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The Influence of Demand-Based Policy Instruments on Urban Innovation Quality—Evidence from 269 Cities in China

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Abstract: Enhancing the quality of urban innovation is a powerful strategy for advancing urban sustainability. A strong public innovation policy is a crucial building block for advancing urban innovation quality. This study identifies innovative procurement instances from over 640,000 public procurement contract data through textual analysis to investigate how urban innovation quality could benefit from demand-based policy instruments. The study's findings indicate the following: (1) It provides evidence that the adoption of public innovation procurement has a significant impact on urban innovation quality, suggesting an inverse U-shaped relationship between the two. (2) Heterogeneity analysis reveals public innovation procurement stimulates urban innovation quality more remarkably in cities with provincial status and provincial capitals, as well as in eastern cities. (3) We discovered that it is not possible to increase the quality of urban innovation in the city when human capital in the city is performing poorly and when there is also a lack of external technology and entrepreneurial activity. Finally, this paper argues that our findings also provide important insights for the development of proactive innovation policy instruments, the construction of innovative cities, and the realization of sustainable development in countries around the world, especially in developing countries.

Keywords: public innovation procurement; urban innovation quality; demand-based policy instruments

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1. Introduction

In recent years, urban sustainability has gained increased recognition as an important component of sustainable development. It has begun to receive political and institutional endorsement on the sustainable development agenda [1,2]. The concept of urban development is essentially a process concentrating on all elements of an area that contribute not only to the creation of a more environmentally friendly city but also to the provision of social equality and economic growth, which together result in a more sustainable urban space. Urban innovation is an important antecedent of urban development, which reflects the levels of innovation and creation activities in cities, and is closely related to sustainable urban economic development. In terms of the role of the government and technological innovation, governments can promote science, technology and innovation, and, thus, sustainable urban development, through the development of public innovation procurement policies. Quantitatively evaluating the impact of public innovation procurement on urban innovation contributes to a better understanding of urban governance and sustainable development.

The Chinese government attaches great importance to innovation; promoting sustainable urban development can be achieved by improving the effectiveness of urban innovation quality and providing policy and financial incentives [3,4] to vigorously facilitate the construction of an innovative country and the development of an innovative economy [5], so that innovation becomes the main driving force, and knowledge, technology, talent, and digitalization become the key factors of production and economic growth.

Under such innovation policies, China has become a mainstay of global innovative growth. In 2019, China surpassed the United States as the top source of international patent applications filed with the World Intellectual Property Organization, and it stayed ahead with 68,720 applications in 2020. By 2020, China ranked second in the world in terms of total R&D expenditure and first in terms of total patent applications. However, The Global Innovation Index 2020: Who Will Finance Innovation? [6] released by the World Intellectual Property Organization (WIPO) ranked China 14th in innovation index and 16th in innovation quality, contrasting starkly with its R&D and patent rankings. As reported in The Global Innovation Index 2020, shifting focus from innovation quantity to innovation quality has become a primary concern of the innovation policy community. Therefore, investigating the quality of innovation is very important for China's innovation development process.

Innovation is a key driver of technology development and economic growth. It provides a means of satisfying the demands of the current market and the potential needs of future markets. Innovation is achieved through more effective products, processes, services, or technologies that are readily available to the current market. There is an increased awareness and recognition among national policy makers about innovation as a key factor in economic growth [7]. Policy makers look to innovation policy frameworks as an instrument to promote innovation, and policymakers can adjust innovation policy frameworks to have an impact on innovation and the economy. Many OECD (Organization for Economic Cooperation and Development)-member countries have enforced strategies and policies to enhance innovation and economic development. In general, government innovation support policies can be classified into supply-side and demand-side instruments [8,9]. In the past two decades, innovation policy discourses predominantly concentrated on supply-side tools, such as R&D subsidies [10], R&D tax incentives [11], intellectual property protections [12], venture capital [13], scientific infrastructure [14], and human capital [15], based on a simplistic linear model where government input in capital, labor, technology, and policy directly and automatically catalyzes innovation. Many academics and policymakers have highlighted the limitations of supply-side innovation policies [8,16,17], related to the crowding-out effects of R&D subsidies [10]. The provision of financial incentives bears a potential risk of crowding out private innovation expenditure, as firms may be keen to reallocate their own innovation resources to other uses and substitute them with public support to innovations [18–20]. In contrast, public procurement as a demand-side innovation policy has been overlooked or undervalued for years. Increasingly, academia demonstrates growing interest in public procurement and its deployment in innovation policy frameworks as a demand-pull, demand-side tool for technological development or industrial upgrading by procuring innovative products or services [8,21–25]. In developed nations, policymakers display a growing emphasis on demand-side innovation policies centering on public procurement [26]. Public procurement has been acknowledged as a more potent innovation policy tool compared to subsidies [9,27]. The case of the United States serves as a compelling example, where military defense procurement has played a pivotal role in shaping the nation's global scientific and technological leadership. Major breakthroughs, such as semiconductors, computers, and the Internet, have all benefited from the support and investments facilitated by defense procurement initiatives. Thus, investigating public procurement's impact on urban innovation quality holds tremendous theoretical and practical significance.

While the recent conceptualization of public procurement as an innovation policy tool is not new, this study posits that the ongoing discourse exaggerates the role of public procurement in enhancing innovation while providing limited guidance for innovation strategies. The literature on public procurement has investigated its connection to innovation [9,23,27,28], yet it predominantly treats public procurement as a unified entity, seldom distinguishing between innovation-focused procurement and the procurement of standard products. A notable distinction arises between innovation procurement and standard items like office supplies (e.g., paper, paper clips) when the government acquires commonplace

off-the-shelf goods devoid of research and development (R&D) processes and devoid of associated R&D investments [29]. It is generally assumed a priori that all publicly procured necessities can impact innovation to varying degrees. However, this body of literature overlooks the notion that standardized goods and services integral to daily life may hold little significance in fostering innovation [30]. In a study by Czarnitzki [31] focusing on Germany, a comparison was made between the innovation impacts of innovation-oriented and conventional public procurement. The results revealed that solely innovation-oriented public procurement substantially bolstered firms' sales of novel products and services. In a study conducted by Caravella and Crespi [32] involving Italian firms, it was discovered that standard public procurement contracts had a detrimental influence on firms' expenditures in research and development (R&D). These investigations demonstrate that the impacts of public innovation procurement diverge significantly from those of public standard product procurement. Conflating the two can result in biased assessments of innovation effects.

Based on these reflections, we conclude that this study makes an important contribution to the literature on public procurement and innovation policy. First, much of the existing literature examines government procurement as a whole, with little distinction made between innovative and conventional procurement. Innovative government procurement is significantly different from conventional government procurement, which occurs when the government buys simple off-the-shelf products that do not involve a research and development (R&D) process and do not require related R&D investments. The research establishes an exclusive city-level dataset encompassing public innovation procurement in China from 2015 to 2020. This is achieved through a textual data mining method employed to distinguish public innovation procurement from the broader public procurement landscape. Secondly, there is no shortage of existing literature that explores the mechanisms by which government procurement affects firms' innovation, but less attention has been paid to urban innovation. The research centers its attention on the influence of public innovation procurement on the quality of urban innovation in China. This addresses the gap in the current literature, which predominantly concentrates on micro-level aspects like firms. Subsequently, this study undertakes a heterogeneity analysis based on the sourcing city's characteristics. This analysis distinguishes between cities with provincial status and provincial capitals and other prefecture-level cities, as well as between eastern cities and mid-western cities.

We empirically analyze a large sample of 269 Chinese prefecture-level cities in the time period between 2015 and 2020. We apply two-way fixed-effects regressions to reveal considerable heterogeneity in the innovation procurement–innovation quality relationship. We find that an inverted "U"-shaped relationship between urban public innovation procurement and its innovation quality, with public innovation procurement contributing more strongly to innovation quality in economically developed eastern regions. Through the study, a better understanding of the relationship between public innovation policy and urban innovation quality can be attained, and valuable references for innovation policy formulation in other similar cities can be provided.

The rest of this paper is structured as follows: In Section 2, this paper presents the conceptual framework and outlines the theoretical assumptions. Section 3 focuses on the construction of empirical equations and provides a detailed explanation of the data and analysis methods employed in this study. Section 4 conducts an examination of these assumptions through the application of econometric techniques. Subsequently, it delves into a discussion of the empirical results. In Section 5, this paper draws its conclusions. In Section 6, this paper draws its policy implications. In Section 7, this paper draws its limitations and future recommendations.

2. Research Hypothesis

Based on the logic of direct and indirect effects, this paper analyses the mechanism of the impact of innovation procurement on the quality of urban innovation from three aspects. The research framework is presented in Figure 1.

Innovation procurement creates or expands the market for the demand for goods or services and significantly reduces the risk of R&D activities. The development of innovation activities, to a large extent, needs to rely on government funding [33], particularly crucial for technological innovation marked by high risk, prolonged cycles, and quasi-public goods characteristics [34], Public innovation procurement plays a pivotal role by generating market demand for inventive products and services, concurrently diminishing risks in the innovation marketplace and uncertainties in R&D [8], thereby fortifying innovative product R&D efforts. Nonetheless, public innovation procurement may have a "downside". Excessive reliance on public innovation procurement can prove detrimental to the innovation endeavors of cities. Overreliance on procurement can foster technological dependency and local disarray, posing a potential threat to the region's long-term competitiveness. Specifically, when innovation procurement overwhelms endogenous innovation activities, local innovation ecosystems are undermined, as most actors are dominated by public procurement needs and there is less incentive to innovate based on the market or the scientific frontier. These challenges ultimately ossify existing innovation dynamics and result in technological lock-in [35]. This suggests the following hypothesis:

Hypothesis 1. *Public innovation procurement improves urban innovation quality and has an inverted "U"-shaped effect.*

The quantity of innovative talent within a region directly influences its level of innovation [36]. The intricate nature of innovation procurement products demands a substantial reservoir of tacit knowledge. To comprehend and assimilate this tacit knowledge, a region necessitates a highly skilled human capital pool and a cadre of research and development experts. Innovation procurement enhances the diversity of the talent factors available regionally, thereby creating opportunities for a wider array of talent combinations conducive to the generation of innovative ideas and tacit knowledge. Furthermore, the agglomeration effect stemming from local flagship innovation procurement projects, such as large-scale scientific facilities, heightens the city's appeal to scientists and leading-edge talents. This triggers a self-reinforcing cycle of talent concentration driven by cumulative causal effects. Simultaneously, the externalities arising from talent agglomeration bolster the local knowledge reservoir. This diminishes losses of information and costs related to knowledge exchange, significantly enhancing the efficiency of knowledge dissemination. Fresh knowledge is frequently exchanged, acquired, and disseminated through both formal and informal networks. This dynamic facilitates talent in comprehending market information, engendering superior innovations, elevating the likelihood of urban innovation, and augmenting the quality of urban innovation.

Public innovation procurement can increase urban external technology introduction while affecting the quality of urban innovation. Scholars focusing on innovation research have noted that technology mixes from different sources, geographical scales, and heterogeneous players seem to favor innovation and regional development [37–40]. Increasingly, innovation processes need to bring together independent knowledge bases between participants distributed within and outside the cluster [41]. On the one hand, public innovation procurement augments the influx of technology external to the city by acquiring innovative products and critical technologies. This strategic approach mitigates the risks linked to technological lock-in within the confines of the city, enhances resilience against shocks, and mitigates crises. On the other hand, the intricate products procured through innovation processes encompass intricate and arduous-to-replicate knowledge and technologies. These assets exhibit a heightened spatial "sticky" and hold substantial value and competitive edge. Consequently, they grant the region the opportunity to tap into a spectrum of diverse external knowledge absorption, indirect knowledge transfers, and the capacity to comprehend and incorporate complexity in future development. This dynamic stands as a pivotal catalyst for elevating the quality of urban innovation.

Public innovation procurement fosters entrepreneurial activity within urban areas. Entrepreneurial activity represents the process through which entrepreneurs optimize and integrate their accessible resources, aiming to generate heightened economic or social value through their endeavors. The multifaceted role of entrepreneurial activity in catalyzing innovation, employment, wealth generation, and urban innovation is unmistakable. Typically, public innovation procurement is initiated by government departments, who articulate their demand for innovative solutions. This process involves subsequent phases such as bidding, negotiation, and consultation, culminating in the establishment of a formal agreement or contract with a competitive supplier for production [8]. Public innovation procurement caters to entrepreneurs' information access requirements. Public innovation procurement serves as a convenient platform for information exchange, a crucial component for seizing business opportunities prior to decision-making, and for facilitating information sharing throughout the entrepreneurial process. The development of public innovation procurement provides a source of information and an information base for decision-making in entrepreneurial activities. Furthermore, public innovation procurement frequently functions as an administrative tool to promote the diffusion of new technologies and products, leading to the emergence and success of new industries. For example, in the field of energy conservation and environmental protection, the government has formulated policies such as preferential procurement and mandatory procurement in projects supported by financial funds, which help to support the development of new energy, environmental protection, and other related emerging industries [42] and promote the establishment of new enterprises and the entry of new industries, which in turn stimulate the enthusiasm of urban innovation. Hence, this paper proposes the following hypothesis:

Hypothesis 2. *Public innovation procurement enhances urban innovation quality through channels such as pooling human capital, increasing external technology introduction, and entrepreneurial activity.*

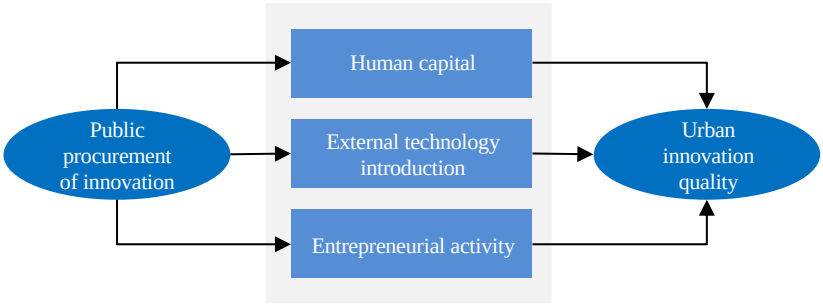

Figure 1. Research framework.

3. Methodology and Data

3.1. Methodology

To test the impact of public innovation procurement on urban innovation quality, drawing on previous studies [43–46], the following two-way fixed effects model was constructed:

$$UIQ_{it} = \alpha_0 + \alpha_1 PIP_{it} + \varphi Controls_{it} + Year_t + \delta_i + \eta_{it} \quad (1)$$

where the subscript i signifies the city, and t stands for the year in the research period (2015–2020). UIQ_{it} is the urban innovation quality. PIP_{it} is public innovation procurement. $Controls_{it}$ is the other control variables, and η_{it} are added to take the deviations into account. In addition, this paper controls for the year ($Year_t$) and city (δ_i) fixed effects, respectively.

3.2. Variables

3.2.1. Explained Variables

Urban innovation quality is the dependent variable in this study. The previous literature often measures innovation levels from the perspectives of innovation input and

output. However, innovation activities involve a certain degree of uncertainty and risk, and innovation input does not necessarily lead to output. Moreover, due to imperfections in China's accounting system, issues such as overreporting of corporate R&D and innovation investments exist, making it difficult to measure a city's true level of innovation using input indicators. Patents, as the most direct output of urban innovation activities, are one of the most widely used indicators in current innovation research. Measuring innovation through patents has two major advantages: first, patent data are publicly available and objective, with a lower possibility of manipulation; second, patent information is updated in a timely manner, accurately reflecting changes in urban innovation trends [47,48]. Therefore, the number of patents is widely used as a proxy indicator for the level of urban innovation. However, simply relying on patent counts cannot effectively capture the differences between technological importance and innovation significance. Due to the existence of "strategic innovation" (utility model and design patents are not suitable to promote genuine technological progress and are often recognized as strategic innovation) and "innovation bubbles" (generally referring to low-quality innovation output, which is speculative behavior for the sake of innovation and often appears in the form of "patent bubbles"), the number of patents does not represent a city's true level of innovation. Therefore, this paper chooses the number of times patents are cited (Citation) and technological complexity (Complexity) to measure the urban innovation quality.

The number of times a patent has been cited (Citation). This is the number of times this patent has been cited by other patents. The number of times a patent is cited is a reflection of the impact and economic value of the patent and is the most common indicator of patent quality [49,50].

Technological complexity (Complexity). This is the quality of technological innovation; the greater a place's ability to create complex technology, the more it can specialize in complex products [51,52]. A patent with high complexity is a metaphor for the more demanding conditions and advanced technology needed to produce it, and a city that contains many complex technologies will be less likely to be copied and produced by many regions, but this tends to be confined to certain cities that have unique specialization with a unique capacity for innovation. This study first uses the Chinese invention-awarded patent dataset to construct a technology dichotomous network of Chinese cities($M_{c,i}$), i.e., a 0–1 matrix with city–technology–field ranks, where each row represents the technology category owned by a city, and each column represents a list of cities that own that technology field. This study then draws on Balassa's 'revealed comparative advantage' (RCA) [53] to compute the comparative advantage of Chinese cities c in the technology domain i. We refer to the fixed threshold adopted by most studies [54,55], i.e., if the RCA is greater than or equal to 1, the technology category is included in the urban technology pool, and 0 otherwise. The formula for RCA is as follows.

$$RCA_{c,i} = \frac{patents_{c,i} / \sum_i patents_{c,i}}{\sum_c patents_{c,i} / \sum_c \sum_i patents_{c,i}} \quad (2)$$

where $RCA_{c,i}$ represents the ratio of the number of patents of city c in patent category i to the number of all patents in the field to the number of all patents in the country or region to the number of all patents in the country. The larger the RCA, the more obvious the advantage in the field.

The generalized economic complexity index (GENEPY) [56] was used to calculate the technical complexity based on the constructed $RCA_{c,i}$. Firstly, the similarity of the technology pool between cities is calculated by measuring the two largest eigenvalues 1 and 2 of the similarity matrix N_{i,i^*} and the corresponding eigenvectors i,1 and i,2, whereby the undirected graph of $M_{c,i}$ is transformed into a symmetric weighted directed graph between the cities, and the formula for the technology complexity is given as:

$$GENEPY_i = \left(\sum_{C=1}^{2} \lambda_C X_{c,i}^2\right)^2 + 2\sum_{c=1}^{2} \lambda_c^2 X_{c,i}^2 \quad (3)$$

The similarity matrix formula is as follows:

$$N_{i,t*} = \sum_c W_{c,i} W_{c,i*} = \sum_i \frac{M_{c,i} M_{c,i*}}{k_i k_{i*} k_c'^2} \text{ if } i \neq i^*$$
$$N_{i,t*} = 0 \text{ if } i = i^* \quad (4)$$

where k_i denotes the degree centrality of the city, i.e.,

$$k_i = \sum_c M_{c,i} \quad (5)$$

3.2.2. Explanatory Variables

Public innovation procurement (PIP). This variable is measured by the total amount of public innovation procurement.

3.2.3. Control Variables

To provide a comprehensive analysis of the influence of urban public innovation procurement on urban innovation quality, it is essential to incorporate control variables [3,4,7,47,57] that could affect the development of urban innovation quality. These include the following: The stage of development of the city, which affects the quality of urban innovation; the level of development of the local economy, which increases and promotes the transformation of the industrial structure towards knowledge, technology, and human capital to create the necessary conditions for the development of innovation in the region; the introduction of the logarithm of the GDP per capita (InGDP) indicator to indicate the level of the economy; the ratio of the secondary and tertiary industries to the GDP of the region to indicate the industrial structure (Industrial); and the logarithm of the wages of workers per capita (InWage) to indicate the level of wages. Additionally, the logarithm of the total amount of imported and exported goods (InOpen) is used to indicate the level of openness to the outside world; the ratio of the balance of deposits and loans of the institutions to the regional GDP is used to indicate the level of financial development (Finance); the logarithm of the R&D input of the city (InR&D) is chosen to characterize the investment in innovation; and the logarithm of the local government's financial expenditure on education is used to indicate the government's support for education (InEducation). The meanings represented by the independent variables are shown in Table 1. Descriptive statistics can be found in Table 2, and Table 3 displays correlation results for all variables.

Table 1. The description summary of variables.

Variables	Abbreviation	Definition
Number of technological citations	Citation	Number of citations of city patents by other patents
Technological complexity	Complexity	The technological complexity of urban patents
public innovation procurement	PIP	Total urban public innovation procurement
Level of economic development	InPGDP	Log of urban GDP per capita
industrial structure	Industrial	The ratio of urban secondary and tertiary industries to GDP
Wages per capita	InWage	Log of urban per capita employee wages
openness level	InOpen	log of total urban exports and imports of goods
Level of financial development	Finance	The ratio of deposit and loan balances of urban banks to regional GDP
Urban R&D inputs	InR&D	Log of urban R&D inputs
Government educational support	InEducation	Log of government fiscal expenditure on education

3.3. Data Source

To identify public innovation procurement and evaluate its effects on urban innovation quality, this study utilizes two datasets: one comprising public procurement data from the China Government Procurement Network (CGPN) which publishes all government contracts. These contracts contain details such as title, signing date, amount, supplier, purchaser, and region. As the government-mandated procurement information disclosure since 2015, enabling access to detailed contract data, this study focuses on contracts from 2015 to 2020 for empirical analysis.

Table 2. Descriptive statistics.

Variables	Observations	Minimum	Maximum	Mean	SD
Citation	1614	0	58,977	1478	4272
Complexity	1614	0.0000109	2.995	0.0624	0.174
PIP	1614	0	2,499,000	21,781	122,287
PGDP	1614	10,987	215,488	59,741	33,591
Industrial	1614	51.30	99.96	88.62	7.339
Wage	1614	4958	185,026	68,654	17,707
Open	1614	26	349,000,000	11,100,000	37,500,000
Finance	1614	0.434	7.203	1.576	0.677
R&D	1614	3	25,700,000	682,762	1,812,000
Education	1614	35,925	11,400,000	877,196	1,079,000

Table 3. Correlation matrix.

Variables	Citation	Complexity	PIP	PGDP	Industrial	Wage	Open	Finance	R&D	Education
Citation	1									
Complexity	0.847 ***	1								
PIP	0.692 ***	0.626 ***	1							
PGDP	0.536 ***	0.492 ***	0.246 ***	1						
Industrial	0.362 ***	0.337 ***	0.174 ***	0.667 ***	1					
Wage	0.542 ***	0.527 ***	0.446 ***	0.604 ***	0.402 ***	1				
Open	0.821 ***	0.728 ***	0.559 ***	0.515 ***	0.333 ***	0.481 ***	1			
Finance	0.443 ***	0.411 ***	0.402 ***	0.120 ***	0.187 ***	0.400 ***	0.363 ***	1		
R&D	0.868 ***	0.808 ***	0.722 ***	0.496 ***	0.363 ***	0.503 ***	0.843 ***	0.394 ***	1	
Education	0.860 ***	0.779 ***	0.699 ***	0.451 ***	0.324 ***	0.553 ***	0.813 ***	0.371 ***	0.844 ***	1

*** $p < 0.001$.

Based on the literature, conflating standard and innovative procurement when examining public innovation procurement's impact can invariably engender estimation bias. This study defines public innovation procurement in China as government procurement of innovative products and services at all levels, identifying instances through text analysis. This study compiled "the Guidance Catalogue for Indigenous Innovation of Major Technical Equipment (2012)" and "the Classification of Strategic Emerging Industries (2018)" issued by the Chinese central government, as well as innovative product catalogs issued by provinces. Jieba, the highest-precision Chinese text segmentation module in Python, facilitated the processing and manual screening of the compiled catalogs. The outcome was an innovation keyword database containing over 3000 terms such as "intelligence", "new energy vehicle", "software", "database", "geological exploration", "robot", etc. Then, over 640,000 public procurement contracts from 2015 to 2020 were matched against the keyword database for contract title, subject matter, and specifications. Contracts were matched based on "contract name", "main subject matter name", and "specification model or service requirements". Contracts containing innovation keywords were identified as public innovation procurement. The cities undertaking public innovation procurement were then extracted using Python programming by aggregating contract addresses to prefecture-level cities and retrieving geocoordinates via Google Maps API.

The second dataset containing the socio-economic data of Chinese prefecture-level cities is from the China City Statistical Yearbook, the China Regional Economic Statistical Yearbook, and the CSMAR database. Any missing data were supplemented using statistical yearbooks and bulletins.

This study utilizes prefecture-level cities as the unit of analysis. To mitigate missing data issues for certain cities and resultant biases, the sample was restricted to 269 cities. It is worth noting that Hong Kong, Macao, and cities in Taiwan were excluded from the study region.

4. Empirical Results

4.1. Regression Results and Analysis

Table 4 presents the baseline results. The first three columns depict regression outcomes where the dependent variable is the count of patent citations, while the last three columns present results with technological complexity as the dependent variable. Specifically, column (1) excludes control variables, and column (2) incorporates them while controlling for year and city fixed effects. Notably, the coefficient for public innovation procurement is significantly positive at the 1 percent level, irrespective of the inclusion of control variables. Furthermore, the regression findings in columns (4) and (5) utilizing technological complexity as an explanatory factor align with those based on patent citation counts. This implies that public innovation procurement exerts a substantial positive influence on innovation quality in urban areas, encompassing both patent citations and technological complexity. Our results broadly suggest that, in terms of the top-level design of national innovation policy systems, there is a need to further strengthen the implementation of public innovation procurement policies by focusing more on the role of demand-side support policies. Hypothesis 1 posits an inverted "U"-shaped relationship between a city's public innovation procurement and its innovation quality. In columns (3) and (6), the positive sign on the linear term and the negative sign on the quadratic term provide statistical support for this hypothesis, that is, the higher the scale of innovation procurement in a city, the more favorable it is for the quality of innovation in the city. However, once the scale of innovation procurement within a city increases to a critical point, the consequences of diminishing returns seem to dominate as the city's innovation offerings become more redundant.

Table 4. Estimated results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Citation	Citation	Citation	Complexity	Complexity	Complexity
PIP	0.0276 ***	0.0273 ***	0.0169 **	0.0047 ***	0.0046 ***	0.0096 **
	(6.91)	(6.70)	(2.30)	(4.05)	(4.02)	(2.06)
PIP^2			−0.0042 *			−0.0004 *
			(1.76)			(1.73)
Control	NO	Yes	Yes	NO	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1614	1614	1614	1614	1614	1614
R^2	0.3536	0.3665	0.3665	0.152	0.166	0.3662

Robust t-statistics in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Various forms of public innovation procurement generate Marshallian externalities characterized by innovation factor agglomeration, which in turn influence urban innovation. Thus, a potential interrelationship exists between public innovation procurement and urban innovation. To mitigate endogeneity concerns and evaluate this paper's results, we employ the relief degree of land surface (IV) for each city as an instrumental variable.

Since the relief degree of the land surface is a non-time-varying variable, we address the need for temporal and city-specific dynamics in the instrumental variable by incorporating the count of public innovation procurement contracts in the previous year at the survey's time point. Furthermore, the relief degree of the land surface is an exogenous variable capturing the unique characteristics of each city beyond the economic domain. The degree of topographic relief, indicative of a city's flatness, holds significant sway over the placement of educational institutions, research centers, and high-tech enterprises. Consequently, a flatter topography often correlates with a more innovative ecosystem, thereby amplifying the demand for innovation procurement within the city. Therefore, the interaction term (IV) between the relief degree of the land surface in each city and

the number of public innovation procurement contracts in the previous year satisfies the "exogeneity" and "correlation" conditions.

The regression results are displayed in columns (1) and (3) of Table 5. The results show that there is no problem of under-identification of instrumental variables and weak instrumental variables identification and that the instrumental variables are valid. The coefficient on public innovation procurement is significantly positive, in full agreement with the previous results. Considering that the IV may not be strictly exogenous, this paper further tests the robustness of the instrumental variables in this paper by adopting the "plausibly exogenous" instrumental variables method [58], which relaxes the strict exogeneity requirement of the instrumental variables. Columns (2) and (4) of Table 5 report the 95% robust confidence intervals for the coefficients of the endogenous variables under the UCI approach. The coefficients on public innovation procurement in columns (1) and (3), respectively, are within the above robust confidence intervals, suggesting that the conclusions drawn from the instrumental variables approach remain robust even if they are not strictly exogenous, thus supporting the theoretical logic of the paper.

Table 5. Endogeneity problem-solving.

Variables	(1)	(2)	(3)	(4)
	Citation	Citation	Complexity	Complexity
	IV	UCI—95% Confidence Interval	IV	UCI—95% Confidence Interval
PIP	0.0654 *** (7.72)	[−1.8112, 1.8647]	0.0039 *** (3.29)	[−18.3803, 18.3803]
Control	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes
Kleibergen–Paap rk LM	13.113 ***	1614	11.357 ***	1614
Kleibergen–Paap rk Wald F	22.570 ***		26.112 ***	
Observations	1614		1614	

Robust t-statistics in parentheses. *** $p < 0.001$.

4.2. Mechanism Test

The preceding analysis elucidates the causal relationship between public innovation procurement and urban innovation quality. However, the underlying mechanism warrants deeper investigation. In this section, we examine human capital, external technology introduction, and entrepreneurial activity as potential channels.

To investigate whether human capital is a channel through which public innovation procurement affects urban innovation quality, this paper uses the share of the total number of employees in scientific research, technical services, and computers to the total number of employees in the city as a measure of human capital and runs a regression. The findings in column (1) of Table 6 indicate that public innovation procurement promotes the clustering of human capital. Theoretically, the government's reliance on flagship innovation procurement projects can increase the attractiveness of cities to scientists and cutting-edge talents and provide talent security for urban innovation. Therefore, the impact of public innovation procurement on human capital is confirmed.

To verify whether external technology introduction is a channel through which public innovation procurement affects urban innovation quality, this paper uses the number of urban external patent rights introductions to measure external technology introduction and conducts regression analyses. The results in column (2) of Table 6 indicate that public innovation procurement increases the size of the city's external technology introduction. Numerous empirical studies have substantiated the influence of introducing external technology on local innovation [35]. The theory of latecomer advantage suggests that, in this way, latecomer countries can take advantage of technological spillovers and diffusion

from developed countries to improve their local technological capabilities. On the one hand, locals can introduce and learn new technologies from other countries to accelerate urban development and renewal. On the other hand, introduced technologies can be used to innovate to catch up quickly with current technologies.

This paper believes that in addition to human capital and external technology introduction, entrepreneurial activity is also an important channel. This paper uses the number of new start-ups in the city in the current year to measure entrepreneurial activity and conducts regression analyses. Theoretically, public innovation procurement can stimulate urban innovation quality by boosting entrepreneurial activity. Public innovation procurement can cultivate more entrepreneurial opportunities by influencing market size, knowledge spillovers, and factor combinations, as well as enriching entrepreneurial resources by accelerating the interaction of information and the dissemination of ideas, thus promoting entrepreneurial activity in the city, which in turn will lead to the enhancement of urban innovation quality.

Table 6. Mechanism test.

Variables	(1)	(2)	(3)
	Human Capital	External Technology Introduction	Entrepreneurial Activity
PIP	0.0186 ***	0.0042 ***	0.0305 **
	(5.67)	(3.53)	(2.40)
Control	NO	Yes	Yes
Year fixed effect	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes
Observations	1614	1614	1614
R^2	0.8624	0.6412	0.4651

Robust t-statistics in parentheses. ** $p < 0.01$, *** $p < 0.001$.

4.3. Heterogeneity Test

Due to the imbalance of regional development in China, i.e., significant differences in policy context, resources, and environment among Chinese cities, these influencing factors are the necessary basis for influencing the quality of urban innovation. Therefore, this study further considers city-region factors and analyzes the impact of innovation sourcing on urban innovation quality. This paper divided the whole sample into two parts four regions (cities with provincial status and provincial capitals vs. other prefecture-level cities, eastern cities vs. mid-western cities), and ran regressions using the methodology described above. The results of the regional heterogeneity estimation are shown in Table 7.

For cities with provincial status and provincial capitals, indeed, the estimated coefficients are positive and significant, suggesting that public innovation procurement contributes significantly to the quality of urban innovation. However, the estimated coefficients for the other cities are not significant, suggesting that public innovation procurement does not have a significant impact on the quality of urban innovation. The main reason for this is that cities with provincial status and provincial capitals are usually the agglomeration of factors and business centers within each province due to their higher administrative level. As a result, they have better platforms for talent and technology transfer than other prefecture-level cities. The higher administrative level, more solid support, and resource advantages enable innovation procurement to exert an innovation quality enhancement effect. Therefore, differentiated policies are crucial for cities at different levels. Government departments can optimize the spatial pattern of the urban economy and environment by allocating innovation procurement resources through scientific and rational administrative means.

The estimation results show that, based on city location, the estimated coefficients are all significantly positive at the 1 percent level for cities in the east, but not for cities in the central and western parts of the country. The reason for this may be that being in the east is conducive not only to benefiting from the locational advantage of importing innovative products but also to fostering a huge consumer demand for innovative products, which is

crucial for expanding innovation sourcing. To some extent, this finding is understandable, given the cities in eastern China are much more developed and have attracted more advanced high-tech firms such as Alibaba, Huawei, and Tencent, so they have the advantage and ability to absorb technology spillovers from innovation sourcing.

Table 7. Heterogeneous results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Municipalities and Provincial Capitals		Other Prefecture-Level Cities		Eastern Cities		Mid-Western Cities	
	Citation	Complexity	Citation	Complexity	Citation	Complexity	Citation	Complexity
PIP	0.0897 ***	0.0323 ***	0.0571	0.0087	0.0613 ***	0.0231 **	0.0148	0.0025
	(8.91)	(4.80)	(1.10)	(1.25)	(7.02)	(2.01)	(1.40)	(1.05)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	192	192	1422	1422	594	594	1020	1020
R^2	0.8654	0.7524	0.7383	0.7057	0.9238	0.8241	0.8019	0.7298

Robust t-statistics in parentheses. ** $p < 0.01$, *** $p < 0.001$.

4.4. Robustness Checks

This paper conducted robustness tests to see if the results remained stable under different conditions. This study mainly considered the following conditions.

Firstly, it is worth noting that the influence of public innovation procurement on urban innovation quality might not manifest immediately; rather, it could exhibit a lagged effect. Consequently, this study introduced a one-year lag in public innovation procurement as the principal explanatory variable for reevaluation purposes. The findings indicate that the lagged public innovation procurement term remains positively associated with urban innovation quality, signifying the persistence and stability of its impact. Consequently, this reinforces the credibility of the initial conclusions.

Secondly, the original independent variables are replaced with the number of innovation procurement contracts for robustness testing. Table 8 demonstrates that even with this alteration in measurement, the impact of public innovation procurement on urban innovation quality remains distinctly positive. This underscores the robustness of the original conclusion despite the change in measurement methodology.

Table 8. Robustness checks.

Variables	(1)	(2)	(3)	(4)
	1-Year Lag	Public Innovation Procurement Contract	Excluding the 2020 Sample	Excluding Cities with Provincial Status
PIP	0.0704 ***	0.0317 ***	0.0327	0.0514
	(7.82)	(4.10)	(0.09)	(0.01)
Year fixed effect	Yes	Yes	Yes	Yes
City fixed effect	Yes	Yes	Yes	Yes
Observations	1614	1614	1345	1590
R^2	0.9158	0.7529	0.7489	0.8854

Robust t-statistics in parentheses. *** $p < 0.001$.

Thirdly, to mitigate the influence of particular years, this study adjusted the timeframe to exclude data from the year 2020 in the regression analysis. The findings indicate that this adjustment in the sample year does not impact the original results.

Fourth, it is noteworthy that in China, the administrative rank of a city correlates with resource allocation, wherein cities holding provincial status, signifying higher political standing, enjoy an advantage in the allocation of innovation resources. This could potentially pose a challenge to the robustness of the results. Consequently, this study conducted a reassessment by excluding a sample of four cities with provincial status. The robustness test outcomes consistently affirm the reliability of the regression findings.

5. Conclusions

In the current context of rapid urbanization, urban innovation has become a key driver of economic growth and sustainable development. Globally, public innovation

procurement serves as a vital innovation policy instrument. With China in a critical phase of innovation catch-up and high-quality growth transition, public procurement, especially innovation procurement, and incentive effects on urban innovation remain unclear, warranting investigation to inform national innovation-driven development.

Concerning our results, we highly support that public innovation procurement enhances urban innovation quality. This is in tandem with the findings of many authors [35,42], suggesting an inverted U-shaped relationship between the two, a conclusion robust to tests addressing endogeneity, variable substitution, and sample size changes. The effectiveness of public innovation procurement primarily functions by accumulating human capital, expanding external technology introduction, and boosting entrepreneurial activity. Regarding our findings, we highly support that there is strong heterogeneity in the impact of public innovation procurement on urban innovation quality. Public innovation procurement in China enhances the quality of innovation more significantly for economically advanced eastern cities and for cities with provincial status and provincial capitals. Such an understanding also guides the formulation of targeted policies and measures to foster urban innovation quality. Ultimately, it helps cities narrow development gaps and propel sustainable socioeconomic progress.

6. Policy Implications

From a policy implication angle, we can propose the following: Firstly, according to the study, China should robustly implement public innovation procurement policies, strategically deploy procurement tools, and further leverage procurement to bolster regional innovation. Specifically, China should align procurement with local needs, pursue diversified and sustained procurement policies, identify priority areas and industries, and increase support for high-tech, emerging industry, and technology-based SMEs. Secondly, considering the heterogeneity analysis, public innovation procurement should be heterogeneous. Procurement policies should judiciously shift their focus towards non-provincial capital cities. This entails enhancing the innovation milieu within these cities, capitalizing on the external benefits emanating from innovation procurement policies, and elevating the innovation quotient within these urban centers. Furthermore, this policy could be extended to encompass cities situated in the central and western regions. This extension necessitates the judicious allocation of financial resources in favor of these central and western cities, while simultaneously harnessing the latent innovation capabilities harbored by these urban locales. Thirdly, from the analysis of the innovation procurement mechanism, in the process of public innovation procurement practice, not only should we take into account the conditions of suppliers, market environment, overall R&D level, and financial market environment but also pay more attention to optimizing the urban innovation environment, attracting talents, increasing the scale of external technology introduction scale, cultivating more entrepreneurial opportunities, enhancing entrepreneurial activity, and improving urban innovation quality.

7. Limitations and Future Recommendations

This paper exhibits certain limitations. For instance, it proved challenging to capture the micro-level mechanisms within innovation sourcing that exert influence on innovation quality, primarily due to the intricate measurement of variables such as innovation quality and innovation sourcing at the industry or firm level. As a future research, further studies could be based on quantile regression but focus on different variables or datasets, employing microdata analysis. These limitations will steer the course of our future research endeavors.

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