



Do pilot free trade zones improve the green total factor productivity? Evidence from a quasi-natural experiment in China

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Abstract

China's pilot free trade zone (PFTZ) is an important national strategy to achieve high-quality development, so it is necessary to discuss the effect of PFTZ implementation on green total factor productivity (GTFP). Based on the data from 279 cities in China from 2004 to 2018, this study takes the establishment of PFTZ as a quasi-natural experiment and uses the difference-in-differences (DID) method to systematically evaluate the effect of PFTZ on urban GTFP. The empirical results of this paper are shown as follows: Firstly, the construction of PFTZ has a significant effect on urban GTFP, and this effect has increased gradually over time. Secondly, the construction of PFTZ mainly promotes the urban GTFP by increasing the level of science and technology innovation, reducing government intervention and improving the level of human capital. Thirdly, the effect of PFTZ construction on GTFP is more pronounced in regions with earlier waves of PFTZ and in western regions where environmental concerns are higher. In addition, there is a significant positive linkage between the construction of the PFTZ and the Belt and Road Initiative to improve the urban GTFP. The findings of this paper enrich the relevant literature on PFTAs and sustainable development and provide a theoretical basis for further promotion of PFTZ construction.

Keywords Pilot free trade zone · Green total factor productivity · Difference-in-differences method · Policy linkage effect

Introduction

The dilemma between environmental pollution and economic growth has been an important topic of frontier research (Grossman and Krueger, 1991; Tavoni and Levin, 2014; Semieniuk et al., 2021; Lee et al., 2021; Gohlke et al., 2008; Wang et al., 2022a, b). With the global economic

development, the deepening of economic globalization and economic complexity will further aggravate regional environmental pollution (Adebayo et al., 2022; Sharif et al., 2019). Therefore, many scholars have explored the reliability of EKC in countries such as the USA and other countries by constructing different theoretical models (Ongan et al., 2021; Ongan et al., 2022; Işik et al., 2019; Godil et al., 2020; Işik et al., 2019; Işik et al., 2021), the industry-induced effects of EKC (Işik et al., 2020; Sharif et al., 2020a, b; Aziz et al., 2020; Dogru et al., 2020), and have an in-depth study on the regulatory effects of EKC (Işik et al., 2022). They found that economic development also leads to increased emissions of various pollutants, and reasonable government expenditure can effectively reduce environmental pollution and economic degradation. In the long term, however, the pace of economic globalization will eventually exacerbate the level of environmental degradation (Suki et al., 2020). In the face of the contradiction between economic growth and environmental pollution, some scholars have also given corresponding policy suggestions. Sharif et al. (2021) believe that establishing efficient renewable energy systems can effectively reduce carbon dioxide emissions. While Khan et al. (2020) and Işik et al. (2021) believe that

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achieving environmentally sustainable development lies in the country to increase green practices and strengthening environmental collaborative governance between countries.

China is currently facing a huge conflict between economic growth and environmental pollution. Since the reform and opening up, the rough-and-tumble economic development model has provided a strong impetus for Chinese development and brought about serious environmental pollution problems. As the reform and opening-up have entered into a bottleneck period, China's economic growth is shifting from speed-oriented to quality-oriented. As the condition for high-quality economic development, it is natural that the environment comes into the spotlight (Zeng and Eastin, 2007). A series of environmental protection measures, introduced by the Chinese government during the 13th Five-Year Plan period, have significantly improved China's environmental quality. The contradiction between economic growth and environmental pollution is still prominent. Fortunately, the construction of PFTZ gives a solution from the perspective of institutional innovation. Since the first PFTZ (Shanghai) construction was set, 21 PFTZs have been approved to establish by the Chinese government, forming a development pattern to put the sea and land under a unified plan, the eastern and western in mutual benefit. Following the construction of PFTZ, a series of innovative institutional measures were implemented, which have effectively reduced obstacles in the process of economic development, created a good business environment, promoted the free flow of factors, and improved regional total factor productivity. Meanwhile, the general plans of each PFTZ specifically propose environmental initiatives to implement the new green development concept, encourage green consumption, and strengthen the environmental awareness of enterprises, which also contributes to the improvement of the local environment. Besides, the environment-related policies of the PFTZ require that the commitments of the Paris Agreement be made realistic in the urbanization construction. Combined with the innovation and environmental protection requirements proposed by the PFTZ policy, the construction of the PFTZ can promote regional GTFP through institutional innovation. In other words, it can improve the efficiency of economic development while taking into account environmental protection, alleviate the huge contradiction between economic growth and environmental pollution faced by China, and effectively accelerate the process of achieving the sustainable development goals in China.

The construction of the PFTZ is an important national solution to reconcile the inherent contradictions between economic development and environmental protection. But whether it has given full play to its institutional advantages and effectively improved the green total factor productivity of the region (hereinafter referred to as GTFP), that is, whether it has effectively adjusted the contradiction between

economic growth and environmental pollution and achieved the sustainable development goals, needs to be figured out by further research and analysis. In light of this, taking the construction of PFTZ as a quasi-natural experiment, we use the difference-in-differences method to systematically explore the effect and mechanism of the PFTZ construction on the urban GTFP. And its heterogeneity in regions, waves, and environmental concerns levels. In addition, based on the commonalities between the PFTZ construction and the Belt and Road Initiative in the historical background, value function and role function, we intend to further study the connected effect of these two policies on promoting GTFP.

The rest of this paper is organized as follows. The “[Literature review](#)” section is the literature review, which explores the marginal contributions of this paper by reviewing previous literature and conducting a different analysis based on previous studies. The “[Mechanism analyses](#)” section represents the theoretical mechanism and research hypothesis to provide the corresponding theoretical basis and research hypothesis for all empirical studies of this paper. The “[Research design](#)” section describes the study design, mainly elaborating on selecting and measuring the econometric model and experimental data. The “[Empirical result analysis](#)” section presents the analysis of empirical results, mainly examining the model identification conditions, benchmark regression, a series of robustness tests, heterogeneity analysis, and transmission mechanism tests. The “[Further analysis: linkage effects](#)” section further empirically studies the policy linkage effect between PFTZ construction and the Belt and Road Initiative. The “[Conclusions and policy suggestions](#)” section presents the conclusions and policy suggestions.

Literature review

The research results closely related to this study mainly include three types: the policy effect of the establishment of PFTZ, the key factors affecting GTFP, and the environmental effect of PFTZ construction.

First, a macro perspective, scholars examining the policy effect of the establishment of PFTZ have used empirical analysis methods such as counterfactual analysis, synthetic control, and DID to evaluate the economic effect of PFTZ construction. They have revealed that institutional dividends released with the construction of PFTZ have effectively stimulated regional economic growth (Cai et al., 2021; Huang et al., 2017; Wang, 2013; Zheng et al., 2016; Zhang et al., 2018), facilitated the free flow of international capital (Yao and Whalley, 2015; Yao and Whalley, 2016; Chen et al., 2021), reinforced the spillover effect of regional knowledge (Li et al., 2020), promoted the development of e-commerce industry (Yang et al., 2021), maintained the

sustainable development of regions (Liu et al., 2021a, b), and elevated the efficiency of port operation (Liu et al., 2021a, b; Fan et al., 2022). From a micro perspective and based on the previous analysis that focused on the regional port operation efficiency impact of PFTZ construction, Li et al. (2021a, b) further shed light on the effects of the construction of PFTZ on the performance of listed companies and conducted empirical researches using the DID method on it. The results indicated that the construction of PFTZ has significantly improved the performance of listed companies. In addition, some scholars have also delved into the regulatory and legal mechanisms behind the various policy effects brought about by the construction of the PFTZ (Peng and Fei, 2017).

Second, existing studies on the factors affecting GTFP can be divided into two types: (i) evaluating the development trend of GTFP in China as a whole (Gao and Yuan, 2022; Tao et al., 2017; Zhang and Tan, 2016) and (ii) exploring the factors that affect GTFP, such as the level of green finance, the openness, the financial separation, the degree of foreign investment openness, the level of science and technology, the environmental supervision and regulation, the human capital, and the industrial structure (Ding et al., 2022; Lee and Lee, 2022; Song et al., 2018; Yu et al., 2021; Wu et al., 2020; Li et al., 2022; Wang et al., 2018; Zhao et al., 2020a, b; Wang et al., 2021a, b, c; Zhu et al., 2019; Lu et al., 2020). In addition, some scholars also explored the policy and institutional factors affecting GTFP from the perspectives of carbon emissions trading pilots, the government environmental information disclosure, the construction of smart city pilots, the construction of e-business pilot cities, and the Belt and Road Initiative (Huang and Chen, 2022; Zhao and Chen, 2022; Cao et al., 2021; Jiang et al., 2021a, b, c; Liu and Xin, 2019a, b).

Third, many studies about PFTZ construction mainly focus on economic effects, and few have noticed its environmental effects. Zhuo et al. (2021) first assess the impact effect of PFTZ construction on regional environmental welfare taking Guangdong PFTZ as the example and find that PFTZ construction can improve the regional environment only by increasing technological progress. Zhou et al. (2022) further explore and evaluate the high-quality green development path of the PFTZ, which proves that the PFTZ can only achieve further development if it adheres to the green development path. With the deepening research on the environmental effects of PFTZ, some scholars have begun to look for suitable indicators to comprehensively study the economic and environmental effects of PFTZ construction and find that GTFP seems to be a suitable indicator. However, the only three relevant studies were due to the late start on this subject. For the first one of these three, Jiang et al. (2021a, b, c) considered Shanghai PFTZ as an example to examine the effect of the construction of PFTZ on GTFP

using the synthetic control method and find that institutional dividends released by PFTZ construction have significantly elevated the GTFP of Shanghai by improving the level of scientific and technological innovation. However, there are 21 PFTZs in China, and they have made significant improvements in trade, investment, financial, and administrative regulatory innovations. The research conclusions drawn only from Shanghai PFTZ are not representative. For another study, Ma et al. (2021) explored the GTFP growth effect of PFTZ construction and its transmission mechanism from the city level. However, this study overlooked the functional positioning of the construction of PFTZ and the synergy of the construction of PFTZ with other policies. Therefore, their research perspective was relatively single, lacking the significance of guiding practice. For the third one, Wang et al. (2022a, b) further studied the effect of the construction of the Shanghai Free Trade Zone on GTFP on the Yangtze River Delta urban agglomeration by using the regression discontinuity method and attempt to fill the research gap of the spatial spillover effect of the construction of the free trade zone on GTFP. But the problem of a single research object still exists, and the empirical results cannot form a broad consensus due to the area limitation of this research.

In summary, previous scholars have conducted comprehensive and in-depth studies on the economic effects, exogenous factors, and environmental effects of PFTZ construction. It provides empirical support and a policy basis for China to further explore the pilot construction of PFTZ and improve regional GTFP. However, there are obvious shortcomings in the existing studies. First, most of the literature on the economic effect of the construction of PFTZ is based on provincial data or a single PFTZ as the research object for empirical analysis. However, 21 PFTZs have been set up so far, so empirical analyses based on provincial data or a single PFTZ may cause biased results. Second, previous research on the policy effects of PFTZ has mostly focused on its economic effects, relatively ignoring the environmental effects of the construction of PFTZ. Besides, research on GTFP has explored the effect of policies such as pilot low-carbon cities, innovative pilot cities, smart city construction, pilot eco-civilized cities, and the Belt and Road Initiative, while only a few studies have focused on the effect of PFTZ construction on urban GTFP. Only three articles discuss the interrelationship between the construction of PFTZ and GTFP, and they are also criticized for the problems of unrepresentative research objects, single research perspectives, and limitations of research areas.

The main contributions of this study are summarized as follows. First, it is one of the few articles to examine the effect of the construction of PFTZ on GTFP, aiming to fill the related research gap. Second, this paper uses the cities in which the first to third waves of PFTZ are located as the research subjects and conducts an empirical study based on

city-level data to avoid research bias owing to provincial panel data or a single PFTZ as the research object. Third, we further explore the policy linkage effect of PFTZ construction on GTFP, which provides an important reference basis for future PFTZ construction in strengthening cooperation and site selection and has strong practical guidance significance. Finally, this study explores the transmission mechanism of the construction of PFTZ on GTFP from the perspective of PFTZ's institutional innovation, thereby providing a policy reference for the construction of PFTZ in other countries to a certain extent.

Mechanism analyses

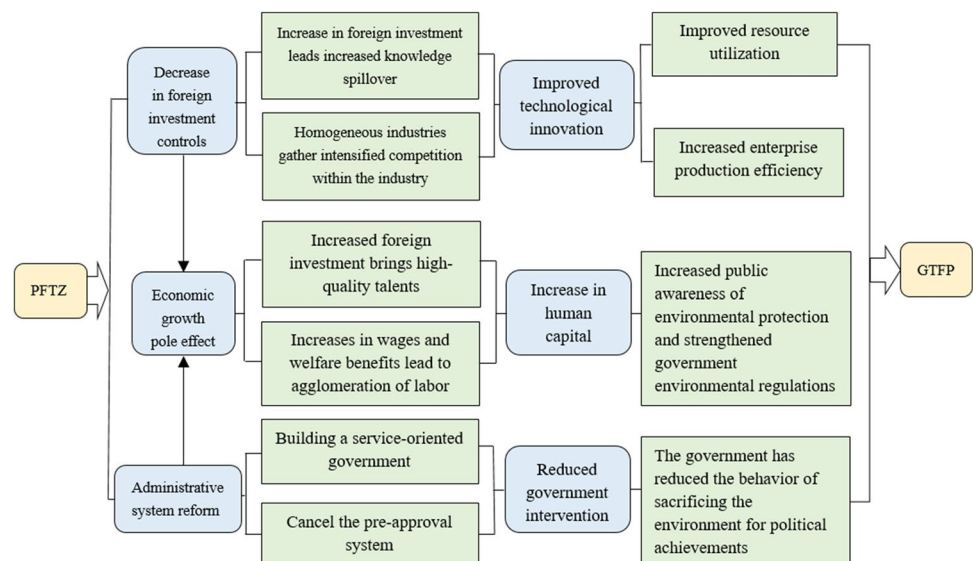
As a strategic measure to promote high-quality development, the construction of PFTZ should aim to coordinate the contradiction between economic growth and environmental protection. The construction of PFTZ has promoted economic growth mainly by allowing full advantages of institutional innovation. Specifically, various institutional innovative measures have been undertaken in trade, investment, finance, supervision, and legal system to improve the facilitation of trade, investment and finance, government service, and legalization of the business environment. The implementation of policies has greatly improved regional service facilitation. The policies of “negative list,” “pre-establishment national treatment (PENT),” and “approval system to record system” have further enhanced investment facilitation. Furthermore, institutional innovation has facilitated the transformation of government functions and reduced government administrative intervention. In terms of environmental protection, the overall plan for the PFTZ also clearly sets out the environmental protection requirements to

implement the new green development concept and explore a new green development model. Specifically, PFTZ aims to meet international environmental protection standards, strengthen the corporate awareness of environmental protection, build a low-carbon industrial cluster, encourage green consumption, and strive to build international eco-friendly industrial parks. The GTFP indicator is constructed based on the traditional total factor productivity and by considering environmental factors. The indicator reflects economic growth and environmental protection. In addition, the indicator reflects the coordinated development of economic growth and environmental protection to a certain extent. This leads us to formulate the following hypothesis:

Hypothesis 1: *The construction of PFTZ can improve urban GTFP.*

As indicated in Fig. 1, regarding the mechanism path, “single window” and “PENT” undertaken in PFTZ will attract considerable foreign capital injection and foreign investment (Yao and Whalley, 2015), leading to the accumulation of capital and industries. The increase in foreign direct investment (FDI) will generate a technology spillover effect (Liu and Wang, 2003) to enhance the scientific and technological innovation in the region. Meanwhile, the accumulation of a large number of homogeneous industries will also drive enterprises towards technological innovation through increased industrial competition. The improvement of technological innovation can directly enhance urban GTFP by promoting the recycling of regional resources, improving enterprise production efficiency, and reducing environmental pollution (Wang et al., 2021a, b, c). In addition, committing to realizing investment liberalization and administrative services, PFTZ construction takes the method of institutional innovation and has gradually become a regional economic growth pole (Dobrescu and Dobre, 2015). Wages and

Fig. 1 The transmission mechanisms of PFTZ on GTFP



benefits in PFTZ are higher than those in non-PFTZ, which will attract capital inflow and high-quality talents (Li et al., 2021a, b). On the one hand, as an element of transforming the elements (technologies, equipment, management experience) of technological innovation into production efficiency, human capital can enhance regional GTFP by improving regional technological innovation (Wang et al., 2021a, b, c). On the other hand, as a measurement indicator of educational level, human capital improvement will induce the government to reinforce environmental regulation and finally improve urban GTFP by enhancing the overall regional environmental awareness. Finally, the establishment plan of PFTZ has clearly proposed to streamline administration and delegate power (Wan et al., 2014), build service-oriented governments, and promote the transformation of government functions from “prior approval” to “operation and post-operation oversight,” thereby reducing government intervention. The decrease in government intervention can enhance urban GTFP by limiting the government’s behavior of promoting urban economic growth and seeking political achievements at the expense of the environment to a certain extent. Based on the discussion above, we put forward the following hypothesis:

Hypothesis 2: *The construction of PFTZ can improve urban GTFP by promoting technological progress, improving the human capital level and reducing government intervention.*

The construction of PFTZ and the Belt and Road Initiative have the same historical background, similar value functions, complementary role functions, and strong connectivity and integration. The Belt and Road Initiative provides Chinese solutions for global economic governance, maintains a multilateral trading system, and creates a more open world economy. This initiative’s proposals of enhancing trade and investment facilitation, strengthening administrative legalization and attention to environmental protection are consistent with the main direction of PFTZ policy. Additionally, the construction of PFTZ provides a domestic platform for implementing the Belt and Road Initiative and a solid carrier for the release of policy dividends. In addition, there are cities that are also pilot cities for free trade and cities along the Belt and Road Initiative.

Hypothesis 3: *There is a linkage effect between the construction of PFTZ and the Belt and Road Initiative in improving urban GTFP.*

Research design

Econometric models

In the choice of econometric model, unlike the general policy of full roll-out, the pilot policy of PFTZ construction

is set in different regions, and the data is continuous. At the same time, compared to normal policy assessment methods, DID method can better address the endogeneity problem (Basri et al., 2021; Londoño-Vélez and Ávila-Mahecha, 2021; Xu et al., 2022; Xu et al., 2021) and more accurately assess the impact effect of the PFTZ construction on urban GTFP. Therefore, based on panel data of 279 cities in China from 2004 to 2018, this study takes the establishment of PFTZ as a quasi-natural experiment and uses the time-varying difference-in-differences method to explore whether the establishment of PFTZ promotes urban GTFP. Compared with the traditional policy evaluation method, DID model can better solve the endogenous problem and more accurately assess the impact of the construction of PFTZ on the GTFP (Cortes and Goodman, 2014). The three waves of cities with PFTZ are the treatment group, whereas those without PFTZ during the sample years were regarded as the control group. The specific model is as follows:

$$GTFP_{it} = \alpha + \beta treat_i \times post_t + \gamma X_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (1)$$

where i and t represent the city and year, respectively. $GTFP_{it}$ denotes green total factor productivity; $treat_i$ denotes grouped dummy variables. The cities with PFTZ are assigned a value of 1; otherwise, it equals 0; $post_t$ denotes the dummy variable, and the value is 0 before the establishment of PFTZ and 1 after its establishment; X_{it} denotes a set of control variables, including industrial structure upgrading, foreign capital dependence, level of financial development, foreign trade openness, infrastructure construction, marketization level, urbanization level, economic growth, and fixed asset investment. ε_{it} denotes the random error term; σ_i and μ_t denote city fixed effect and time effect. If β is significantly positive, it will demonstrate that the establishment of PFTZ can promote the urban GTFP; otherwise, there will be no significant promotion effect.

Variables and data

Based on the availability and integrity of data, we selected the annual data on 279 cities in China from 2004 to 2018 as research samples to evaluate the effect of PFTZ on GTFP. All data are sourced from the *China Urban Statistical Yearbook* and the local statistical yearbooks.

Explained variable: GTFP

We referred to the construction of GTFP proposed by Liu and Xin (2019a, b). Furthermore, we used DDF–GML to calculate the GTFP of each city by using MaxDEA 8.0.

However, the MI index does not represent the absolute size of GTFP of each city but only reflects its growth rate. Accordingly, 2004 was further set as the base year, and its corresponding MI was assigned the value 1, thereby obtaining the GTFP of each city through multiplicative calculation. Notably, input indicators such as capital, labor, and energy input and output indicators such as desirable and undesirable output were included in the index construction. Desirable output was represented by the GDP converted at constant prices in 2004, and undesirable output represented the definition adopted by Xin and Qu (2019). The authors adopted the entropy evaluation method to integrate sulfur dioxide, wastewater, and industrial smoke and dust emissions as a comprehensive pollution index. Moreover, we measured variable GTFP (VGTFP) and constant GTFP (CGTFP) to avoid overemphasis on a single explained variable. Due to VGTFP being more consistent with the real situation, the main empirical part of this study adopted VGTFP. Unless otherwise specified, all GTFP described herein are VGTFP.

Key explanatory variable

The key explanatory variable is $treat_i \times post_t$, which was based on the list of PFTZ published by the Department of Foreign Investment Management of Commerce of China and the time of their establishment. If a PFTZ is established in a certain year, the value for and after that year is assigned the value 1, and if no PFTZ is established, the value is assigned as 0. To clearly state, there are three waves of PFTZ studied in this paper: the first wave is the Shanghai PFTZ established in 2013; the second wave is the Guangzhou, Shenzhen, Zhuhai, Tianjin, Xiamen, and Fuzhou PFTZ established in 2015; and the third wave is the Dalian, Shenyang, Yingkou, Zhoushan, Zhengzhou, Kaifeng, Luoyang, Wuhan, Xiangyang, Yichang, Chongqing, Chengdu, Luzhou, Xi'an, and Xianyang PFTZ established in 2017.

Control variable

Based on previous studies (Lee and Lee, 2022; Ding et al., 2022; Yu et al., 2021; Li et al., 2022; Zhu et al., 2019), we selected the following indicators as control variables: industrial structural upgrading (stru) is represented by the ratio of added value of the tertiary industry to that of the secondary industry; foreign investment openness (fdi) is represented by the proportion of foreign investment actually utilized in the GDP; financial development level (fin) is measured by the logarithm of the balance of RMB loans of financial institutions; infrastructure construction (infra) is expressed by the logarithm of road area of each city; marketization level (market) is represented by the proportion of the employment of urban private enterprises in the total employment

of cities; urbanization level (urban) is represented by the logarithm of built-up area of each city; economic growth (economic) is expressed by the logarithm of GDP per capita, and fixed asset investment (asset) is represented by the ratio of the fixed asset investment to the total GDP of each city. Descriptive statistics for the variables are shown in Table 1.

Empirical result analysis

Based on the above analysis, this paper empirically tests the effect of PFTZ on urban GTFP. For the reliability of the experimental design, we first test the parallel trend. Then, we analyzed the baseline regression results and conducted a series of robustness tests on the empirical results from many perspectives, such as placebo test, consideration of other policy interference, data tail reduction, and shortening of sample interval to improve empirical robustness.

Parallel trend test

To evaluate whether the construction of the PFTZ has the expected effect on the improvement of GTFP, this paper compares the changes in the mean value of GTFP of the treatment group and control group before and after the policy shock. We could infer that the establishment of a PFTZ had an unforeseeable effect on the explained variable. Thus, no randomness was observed during the establishment of PFTZ. Fig. 2 depicts the changes in the mean GTFP between the treatment group and the control group before and after the establishment of PFTZ. We can find that there is no significant difference existed in the mean GTFP between the two groups before the establishment of PFTZ. However, such differences gradually increased after

Table 1 Descriptive statistics.

Variables	Obs	Mean	Std. dev.	Min	Max
GTFP	4185	1.233	0.426	0.205	3.842
Treat×Post	4185	0.014	0.119	0.000	1.000
stru	4185	1.019	0.611	0.094	5.900
fdi	4185	0.020	0.023	0.000	0.285
fin	4185	14.347	2.803	4.231	20.373
infra	4185	6.858	1.054	1.095	9.975
market	4185	0.978	0.696	0.000	17.141
urban	4185	4.419	0.830	2.022	7.312
economic	4185	10.576	0.731	7.522	15.675
asset	4185	0.684	0.315	0.087	8.088
tech	4185	0.002	0.003	0.000	0.063
gov	4185	0.176	0.131	0.000	2.279
hc	4185	9.478	3.025	0.000	13.955

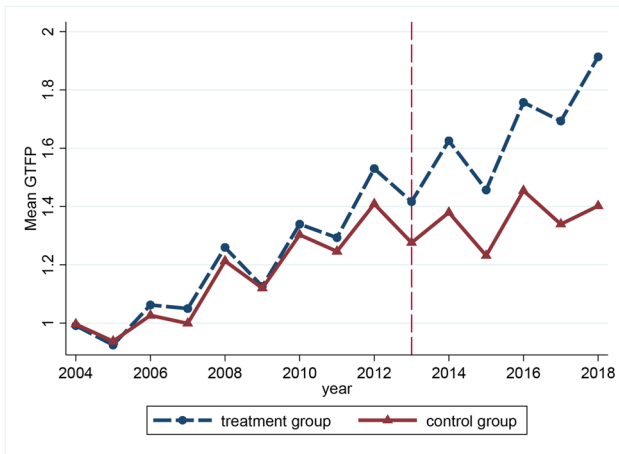


Fig. 2 Mean GTFP between the treatment group and the control group (2004–2018)

the establishment of PFTZ. The model passed the validation of the parallel trend.

Baseline regression

Table 2 presents the baseline regression results of the effect of the establishment of PFTZ on GTFP. (1) and (2) present the empirical regression results with control variables and without control variables, respectively. Obviously, with or without control variables, the construction of PFTZ has improved urban GTFP at the significance level of 1%. Therefore, H1 is verified.

Robustness test

Placebo test

To further verify the promotion of urban GTFP by the construction of the PFTZ is a policy effect brought about by the construction of the PFTZ rather than being influenced by other policy or stochastic factors. Referring

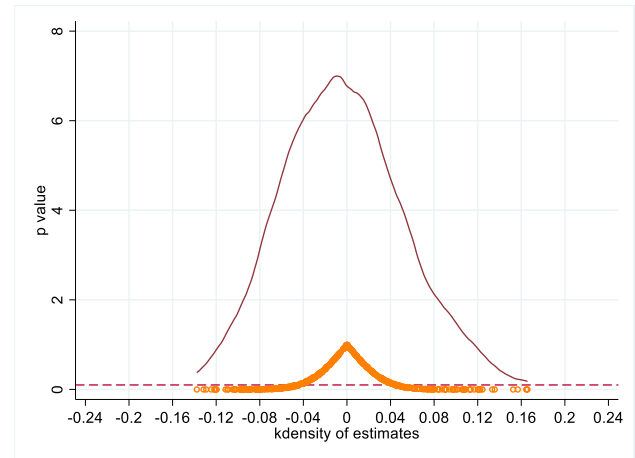


Fig. 3 Placebo test

to Cai et al. (2016), we use a placebo test to ensure the robustness of the baseline regression result. We conduct a placebo test through a random assignment policy pilot city. In particular, 22 cities were randomly selected from 279 cities as the intervention group, assuming that those cities implemented the PFTZ policy, while others served as the control group. Random sampling ensures that the policy dummy variable PFTZ has no effect on GTFP. Accordingly, 500 random samplings were conducted, and the regression was performed in accordance with the baseline regression model. Fig. 3 presents the mean distribution of the estimated coefficients and the corresponding *p* value distribution after 500 random assignments. The results indicated the following: (1) the mean distribution of 500 estimated coefficients was near 0. (2) Most estimated *p* values are greater than 0.1. Therefore, the effect of the promotion of PFTZ construction on urban GTFP is brought by their construction, which is unlikely to be caused by non-observable factors in city-years.

Table 2 Baseline regression results.

Variables	(1)	(2)
Treat×Post	0.320*** (9.53)	0.272*** (7.81)
Control variables		Yes
Year fixed effects	Yes	Yes
City fixed effects	Yes	Yes
Constant	0.996*** (74.47)	0.180 (0.61)
<i>N</i>	4,185	4,185
<i>R</i> ²	0.398	0.441

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

Table 3 Robustness tests: replacing explained variables.

Variables	(1) CGTFP	(2) CGTFP
Treat×Post	0.198*** (4.57)	0.170*** (3.98)
Control variables		Yes
Year fixed effects	Yes	Yes
City fixed effects	Yes	Yes
Constant	1.077*** (62.41)	-1.641*** (-4.33)
<i>N</i>	4,185	4,185
<i>R</i> ²	0.505	0.550

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

Table 4 Robustness tests: excluding other policy interference.

Variables	(1) GTFP	(2) GTFP	(3) GTFP	(4) GTFP
Treat×Post	0.271*** (7.79)	0.270*** (7.76)	0.248*** (7.15)	0.223*** (6.11)
Control variables	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Constant	0.166 (0.56)	0.169 (0.57)	0.219 (0.75)	0.201 (0.68)
<i>N</i>	4,185	4,185	4,185	4,185
<i>R</i> ²	0.441	0.442	0.452	0.444

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

Replacing the explained variable

We mainly considered VGTFP as the explained variable, which is relatively single and limited. We constructed CGTFP to replace the original explained variable for the same baseline regression and comparative analysis to further improve the reliability of empirical results. Table 3 reports the empirical results with CGTFP as the explained variable. Columns (1) and (2) indicate the regression results with or without control variables, respectively. The results have shown that the construction of PFTZ has improved urban GTFP at the significance level of 1%.

Excluding other policy interference

According to the existing literature (Qiu et al., 2021; Fan et al., 2022; Jiang et al., 2021a, b, c; Liu and Xin, 2019a, b), many policies affect regional GTFP, such as low-carbon pilot cities, construction of the ecological civilized pilot cities, innovative cities, and the Belt and Road Initiative. Therefore, we conclude that these policies may influence the effect of the significant promotion of the construction of PFTZ on urban GTFP. Furthermore, we added dummy variables¹ of these policies into the model as control variables and conducted the same regression with the initial model to control such interference and further improve the robustness of the empirical results. Table 4 presents the regression results with excluding other policy interference. Columns (1)–(4) give the experimental results considering the above four kinds of policy interference. The results revealed that after excluding the effects of pilot low-carbon cities, construction of the eco-civilized cities, innovative cities, and the Belt and Road Initiative, the construction of PFTZ had a significant promotion effect on urban GTFP, further verifying the robustness of the baseline regression result. Regarding the size of the interaction coefficients, the interaction coefficients of regression

results after policy interference were less than those of the baseline regression result. Thus, we can conclude that other policies can interfere in the promotion effect of the construction of PFTZ on urban GTFP and that other policy interference should be considered in the experimental result. Among the four policies, the Belt and Road Initiative had the most significant effect on the experimental result, providing realistic support for exploring the connected effect between the initiative and the promotion effect of the construction of PFTZ on urban GTFP in the following parts.

PSM-DID

Considering the construction of PFTZ is a strategic decision at the national level, there may be a problem of subjective choice of location for the FTZ. Thus, there may be a problem of selection bias in using the establishment of PFTZ as a quasi-natural experiment. We used the PSM–DID method of nearest neighbor matching with a caliper 1:1 to conduct further robustness analysis to tackle sample selection bias and the endogenous problem of policies. Table 5 presents the regression results using the PSM–DID method. Columns (1) and (2) indicate the regression results with or without control variables, respectively. The construction of PFTZ significantly improved urban GTFP regardless of the presence or absence of control variables. This result indicated no obvious selection bias in the establishment of PFTZ. The baseline results are valid. Fig. 4 indicates the effect of propensity score matching. Most of the sample data after matching gathered around 0, indicating a good PSM effect and a robust experimental conclusion.

Shortening the sample interval and winsorizing the data

In addition to considering the universality of constructing the explained variable index, other policy interference, and potential selection bias of the model, the other unconsidered policy interference due to the extremes of data itself and the excessively long sample interval may also affect the empirical results. Accordingly, all variables were further processed

¹ The policy dummy variable herein refers to the grouped dummy variables of policies and the interaction terms of policy point dummy variable.

Table 5 Robustness tests: PSM–DID

Variables	(1)	(2)
	GTFP	GTFP
Treat×Post	0.290*** (9.08)	0.238*** (7.31)
Control variables		Yes
Year fixed effects	Yes	Yes
City fixed effects	Yes	Yes
Constant	0.996*** (78.37)	−0.170 (−0.59)
<i>N</i>	3,567	3,567
<i>R</i> ²	0.413	0.466

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

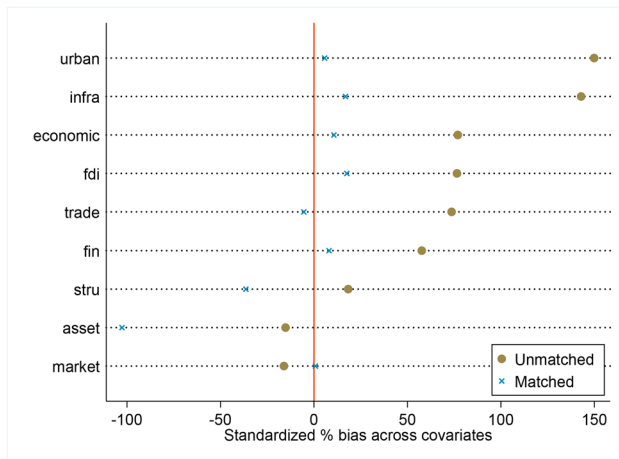


Fig. 4 Effect of propensity score matching

by extreme winsorization of 1% above and below and by shortening sample interval in addition to the policy dummy variable. The regression results are shown in Table 6. The results indicated that the construction of PFTZ significantly improved urban GTFP regardless of data winsorization or sample interval shortening.

Table 6 Robustness test: winsorizing data and shortening sample interval.

Variables	(1)	(2)	(1)	(2)
	Shortening sample interval		Winsorizing data	
	GTFP	GTFP	GTFP	GTFP
Treat×Post	0.235*** (6.70)	0.215*** (5.96)	0.290*** (9.08)	0.238*** (7.31)
Control variables		Yes		Yes
Year fixed effects	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Constant	1.250*** (102.51)	0.628 (1.23)	0.996*** (78.37)	−0.170 (−0.59)
<i>N</i>	2,232	2,232	4,185	4,185
<i>R</i> ²	0.177	0.234	0.413	0.466

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

Heterogeneity analysis

Dynamic heterogeneity

China’s PFTZ establishment is characterized by a development mode of point, line, and surface in different waves. Since the first wave of PFTZ was set up in Shanghai in 2013, the second wave of PFTZ was set up in Guangdong, Fujian, and Tianjin in 2015 successively. In 2017, the third wave of PFTZ was set up in Shannxi, Liaoning, Zhejiang, Henan, Sichuan, Chongqing and Hubei, gradually forming a dynamic grid pattern. We further analyzed the effect of the construction of the first, second, and third waves of PFTZ on urban GTFP. Table 7 presents the promotion effect of different waves of PFTZ on The three waves of PFTZ construction significantly improved urban GTFP. From the perspective of heterogeneity, the promotion effects of the first, second, and third waves of PFTZ on GTFP decreased gradually, indicating a time lag in the promotion effect of PFTZ construction on GTFP.

Regional heterogeneity

Certain differences exist in the regional economic development in China (Qi et al., 2013), indicating a stepped development trend from the eastern coastal land to the western inland. China’s PFTZ has spread across the east, central, and west economic zones. Among the 22 cities with PFTZ, 11 cities are located in the eastern coastal land, 6 cities are located in central regions, and the remaining 5 cities are located in western regions. We evaluated the effect of this policy on the eastern, central, and western PFTZ to further explore the regional heterogeneity of the promotion effect of PFTZ construction on GTFP. The results are presented in Table 8. The promotion effect of PFTZ construction on GTFP increased gradually from western to eastern China, which may be caused by the substantial achievements of China’s Central Rise and Western Development strategies. In

Table 7 Dynamic heterogeneity analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	1st wave		2nd wave		3rd wave	
	GTFP		GTFP		GTFP	
Treat×Post	0.598*** (5.09)	0.497*** (4.18)	0.136*** (5.08)	0.099*** (3.53)	0.108*** (7.16)	0.101*** (6.52)
Control variables		Yes		Yes		Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.997*** (72.01)	0.149 (0.50)	0.997*** (72.83)	0.160 (0.54)	0.995*** (73.46)	0.012 (0.04)
<i>N</i>	3,870	3,870	3,945	3,945	4,080	4,080
<i>R</i> ²	0.374	0.418	0.377	0.421	0.386	0.427

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

Table 8 Regional heterogeneity.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Eastern		Central		Western	
Treat×Post	0.278*** (6.55)	0.211*** (4.79)	0.340*** (4.86)	0.315*** (4.52)	0.456*** (5.95)	0.476*** (5.52)
Control variables		Yes		Yes		Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.997*** (73.75)	0.264 (0.89)	0.996*** (72.59)	0.066 (0.22)	0.995*** (71.93)	0.086 (0.29)
<i>N</i>	4,020	4,020	3,945	3,945	3,930	3,930
<i>R</i> ²	0.383	0.428	0.377	0.418	0.377	0.421

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

addition, the two regions increasingly focused on constructing ecological civilization while promoting the economy.

Heterogeneity of environmental concerns

Over the past few years, China has attached more significance to environmental construction in its economic development. However, different efforts toward environmental implementation have been made in different areas (Zhao et al., 2020a, b). It is of practical significance to explore the heterogeneity of PFTZ with different environmental concerns on urban GTFP. Therefore, eco-friendly and non-eco-friendly PFTZ were differentiated according to whether they were low-carbon and eco-civilized cities at the same time. If a PFTZ city was a low-carbon city and an eco-civilized city at the same time, it was classified as an eco-friendly PFTZ; otherwise, it was a non-eco-friendly PFTZ. We further analyzed the promotion effect of such two types of PFTZ on GTFP growth. Table 9 presents the heterogeneity of the effect of PFTZ with different environmental concerns on GTFP. Columns (1) to (4) report the effect of eco-friendly and non-eco-friendly PFTZ on urban GTFP. The results revealed that the two types of PFTZ significantly improved urban GTFP, among which the promotion effect

of eco-friendly PFTZ was much higher than that of non-eco-friendly PFTZ. This finding indicates that we should focus more on ecological environment construction in the future PFTZ construction, highlighting economic and environmental effects.

Transmission mechanism analysis

The benchmark regression results in Table 2 show that the construction of the PFTZ significantly increased the urban GTFP. So, we want to explore the construction of the PFTZ through what transmission mechanisms affect the GTFP? To address this question, based on the transmission mechanism analysis and theoretical analysis of hypotheses, we introduced three intervening variables: scientific and technological innovation (*tech*), government intervention (*gov*), and human capital (*hc*). These variables were measured by the proportion of scientific and technological expenditure in the GDP of each city, the proportion of government financial expenditure in fiscal revenue, and the logarithm of total students at primary school, middle school, high school, colleges, and above, respectively. According to Cao et al. (2017), we construct the following econometric models to analyze the transmission mechanisms:

Table 9 Heterogeneity of environmental concerns

Variables	(1)	(2)	(3)	(4)
	Eco-friendly cities		Non-eco-friendly cities	
Treat×Post	0.357*** (8.47)	0.284*** (6.39)	0.265*** (4.99)	0.237*** (4.52)
Control variables		Yes		Yes
Year fixed effects	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Constant	0.995*** (73.28)	0.163 (0.55)	0.997*** (73.10)	0.089 (0.30)
<i>N</i>	4,050	4,050	3,990	3,990
<i>R</i> ²	0.393	0.437	0.375	0.417

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

Table 10 Transmission mechanism test

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	GTFP	tech	gov	hc	GTFP	GTFP	GTFP
Treat×Post	0.272*** (7.81)	0.146*** (4.24)	−0.033** (−2.42)	0.702*** (2.61)			
tech					0.042** (2.38)		
gov						−0.240*** (−5.33)	
hc							0.009*** (3.89)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.996*** (74.47)	−1.214*** (−4.14)	−0.090 (−0.78)	11.068*** (4.84)	0.231 (0.78)	0.159 (0.54)	0.083 (0.28)
<i>N</i>	4,185	4,185	4,185	4,185	4,185	4,185	4,185
<i>R</i> ²	0.398	0.288	0.381	0.303	0.442	0.446	0.444

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

$$GTFP_{it} = \alpha + \beta treat_i \times post_t + \gamma X_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (2)$$

$$M_{it} = \alpha + \varphi treat_i \times post_t + \gamma X_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (3)$$

$$GTFP_{it} = \alpha + \rho treat_i \times post_t + \theta M_{it} + \gamma X_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (4)$$

In Models (2) to (4), *M_{it}* denotes a set of intervening variables (scientific and technological innovation, government intervention, and human capital), and other variables are consistent with Model (1). Table 10 reports the empirical results of mechanism analysis, in which column (1) corresponds to the estimated results of Model (2); columns (2)–(4) are the estimated results based on Model (3), with scientific and technological innovation, government intervention, and human capital as explained variables; columns

(5)–(7) are the estimated results based on Model (4), with scientific and technological innovation, government intervention, and human capital as explanatory variables. When scientific and technological innovation, government intervention, and human capital served as explained variables, the construction of PFTZ improved urban scientific and technological innovation and human capital at the significance level of 1% and reduced government intervention at the significance level of 5%. When they were evaluated as explanatory variables, scientific and technological innovation and human capital significantly improved urban GTFP, while government intervention negatively affected GTFP.

The above empirical analyses indicate that PFTZ can significantly improve urban GTFP by enhancing scientific and technological innovation and human capital and reducing government intervention. Therefore, H2 is verified.

Further analysis: linkage effects

In the overall plan for setting up PFTZ, it has been clearly proposed to build PFTZ into an important hub and core area of “the 21st century Maritime Silk Road” as well as a new plateau of opening up and cooperation for countries and regions along the route. As an important platform for the Belt and Road Initiative, the PFTZ aims at building a more open world economy. The similarity between the two in terms of historical background and value function inevitably creates a linkage effect between the Belt and Road Initiative and the construction of the FTZ.

Accordingly, we further explored whether a connected effect existed between the construction of PFTZ and the Belt and Road Initiative in the improvement of GTFP. The specific model is as follows:

$$GTFP_{it} = \alpha + \beta treat_i \times post_t \times road_j + \gamma X_{it} + \mu_t + \sigma_i + \varepsilon_{it} \quad (5)$$

where $road_j$ denotes the identification variable of cities along the route. If it was a province and city along the Belt and Road², the $road_j$ equals 1; otherwise, its value is 0. Other variables are in accordance with Model (1).

Columns (1) and (2) in Table 11 describe the connected effect between the construction of PFTZ and the Belt and Road Initiative with and without control variables. The empirical results indicated a significant connected effect between the construction of PFTZ and the Belt and Road Initiative in the improvement of urban GTFP. By comparing the interaction coefficient ($treat_i \times post_t$) in Table 2 which is 0.272 and the triple interaction coefficient ($treat_i \times post_t \times road_j$) in Table 11 which is 0.336, we observed that the promotion effect of PFTZ construction on urban GTFP could be positively affected by the Belt and Road Initiative. In other words, in improving urban GTFP, a significant and positive connected effect exists between PFTZ policy and the Belt and Road Initiative. Therefore, H3 is verified.

Conclusions and policy suggestions

The construction of PFTZ is one of China’s major national strategies for high-quality economic development. Based on the data of 279 cities from 2004 to 2018, we used the DID method to evaluate the effect of PFTZ construction on urban

² The cities along the Belt and Road include Xi’an, Lanzhou, Xining, Chongqing, Chengdu, Zhengzhou, Wuhan, Changsha, Nanchang, Hefei, Shanghai, Tianjin, Ningbo, Zhoushan, Guangzhou, Shenzhen, Zhanjiang, Shantou, Qingdao, Yantai, Dalian, Fuzhou, Xiamen, Quanzhou, and Sanya. The data were obtained from the *Vision and Action of Jointly Building Silk Road Economic Belt and the 21st Century Maritime Silk Road* published in 2015.

Table 11 The linkage effect between PFTZ and the Belt and Road Initiative

Variables	(1)	(2)
$treat_i \times post_t \times road_j$	0.375*** (9.07)	0.336*** (7.86)
Control variables		Yes
Year fixed effects	Yes	Yes
City fixed effects	Yes	Yes
Constant	0.996*** (74.39)	0.128 (0.43)
N	4,185	4,185
R ²	0.413	0.466

***, **, and * indicate significance levels of 1%, 5%, and 10%. The numbers in parentheses are the *t*-value.

GTFP systematically. We further analyzed the connected effect between the construction of PFTZ and the Belt and Road Initiative. Our conclusions are as follows.

- (1) The construction of PFTZ significantly improves urban GTFP, which remains significantly valid after a series of robustness tests.
- (2) The promotion effect of the construction of PFTZ on urban GTFP is mainly by improving scientific and technological innovations level, reducing government intervention, and accumulating human capital.
- (3) The empirical results on regional heterogeneity manifest the achievements acquired in the implementation of western development and central rise strategies in China. Environmental heterogeneity indicates that the higher the environmental concern is in an area, the more obvious the facilitation effect of the construction of PFTZ on GTFP there, inspiring that we should focus more on the construction of an ecological environment in the process of economic development.
- (4) The further study indicates that a significant and positive connected effect exists between the construction of PFTZ and the Belt and Road Initiative in improving urban GTFP.

The following suggestions may be drawn from the conclusions:

Based on the domestic perspective, it is necessary to speed up the process of implementing various policies and accelerate the further release of the innovation dividends of the PFTZ construction system. Moreover, the eastern regions should consider the construction of ecological civilization in economic development and promote the coordinated development of the economic environment in the eastern region. In addition, the government should further support foreign investment, guide foreign investment into enterprises and regions with innovation potential to relieve their financing pressure, and create a healthy competitive environment for domestic and foreign enterprises to improve the level of science and technology innovation in the

PFTZ. Moreover, to optimize human capital structure, PFTZ should improve the regional education level and reduce the actions of improving government performance at the expense of the environment. The linkage effect between the construction of PFTZ and the “Belt and Road” Initiative enlightens us to consciously consider the synergy and complementarity between various types with the same policy objectives in the same period in the process of policy formulation and implementation and strengthen the cooperation between various policies to better implement the common policy objectives.

Furthermore, from the perspective of the severe international situation, facts like the COVID-19 epidemic sweeping the world, the rise of economic counter-globalization, the local military conflicts, and the global economic uncertainty have increased (Sharif et al., 2020a, b; Işık et al., 2020). Under the current situation, it is necessary to implement the new concept of dual circulation, and PFTZ is supposed to play a bridge role in communicating the internal and external cycles. On the one hand, PFTZ should further streamline administration and delegate power, cancel the cumbersome administrative approval system, build a good business environment, and promote the development of the domestic economic cycle. On the other hand, considering the relatively stable epidemic situation in China, PFTZ should play an active role as a capital refuge and improve the openness of foreign investment through policy means attracting a large number of foreign capital and foreign-funded enterprises, further stimulating the domestic economic cycle. And in terms of trade, considering the severe epidemic situation, PFTZ can actively explore new trade methods to encourage and support the development of the cross-border e-commerce industry, seize the online foreign trade market share, and further expand the opening up of foreign trade. Ultimately, it will promote the integration of domestic and foreign trade and the development of domestic and international dual cycles.

Based on the international perspective, in recent years, the construction of China’s PFTZ has achieved remarkable results, which has effectively promoted the sustainable and high-quality development of China’s economy. Behind these remarkable achievements, other countries also have some excellent experiences worth learning, especially emerging economies with similar national conditions to China. Firstly, as the externalization of China’s institutional innovation, the construction of PFTZ is a good case for the construction of PFTZ or the expansion of opening up in other countries. A series of institutional innovation policies such as single window, pre-establishment national treatment, first-line liberalization, second-line control, and allowing cross-border RMB handling were adopted to achieve investment liberalization, trade liberalization, financial liberalization, and transformation of government functions. Secondly, the pilot construction of China’s PFTZ is a creative development model in China, that is, by giving priority to selecting some regions for

policy-oriented pilots, learning from successful experiences, and summarizing the lessons of failure after the success of the pilot to further expand the pilot and ultimately achieve overall development. This combination of dots and lines is also worth learning for other countries.

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