Asian Economic and Financial Review
ISSN(e): 2222-6737
ISSN(p): 2305-2147
DOI: 10.55493/5002.v15i2.5312
Vol. 15, No. 2, 267-286.

URL: www.aessweb.com

Empirical analysis of the effect of the establishment of pilot free trade zone on regional innovation development

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Article History
Received: 29 November 2024
Revised: 27 January 2025
Accepted: 13 February 2025
Published: 11 March 2025

Keywords
Countermeasures and suggestions
Establishment of PFTZs
Regional innovation development.

JEL Classification:
F41; O00; O31; R19.

ABSTRACT

In order to positively meet new international trade rules, China has put forward the strategy to implement Pilot Free Trade Zones (PFTZs). The extensive establishment of PFTZs has offered a good innovation environment for regional economic development. Consequently, based on data from 30 provinces from 2007 to 2022 as research samples, this study discusses the impact of establishing PFTZs on regional innovation development and examines the policy effect heterogeneities. In addition, digital finance (DF) and the digital economy (DE) are introduced as mediating variables to verify whether DF and DE play a mediating role between building PFTZs and regional innovation. Empirical results show that building PFTZs is beneficial for boosting the regional innovation level. The heterogeneity analysis indicates that the effect of PFTZs policies on the regional innovation level is more pronounced in provinces and cities with higher economic development levels, coastal provinces and cities, and provinces with larger population scales. Furthermore, according to the mediating effect test, it can be found that PFTZs will enhance the regional innovation level through DF and DE. Therefore, it is suggested to continuously promote the strategy of building PFTZs, pay full attention to the deep integration of DF, DE, and regional innovation, and generally improve the regional innovation level.

Contribution/ Originality: This study adopts different batches of PFTZS as samples; the multi-period DID model is used to analyze the impact of the establishment of PFTZS on regional innovation development through heterogeneity analysis and mediating effect tests. The innovation of the research perspective and research method is the biggest contribution of this paper.

1. INTRODUCTION

The creation of PFTZs is an essential strategy for China in the new era to align with high-level and demanding international economic and trade rules and undertake regional development strategies. The core of PFTZs is to deepen reform and further expand opening-up, aiming to gather global innovation resources such as innovative talents, innovative capital, and innovative technology, improve the regional innovation development level, and promote social and economic development (Liu & Zhao, 2023). The foundation of PFTZs is a national strategy and an inherent requirement for high-quality economic development (HQED). The purpose of setting up PFTZs is not only to drive and enhance regional development through regional innovation but also to form replicable and scalable experiences, build a new pattern of innovation-driven development, and realize the transformation and upgrading of development momentum, which has gradually become a new engine for China's economic growth (Ye, 2018). In

September 2013, China set up its first PFTZ, the Shanghai PFTZ. In 2015, China established Fujian, Guangdong, and Tianjin PFTZs respectively. In 2017, China built Liaoning, Zhejiang, Henan, Hubei, Chongqing, Sichuan, and Shanxi PFTZs one after another, formulating a "1+3+7" opening-up model. Then, the Hainan PFTZ was set up in 2018, and Shandong, Jiangsu, Guangxi, Hebei, Yunnan, and Heilongjiang PFTZs were created in 2019. Beijing, Hunan, Anhui, and Zhejiang PFTZs were constructed in 2020 (Li, 2020). Until 2020, China has set up 21 PFTZs in six batches, and each PFTZ has its unique characteristics in geographical location and industrial structure and carries different historical missions (Kong, 2021).

Sustainable economic growth cannot be achieved without technological innovation and scientific and technological progress, and innovation is the internal driving force for HQED (Liu & Wang, 2018). Romer (1990) pointed out that the more innovation factors are invested in a region, the higher the economic growth rate will be in that region. Regional innovation exerts a decisive role in the overall development of a region and country. Under the complex international and domestic situations, as a new engine to prompt China's innovation and development, PFTZs' construction focuses on innovation, supports innovation by first trial and first test, encourages innovation by integrating the business environment with international economic and trade rules, and accelerates innovation by replication and spreading in the surrounding areas. The construction of PFTZs provides a strategic layout for China's economic transformation and upgrading (Li & Gao, 2019).

Founding PFTZs has effectively raised the trade liberalization level and promoted HQED. As a high ground for accelerating economic growth and talent flow, PFTZs provide a broad platform and policy support for regional innovation (Gao & Li, 2019; Xu, Lei, & Xing, 2020). Under this background, it is important to explore the influence of PFTZs on regional innovation for building an innovative country, deepening the One Belt and One Road strategy, and HQED. So, what does the establishment of PFTZs impact regional innovation development? Has the creation of PFTZs improved the scale of regional innovation development? What are the different impacts of the establishment of different batches of PFTZs on regional innovation? What are the main mechanisms through which PFTZs affect regional innovation development? It has great theoretical and practical significance to analyze and discuss these problems.

2. LITERATURE REVIEW

PFTZs are an important national strategy, and their development has attracted great attention from society; therefore, studies have been conducted in-depth from several aspects.

First of all, after the creation of PFTZs, many scholars analyzed the impact of PFTZs' policies from the perspectives of establishment background, operational basis, institutional innovation, and policy influence. Chen and Liu (2014) discussed the background and significance of establishing PFTZs and analyzed PFTZs' promotional effect on regional economic development from government role transformation and system innovation. Wang, Zhang, and Zhou (2014) analyzed the operational basis, functions, and advantages of the Shanghai PFTZ and pointed out that the effective operation of PFTZs is conducive to the construction of Shanghai's four centers. Pei and Liu (2019) assessed PFTZs' policy dividends from the aspects of institutional innovation and policy advantages. Yao and Whalley (2016) discussed the institutional dividends and policy effects brought about by the establishment of PFTZs. Wu and Xie (2019) pointed out that the dividend effect of the policies of Shanghai, Guangdong, Fujian, and Tianjin PFTZs has not been fully realized, so PFTZs' policies need to be further optimized. Du, Xu, and Yin (2020) proposed that more efforts should be made to boost high-level opening-up, grant PFTZs greater reform autonomy, accelerate institutional innovation at a deeper level and with higher standards, facilitate the normalization of institutional innovation paths, and demonstrate the role of institutional dividends in industrial agglomeration and upgrading.

In the next place, some experts and scholars discussed the influence of the creation of PFTZs on regional economy, trade, foreign direct investment (FDI), industrial structure upgrading and other aspects.

There are different study conclusions regarding PFTZs and their impact on regional economic growth. Some scholars believe that the policies of PFTZs can promote regional economic growth. Sun, Lin, and Kang (2020); Wei and Li (2020); Ye (2020); Zhang and Yu (2020); Chauffour and Maur (2011) and Castilho, Menéndez, and Sztulman (2019), based on different research perspectives, adopted various analytical and empirical models to verify that PFTZs can promote regional economic growth and HQED. In addition, Peng and Yang (2020) and Yang (2020) found that establishing PFTZs has economic spillover effects and an active driving impact on the neighboring areas. At the same time, Liu and Wang (2018) and Zhang, Yan, Feng, and Li (2018) also found that the promotion effect of different PFTZs on economic growth is heterogeneous. Hu, Shi, and Yang (2022) took Hubei PFTZ as an example to analyze the spillover effects of building inland PFTZs, and the results indicated that the inland PFTZ had radiation effects and siphon effects on economic development, with the distribution being inverted U-shaped or S-shaped. Some scholars also believe that PFTZs exert a restraining effect on economic growth to a certain extent and play siphon effects on the regional economy (Chen & Liu, 2014; Pei & Liu, 2019; Wang & Wu, 2021; Yücer & Siroën, 2017).

The founding of PFTZs has improved trade facilitation and promoted capital flow. Some scholars have discussed trade development and capital flow. Zhu (2017) proposed that PFTZs can accelerate trade facilitation from a theoretical perspective. A-rom Kim and Lu (2016) showed that setting up PFTZs would generate trade creation effects. Sun and Chen (2021) believed that establishing Sichuan PFTZ dramatically promoted the total volume of regional imports and exports. However, some scholars have come to the opposite conclusion. Hamada (1974) argued that export processing in PFTZs did not significantly improve regional welfare levels. The research of Xiang and He (2016) indicated that PFTZs accelerated trade imports but had no significant impact on trade exports. In terms of capital mobility, Luo and Hu (2021) and Si, Sun, and Luo (2021) adopted the Differences-in-Differences (DID) method to verify the promotion effect of PFTZs on regional capital flows, improve the level of capital flows, and believed that regional heterogeneity existed in the promotion effect. Huang (2018) and He and Wu (2020) took Shanghai PFTZ as the research sample, verifying that Shanghai PFTZ's policy facilitated FDI based on the synthetic control method (SCM), and showing that PFTZ policy can contribute to restraining foreign investment fluctuations.

Some other studies have revealed that PFTZs can have an impact on regional industrial structure, fostering the optimization and upgrading of the regional industrial structure by boosting the capability of scientific and technological innovation and playing a promoting role in industrial development. Li and Zhao (2019); Fang (2020); Guan, Huang, Jiang, and Xu (2023); Zhi, Huang, and Chen (2021); Fang (2020) and Feng, Chen, and Liu (2020), based on different perspectives, found that building PFTZs had a vital promoting effect on the upgrading of industrial structure. Nei (2019), from the perspective of industrial structure rationalization, believed that PFTZs can promote the rationalization of the manufacturing structure and emphasized the import quality effect of trade facilitation and the specialization effect of investment facilitation. Liang, Hou, and Cui (2020) employed the Bootstrap non-parametric estimation method and mediating effect model to demonstrate that establishing PFTZs can contribute to improving the optimization and upgrading of industrial structure and the rationalization of industrial structure.

Finally, innovation is the internal driving force to promote regional HQED. Scholars have also discussed regional innovation. Some experts and scholars have investigated the influencing factors of regional innovation from the perspectives of R&D investment (Furman, Porter, & Stern, 2002; Hou, Liu, & Jian, 2014; Yan, Zhou, & Gong, 2010; Yang, Wang, Liu, & Niu, 2019; Zhang & Li, 2017) human capital (Li & Liu, 2014; Qian, Chi, & Li, 2010) FDI (Bütfering, 2010; Iammarino, Padilla-Pérez, & Von Tunzelmann, 2008; Jin & Yan, 2017; Ran, Xu, & Lu, 2013) innovation environment (Dang, Kang, & Xu, 2013; Hou et al., 2014) and financial capital (Liu, 2017; Zhang & Li, 2017). Up to now, only a few literatures have researched the impact of building PFTZs on regional innovation. Some literatures focus on the innovative effects of setting up PFTZs. Liu and Wang (2018) evaluated the effect of PFTZs' building on Shanghai's innovation capacity with the Synthetic Control Method (SCM). Aloise and Macke (2017) investigated that the establishment of PFTZs has a driving force for sustainable innovation through in-depth interviews and direct observation analysis. Gao and Li (2019) analyzed the influence path of China's PFTZs on

regional innovation development, based on the DID method, finding that the establishment of PFTZs effectively promoted regional innovation and development. Taking Liaoning PFTZ as an example, Zhang and Lu (2019) employed provincial panel data to discuss the influence of building Liaoning PFTZ on regional innovation and showed that the introduction of high-tech enterprises into Liaoning PFTZ significantly improved the overall innovation capability. Taking Shanghai, Fujian, Guangdong, and Tianjin as research subjects, Xu et al. (2020) examined the impact of PFTZs' establishment on regional innovation development with SCM and found that PFTZs policy promoted regional innovation quality through policy incentives and institutional guarantees, but the regional innovation promotion quality was not significant enough. Based on the SCM, Xi, Huo, and Liu (2022) studied the influence of establishing PFTZs in Shanghai, Tianjin, Fujian, and Guangdong on the regional innovation level and indicated that the innovation output of Guangdong and Tianjin PFTZs had significantly improved.

To sum up the above literature, it can be found that scholars' studies on PFTZs mainly emphasize the following three aspects: Firstly, some scholars have conducted in-depth discussions on establishing background, operational basis, institutional dividends, and policy impacts from the perspectives of theoretical analysis, and analyzed PFTZs' positive or negative effects on the economy. Secondly, some scholars employed different empirical methods to verify the impacts of building PFTZs on regional economy, trade, foreign investment, industrial structure upgrading, etc. However, most of the studies selected a single PFTZ or several representative PFTZs such as Shanghai, Tianjin, and Guangdong as samples, and the research results were not entirely representative. Thirdly, regarding the research on regional innovation development in PFTZs, scholars have discussed the influencing factors of regional innovation from different perspectives and tested the effect of PFTZs on innovation with a variety of quantitative analysis methods, but the research objectives are relatively simple. So far, there are 21 PFTZs in China. Due to the different times and batches of creation, each PFTZ has its unique function and positioning. The research results of a single PFTZ or representative PFTZs are one-sided, lacking strong generalizability. Fourthly, few scholars have conducted in-depth research on the mechanism of influence of PFTZs on regional innovation.

Based on the above discussion, this study utilizes the panel data of 30 provinces from 2007 to 2022, selects the coastal and inland PFTZs as research samples, and constructs the multi-period DID method to explore the impact of building different batches of PFTZs on regional innovation development. The heterogeneity of policy impact is studied from the economic development level, geographical location, and population size. In addition, DF and DE are introduced as mediating variables to further examine the mediating effect and transmission path. According to the empirical results, countermeasures and suggestions are put forward. The main marginal contributions of this paper are: 1) From the perspective of research methods, previous studies on the policies of PFTZs were mainly qualitative, while quantitative studies were few. This paper empirically analyzed the impact of setting up PFTZs on regional innovation development with the multi-period DID model and through heterogeneity analysis and mediation effect tests, thus achieving innovation in research methods. 2) In terms of research perspective, previous studies mainly focused on the effects of building PFTZs on economic growth, trade effects, investment effects, and industrial structure, etc. Few literatures have conducted a detailed analysis of PFTZs on regional innovation. 3) About research objects, previous scholars only selected a single coastal or inland PFTZ as research samples, with a single sample selection, few research objects, and a narrow scope, and did not highlight the influence of different types of PFTZs on regional innovation. In this article, coastal and inland PFTZs are selected as samples according to the different batches of establishing PFTZs. The empirical analysis in this study not only expands the sample size but also makes the research results more comprehensive and detailed. 4) From the perspective of heterogeneity and mediating effect analysis, the inclusion of population size heterogeneity analysis, DF, and DE mediating effect tests in this paper is an expansion of existing research content and provides a new research perspective for studying regional innovation in PFTZs.

3. RESEARCH DESIGN

3.1. Research Design

Founding PFTZs is both a sustainable and regional policy research topic. In this paper, the provinces and cities that have set up PFTZs are regarded as the treatment group, and the cities that have not established PFTZs are regarded as the control group. A multi-period Difference-in-Differences model is constructed to evaluate the influence of PFTZ policies on regional innovation development. To avoid the endogeneity of missing variables, appropriate control variables are selected from aspects of economic development level, industrial structure, urbanization level, social consumption, and foreign trade dependence. As for the provincial panel data analysis, this paper employs a two-way fixed effect model of province and year, and also adopts Cluster Robust Standard Error to estimate the model. In addition, to deeply discuss the impact mechanism of PFTZ policy on regional innovation, indicators such as DE and DF are considered as mediating variables to build mediating effect models.

3.2. Research Hypothesis

According to institutional theory and regional innovation theory, urban innovation ability is not only constrained by regional innovation resources but is also influenced by regional formal and informal factors, which, in particular, exert a deep influence on making and implementing urban innovation strategies. China is the second largest economy in the world; scientific and technological innovation has become a vital driving force to promote sustainable economic growth with the gradual weakening of the demographic dividend. On the other hand, China's technological innovation should also shift from internal resources to open innovation, break organizational boundaries, strengthen external cooperation, and actively utilize external capital, technology, and markets to consolidate its own innovation foundation (Yang & Zhao, 2020). The construction of PFTZs considers resource integration and system innovation so that the flows of goods, capital, talent, technology, and data in PFTZs can be better converged to promote PFTZs' innovation development level continuously. Based on this, the first hypothesis is put forward:

Hypothesis 1: The establishment of PFTZs contributes to improving regional innovation and development levels.

Digital finance (DF) refers to a model that widely applies emerging digital technologies to the financial industry to provide faster and more convenient services for payment, investment, and financing, as well as various financial businesses (Huang & Huang, 2018). As a fusion product of the innovative generation of information technology, such as the Internet, cloud computing, big data, and traditional finance, DF has a series of inherent advantages, such as high efficiency, all-roundness, low threshold, and low cost (Demertzis, Merler, & Wolff, 2018), which can easily affect regional innovation and development. DF is mainly reflected in three aspects: first, DF can effectively expand the financing channels of regional innovation and development; second, DF can reduce the financing cost of regional innovative development; third, DF can boost the allocation level of regional innovation capital (Han, Chen, Li, & Song, 2023). DF's development will force traditional financial institutions to accelerate their digital transformation, compelling them to use new technologies to accurately invest limited financial resources into the development subjects of technological innovation, causing capital to rapidly gather in innovative projects with strong innovation ability, great potential, and high added value, thus promoting the continuous improvement of the regional innovation level. PFTZs' policy can provide certain conveniences in terms of the financial system, and the financial capital flow in PFTZs is more efficient and smoother, thus providing better institutional services for the development of Digital Finance in scientific and technological innovation. In other words, FTZs policies will promote regional innovation by improving the digital financial environment. Based on this, the second hypothesis is proposed:

Hypothesis 2: The establishment of PFTZs indirectly promotes regional innovation through Digital Finance.

Digital economy (DE) refers to a new economic activity involving information communication technology and digital technology (Peng, Niu, & Chen, 2021; Xiang & Wu, 2018). Shi, Meng, Cheng, and Zhao (2024) pointed out that DE's impact on regional innovation development is mainly manifested in three aspects: Firstly, DE has created favorable conditions for the smooth development of technological innovation. DE can utilize advanced technologies

such as the Internet of Things and artificial intelligence (AI) to rapidly integrate information resources, accurately control production tasks, boost production efficiency, greatly decrease enterprise production costs, and promote industrial development in an intelligent and green direction. Secondly, DE enables different innovation subjects to participate in the activities of innovation and development. Digital technology can break time and space restrictions, overcome previous limitations caused by cross-regional communication, and facilitate the integration of information resources in PFTZs. DE can further exert its advantages and promote the continuous improvement of the regional innovation level. Thirdly, DE compels industries to increase investment in technological innovation. DE first acts on enterprises and industries to promote the continuous improvement of the regional innovation level. Based on this, the third hypothesis of this paper is proposed:

Hypothesis 3: The establishment of PFTZs indirectly promotes regional innovation by means of DE.

3.3. Variables Selection and Data Source

3.3.1. Explained Variables

According to Gao and Li (2019), the proportion of Research & Development (R&D) expenditure of industrial enterprises above the designated size in GDP is adopted as the input variable for regional innovation development. R&D (Research and Development) refers to the activities carried out by enterprises, research institutions, or governments to innovate, improve products or services, and develop new technologies or methods. GDP (Gross Domestic Product) refers to the total value of all final products and services produced by a country (or region) in a certain period (usually 1 year). Generally speaking, the innovation level in a region is first reflected in the R&D results of industrial enterprises. Industrial enterprises are the main positions for the transformation of scientific research results, and R&D expenditure of industrial enterprises has important directional significance. On the other hand, to analyze the impact of the influence of PFTZs on regional innovation development from the perspective of innovation output, the pair value of the logarithm of the number of authorized regional patent applications is used as the replacement variable for the explained variable, with reference to the study of Liu and Wang (2018).

3.3.2. Explanatory Variable

Since 2013, China has completely built 21 PFTZs in six batches, with the latest batch including Beijing, Hunan, and Anhui in 2020. The explanatory variable is defined as follows: If a province or city has established a PFTZ in the corresponding year, the policy of that province or city is set to 1 in that year and in subsequent years; otherwise, it is set to 0. If a province or city has not established a PFTZ, the policy is set to 0. It can be clearly seen that the policy is a multi-period DID variable.

3.3.3. Control Variables

After sorting out the existing studies, this research chooses six control variables from dimensions of economic development level, industrial structure, urbanization level, social consumption, foreign trade dependence, and education level to avoid the problem of missing variables in the regression model.

Considering data availability and reliability, this study selects macro-level data from 30 provinces, municipalities, and autonomous regions (excluding Tibet) from 2007 to 2022. The basic indicators of the explained variable and control variables are mainly from the China Statistical Yearbook and the website of the National Bureau of Statistics, and the explanatory variable is set according to the implementation year of the PFTZ's policy document. The indicators of the explained variable, explanatory variable and control variables are listed in Table 1.

Table 1. Key variables definition.

Types of variables	Variable's name	Variable's symbol	Variable meaning
Explained variable	Innovation input	RD	Industrial enterprises above the designated size R&D expenditure/GDP
Explanatory variable	Establishment of PFTZs	Policy	The value of building a PFTZ is 1; otherwise, it is 0.
Control variables	Industrial structure advanced	Struct	Value added of the tertiary industry / Value added of the secondary industry
	Per capital GDP	lnPGDP	Regional GDP/ Total population at year-end takes the logarithmic value.
	Urbanization rate	Urban	Urban population/Total population at year-end
	Consumption level	Consumption	Total retail sales of consumer goods /GDP
	Foreign trade dependence	Open	Foreign enterprises' total investment/GDP
	Educational level	Edu	Local fiscal expenditure on education/Total population at year-end

3.3.4. Mediating Variables

DE: Based on the studies of Hu et al. (2022) and Zhao, Zhang, and Liang (2020), the DE development index is constructed. The secondary indicators include internet development and DF. Among them, internet development contains four indicators, including optical cable length, mobile phone penetration rate, internet broadband access ports, and the number of internet domain names. Digital Finance adopts the China Digital Financial Inclusive Index (Guo et al., 2020) released by the Institute of International Development of Peking University. Table 2 lists the indicators. The entropy weight method is used to calculate the DE development index (Zeng, Liu, & Li, 2024).

Table 2. Digital economy index system.

First grade indicator	Second grade indicator	Third grade indicator	Indicator unit
DE development index	Internet development	Optical cable length	Kilometer (km.)
		Mobile phone penetration rate	Set/100 people
		Internet broadband access port	Ten thousand
		Internet domain name number	Ten thousand
	Digital finance	Digital financial inclusive index	%

3.4. Model Specification

3.4.1. Panel Regression Model Settings

According to the research design and variable selection, the following model is to verify hypothesis 1. To eliminate heteroscedasticity and endogeneity problems of missing variables, province fixed effects and year fixed effects are added to the model, and Cluster Robust Standard Errors are used to estimate the model coefficients (Zhang & Zhang, 2024). The model formula is as follows:

$$RD_{ij} = \beta_0 + \beta_1 * Policy_{it} + \sum_j \beta_j * X_{ij} + \mu_s + year_t + \varepsilon_{ij}$$

In the above formula, β represents each variable's coefficient, X_{ij} represents control variables, μ_s represents province fixed effect, added to the model in the form of a province dummy variable, $year_t$ represents year fixed effect, added to the model in the form of a year dummy variable, and ε_{ij} represents the random interference term.

The purpose of Cluster Robust Standard Errors is to solve the problem that standard errors may be underestimated, especially in the presence of heteroscedasticity and intra-group correlation. The calculation formula for Cluster Robust Standard Errors is shown as follows:

$$clusters.e. = \sqrt{\frac{\sum_{c=1}^{C}(u_c u_c')}{N-K}(X'X)^{-1}}$$

Where, u_c is the residual vector in the c[th] cluster; $u_c u_c'$ is the product of the residuals vector and its transpose vector in the c[th] cluster, representing the sum of residuals squares; C is the number of clusters; N represents the total number of observations; X is a design matrix that contains explanatory variables.

3.4.2. Entropy Weight Method (EWM)Introduction

EWM: According to the model of Zeng et al. (2024) it includes the following steps:

Step 1: Use the method of polarization to standardize the indicators. The formula is as follows:

$$Z_{ij} = \frac{X_{ij} - X_{min}}{Xmin_{max}}$$

Where, $Z_{ij}$is X_{ij}Is the standardized value. The value range is [0,1].

Step 2: Solve the information entropy of each evaluation index. The entropy value of item i is calculated as follows:

$$E_i = -(\sum_{j=1}^{m} e_{ij}\, ln\, e_{ij}) / ln\, m$$

Where, $e_{ij} = Z_{ij} / \sum Z_{ij}$, if e_{ij}=0, then define $\lim_{e_{ij}\to 0} e_{ij}\, ln\, e_{ij} = 0$.

Step 3: Determine the evaluation index weight. The calculation formula is as follows:

$$w_i = \frac{1 - E_i}{N - \sum_{i=1}^{N} E_i}$$

Step 4: Calculate the comprehensive evaluation index. The formula is as follows:

$$R_i = \sum_{j=1}^{m} w_i Z_{ij}$$

Therefore, the score of a comprehensive evaluation of the digital economy systems can be calculated.

Table 3. Variable description statistics.

Variables	Observed number	Mean	Std. dev	Max.	Min.
RD	480	1.039	0.590	3.242	-0.041
Policy	480	0.237	0.426	1.000	0.000
Struct	480	1.270	0.713	5.244	0.527
lnPGDP	480	10.660	0.588	12.150	8.959
Urban	480	0.575	0.134	0.896	0.282
Consumption	480	0.384	0.065	0.610	0.180
Open	480	0.008	0.037	0.560	0.001
Edu	480	7.359	0.571	8.587	5.853

3.5. Descriptive Statistical Results

The descriptive statistical results of variables involved in the empirical analysis in this paper are listed in Table 3.

3.6. Correlation Analysis

Table 4 presents the results of the Pearson correlation analysis for the variables. It can be observed that the absolute values of the correlation coefficients between the variables are all less than 0.8, indicating that there is no obvious collinearity between the variables, and subsequent panel model regression can be carried out.

Table 4. Correlation analysis table.

Variables	RD	Policy	Struct	lnPGDP	Urban	Consumption	Open	Edu
RD	1							
Policy	0.352*	1						
Struct	-0.058	0.253*	1					
lnPGDP	0.601*	0.559*	0.483*	1				
Urban	0.608*	0.434*	0.546*	0.866*	1			
Consumption	0.290*	0.119*	0.090*	0.172*	0.169*	1		
Open	-0.064	0.190*	0.260*	0.108*	0.100*	-0.047	1	
Edu	0.283*	0.428*	0.518*	0.828*	0.652*	0.061	0.119*	1

Note: * Correlation is significant at the 0.05 level (2-tailed).

Table 5. Benchmark model regression.

Variables	(1)	(2)	(3)
	RD	RD	RD
Policy	0.217***	0.140***	0.100**
	(0.066)	(0.047)	(0.045)
Struct	-	-0.283***	-0.350***
		(0.071)	(0.106)
lnPGDP	-	-0.610**	-1.036***
		(0.276)	(0.314)
Urban	-	1.692**	0.928
		(0.802)	(0.915)
Consumption	-	1.234***	1.725***
		(0.378)	(0.404)
Open	-	0.062	-0.049
		(0.161)	(0.169)
Edu	-	0.650***	0.915***
		(0.183)	(0.263)
_cons	0.988***	1.638	4.431*
	(0.016)	(1.374)	(2.179)
Individual effect	Yes	Yes	Yes
Year effect	No	No	Yes
N	480	480	480
r2	0.120	0.598	0.653

Note: 1. Cluster-Robust standard errors are in parentheses, 2. * means 10% level is significant, ** means 5% level is significant and *** means 1% level is significant.

4.EMPIRICAL RESULT ANALYSIS

4.1. Benchmark Regression Result

The benchmark regression model is shown in Table 5. The first column presents the regression results without control variables, the second column displays the results with control variables but without year fixed effects, and the third column illustrates the regression results with control variables and year fixed effects. From the perspective of the explanatory variable Policy, all three regression results are significantly positive, indicating that the construction of PFTZs has an important boosting effect on the regional innovation and development level. After adding control variables, the Policy coefficient becomes smaller; furthermore, after adding the year fixed effect, the explanatory variable coefficient decreases even more, suggesting that there are omitted variables in the regression results of the first column. The two-fixed effect model further reduces the influence of endogeneity results, thereby verifying hypothesis 1.

4.2. Heterogeneity Analysis

To further analyze the influence of different sub-samples of PFTZ policies on regional innovation development, this paper carries out a heterogeneity analysis from the aspects of economic development level, geographical location factors, and population size factors.

4.2.1. Heterogeneity of Economic Development Level

According to GDP per capita, the heterogeneity of the economic development level is divided into sub-samples above the mean and sub-samples below the mean.

Table 6. Results of heterogeneity test of economic development level.

Variables	Economic development level relatively high		Economic development level relatively low	
	RD	RD	RD	RD
Policy	0.218*	0.178**	0.216**	0.126**
	(0.112)	(0.090)	(0.076)	(0.053)
Struct	-	-0.492***	-	-0.351**
		(0.044)		(0.142)
lnPGDP	-	0.355*	-	-0.690**
		(0.197)		(0.301)
Urban	-	1.360**	-	-0.112
		(0.560)		(1.570)
Consumption	-	3.245***	-	1.485***
		(0.623)		(0.449)
Open	-	35.962***	-	-0.085
		(8.925)		(0.226)
Edu	-	0.210	-	0.742***
		(0.166)		(0.208)
_cons	1.451***	-5.665***	0.720***	2.372
	(0.040)	(1.318)	(0.013)	(2.236)
Individual effect	Yes	Yes	Yes	Yes
Year effect	No	Yes	No	Yes
N	176	176	304	304
r2	0.102	0.532	0.147	0.671

Note: 1. Cluster-Robust standard errors are in parentheses, 2. * means 10% level is significant, ** means 5% level is significant and *** means 1% level is significant.

According to the average per capita GDP of each province and city in the study year, the provinces and cities are classified based on whether their average value is above or below the average value. Those above the average value are classified as Category One, while those below the average value are classified as Category Two.

Table 6 demonstrates the heterogeneity test results of economic development levels. It is observed that, in provinces and cities with higher economic development levels, the construction of PFTZs significantly improves the level of regional innovation and development without adding the regression results of control variables. After adding control variables, the policy variables are still significantly positive, but the coefficient becomes smaller. In the sample of provinces and cities with lower economic development levels, the significance and direction of the coefficient are basically similar to those of provinces and cities with higher economic development levels. From the sub-sample regression results of the two types of provinces and cities, it can be found that, in the provinces and cities with higher economic development levels, the coefficient of PFTZ policies on the regional innovation level is larger, indicating that the policy effect is more obvious. The benchmark regression model verifies that the construction of PFTZs has a significant promoting effect on regional innovation and development, which lays an analytical foundation for the following analysis of the mediating effect and mechanism in this paper. At the same time, the baseline regression results also confirm the consistency with the results of existing studies.

4.2.2. Geographical Location Heterogeneity

According to the National Bureau of Statistics on provinces division, China is divided into coastal and inland regions. The coastal provinces contain 11 provinces and cities, including Liaoning, Hebei, Beijing, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Guangxi, while the rest are inland provinces.

Table 7. Test results of geographical location heterogeneity.

Variables	Coastal areas		Inland area	
	RD	RD	RD	RD
Policy	0.159*** (0.050)	0.234*** (0.081)	0.283*** (0.068)	0.156** (0.060)
Struct	-	-0.560*** (0.036)	-	-0.288** (0.129)
lnPGDP	-	0.442** (0.185)	-	-0.258 (0.334)
Urban	-	2.032*** (0.534)	-	-0.118 (1.544)
Consumption	-	1.529*** (0.582)	-	1.124** (0.426)
Open	-	-3.178 (6.208)	-	-0.209 (0.213)
Edu	-	0.341** (0.162)	-	0.507*** (0.164)
_cons	1.451*** (0.029)	-6.938*** (1.014)	0.721*** (0.011)	-0.253 (3.039)
Individual effect	Yes	Yes	Yes	Yes
Year effect	No	Yes	No	Yes
N	176	176	304	304
r2	0.059	0.665	0.230	0.687

Note: 1.Cluster-Robust Standard Errors are in parentheses, 2 ** means 5% level is significant and *** means 1% level is significant.

Table 7 shows the test results of geographical heterogeneity. It clearly indicates that, in coastal provinces and cities, without the regression results of control variables, the construction of PFTZs significantly improves the level of regional innovation and development, and the policy variables remain dramatically active after adding control variables. In the sample of inland provinces and cities, the significance and direction of coefficients are similar to those of coastal provinces and cities. From the regression results of two types of provincial and municipal subsamples, it can be observed that the coefficient of PFTZs policies in coastal provinces and cities on the regional innovation level is larger, indicating that the policy effect is more pronounced. Some existing studies also conducted subsample regression from coastal and inland areas, and the results of this study are similar; the PFTZs policy in coastal areas has a greater impact on the regional innovation level.

4.2.3. Population Size Heterogeneity

Similar to the sampling idea of economic development level, according to the average total population at the end of the study year in each province and city, they are classified according to above and below the mean, with those above the mean as one category and those below the mean as the other. Table 8 shows the test results of population size heterogeneity. It obviously shows that, in provinces and cities with large populations, without the regression result of control variables, the construction of PFTZs significantly improves the level of regional innovation and development. After control variables are added, the policy variables are still remarkably active, but the coefficient becomes smaller. In the sample of provinces and cities with small population sizes, the significance and direction of coefficients are similar to those of provinces and cities with higher economic levels. From the regression results of the two types of sub-samples of provinces and cities, it can be found that, in provinces and cities with larger populations, the coefficient of the policies of PFTZs on the regional innovation level is larger, indicating that the

policy effect is more obvious. The population size heterogeneity test is the expansion of existing research content. The larger the population size of a province, the different economic policies, and the corresponding adjustment of talent policies will occur accordingly, and the possibility of talent agglomeration is relatively higher. Empirical results also support this hypothesis. In provinces and cities with larger populations, the impact of PFTZs policies on regional innovation levels tends to be greater.

Table 8. Test results of population size heterogeneity.

Variables	Large population size		Small population size	
	RD	RD	RD	RD
Policy	0.354***	0.074*	0.499***	0.065*
	(0.062)	(0.042)	(0.074)	(0.038)
Struct	-	-0.144	-	-0.394***
		(0.143)		(0.061)
lnPGDP	-	-0.446**	-	-0.710***
		(0.186)		(0.169)
Urban	-	2.028*	-	0.150
		(1.081)		(0.544)
Consumption	-	0.598*	-	1.599***
		(0.361)		(0.218)
Open	-	-10.630**	-	0.309
		(4.556)		(0.238)
Edu	-	0.599***	-	0.543***
		(0.104)		(0.085)
_cons	1.137***	0.535	0.806***	-76.187***
	(0.019)	(1.067)	(0.033)	(28.162)
Individual effect	Yes	Yes	Yes	Yes
Year effect	No	Yes	No	Yes
N	192	192	288	288
r2	0.317	0.771	0.137	0.487

Note: 1. Cluster-Robust standard errors are in parentheses, 2. * means 10% level is significant, ** means 5% level is significant and *** means 1% level is significant.

4.3. Robustness Test

To examine the robustness of the empirical results, this research adopts two methods to carry out the robustness test. One method is to replace the explained variable with the logarithm of the number of authorized patent applications in each province and city, and the other is to conduct a counterfactual test and assess the policy variables of PFTZs one year in advance.

4.3.1. Replacing the Explained Variable

The proportion of industrial R&D expenditure on the explained variable gauge in the benchmark model was replaced by the numerical value of the number of domestic patent applications granted, and the model was re-estimated. The regression results are shown in Table 9.

It can be found that the empirical results of replacing the explained variables are similar to the benchmark model regression results. In the three columns of regression results, the policy variables are all dramatically positive, indicating that the policies of PFTZs can obviously boost the level of regional innovation and development. From the perspective of the coefficients of the three models, after control variables and the results of the fixed effect of the year are added, the coefficients of policy variables gradually become smaller, indicating that the endogeneity problem of missing variables has been alleviated to a certain extent, and empirical results are robust.

Table 9. Robustness test results of replacing explained variables.

Variables	(1)	(2)	(3)
	Patent	Patent	Patent
Policy	1.402***	0.312***	0.150***
	(0.068)	(0.100)	(0.039)
Struct	-	-0.166***	-0.167**
		(0.051)	(0.068)
lnPGDP	-	4.398***	0.788***
		(0.171)	(0.168)
Urban	-	-5.291***	1.387**
		(0.425)	(0.625)
Consumption	-	3.792***	0.094
		(0.533)	(0.253)
Open	-	-1.701***	1.994***
		(0.325)	(0.331)
Edu	-	-1.692***	0.144
		(0.115)	(0.138)
_cons	9.555***	-22.822***	-0.875
	(0.016)	(1.168)	(1.370)
Individual effect	Yes	Yes	Yes
Year effect	No	No	Yes
N	480	480	480
r2	0.338	0.777	0.498

Note: 1. Cluster-Robust standard errors are in parentheses, 2. ** means 5% level is significant and *** means 1% level is significant.

4.3.2. Counterfactual Test

Assuming the time of setting up PFTZs is advanced by one year, the benchmark model is re-estimated, and the regression results obtained are shown in Table 10.

Table 10. Results of the counterfactual test.

Variables	(1)	(2)	(3)
	RD	RD	RD
Policy2	0.092	0.037	0.058
	(0.061)	(0.048)	(0.047)
Struct	-	-0.379***	-0.151
		(0.103)	(0.094)
lnPGDP	-	-0.559*	-0.544
		(0.325)	(0.379)
Urban	-	1.550*	2.672**
		(0.897)	(1.283)
Consumption	-	1.184***	1.081***
		(0.333)	(0.325)
Open	-	0.217	-0.213
		(0.174)	(0.144)
Edu	-	0.890***	1.172***
		(0.291)	(0.333)
_cons	1.080***	-0.487	-3.382
	(0.023)	(1.396)	(3.955)
Individual effect	Yes	Yes	Yes
Year effect	No	No	Yes
N	360	360	360
r2	0.036	0.473	0.574

Note: 1. Cluster-Robust Standard Errors are in parentheses, 2.* means 10% level is significant, ** means 5% level is significant and *** means 1% level is significant.

The regression of the benchmark model is carried out one year in advance of the policy variables. From Table 10, we can see that the results of the three columns of regression are not significant, indicating that it is actually the policy year of PFTZs that improves the regional innovation and development level.

Table 11. Test results of digital finance mediating effect.

Variables	(1)	(2)	(3)
	RD	DigFin	RD
Policy	0.100**	0.033***	0.055**
	(0.045)	(0.013)	(0.028)
DigFin	-	-	0.444***
			(0.113)
Struct	-0.350***	0.067**	-0.288***
	(0.106)	(0.032)	(0.052)
lnPGDP	-1.036***	0.162*	-0.477***
	(0.314)	(0.086)	(0.156)
Urban	0.928	-2.694***	3.419***
	(0.915)	(0.288)	(0.501)
Consumption	1.725***	0.559***	1.019***
	(0.404)	(0.100)	(0.190)
Open	-0.049	-0.277***	0.114
	(0.169)	(0.103)	(0.225)
Edu	0.915***	0.337***	0.818***
	(0.263)	(0.056)	(0.115)
_cons	4.431*	-2.531***	-1.979
	(2.179)	(0.860)	(1.535)
Individual effect	Yes	Yes	Yes
Year effect	Yes	Yes	Yes
N	480	360	360
r2	0.653	0.997	0.570

Note: 1. Cluster-Robust standard errors are in parentheses, 2. * means 10% level is significant, ** means 5% level is significant and *** means 1% level is significant.

4.4. Mechanism Analysis

4.4.1. Digital Finance

Table 11 demonstrates the test results of the digital finance mediating effect. From the second column of regression results, it shows that the policies of PFTZs are remarkably positive for DF. In the third column of regression results, after digital finance is added, both policy variables and digital finance variables are significantly positive, demonstrating that the mediating effect of DF is established. On the one hand, the policy variables of PFTZs will directly affect the regional innovation development level (the first column regression results). On the other hand, PFTZs policy will indirectly improve the level of regional innovation development by positively boosting the DF level (Column 2 and Column 3 regression results). The test of the DF mediating effect expands the existing research content and provides a new research perspective for the regional innovation and development level in PFTZs. The continuous development of DF can reduce enterprises' financing constraints, thus further promoting the regional innovation level.

4.4.2. DE

Table 12 displays the test results of the mediating effect of DE. From the second column of regression results, it clearly shows that the policies of PFTZs are significantly positive for DE. In the third column of regression results after DE is added, both the policy variables and DE variables are remarkably positive, demonstrating that the mediating effect of DE is established. On the one hand, the policy variables of PFTZs will directly affect the regional innovation development level (the first column regression results). On the other hand, PFTZs policy will indirectly improve the level of regional innovation development by positively improving the DE level (Column 2 and Column 3 regression results). Existing studies rarely explore the mediating effect of DE. This study innovatively explores its transmission mechanism, and empirical results verify that DE can effectively promote enterprise intelligence and digital transformation, and help promote the regional innovation and development level.

Table 12. Test results of mediating effect of DE.

Variables	(1)	(1)	(2)
	RD	DigEco	RD
Policy	0.100**	0.043***	0.095*
	(0.045)	(0.006)	(0.054)
DigEco	-	-	1.482***
			(0.232)
Struct	-0.350***	-0.008	-0.143
	(0.106)	(0.015)	(0.087)
lnPGDP	-1.036***	-0.037	-0.515
	(0.314)	(0.041)	(0.372)
Urban	0.928	0.005	2.764**
	(0.915)	(0.139)	(1.208)
Consumption	1.725***	0.089*	0.988***
	(0.404)	(0.048)	(0.336)
Open	-0.049	-0.195***	-0.055
	(0.169)	(0.049)	(0.151)
Edu	0.915***	0.185***	1.022***
	(0.263)	(0.027)	(0.356)
_cons	4.431*	-0.879**	-2.696
	(2.179)	(0.415)	(3.914)
Individual effect	Yes	Yes	Yes
Year effect	Yes	Yes	Yes
N	480	360	360
r2	0.653	0.950	0.591

Note: 1. Cluster-Robust standard errors are in parentheses, 2. * means 10% level is significant, ** means 5% level is significant and *** means 1% level is significant.

5. CONCLUSION AND POLICY IMPLICATION

5.1. Research Conclusions

This research takes regional innovation development as the research perspective, selects panel data from 30 provinces from 2007 to 2022 as research samples, constructs a multi-period DID model. The province fixed effect and year fixed effect are added to the model, and the Cluster Robust Standard Error is used to estimate the model. It discusses the effects of the establishment of different batches of PFTZs on regional innovation development; the heterogeneity analysis and mechanism tests are also carried out. The results indicate that the establishment of PFTZs is conducive to improving the regional innovation development level. After a series of robustness tests, such as the parallel trend test, placebo test, and replacement of explained variables, the conclusion remains valid. PFTZs exhibit heterogeneity in regional innovation development; provinces and cities with a higher economic development level, coastal provinces and cities, and provinces with larger populations have more pronounced effects on the regional innovation level. PFTZs indirectly improve the regional innovation and development level through two driving mechanisms of DE and DF, which play a mediating role. Among them, the population size heterogeneity analysis and the mediating effect tests of DF and DE expand the existing research content and provide a new research perspective for the regional innovation and development level of PFTZs.

5.2. Policy Implications

It can be seen from the research results that the PFTZs' establishment can boost the regional innovation level and afford impetus for HQED. By virtue of its geographical advantages, business environment advantages, financial advantages, scientific and technological advantages, talent advantages, and other advantages, PFTZs give a strong driving force to regional innovation. Therefore, it is necessary to continue to promote the strategy of building PFTZs.

First of all, it is necessary to strengthen the strategic positioning and top-level design of PFTZs, increase the input of talents, capital, technology, and other aspects, boldly try and practice, and promote regional innovation and development in the continuous reform and opening up. Government departments should set up coordination

institutions among various PFTZs and strengthen the division of labor and cooperation in PFTZs. PFTZs should focus on developing their own characteristic industries and improving resource utilization efficiency according to their different functional positioning to improve resource utilization efficiency. We will adopt differentiated policies for PFTZs in different regions, with large populations and in coastal areas. We will consolidate the quality of innovation achievements in provinces and cities with superior resource endowments and provide corresponding policies, human resources, and capital support to provinces and cities in the central and western regions with initially inferior factor endowments. We will strengthen cooperation among different PFTZs to complement each other's strengths to generally boost the regional innovation level.

Secondly, it is also necessary to strengthen the construction of platforms such as research and development centers and innovation and entrepreneurship incubation centers in PFTZs, provide platform support for innovative behaviors, and promote the transformation of innovation achievements into regional innovation and development. Furthermore, we also pay close attention to the deep integration of digital finance, DE, and regional innovation, formulate action plans for digital technology, and boost the promotion of digitalization and key technologies. We should accelerate the full coverage of the 5G network in urban areas, improve the construction of big data centers, cloud computing platforms, and artificial intelligence (AI) applications and development, and promote the construction of digital infrastructure to support the digital development of PFTZs. Promoting the construction of digital PFTZs to drive the digital transformation of cities, so as to enhance the regional innovation level and drive HQED.

Funding: This study received no specific financial support.
Institutional Review Board Statement: Not applicable.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Data Availability Statement: The corresponding author can provide the supporting data of this study upon a reasonable request.
Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: Both authors contributed equally to the conception and design of the study. Both authors have read and agreed to the published version of the manuscript.

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