, Y. C. (2016). Innovation and technology creation effects on organizational performance. *Journal of business research, 69*(6), 2187–2192. https://doi.org/10.1016/j.jbusres.2015.12.028
Huang, Y., & Huang, Z. (2018). The development of digital finance in China: Present and future. *China Economic Quarterly, 17*(4), 205–218.
Hui, P., Zhao, H., Liu, D., & Li, Y. (2023). How does digital finance affect regional innovation capacity? A spatial econometric analysis. *Economic Modelling, 122*, Article 106250. https://doi.org/10.1016/j.econmod.2023.106250
Hurst, E., & Lusardi, A. (2004). Liquidity constraints, household wealth, and entrepreneurship. *Journal of Political Economy, 112*(2), 319–347. https://doi.org/10.1086/381478
Ilmanen, A. (2022). *Investing amid low expected returns: Making the most when markets offer the least*. John Wiley & Sons.
Impullitti, G. (2022). Credit constraints, selection and productivity growth. *Economic Modelling, 111*, Article 105797. https://doi.org/10.1016/j.econmod.2022.105797
Jiang, Z., Ma, G., & Zhu, W. (2022). Research on the impact of digital finance on the innovation performance of enterprises. *European Journal of Innovation Management, 25*(6), 804–820. https://doi.org/10.1108/EJIM-02-2022-0094
Jie, T., Qiuyun, T. A. N., & Jingyu, J. I. N. (2021). Can Digital Finance Improve Misallocation of Resourses? *Collected Essays on Finance and Economics, 37*(4), 49. https://cjlc.zufe.edu.cn/EN/Y2021/V37/I4/49.
John Mathis, F., & Cavinato, J. (2010). Financing the global supply chain: Growing need for management action. *Thunderbird International Business Review, 52*(6), 467–474. https://doi.org/10.1002/tie.20373
Julio, B., & Yook, Y. (2012). Political uncertainty and corporate investment cycles. *The Journal of Finance, 67*(1), 45–83. https://doi.org/10.1111/j.1540-6261.2011.01707.x
Kang, W., Lee, K., & Ratti, R. A. (2014). Economic policy uncertainty and firm-level investment. *Journal of Macroeconomics, 39*, 42–53. https://doi.org/10.1016/j.jmacro.2013.10.006
Kapoor, A. (2014). Financial inclusion and the future of the Indian economy. *Futures, 56*, 35–42. https://doi.org/10.1016/j.futures.2013.10.007
González, J.L., & Ferencz, J. (2018). Digital trade and market openness. doi:10.1787/1bd89c9a-en.
Ketterer, J.A. (2017). Digital finance: New times, new challenges, new opportunities. doi:10.18235/0007028.
Kong, T., Sun, R., Sun, G., & Song, Y. (2022). Effects of digital finance on green innovation considering information asymmetry: An empirical study based on Chinese listed firms. *Emerging Markets Finance and Trade, 58*(15), 4399–4411. https://doi.org/10.1080/1540496X.2022.2083953
Li, C., Wang, Y., Zhou, Z., Wang, Z., & Mardani, A. (2023). Digital finance and enterprise financing constraints: Structural characteristics and mechanism identification. *Journal of Business Research, 165*, Article 114074. https://doi.org/10.1016/j.jbusres.2023.114074
Li, J., & Li, B. (2022). Digital inclusive finance and urban innovation: Evidence from China. *Review of Development Economics, 26*(2), 1010–1034. https://doi.org/10.1111/rode.12846
Li, J., Wu, Y., & Xiao, J. J. (2020). The impact of digital finance on household consumption: Evidence from China. *Economic Modelling, 86*, 317–326. https://doi.org/10.1016/j.econmod.2019.09.027
Li, X., Shao, X., Chang, T., & Albu, L. L. (2022). Does digital finance promote the green innovation of China's listed companies? *Energy Economics, 114*, Article 106254. https://doi.org/10.1016/j.eneco.2022.106254
Li, Z., Chen, H., & Mo, B. (2023). Can digital finance promote urban innovation? Evidence from China. *Borsa Istanbul Review, 23*(2), 285–296. https://doi.org/10.1016/j.bir.2022.10.006
Lim, D. S., Morse, E. A., Mitchell, R. K., & Seawright, K. K. (2010). Institutional environment and entrepreneurial cognitions: A comparative business systems perspective. *Entrepreneurship Theory and Practice, 34*(3), 491–516. https://doi.org/10.1111/j.1540-6520.2010.00384.x
Lin, A., Peng, Y., & Wu, X. (2022). Digital finance and investment of micro and small enterprises: Evidence from China. *China Economic Review, 75*, Article 101846. https://doi.org/10.1016/j.chieco.2022.101846
Lin, B., & Ma, R. (2022). How does digital finance influence green technology innovation in China? Evidence from the financing constraints perspective. *Journal of Environmental Management, 320*, Article 115833. https://doi.org/10.1016/j.jenvman.2022.115833
Liu, H., Cui, C., Chen, X., & Xiu, P. (2023). How can regional integration promote corporate innovation? A peer effect study of R&D expenditure. *Journal of Innovation & Knowledge, 8*(4), Article 100444. https://doi.org/10.1016/j.jik.2023.100444
Luo, S. (2022). Digital finance development and the digital transformation of enterprises: Based on the perspective of financing constraint and innovation drive. *Journal of Mathematics, 2022*(1), Article 1607020. https://doi.org/10.1155/2022/1607020
Lu, Y., Tao, Z., & Zhu, L. (2017). Identifying FDI spillovers. *Journal of International Economics, 107*, 75–90. https://doi.org/10.1016/j.jinteco.2017.01.006
Majewska, M. H., & Rawińska, M. (2018). The unemployment rate and innovative activity: A cross-country analysis. *Torun Business Review, 17*(4), 1–20. https://doi.org/10.19197/tbr.v17i4.305
Manyika, J., Lund, S., Singer, M., White, O., & Berry, C. (2016). *Digital finance for all: Powering inclusive growth in emerging economies* (pp. 1–15). McKinsey Global Institute.
Marcus, A. A. (1981). Policy uncertainty and technological innovation. *Academy of Management Review, 6*(3), 443–448. https://doi.org/10.5465/amr.1981.4285783
Martin, P., & Ottaviano, G. I. (2001). Growth and agglomeration. *International Economic Review, 42*(4), 947–968. https://doi.org/10.1111/1468-2354.00141
Mention, A. L. (2012). Intellectual capital, innovation and performance: A systematic review of the literature. *Business and Economic Research, 2*(1). https://doi.org/10.5296/ber.v2i1.1937
Myers, S. C. (1977). Determinants of corporate borrowing. *Journal of financial economics, 5*(2), 147–175. https://doi.org/10.1016/0304-405X(77)90015-0
Nair, S., & Howlett, M. (2020). Policy myopia as a source of policy failure: Adaptation and policy learning under deep uncertainty. In *Policy Learning and Policy Failure* (pp. 133–154). Policy Press. https://doi.org/10.51952/9781447352013.ch007.
Nambisan, S., & Baron, R. A. (2013). Entrepreneurship in innovation ecosystems: Entrepreneurs' self–regulatory processes and their implications for new venture success. *Entrepreneurship Theory and Practice, 37*(5), 1071–1097. https://doi.org/10.1111/j.1540-6520.2012.00519.x
Nelson, R. R., & Phelps, E. S. (1966). Investment in humans, technological diffusion, and economic growth. *The American Economic Review, 56*(1/2), 69–75. https://www.jstor.org/stable/1821269.
Nguyen, P. T., & Nguyen, L. T. M. (2023). A multi-country analysis of policy uncertainty and Blockchain Innovation. *Journal of Innovation & Knowledge, 8*(3), Article 100379. https://doi.org/10.1016/j.jik.2023.100379
Nie, X., Jiang, P., Zheng, X., & Wu, Q. (2021). Research on digital finance and regional technology innovation. *Journal of Financial Research, 3*, 132–150.
North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge university press.

Noseleit, F. (2013). Entrepreneurship, structural change, and economic growth. *Journal of Evolutionary Economics, 23*, 735–766. https://doi.org/10.1007/s00191-012-0291-3

Nunn, N., & Qian, N. (2014). US food aid and civil conflict. *American Economic Review, 104*(6), 1630–1666. https://doi.org/10.1257/aer.104.6.1630

Olatunji, T. E., & Adegbite, T. A. (2014). Investment in fixed assets and firm profitability: Empirical evidence from the Nigerian banking sector. *Asian Journal of Social Sciences and Management Studies, 1*(3), 78–82. http://www.asianonlinejournals.com/index.phD/AJSSMS.

Pal, A., Herath, T., & Rao, H. R. (2021). Why do people use mobile payment technologies and why would they continue? An examination and implications from India. *Research Policy, 50*(6), Article 104228. https://doi.org/10.1016/j.respol.2021.104228

Pastor, L., & Veronesi, P. (2012). Uncertainty about government policy and stock prices. *The Journal of Finance, 67*(4), 1219–1264. https://doi.org/10.1111/j.1540-6261.2012.01746.x

Peng, X. Y., Zou, X. Y., Zhao, X. X., & Chang, C. P. (2023). How does economic policy uncertainty affect green innovation? *Technological and Economic Development of Economy, 29*(1), 114–140. https://doi.org/10.3846/tede.2022.17760

Peng, Y., Huang, X., & Shen, J. (2018). Real estate investment and financial efficiency: Regional variation in shifting financial resources from real to fictitious sector. *Journal of Financial Research, 458*(8), 51–68.

Pierrakis, Y., & Collins, L. (2013). Crowdfunding: A new innovative model of providing funding to projects and businesses. Available at SSRN 2395226. doi:10.2139/ssrn.2395226.

Qin, X., Wu, H., & Li, R. (2022). Digital finance and household carbon emissions in China. *China Economic Review, 76*, 101872. https://doi.org/10.1016/j.chieco.2022.101872

Rao, S., Pan, Y., He, J., & Shangguan, X. (2022). Digital finance and corporate green innovation: Quantity or quality? *Environmental Science and Pollution Research, 29*(37), 56772–56791. https://doi.org/10.1007/s11356-022-19785-9

Ren, X., Zeng, G., & Gozgor, G. (2023). How does digital finance affect industrial structure upgrading? Evidence from Chinese prefecture-level cities. *Journal of Environmental Management, 330*, Article 117125. https://doi.org/10.1016/j.jenvman.2022.117125

Reynolds, P., Bosma, N., Autio, E., Hunt, S., De Bono, N., Servais, I., & Chin, N. (2005). Global entrepreneurship monitor: Data collection design and implementation 1998-2003. *Small Business Economics, 24*, 205–231. https://doi.org/10.1007/s11187-005-1980-1

Risman, A., Mulyana, B., Silvatika, B., & Sulaeman, A. (2021). The effect of digital finance on financial stability. *Management Science Letters, 11*(7), 1979–1984. https://doi.org/10.5267/j.msl.2021.3.012

Rosenthal, S. S., & Strange, W. C. (2006). The micro-empirics of agglomeration economies. *A Companion to Urban Economics*, 7–23. https://doi.org/10.1002/9780470996225

Sarma, M., & Pais, J. (2011). Financial inclusion and development. *Journal of International Development, 23*(5), 613–628. https://doi.org/10.1002/jid.1698

Schumpeter, J. A., & Swedberg, R. (2021). *The theory of economic development*. Routledge. https://doi.org/10.4324/9781003146766

Shanshan, W., Jinchun, B., & Jie, M. (2024). Public investment and urban entrepreneurship activity: From the perspective of municipal bonds. *Journal of Finance and Economics, 50*(07), 65–79. https://doi.org/10.16538/j.cnki.jfe.20240430.201

Shao, L., & Chen, J. (2023). Digital finance and regional green innovation: The perspective of environmental regulation. *Environmental Science and Pollution Research, 30*(36), 85592–85610. https://doi.org/10.1007/s11356-023-28356-5

Shen, H., Lan, F., Xiong, H., Lv, J., & Jian, J. (2020). Does top management team's academic experience promote corporate innovation? Evidence from China. *Economic Modelling, 89*, 464–475. https://doi.org/10.1016/j.econmod.2019.11.007

Shi, Y., Gong, L., & Chen, J. (2019). The effect of financing on firm innovation: Multiple case studies on Chinese manufacturing enterprises. *Emerging Markets Finance and Trade, 55*(4), 863–888. https://doi.org/10.1080/1540496X.2018.1478284

Siegel, P. B., Johnson, T. G., & Alwang, J. (1995). Regional economic diversity and diversification. *Growth and Change, 26*(2), 261–284. https://doi.org/10.1111/j.1468-2257.1995.tb00171.x

Singh, S. K., & Del Giudice, M. (2019). Big data analytics, dynamic capabilities and firm performance. *Management Decision, 57*(8), 1729–1733. https://doi.org/10.1108/MD-08-2019-020

Stiglitz, J. E. (1989). Markets, market failures, and development. *The American economic review, 79*(2), 197–203. https://www.jstor.org/stable/1827756.

Stiglitz, J. E. (2014). Unemployment and innovation (No. w20670). *National Bureau of Economic Research*. https://doi.org/10.3386/w20670

Stiglitz, J. E., & Weiss, A. (1981). Credit rationing in markets with rationing credit information imperfect. *The American Economic Review, 71*(3), 393–410.

Sun, Y., & You, X. (2023). Do digital inclusive finance, innovation, and entrepreneurship activities stimulate vitality of the urban economy? Empirical evidence from the Yangtze River Delta, China. *Technology in Society, 72*, Article 102200. https://doi.org/10.1016/j.techsoc.2023.102200

Sun, Y., Zhang, T., Wang, X., & Li, D. (2021). Status, problems and prospects of digital inclusive finance in China. *The Journal of Quantitative & Technical Economics, 38*, 43–59.

Szirmai, A., Naudé, W., & Goedhuys, M. (2011). *Entrepreneurship, innovation, and economic development*. Oxford University Press.

Tajaddini, R., & Gholipour, H. F. (2021). Economic policy uncertainty, R&D expenditures and innovation outputs. *Journal of Economic Studies, 48*(2), 413–427. https://doi.org/10.1108/JES-12-2019-0573

Tang, K., Wang, Y. Y., & Wang, H. J. (2024). The impact of innovation capability on green development in China's urban agglomerations. *Technological Forecasting and Social Change, 200*, Article 123128. https://doi.org/10.1016/j.techfore.2023.123128

Tao, Z., Zhang, Z., & Shangkun, L. (2022). Digital economy, entrepreneurship, and high-quality economic development: Empirical evidence from urban China. *Frontiers of Economics in China, 17*(3), 393. https://doi.org/10.3868/s060-015-022-0015-6

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic management journal, 18*(7), 509–533.

Teng, L., & Ma, D. G. (2020). Can digital finance help to promote high-quality development? *Statistical Research, 37*(11), 80–92.

Turner, A. (2012). *Economics after the crisis: Objectives and means*. MIT Press.

Veeraraghavan, V. (2009). Entrepreneurship and innovation. *Asia Pacific Business Review, 5*(1), 14–20. https://doi.org/10.1177/097324700900500102

Wang, J., Mishra, S., Sharif, A., & Chen, H. (2024). Dynamic spillover connectedness among green finance and policy uncertainty: Evidence from QVAR network approach. *Energy Economics, 131*, Article 107330. https://doi.org/10.1016/j.eneco.2024.107330

Wang, Q., Yang, L., & Yue, Z. (2022). Research on development of digital finance in improving efficiency of tourism resource allocation. *Resources, Environment and Sustainability, 8*, Article 100054. https://doi.org/10.1016/j.resenv.2022.100054

Wang, Q., & Zhang, F. (2021). The effects of trade openness on decoupling carbon emissions from economic growth–evidence from 182 countries. *Journal of Cleaner Production, 279*, Article 123838. https://doi.org/10.1016/j.jclepro.2020.123838

Wang, X., & Wang, Q. (2021). Research on the impact of green finance on the upgrading of China's regional industrial structure from the perspective of sustainable development. *Resources Policy, 74*, Article 102436. https://doi.org/10.1016/j.resourpol.2021.102436

Wang, X. Y., & Bu, L. F. (2019). International export trade and enterprise innovation—Research based on a quasi-natural experiment of "CR Express. *China Industrial Economics, 10*, 80–98.

Wang, Y., Wei, Y., & Song, F. M. (2017). Uncertainty and corporate R&D investment: Evidence from Chinese listed firms. *International Review of Economics & Finance, 47*, 176–200. https://doi.org/10.1016/j.iref.2016.10.004

Wang, Z. (2022). Digital finance, financing constraint and enterprise financial risk. *Journal of Mathematics, 2022*(1), Article 2882113. https://doi.org/10.1155/2022/2882113

Wei, F., & Jiajia, L. (2019). Entrepreneurship and industrial upgrading: A study based on the original motivation of economic growth. *Foreign Economics & Management, 41*(06), 29–42. https://doi.org/10.16538/j.cnki.fem.2019.06.003

Welter, F., & Smallbone, D. (2011). Institutional perspectives on entrepreneurial behavior in challenging environments. *Journal of Small Business Management, 49*(1), 107–125. https://doi.org/10.1111/j.1540-627X.2010.00317.x

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.

Xie, X., Shen, Y., Zhang, H., & Guo, F. (2018). Can digital finance promote entrepreneurship? Evidence from China. *China Economic Quarterly, 17*(4), 1557–1580.

Xiong, M., Li, W., Xian, B. T. S., & Yang, A. (2023). Digital inclusive finance and enterprise innovation—Empirical evidence from Chinese listed companies. *Journal of Innovation & Knowledge, 8*(1), Article 100321. https://doi.org/10.1016/j.jik.2023.100321

Xu, H., & Jiao, M. (2021). City size, industrial structure and urbanization quality—A case study of the Yangtze River Delta urban agglomeration in China. *Land Use Policy, 111*, Article 105735. https://doi.org/10.1016/j.landusepol.2021.105735

Xu, Z. (2020). Economic policy uncertainty, cost of capital, and corporate innovation. *Journal of Banking & Finance, 111*, Article 105698. https://doi.org/10.1016/j.jbankfin.2019.105698

Xun, Z., Guanghua, W., Jiajia, Z., & Zongyue, H. (2020). Digital economy, financial inclusion and inclusive growth. *China Economist, 15*(3), 92–105. https://doi.org/10.19602/j.chinaeconomist.2020.05.07

Yang, L., & Zhang, Y. (2020). Digital financial inclusion and sustainable growth of small and micro enterprises—Evidence based on China's new third board market listed companies. *Sustainability, 12*(9), 3733. https://doi.org/10.3390/su12093733

Yang, P., Fan, M., Li, Z., Cao, J., Wu, X., Wu, D., & Lu, Z. (2022). Digital finance, spatial spillover and regional innovation efficiency: New insights from China. *Electronic Research Archive, 30*(12), 4635–4656.

Yu, H., Ke, H., Ye, Y., & Fan, F. (2023). Agglomeration and flow of innovation elements and the impact on regional innovation efficiency. *International Journal of Technology Management, 92*(3), 229–254. https://doi.org/10.1504/IJTM.2023.128840

Yu, J., Zhou, K., & Yang, S. (2019). Land use efficiency and influencing factors of urban agglomerations in China. *Land Use Policy, 88*, Article 104143. https://doi.org/10.1016/j.landusepol.2019.104143

Yu, X., Wu, Z., Zheng, H., Li, M., & Tan, T. (2020). How urban agglomeration improve the emission efficiency? A spatial econometric analysis of the Yangtze River Delta urban agglomeration in China. *Journal of Environmental Management, 260*, Article 110061. https://doi.org/10.1016/j.jenvman.2019.110061

Yu, Y. (2011). Innovation cluster, government support and the technological innovation efficiency: Based on spatial econometrics of panel data with provincial data. *Economic Review, 2*, 93–101.

Zahra, S. A., & Nambisan, S. (2011). Entrepreneurship in global innovation ecosystems. *AMS Review, 1*, 4–17. https://doi.org/10.1007/s13162-011-0004-3

Zeng, J. J., & Wen, Y. L. (2021). Effect of government entrepreneurship policy on urban entrepreneurship: A quasi-natural experiment based on national entrepreneurial cities. *Economics and Management, 43*, 55–70.

Zhang, L. (2017). The knowledge spillover effects of FDI on the productivity and efficiency of research activities in China. *China Economic Review, 42*, 1–14. https://doi.org/10.1016/j.chieco.2016.11.001

Zhang, Z., Zhou, Z., Zeng, Z., & Zou, Y. (2023). How does heterogeneous green technology innovation affect air quality and economic development in Chinese cities? Spatial and nonlinear perspective analysis. *Journal of Innovation & Knowledge, 8*(4), Article 100419. https://doi.org/10.1016/j.jik.2023.100419

Zhenjie, W. (2016). Credit discrimination, the cost of debt and technological innovation investment—An empirical study of Credit allocation efficiency. *Science Research Management, 37*(10), 9.

Zhou, H., Zhang, X., & Ruan, R. (2023). Firm's perception of economic policy uncertainty and corporate innovation efficiency. *Journal of Innovation & Knowledge, 8*(3), Article 100371. https://doi.org/10.1016/j.jik.2023.100371