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The Impact of Innovation-driven Development on the Urban TFP: A Natural Experiment Based on the Construction of Innovative Cities in China

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Keywords

Innovative Cities; Innovation-driven; Urban TFP; Natural Experiment

Abstract

With the construction of national innovative cities as a natural experiment of innovation-driven development, based on the panel data of 281 prefecture-level cities in China from 2003 to 2016, this paper utilizes the new economic growth model to distinguish the difference in the impacts of independent innovation and technology-introduction innovation on urban TFP. According to the relevant research conclusions, it indicates that innovation-driven can indeed improve urban TFP. Nevertheless, the core of innovation-driven improvement of urban TFP lies in the improvement of the independent innovation ability of innovative cities, rather than the technology-introduction innovation ability. The important policy-related implication of this paper lies in that the further promotion of the construction of national innovative cities requires the implementation of independent innovation-driven development strategies and the improvement of the urban TFP level of economic cities.

1. Introduction

A noteworthy question is how to realize the urban TFP of China's economic cities. At the present stage, China's economy has entered the urban TFP stage from the high-speed growth stage (Aghion & Howitt, 1992). It is worthy of recognition that China's scientific and technological level and innovation capability are showing a trend of continuous improvement. Nevertheless, innovation-driven development is still regarded as one of the key weak links in China's real economy. Specifically, it mainly exposes a series of defects, including weak basic research, insufficient key core technology reserves, weak independent innovation capability of enterprises, and narrow urban innovation foundation. Within this context, studying the relationship between innovation-driven development and urban TFP becomes the core of this paper.

The research on the mechanism of innovation-driven economic growth and development in the existing literature can be roughly summarized into the following two aspects. On the one

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hand, some studies are mainly based on the perspective of products. For instance, relevant scholars argue that product-related innovation drives economic specialization and high-quality growth and that the market can stimulate more potential consumer markets through professional and diversified product or service innovation, thus enhancing the specialization of production and further improving production efficiency. On the other hand, other studies are mainly based on the perspective of the industry. For instance, Aghion et al. advocate that innovative products and services take innovation-driven industrial transformation as the core to replace the original consumption pattern (Aghion & Howitt, 1992).

Wu et al. (2017) construct a theoretical framework to explore the impact of government expenditure and corruption on TFP. Dunbar and Easton (2013) found that the composition of parents' labor force is also beneficial to explain the differences in labor productivity among American states. The research of Zhang (2015) confirms that technological progress plays a leading role in TFP. Likewise, Liu and Lu (2011) consider the influence of information technology on TFP through substitution. Kreuser and Newman (2018) adopt firm-level data to estimate the TFP of the manufacturing industry in South Africa. In addition, Zhang (2019) utilizes the index model to dynamically decompose the TFP of China's marine economy, thereby analyzing the variation tendency and influencing factors of total factor productivity concerning the marine economy.

Despite the fact that the foregoing literature provides a beneficial reference for the study of innovation-driven urban TFP in this paper, there is still room for further improvement. Specifically, first of all, given that the vast majority of the existing literature focuses on the correlation between innovation-driven and economic growth, they are incapable of avoiding the problem that the two are mutually causal, nor can they effectively distinguish between economic growth and urban TFP, thus making it difficult to identify the causal effects related to innovation-driven urban TFP. Secondly, the existing research typically regards innovation as a whole without distinguishing the differences related to the influence of different forms of innovation, thereby resulting in unstable results. Lastly, most research on the mechanism of innovation-driven economic growth is limited to the theoretical level. Few scholars have verified the mechanism of action related to innovation-driven urban TFP from the perspective of natural experiments. Hence, this paper will further enrich the preliminary research from the above-mentioned three perspectives.

2. Theoretical Model

From the perspective of expediting the replacement of old growth drivers with new ones concerning urban TFP and regional competition, it is the key of regional competition to shift the economy from investment-driven development to innovation-driven and TFP-driven development. In this connection, this paper constructs the theoretical model of innovation-driven urban TFP and innovation-driven total factor productivity growth (urban TFP). In this model, this paper not only introduces innovative R&D factors related to intermediate products but also constructs a new economic growth model composed of the final-product production department, intermediate-product production department, innovation and R&D department, and household consumption department.

2.1 Final-product Production Department

The final-product production department invests capital, labor, and intermediate products to produce a single final product under the condition of perfect competition, with its production function as follows:

$$Yt = L_{Yt}^{a}[At \int_{1}^{N} xit^{\beta} di + \mu At^{*} \int_{1}^{N} xit^{*\beta}\, di] Kt^{1-a} \tag{2.1}$$

Where, Yt is the output of the final product. LYt and Kt are the labor and capital inputs related to the final product. xit and xit^{*} are the intermediate products independently researched and developed by China as well as the intermediate products researched and developed through technology introduction and drawing lessons from foreign technologies. μ is the technology introduction coefficient while At is the total factor productivity. Meanwhile, under the condition of a balanced market, the labor remuneration of the final-product production department and the price of intermediate products can be further solved.

$$wYt = aL_{Yt}^{a-1}[At \int_{1}^{N} xit^{\beta} di + \mu At^{*} \int_{1}^{N} xit^{*\beta} di] K_{t}^{1-a} \tag{2.2}$$

$$P_{xit} = \beta L_{Yt}^{a} A_{t} xit^{\beta-1} {K_{t}}^{1-a} \tag{2.3}$$

$$P_{xit^{*}} = \beta L_{Yt}^{a} \mu {A_{t}}^{*} xit^{*\beta} {K_{t}}^{1-a} \tag{2.4}$$

2.2 Intermediate-product Production Department

Assuming that there is only one intermediate-product production department, which only converts raw materials into intermediate products and has no labor input, $x_{it} = {x_{it}}^{*}$ is established. Therefore, $\int_{1}^{N} xit^{\beta} di = \int_{1}^{N} xit^{*\beta} di = \overline{Y}$. By simultaneous equations (2.3) and (2.4), the price of the intermediate product in an equilibrium state can be obtained, that is, $P_{xit} = \frac{A_{t}}{\mu {A_{t}}^{*}} P_{xit^{*}}$. At the same time, considering that the reference to foreign technology is exogenous, it is assumed that the $P_{xit^{*}} = \frac{1}{\beta}$ is exogenously given. Therefore, the function of the final production department, the labor remuneration, and the profit of the intermediate-product production department are as follows:

$$Y_{t} = \beta^{\frac{2\beta}{1-\beta}} {L_{Yt}}^{\frac{a}{1-\beta}} [A_{t} + \mu {A_{t}}^{*}] {K_{t}}^{\frac{1-a}{1-\beta}} \tag{2.5}$$

$$w_{t} = a\beta^{\frac{2\beta}{1-\beta}} {L_{Yt}}^{\frac{a+\beta-1}{1-\beta}} [A_{t} + \mu {A_{t}}^{*}] {K_{t}}^{\frac{1-a}{1-\beta}} \tag{2.6}$$

$$\pi_{t} = (1-a)\, \beta^{\frac{2\beta}{1-\beta}} {L_{Yt}}^{\frac{a}{1-\beta}} {K_{t}}^{\frac{1-a}{1-\beta}} \tag{2.7}$$

2.3 Innovation and R&D Department

In this paper, the innovative R&D department acts the result of innovation and R&D on the intermediate-product production department, with the structure of the output function model of marginal innovation and R&D is as follows:

$$\dot{R_{t}} = \gamma L_{Rt} {R_{t}}^{\theta} \left(\frac{{R_{t}}^{*}}{R_{t}}\right)^{\phi}$$

$$R_{t+1} = (1-\delta) R_{t} + \dot{R_{t}} \tag{2.8}$$

Where, L_{Rt} refers to the input of skilled labor for R&D and innovation. R_t means innovation and R&D accumulation. γ is R&D efficiency. θ is the technology spillover rate, which can measure the ability of independent innovation L_{Rt}. $\frac{R_t^*}{R_t}$ is the gap between China and foreign countries, while ϕ is the learning ability index of technology introduction. The second equation is the R&D and innovation accumulation function, which is the same as the capital accumulation function and is obtained by summing up the innovation and R&D accumulation of the previous period without depreciation rate and the marginal output of the innovation and R&D accumulation of the current period.

Among them, the marginal output of innovative R&D multiplied by conversion rate τ means that new technology $\dot{A}_t$ is sold to middlemen at price P_{At}. Therefore, the profit of middlemen is zero in the equilibrium state, with the labor income and equilibrium price P_{At} of the technology R&D department at this time as follows:

$$P_{At} = \frac{1}{r_t}\ (1-a)\ \beta^{\frac{2\beta}{1-\beta}} L_{Yt}^{\frac{a}{1-\beta}} K_t^{\frac{1-a}{1-\beta}} \tag{2.9}$$

$$w_{At} = \frac{1}{r_t}\ (1-a)\ \beta^{\frac{2\beta}{1-\beta}} \gamma R_t^{\theta} \left(\frac{R_t^*}{R_t}\right)^{\phi} L_{Yt}^{\frac{a}{1-\beta}} K_t^{\frac{1-a}{1-\beta}} \tag{2.10}$$

2.4 Household Consumption Department

Assuming that the family has a fixed consumption preference, based on Ramsey Model, its consumption elasticity is constant, namely:

$$\frac{\dot{c}_t}{c_t} = \frac{1}{\sigma}(r_t - \rho) \tag{2.11}$$

2.5 Equilibrium State

Under the equilibrium state, that is, the steady-state economy and the equilibrium state of the income labor force are satisfied, the following equation is established:

$$\frac{\dot{y}_t}{y_t} = \frac{\dot{c}_t}{c_t} = \frac{\dot{k}_t}{k_t} = \frac{\dot{A}_t}{A_t} + \frac{\dot{L}_t}{L_t},\ wAt = wt,\ LYt + LRt = Lt \tag{2.12}$$

Through the simultaneous equations (2.6), (2.8), (2.10), and (2.12), the following results can be obtained:

$$g = \frac{\tau\gamma LRtR_t^{\theta}\left(\frac{R_t^*}{R_t}\right)^{\phi} - \frac{a\rho}{\beta(1-\beta)} L_{Yt}(A_t + \mu A_t^*)}{A_t + \frac{a\rho}{\beta(1-\beta)} L_{Yt}(A_t + \mu A_t^*)} \tag{2.13}$$

By solving the partial derivative R_t for $\dot{A}_t$, the following equation is established:

$$\frac{\partial \dot{A}_t}{\partial R_t} = (\theta - \phi)\tau LRtR_t^{\theta-\phi-1} R_t^{*\phi} \tag{2.14}$$

Where, it indicates that the influence of R&D innovation on urban TFP depends on the degree of independent innovation ability and technology-introduction innovation ability $(\theta - \phi)$. In the case where the independent innovation ability is greater than the technology-introduction innovation ability $(\theta > \phi)$, then $\frac{\partial \dot{A}_t}{\partial R_t} > 0$ is established, that is, innovation is capable of promoting urban TFP; In the case where the independent innovation ability is less than the technology-introduction innovation ability ($\theta < \phi$), then $\frac{\partial \dot{A}_t}{\partial R_t} < 0$ is established, that is, innovation hinders the growth of urban TFP. Lastly, the model of this paper theoretically proves the effect of innovation-driven development on urban TFP by distinguishing the differences between different types of innovation.

3. Research Design

3.1 Data Description

The explanatory variable of this paper is the urban TFP of economic cities. In this paper, total factor productivity (TFP) is taken as another indicator of urban TFP, aiming to be consistent with the theoretical model set in this paper. Labor productivity is expressed by per capita output, while total factor productivity is measured in two methods as follows:

The first method is to utilize the stochastic frontier model of translog based on the C-D production function to measure total factor productivity, with the calculation formula as follows:

$$ln\,y = t + t^2 + ln\,k + ln\,l + ln\,k * ln\,k + ln\,l * ln\,l + ln\,k * ln\,l + ln\,k * t + ln\,l * t \quad (3.1)$$

The second method is to utilize ATFP to measure TFP by referring to the research of Shi and Zhang (2016), with the calculation formula as follows:

$$atfp = ln(y/l) - \theta\, ln(k/l) \quad (3.2)$$

Where, y is the GDP of the city. k is the capital stock. l is the labor force.$\theta$is the output elasticity of capital, which is set to 1/3.

Considering the lack of data in some years and some prefecture-level cities, this paper uses the average growth rate to make up for the related defects (Shi et al., 2018). Table 1 is descriptive statistics of the main variables. From Table 1, it can be seen that the three measurement indexes related to urban TFP in the experimental group are all higher than those in the control group, which preliminarily indicates that innovative cities show a higher level of urban TFP than non-innovative cities. However, further policy effects need to be verified by introducing more systematic empirical methods. This further illustrates the necessity and feasibility of the application of DID method.

Table 1 *Descriptive statistics*

Variables	Full Samples			Control Group			Experimental Group		
	Sample Size	Mean	Standard Deviation (SD)	Sample Size	Mean	Standard Deviation (SD)	Sample Size	Mean	Standard Deviation (SD)
Labor Productivity	3934	5.2530	0.7363	3332	5.1468	0.7065	602	5.8412	0.6103
Total Factor Productivity	3934	0.2076	0.1529	3332	0.1696	0.0970	602	0.4180	0.2202
Approximate Total Factor Productivity	3934	8.6629	0.7537	3332	8.6275	0.7414	602	8.8585	0.7911
Financial Development	3934	0.6192	0.3901	3332	0.5624	0.3432	602	0.9335	0.4755
Government R&D Investment	3934	-0.4318	1.0136	3332	-0.5357	0.9620	602	0.1428	1.0970
Infrastructure	3934	3.1975	0.6109	3332	3.2523	0.6091	602	2.8942	0.5266
Internet	3934	-2.6753	1.0579	3332	-2.7998	1.0323	602	-1.9859	0.9243
Industrial Structure	3934	0.1883	0.5634	3332	0.2187	0.5796	602	0.0196	0.4265
Population Density	3934	5.6915	0.9389	3332	5.5892	0.9490	602	6.2576	0.6316

3.2 Model Specification

As mentioned above, the evaluation system for the construction of innovative cities is in high agreement with the national innovation-driven development strategy. Consequently, this paper can regard the construction of national innovative cities as a quasi-natural experiment of innovation-driven development, which provides an excellent opportunity for this research to evaluate the impact of innovation-driven development on urban TFP by using the difference-in-differences (DID) method. This paper mainly uses the DID method to evaluate the impact of innovation-driven development on urban TFP, with the cities that were set up as the innovative pilot cities being incorporated into the experimental group, and the cities that were set up as non-innovative pilot cities being incorporated into the control group. Based on the rules established by the DID method, this paper mainly constructs two dummy variables. Specifically, first, the dummy variables of the experimental group and the control group are du. Cities belonging to innovative pilot cities are included in the experimental group, which is defined as 1; otherwise, they are included in the control group and defined as 0. Secondly, the dummy variable related to the occurrence of the pilot is dt. The time of the year when a city is set up as an innovative pilot city is defined as 1, while the previous time is defined as 0. Considering that this paper uses the panel data of prefecture-level cities, in order to ensure the consistency of the data, this paper deletes the sample cities as municipalities directly under the central government (some districts under municipalities directly under the central government are set up as innovative cities, such as Haidian District in Beijing and Binhai New Area in Tianjin). The control group of this paper selects other non-innovative cities in the same province as innovative cities. The final samples of the experimental group and control group are shown in Table 2.

Table 2 *Sample distribution of innovative cities*

2008	Shenzhen	2009	Dalian, Qingdao, Xiamen, Shenyang, Xi'an, Guangzhou, Nanchang, Nanjing, Hangzhou, Hefei, Changsha, Suzhou, Wuxi, and Yantai
2010	Tangshan, Baotou, Harbin, Ningbo, Jiaxing, Jinan, Luoyang, Wuhan, Chengdu, Lanzhou, Haikou	2011	Lianyungang, Xining, Qinhuangdao, and Hohhot
2012	Zhengzhou, Nantong, Urumqi	2013	Yichang, Yangzhou, Taizhou, Yancheng, Huzhou, Pingxiang, Jining, Nanyang, Xiangyang, Zunyi

Note: Figures in brackets represent the number of prefecture-level cities covered by the experimental group and the control group. Source: Author's Calculation

The premise of using the DID model is that the experimental group and the control group have the same time trend before the policy occurs. Therefore, this paper uses the regression method to identify whether the assumptions related to the common trend are met by solving the cross-product term of the virtual variables of the experimental group and the control group as well as the virtual variables of the time before the policy occurs. The estimated results are shown in Table 3. The results in Table 3 indicate that the coefficient of the cross-product term before the policy occurs is not significant. Therefore, it can be preliminarily judged that the DID model in this paper can satisfy the assumptions related to the common trend.

Table 3 *Examination of common trends*

Explained Variables	Labor Productivity	Total Factor Productivity	Approximate Total Factor Productivity
$du^{*}dt_{2003}$	0.028	-0.001	-0.003
	(0.04)	(0.01)	(0.05)
$du^{*}dt_{2004}$	0.039	-0.001	-0.022
	(0.03)	(0.01)	(0.05)
$du^{*}dt_{2005}$	0.022	-0.001	-0.040
	(0.03)	(0.02)	(0.04)
$du^{*}dt_{2006}$	0.035	-0.001	-0.034
	(0.03)	(0.03)	(0.04)
$du^{*}dt_{2007}$	0.023	-0.001	-0.018
	(0.02)	(0.01)	(0.03)
Control Variable	YES	YES	YES
Time Effect	YES	YES	YES
Fixed Effect	YES	YES	YES
N	3934	3934	3934
F	412.624	328.076	368.626
r2_a	0.940	0.955	0.901
N_g	281	281	281

Note: The standard deviation of robustness is shown in brackets. *, ** and *** respectively indicate that related items are significant at 10%, 5% and 1% levels.

Based on the above-mentioned discussion, the settings of DID model are as follows:

$$TFPit = ai + a1du * dt + \sum_{i=1}^{N} bjXit + \gamma t + \varepsilon it \quad (3.3)$$

Where, TFP includes three indicators including labor productivity, total factor productivity, and approximate total factor productivity. X is a set of control variables that affect the urban TFP. $ai$is an unobservable fixed effect of the city. γt is a fixed effect that changes with time. ε is a random disturbance term.

In view of the fact that DID difference method is incapable of reflecting the time-varying influence of individual characteristics on outcome variables, three kinds of cross-product terms in this paper are controlled to evaluate policy effects more flexibly: ① the cross-product term of selection standard variables and time cubic term concerning innovative cities is used to control the time-varying influence of selection variables on outcome variables; ② the cross-product term of the selection standard variables and the dummy variable of policy time concerning innovative cities is used to control the difference of the influence of selection variables on outcome variables before and after the policy, and; ③ the cross-product term of the selection standard variables and the time dummy variable concerning innovative cities is beneficial to more flexibly control the time effect of the selection variable on the outcome variable. Lastly, this paper designs a more flexible DID estimation model:

$$TFPit = ai + a1du * dt + (S * f(t))'\theta + \sum_{i=1}^{N} bjXit + \gamma t + \varepsilon it \quad (3.4)$$

Where, S is the selection standard variable of innovative cities in the above text. $f(t)$ is regarded as the setting for three different time trends. The first cross-product term is S^*T, S^*T^2, and S^*T^3. The second cross-product term is S^*Post. The third cross-product term is $S^*\gamma t$.

4. Empirical Results and Analysis

4.1 The Impact of Innovation-Driven Development on Urban TFP

As an important link of national innovation-driven development strategy, the construction of national innovative cities provides us with a quasi-natural experiment to evaluate the innovation-driven policy effect. Therefore, this paper mainly tests the influence of innovation-driven development on the urban TFP of economic cities based on DID model. The estimated results are shown in Tables 4 to 6. Table 4 shows the urban TFP model measured by labor productivity, whereas Table 5 shows the urban TFP model measured by total factor productivity. Lastly, Table 6 shows the urban TFP model measured by approximate total factor productivity. Among the three models, the second column is the benchmark model without control variables, while the third column is the model with control variables. The fourth to sixth columns are the cross-product term for controlling selection variables and time polynomials, the cross-product term for selection variables and policy dummy variables, and the cross-product term for selection variables and time dummy variables, respectively. The seventh column is the extended model for controlling all the foregoing control variables and cross-product terms. From the perspective of estimation effects of different models, the seventh column model greatly improves the coefficient and significance of DID terms by controlling all control variables and cross-product terms, showing the largest adjusted coefficient of determination among all models. It is indicated that the estimation accuracy of the model is significantly improved by controlling these variables. This treatment is statistically reasonable. In the subsequent part, all the analyses in this paper are based on the extended model in the seventh column. From the perspective of the estimated results of the models, the innovation-driven coefficients of all models are significantly positive, which indicates that innovation-driven not only significantly improves the level of urban TFP but also can promote China's economy to improve urban TFP. This conclusion is consistent with the expectation of this paper. On the one hand, the concrete practice of innovative cities in conducting innovation-driven development strategy has greatly increased the investment in innovative resources represented by R&D funds and personnel through policy power. On the other hand, by virtue of constructing the institutional, legal and industrial environment conducive to promoting innovation, it provides strong support for innovation activities, thus continuously improving the innovation level of innovative cities and gradually improving the innovation-driven ability. Benefiting from the improvement of innovation-driven ability, industrial technology innovation in innovative cities will enhance the upgrading level of industries, produce a technology spillover effect and promote the structural upgrading of the whole industry, thereby ultimately contributing to the urban TFP of economic cities.

Table 4 *Impact of innovation-driven development on urban TFP (1)*

Explained Variable: Labor Productivity	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
DID	0.656***	0.145***	0.124***	0.224*	0.116***	0.601***
	(0.03)	(0.03)	(0.03)	(0.12)	(0.03)	(0.11)
Control Variable	YES	YES	YES	YES	YES	YES
Time Effect	YES	YES	YES	YES	YES	YES
Fixed Effect	YES	YES	YES	YES	YES	YES
S*T			YES			YES
S*T2			YES			YES
S*T3			YES			YES
S*Post				YES		YES
S*year dummy					YES	YES
N	3934	3934	3934	3934	3934	3934
F	625.003	560.665	436.930	356.021	223.208	239.090
r2_a	0.077	0.848	0.941	0.849	0.942	0.945
N_g	281	281	281	281	281	281

Note: The standard deviation of robustness is shown in brackets. *, ** and *** respectively indicate that related items are significant at 10%, 5% and 1% levels.

Table 5 *Impact of innovation-driven development on urban TFP (2)*

Explained Variable: TFP	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
DID	0.013***	0.004***	0.001**	0.004	0.001**	0.010***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Control Variable	YES	YES	YES	YES	YES	YES
Time Effect	YES	YES	YES	YES	YES	YES
Fixed Effect	YES	YES	YES	YES	YES	YES
S*T			YES			YES
S*T2			YES			YES
S*T3			YES			YES
S*Post				YES		YES
S*year dummy					YES	YES
N	3934	3934	3934	3934	3934	3934
F	805.110	403.014	375.241	272.429	151.120	866.584
r2_a	0.122	0.834	0.961	0.835	0.960	0.964
N_g	281	281	281	281	281	281

Note: The standard deviation of robustness is shown in brackets. *, ** and *** respectively indicate that related items are significant at 10%, 5% and 1% levels.

Table 6 *Impact of innovation-driven development on urban TFP (3)*

Explained Variable: ATFP	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
DID	0.635***	0.103**	0.151***	0.399**	0.133***	0.817***
	(0.03)	(0.04)	(0.05)	(0.19)	(0.05)	(0.14)
Control Variable	YES	YES	YES	YES	YES	YES
Time Effect	YES	YES	YES	YES	YES	YES
Fixed Effect	YES	YES	YES	YES	YES	YES
S*T			YES			YES
S^*T^2			YES			YES
S^*T^3			YES			YES
S*Post				YES		YES
S*year dummy					YES	YES
N	3934	3934	3934	3934	3934	3934
F	479.626	357.916	322.073	205.441	164.735	170.429
r2_a	0.047	0.712	0.892	0.713	0.895	0.899
N_g	281	281	281	281	281	281

Note: The standard deviation of robustness is shown in brackets. *, * * and * * * respectively indicate that related items are significant at 10%, 5% and 1% levels.

4.2 Urban TFP: Independent Innovation or Technology-introduction Innovation?

As the theoretical model proposed in this paper has proved, the promotion of urban TFP by innovation-driven development depends on the strength of independent innovation and technology-introduction innovation. Therefore, in the interest of further verifying the authenticity of the promotion of urban TFP by innovation-driven development, it is necessary to test whether the promotion of urban TFP by innovation-driven development is due to the higher effect of independent innovation level on urban TFP than that by technology-introduction innovation. To effectively measure independent innovation and technology-introduction innovation, the cross-product term of the proxy indicators of the two innovation models and the time dummy variable concerning the occurrence of policies is calculated to replace the benchmark DID term. At the same time, it is put into the extended model. By analyzing the differences related to the coefficients and significances of the two different innovation models, this paper judges whether the promotion of urban TFP by innovation-driven development is due to the fact that the level of independent innovation is higher than that of technology-introduction innovation. According to the estimation results in Table 7, three different high-quality measurement models all indicate that the influence coefficient of the promotion of independent innovation level of innovative cities on urban TFP is significantly positive, whereas the influence of the promotion of technology-introduction innovation level on urban TFP is no longer significant. This conclusion demonstrates that innovative cities are more inclined to improve the level of independent innovation to realize the promotion of urban TFP by innovation-driven development. On the same note, this conclusion provides such a direct revelation, that is, the implementation of innovation-driven development strategies shall change the technology-introduction innovation model that was relied on in the past, focusing more on improving the level of independent innovation to achieve the economic growth goal. Moreover, the empirical results of this paper show that innovative cities have achieved their own urban TFP by practicing innovation-driven development based on improving their independent innovation ability. Hence, from this perspective, the pilot policy of innovative cities is highly effective.

Table 7 *Impact of independent innovation and technology-introduction innovation on urban TFP*

Explained Variables	Labor Productivity	Total Factor Productivity	Approximate Total Factor Productivity
Independent Innovation*dt	0.073***	0.001**	0.092***
	(0.02)	(0.00)	(0.02)
Technology-Introduction Innovation*dt	0.019	0.001**	-0.003
	(0.03)	(0.00)	(0.06)
Control Variable	YES	YES	YES
Time Effect	YES	YES	YES
Fixed Effect	YES	YES	YES
S*T	YES	YES	YES
S^*T^2	YES	YES	YES
S^*T^3	YES	YES	YES
S*Post	YES	YES	YES
S*year dummy	YES	YES	YES
N	3934	3934	3934
F	237.270	223.728	175.554
r2_a	0.944	0.963	0.897
N_g	281	281	281

Note: The standard deviation of robustness is shown in brackets. *, * * and * * * respectively indicate that related items are significant at 10%, 5% and 1% levels.

5. Further Mechanism Test and Heterogeneity Analysis

5.1 Mechanism Verification: Innovation Effect and Structural Effect

To verify the above mechanism, this paper uses the research method adopted by Baron and Kenny (1986) for reference to verify the existence of the innovation effect and structural effect. Regarding the concrete empirical test steps, this paper mainly adopts the three-step verification method. Specifically, the first step is to regress the DID term with the urban TFP. If the coefficient is significant, it indicates that innovation-driven development has achieved urban TFP. The second step is to regress the DID term with innovation effect and structural effect respectively. If the coefficient is significant, it indicates that innovation-driven development produces innovation effect and structural effect. The third step is to put the DID term, innovation effect, and structural effect into the model simultaneously and make regression with high quality. If the coefficient of DID item is not significant or significant but the coefficient is reduced, it proves that innovation-driven development has achieved urban TFP through innovation effect and structural effect so that the mechanism is verified. According to the above-mentioned verification steps, the mechanism verification model proposed in this paper is set as follows:

(1) Verify the impact of innovation-driven development on urban TFP:

$$ln\, zrgdpit(tfpit/atfpit) = \alpha 0 + \alpha 1du * dt + (S * f(t))' * \theta + \varepsilon it \quad (4.1)$$

(2) Verify the impact of innovation-driven development on innovation effect and structural effect

$$ln\, cxit(ln\, jgit) = \alpha 0 + \alpha 1du * dt + (S * f(t))' * \theta + \varepsilon it \quad (4.2)$$

(3) The DID term, innovation effect index, and structural effect index are put into the regression equation simultaneously

$$ln\, zrgdpit(tfpit/atfpit) = \alpha 0 + \alpha 1du * dt + ln\, cxit(ln\, jgit) + (S * f(t))' * \theta + \varepsilon it \quad (4.3)$$

Where, cx is the index of the innovation effect, whereas jg is the index of structural effect. The innovation effect index of this paper is represented by the performance index of urban innovation, which can comprehensively reflect all aspects of urban innovation. In addition, this paper also constructs two indexes, including the upgrading of industrial structure and the rationalization of industrial structure. Among them, the upgrading of industrial structure includes the quantity and quality of industrial structure upgrading. From the perspective of the innovation effect, the results in Table 8 show that the coefficient of the first step results is significantly positive, indicating that innovation-driven development promotes urban TFP. The results of the second step show that the coefficient of innovation-driven development to innovation effect is significantly positive. The results of the third step show that the coefficient of innovation-driven urban TFP is no longer significant after adding both innovation effect and DID term, indicating that innovation effect is the intermediary mechanism of innovation-driven development to promote urban TFP, thus confirming the existence of innovation effect. From the perspective of structural effect, the results in Table 9 show that the coefficient of the first step results is significantly positive, indicating that innovation-driven development promotes urban TFP. The results of the second step show that the quantitative and qualitative coefficients of innovation-driven development on the upgrading of the industrial structure are significantly positive, while the coefficient of it on the rationalization of industrial structure is not significant, indicating that innovation-driven development improves the upgrading of industrial structure without realizing the rationalization of industrial structure. The results of the third step show that the coefficient of innovation-driven urban TFP is no longer significant after adding structural effect and DID term simultaneously. Combining the results of the first step and the second step, it can be seen that the mechanism of innovation-driven to improve urban TFP by improving the upgrading of industrial structure has been verified, while its mechanism of improving urban TFP by improving the rationalization of industrial structure has not been verified. The explanation of this result lies in that the rationalization of the industrial structure reflects the degree of coordination among industries and the effective utilization of resources. In view of the fact that innovative cities are mainly created under the leadership of local governments, they involve more intervention of government administrative forces. As a result, the innovation elements are distorted to different degrees. In the case of distorted factors, the role of innovation-driven development will be restrained to varying degrees, thus limiting the ability of innovation-driven development in optimizing resource allocation, improving resource utilization efficiency, and realizing coordinated development among industries. In the end, it will further lead to the insignificant role of innovation-driven development in influencing urban TFP through the rationalization mechanism of industrial structure. Based on the test of the structural effect mechanism of innovation-driven development, innovation-driven development mainly improves the urban TFP by improving the quality and quantity of the industrial structure upgrading. Therefore, it can basically prove the existence of the structural effect.

Table 8 *Test of the promotion mechanism of innovation-driven development to urban TFP - innovation effect*

Explained Variables	Total Factor Productivity	Innovation Effect	Total Factor Productivity	Approximate Total Factor Productivity	Innovation Effect	Approximate Total Factor Productivity	Labor Productivity	Innovation Effect	Labor Productivity
DID	0.010***	2.430***	0.005	0.721***	2.430***	0.421	0.505***	2.430***	0.005
	(0.00)	(0.38)	(0.00)	(0.15)	(0.38)	(0.38)	(0.13)	(0.38)	(0.14)
Innovation Effect			0.002***			-0.086***			-0.053**
			(0.00)			(0.03)			(0.02)

Note: The standard deviation of robustness is shown in brackets. *, ** and *** respectively indicate that related items are significant at 10%, 5% and 1% levels.

Table 9 *Test of the promotion mechanism of innovation-driven development to urban TFP - structural effect*

Explained Variables	Total Factor Productivity	Approximate Total Factor Productivity	Labor Productivity	Quantity of Industrial Structure Upgrading	Total Factor Productivity	Approximate Total Factor Productivity	Labor Productivity
DID	0.010***	0.721***	0.505***	0.035**	-0.001	0.328	-0.053
	(0.00)	(0.15)	(0.13)	(0.02)	(0.00)	(0.38)	(0.14)
Quantity of Industrial Structure Upgrading					-0.001	0.148	0.125
					(0.00)	(0.29)	(0.22)
Explained Variables	Total Factor Productivity	Approximate Total Factor Productivity	Labor Productivity	Quality of Industrial Structure Upgrading	Total Factor Productivity	Approximate Total Factor Productivity	Labor Productivity
DID	0.010***	0.721***	0.505***	0.829***	-0.001	0.314	-0.065
	(0.00)	(0.15)	(0.13)	(0.18)	(0.00)	(0.38)	(0.13)
Quality of Industrial Structure Upgrading					0.000	0.120***	0.102***
					(0.00)	(0.04)	(0.02)
Explained Variables	Total Factor Productivity	Approximate Total Factor Productivity	Labor Productivity	Rationalization of Industrial Structure	Total Factor Productivity	Approximate Total Factor Productivity	Labor Productivity
DID	0.010***	0.721***	0.505***	-0.004	-0.001	0.331	-0.051
	(0.00)	(0.15)	(0.13)	(0.04)	(0.00)	(0.38)	(0.13)
Rationalization of Industrial Structure					0.000	-0.050	-0.029
					(0.00)	(0.06)	(0.03)

Note: The standard deviation of robustness is shown in brackets. *, ** and *** respectively indicate that related items are significant at 10%, 5% and 1% levels.

5.2 Heterogeneity Analysis

This section further analyzes the heterogeneity of innovation-driven urban TFP, with the heterogeneity analysis being developed from three levels, namely, region, city scale, and city levels. With regard to the analysis of regional heterogeneity, this paper divides the sample area into three regions, including eastern China, central China, and western China. The scale of cities is divided according to the latest standard of the Notice on Adjusting the Standards of City Scale Division issued by the State Council in 2014: cities with a permanent population of less than 500,000 in urban areas are small-sized cities; cities with a permanent population of 500,000 to 1 million are medium-sized cities; cities with a permanent population of between 1 million and 5 million are large cities, among which cities with a permanent population of between 3 million and 5 million are type-I cities, while cities with a permanent population of between 1 million and 3 million are type-II cities. Due to the limited samples, a small number of small and medium-sized cities lead to the unreliability of the regression results. For this reason, this paper only reports the results of cities above large-sized cities. Cities levels are divided into sub-provincial cities, provincial-capital cities, and general prefecture-level cities. Table 10 reports the results of the heterogeneity analysis. The results of regional heterogeneity show that the role of innovation-driven urban TFP in eastern China, central China, and western China is increasing, with central China and western China being more affected by the innovation-driven role. The results of city-scale heterogeneity show that innovation-driven in different city scales can promote urban TFP. However, with the increase in city scales, the role of innovation-driven urban TFP presents a corresponding descending feature. The results of city-level heterogeneity show that innovation-driven can promote urban TFP in cities with different levels. Nonetheless, cities with lower levels show a stronger innovation-driven urban TFP effect.

Table 10 *Heterogeneity analysis based on region, scale, and level*

Regional Variations	Eastern China	Central China	Western China	
DID	0.002**	0.005***	0.007***	
	(0.00)	(0.00)	(0.00)	
City-scale Difference	Large Cities	Type-II Large Cities	Type-I Large Cities	Megacities
DID	0.0040***	0.0050***	0.0045***	0.0030***
	(0.00)	(0.00)	(0.00)	(0.00)
City-level Difference	Sub-provincial Cities	Provincial-capital Cities	General Prefecture-level Cities	
DID	0.0030***	0.0028**	0.0038***	
	(0.00)	(0.00)	(0.00)	

Note: The standard deviation of robustness is shown in brackets. *, ** and *** respectively indicate that related items are significant at 10%, 5% and 1% levels.

6. Conclusions and Implications

To sum up, based on the panel data of China's prefecture-level cities from 2003 to 2016 and the construction of the theoretical model of innovation-driven urban TFP, this paper adopts the DID model and PSM-DID model to conduct an empirical test on the impact of innovation-driven development on urban TFP and its mechanism, further analyzing the heterogeneity of innovation-driven urban TFP. Relevant research findings indicate that innovative cities have significantly improved the level of urban TFP by implementing innovation-driven development, whether it is measured by labor productivity or total factor productivity. Moreover, this effect mainly lies in the fact that the construction of innovative cities depends on the improvement of the independent innovation ability of cities. The mechanism test shows that innovative cities have produced innovation effect and structural effect by implementing innovation-driven development, thereby realizing urban TFP. In addition, heterogeneity analysis demonstrates that the role of innovation-driven urban TFP in central and western China is stronger than that in eastern China, and that the role of innovation-driven urban TFP is decreasing with the increase of cities scale, as well as that the lower-level cities are more likely to improve urban TFP from innovation-driven development.

The important policy-related implications of this paper can be summarized as follows: (1) From the national perspective, it is necessary to further promote the construction of innovative cities and attach great importance to improving the independent innovation level of cities. Actually, innovative cities are more inclined to achieve innovation-driven urban TFP by improving the level of independent innovation. Nevertheless, for a long time in the past, most of China's innovations depended on imitation-based innovation, which essentially restricted the improvement of China's overall innovation level, despite the fact that it reduced innovation costs and saved innovation time. Consequently, the implementation of innovation-driven development strategies and the promotion of the construction of innovative cities need to change the development mode of technology-introduction innovation that was relied on in the past, paying more attention to the improvement of independent innovation level to achieve the goal of urban TFP.

(2) From the regional perspective, the key point is to improve the allocation of innovation resources in the central and western regions of China and the balance of the overall implementation of the innovation-driven strategy. The construction of innovative cities in the central and western regions of China needs to break through the defects concerning capital shortage and financing constraints. Specifically, based on making full use of the marginal growth advantages of innovation, innovative cities in the central and western regions of China can release their innovation potential and attract the orderly inflow of R&D funds, scientific and technological talents, and other innovative resources by building an institutional environment and service platform conducive to innovation, to improve the technological innovation level of cities and industries as well as the production efficiency of regional cities and enterprises, with a view to realizing the urban TFP of economic cities in backward regions.

(3) From the perspective of cities, it is strongly recommended to control the city scale reasonably, highly value the innovation efficiency of cities, and attach great importance to the innovation quality and innovation development level of small and medium-sized cities. Under the spillover effect of technological innovation, with the expansion of the scale of cities, the effect of innovation-driven urban TFP will show a decreasing feature. By eliminating the backward production capacity of large cities, technological innovation is beneficial to realize the optimal allocation of urban innovative resources and the reasonable scale of cities, thus promoting the transformation of the urban industry from an extensive growth model to an intensive and high-tech model. On the other hand, small and medium-sized cities shall make use of innovation elements to gather advantages, reduce supervision costs and give full play to the scale effect of resources, intending to improve the innovation efficiency of small and medium-sized cities and then improve the level of urban TFP.

(4) It is necessary to strengthen the innovation ability of general prefecture-level cities and weaken the siphonic effect formed by the large cities on the innovation elements of prefecture-level cities. Specifically, based on weakening the policy power of urban administrative levels, it can be considered to strengthen the investment of general prefecture-level cities in R&D funds, scientific and technical personnel, and other innovative resources and continue to provide corresponding preferential policies for related fields. Moreover, it is also necessary to build a system, policy, law, and industrial environment conducive to the development of innovation, provide comprehensive and systematic support for innovation activities and expand the marginal revenue brought by innovative pilot cities, with the aim of continuously improving the innovation level of innovative cities and progressively enhancing the innovation-driven urban TFP capability.

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