The Influence of Cities' Synchronization on Total Factor Productive: Based on the Panel Data of 21 Cities in Guangdong

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Abstract. In the context of Guangzhou and Foshan synchronization, this paper analyzes the impact of cities' synchronization on total factor productive with difference in differences model based on the panel data of 21 cities in Guangdong from 2000 to 2016. For further analyzing the source of cities' synchronization effect, the total factor productive is decomposed into technology progress and technology efficiency. The results show that the cities' synchronization of Guangzhou and Foshan can significantly improve their own total factor productive through the contributions of technology progress and technology efficiency. The other factors, such as Innovation investment, foreign direct investment, road infrastructure, have different types of influence on total factor productive. Moreover, total factor productive and technique progress of Guangdong province get improvements from 2001 to 2016, while technique efficiency, by contrast, is declining.

Keywords: Cities' synchronization · total factor productive · Guangzhou-Foshan integration · technique progress · technique efficiency

1 Introduction

In 2009, Guangzhou and Foshan signed the "Guangzhou-Foshan Synchronization Construction & Cooperation Framework Agreement" as well as four docking agreements on urban planning, transportation infrastructure, industrial collaboration, and environmental protection, making them the only two cities in Guangdong Province to do so. The goal of the Guangzhou-Foshan synchronization is to break down the boundaries between the two economic administrative divisions in order to optimize resource allocation, industrial collaboration, and innovation in the region. The purpose of this paper is to determine whether and to what extent cities' synchronization can improve resource allocation efficiency. The Guangzhou-Foshan synchronization impact study is useful for other Chinese cities in developing urban integration and performing the driving function of the Guangzhou-Foshan pole in the creation of the Guangdong-Hong Kong-Macao Greater Bay Area.

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2 An Overview of Cities' Synchronization and Total Factor Productivity

2.1 Cities' Synchronization

Cities' synchronization is a regional economic development strategy in which cities that are geographically and geographically interdependent and complementary gradually dilute their administrative boundaries for common development interests, achieving shared policies and facilities, coordinated industrial development, and mutual market integration, and ultimately promoting win-win urban economic development and improving overall competitiveness. Appropriate development stages, geographic proximity, different resource advantages, complementary industrial structures, unified market systems, and the same cultural history are all prerequisites for cities' synchronization, as is a mechanism to achieve a high degree of coordination and unity among cities through the common allocation of economic factors. Cities' synchronization is a more feasible, relevant, and operational option than urban integration, and it is the first step in the development of a metropolitan economic circle.

The extant literature on cities' synchronization investigates the conditions and construction contents of cities' synchronization, spatial structure planning, cities' synchronization development models, cities' synchronization governance and cross-border control studies, transportation planning, and so on. Cities' synchronization aims to break down traditional administrative barriers and protectionism between cities, leveraging the complementarity of production factors and economic and technological levels, achieving resource sharing and integrated collaboration, promoting integrated development, and improving city and regional competitiveness. However, given the diversity of governance objectives and realistic resource constraints among city governments, as well as the existence of industrial and resource competition within cities, an empirical evaluation of the results of cities' synchronization is required to determine whether it has truly transformed cities from competition to cooperation and competition.

According to a study of the literature, quantitative research on the effects of urbanization have primarily concentrated on two aspects: (1) a method of determining the degree of urbanization. The index of urbanization was computed based on the notion of urbanization in terms of the strength of economic links between cities, industrial integration, market integration, and infrastructural integration by Hao and Qiu [6]. To calculate the cities' synchronization index from the standpoint of travel expenses, Li and Wang [10] used a questionnaire. He [7] used Point of Interest (POI) data to assess the degree of cities' synchronization in terms of spatial agglomeration and integration. (2) Measurements of the cities' synchronization effect. The coordination index was utilized by Liu and Yang [11], Zhang and Li [21] to quantify the influence of cities' synchronization on the optimization of industrial restructuring, respectively. The agglomeration effect, diffusion effect, welfare effect, and brand effect caused by cities' synchronization were studied by Yi and Huang [20]. Huang [8] divided co-effects location's into four categories: regional economic growth, industrial agglomeration and diffusion, regional innovation, and regional branding, as well as creating a cities' synchronization development evaluation index system. The spatial influence of Nanjing-Zhen-Yang cities' synchronization on Nanjing in the Yangtze River Delta city cluster is investigated by Ma and Yao [17].

The ultimate purpose of cities' synchronization is to create a single market for production factors and goods, as well as to improve the area economy's overall competitiveness. Cities' synchronization, from the standpoint of factor resources, is a way to improve resource allocation efficiency through resource sharing and integration, hence contributing to high-quality economic growth. However, empirical examination of the economic effects of cities' synchronization, particularly the influence of cities' synchronization on resource allocation efficiency, is still lacking. The impact of cities' synchronization on resource factor allocation efficiency is investigated in this research, and total factor productivity is employed as a measure of resource allocation efficiency, which has also been proven to be substantially connected with economic development.

2.2 Total Factor Productivity

Solow [18] proposed the Total Factor Productivity (TFP), which divides output growth into two parts: input growth and residual value increase. TFP was initially calculated using the Cobb-Douglas production function.

$$Y = Af(L, C) = AL^{\alpha}C^{\beta}$$

where A is a parameter related to the level of technology and assuming $\alpha + \beta = 1$, i.e., constant economies of scale, that national income Y is distributed only between the amount of capital input C and the amount of labour input L, three main sources of national income growth $\frac{\Delta Y}{Y}$ are deduced:

$$\frac{\Delta Y}{Y} = \frac{\Delta A}{A} + \alpha \times \frac{\Delta L}{L} + (1 - \alpha) \times \frac{\Delta C}{C} \tag{1}$$

where $\frac{\Delta L}{L}$ is the growth rate of labor factor input, $\frac{\Delta C}{C}$ is the growth rate of capital factor input, α and $1 - \alpha$ are the share of labor factor and capital factor in the national income distribution, respectively, and $\frac{\Delta A}{A}$ is the part of national income growth that is brought by subtracting the growth of labor factor and capital factor input, i.e. total factor productivity growth.

With the widespread use of panel data, TFP measurement methods have been expanded and the main methods used include data envelopment analysis (DEA) and stochastic frontier analysis (SFA). Tian [19] found that DEA is a more applicable TFP measure based on macro sub-industry panel data, while number of employed persons should be selected as the indicator of labor input.

Du and Xu [2] presented four important elements affecting total factor productivity, including R&D innovation, human capital, institutional system, and government governance, in his research on the main influencing factors of TFP.

Transportation infrastructure has a large beneficial impact on total factor productivity in China, with highway and secondary road infrastructure having the most significant driving effect [12]. Jiang [9] proposed four main factors, namely the indicator of technological progress, the indicator of economic system reform, the variable of external opening, and the indicator of infrastructure construction, which together could explain 85.92% of the factors influencing total factor productivity in China.

The signing of the Guangzhou-Foshan Cities' synchronization Agreement established a contractual basis for the government's coordination of policies and development plans, resulting in an institutionalized collaboration model and process that will play a positive and significant role in promoting infrastructure development, R&D resource allocation, personnel mobility, and the promotion of exchanges and cooperation between enterprise organizations, thereby improving productivity. Through a quantitative analysis of a difference in difference model, this study examines whether the cities' synchronization of Guangzhou and Foshan cities has an impact on total factor productivity using panel data from 21 cities in Guangdong Province from 2000 to 2016.

3 Study Design

3.1 Model Design

DID (Difference in Differences) is a method borrowed from natural science studies and used in economics to explicitly examine the effects of policy. By combining "before and after differences" and "with and without differences," as well as adding other control variables to further control for certain "noisy" influences in the experimental and control groups, DID is used to control for the effects of certain factors other than intervention factors. This research proposes to utilize a DID model to investigate the influence of homogeneity on total factor productivity, the regression model is as follow:

$$TFP_{it} = \beta_0 + \beta_1 w_{it} + \beta_2 t_{it} + \beta_3 w_{it} \times t_{it} + X_{it} + \mu_i + \varepsilon_{it} \tag{2}$$

The explanatory variable TFP_{it} indicates total factor productivity for each region in each period, with i representing region and t year. w_{it} stands for the regional dummy variable, which is set to 1 if the city is co-located and 0 otherwise. The time dummy variable t_{it} has a value of 0 before the cities' synchronization agreement is signed and 1 once it is signed. $w_{it} \times t_{it}$ denotes the estimate of the different in difference between the cross product term of the regional dummy variable and the time dummy variable, whose coefficients β_3 denote the effect of cities' synchronization on total factor productivity; X_{it} denotes other control variables, which are other factors that affect the dependent variable; μ_i denotes fixed effects for each municipality, which denote differences in the individual municipalities themselves that do not vary over time; and ε_{it} denotes the random disturbance.

Six variables are chosen as control variables X_{it} that influence TFP_{it}, based on Jiang [9] and other scholars' research on the factors that influence China's total factor productivity: employment in the non-state economy (*NSE*), real utilized foreign capital (*FDI*), total value of imports and exports (*IO*), R&D investment (*RDR*), number of internet subscribers (*IU*), and road mileage (*ROAD*). The China Economic Database, a sub-database of the CEIC Macroeconomic Database, provides information on fiscal expenditure, real utilized foreign investment, total value of imports and exports, number of internet broadband subscribers, and road mileage. With relevant data from the Guangdong Statistical Yearbook and statistical yearbooks of various cities, the number of people employed in the non-state economy (*NSE*) is expressed in terms of private and individual employees, and R&D investment (*RDR*) is used as a proxy indicator for research and experimental development expenditure of large and medium-sized industrial enterprises.

In the study of Cheng and Lu [1], total factor productivity TFP was calculated by using the method of converting the Malmquist productivity change index into TFP, i.e., assuming that TFP = 1 for city i in base year t, TFP for year t + 1 is equal to TFP for year t multiplied by the Malmquist productivity change index for year t + 1, i.e. $TFP_{i(t+1)} = TFP_{it} \times Malmquist_{i(t+1)}$, and so on. This is calculated using the DEAP 2.1, based on the constant returns and input-oriented Malmquist-DEA model, with output (Y), labor input (L), and fixed capital stock (C) as input for each city in each year. With the relevant data obtained from the Guangdong Statistical Yearbook, output (Y) is expressed in terms of regional GDP (*GDP*), labor input (L) is expressed in terms of the number of employees in society at the end of the year (*LAB*), and fixed capital stock (C) is a proxy for the amount of investment in fixed assets in society (*INV*).

The Malmquist productivity change index may be divided into the product of the technical efficiency change index and the rate of technological progress index under the premise that the scale effect of production technology is constant. A technical efficiency index of greater than 1 indicates an increase in technical efficiency from period t to period t + 1, a technical efficiency index of less than 1 indicates a decrease in technical efficiency, and a technical efficiency index of equal to 1 indicates no change in technical efficiency. A rate of technical progress index of greater than 1 indicates technological advancement, less than 1 indicates technological regression, and 1 indicates no change in technology. To put it another way, total factor productivity can be broken down into two components: technical advancement (*TC*) and technical efficiency (*EC*), which are computed in the same way as total factor productivity. This paper further investigates whether the effect of cohabitation on TFP is due to an improvement in technical efficiency, a facilitation of technical progress or both, and develops the corresponding regression model as follows.

$$TC_{it} = \beta_0 + \beta_1 w_{it} + \beta_2 t_{it} + \beta_3 w_{it} \times t_{it} + X_{it} + \mu_i + \varepsilon_{it} \tag{3}$$

$$EC_{it} = \beta_0 + \beta_1 w_{it} + \beta_2 t_{it} + \beta_3 w_{it} \times t_{it} + X_{it} + \mu_i + \varepsilon_{it} \tag{4}$$

3.2 Sample Selection and Descriptive Statistics

The co-located cities analyzed in this research, Guangzhou and Foshan, are both located in Guangdong. The remaining 19 cities in Guangdong province were chosen as the control group for comparison, in addition to Guangzhou and Foshan. Because the Framework Agreement on Deepening Cooperation among Guangdong, Hong Kong, and Macao to Promote the Construction of the Greater Bay Area was officially signed in 2017, this major policy change will have a significant impact on the cities in the Greater Bay Area, including Guangzhou and Foshan, interfering with the study of the cities' synchronization effect. The model variables were chosen as 2001–2016 as the sample period to better focus the investigation of the cities' synchronization effect of Guangzhou-Foshan cities' synchronization and to maintain the balance of time. Due to the base period of computing

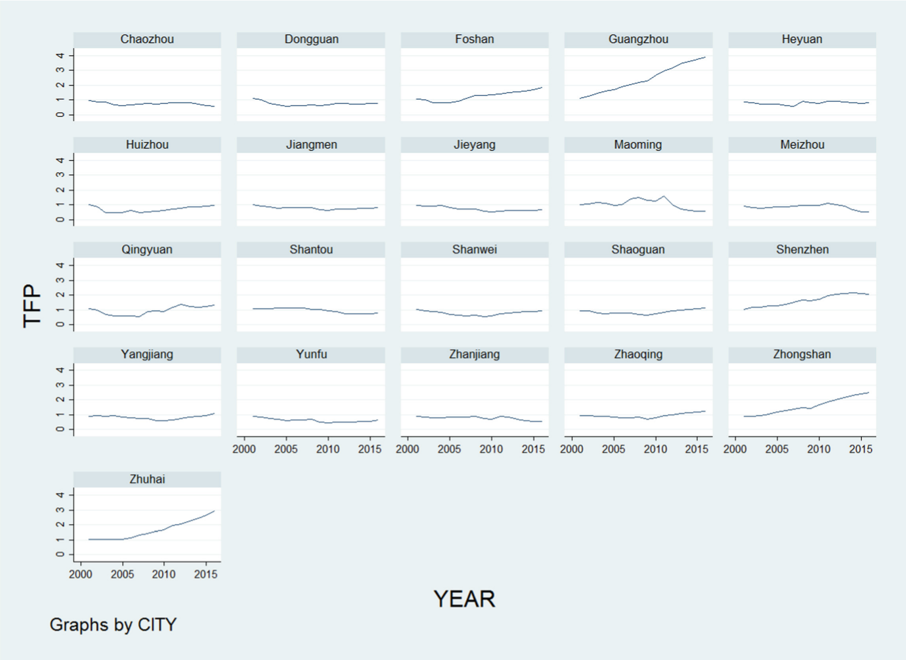

Fig. 1. TFP for Guangdong 21 cities (2001–2016).

Table 1. Descriptive statistics of variables.

Abbr of variable	Variable	Unit	Average	Standard deviation	Minimum	Maximum	Number of samples
GDP	Gross local product	billion	2057.34	3226.67	97.28	19547.44	336
LAB	Employees	10,000 people	259.29	173.56	81.80	926.38	336
INV	Total fixed asset investment	billion	683.56	841.94	33.80	5703.59	336
TFP	Total Factor Productivity	–	1.03	0.54	0.45	3.88	336
TC	Technological advances	–	0.99	0.27	0.61	2.29	336
EC	Technical efficiency	–	1.03	0.33	0.45	1.80	336

(*continued*)

Table 1. (*continued*)

Abbr of variable	Variable	Unit	Average	Standard deviation	Minimum	Maximum	Number of samples
w	Regional factors	–	0.10	0.29	0	1	336
t	Time factors	–	0.50	0.50	0	1	336
$w \times t$	Cities' synchronization factor	–	0.05	0.21	0	1	336
NSE	Employment in the non-state section	10,000 people	593.39	839.02	-978.08	4701.46	336
FDI	Actual utilization of foreign capital	billion	64.15	89.21	1.33	467.02	336
IO	Total value of imports and exports	billion	2181.10	4919.51	13.08	32737.03	336
RDR	R&D input	billion	31.77	87.00	0.01	760.03	336
IU	Number of Internet users	Thousands of households	782.92	1122.26	0.24	7660.00	336
ROAD	Number of road miles	km	8030.55	5545.43	983.00	24803.91	336

TFP, which requires the year 2000 as the base period of 2001, the Malmquist Productivity Change Index is derived using the years 2000–2016 as the sample period. The sample data are mainly obtained from the CEIC Macroeconomic Database, Guangdong Statistical Yearbook and statistical yearbooks of various cities in Guangdong, where missing data in the number of people employed in the non-state economy (*NSE*), number of Internet users (*IU*) were obtained by interpolation extrapolation. Foreign direct investment and total imports and exports were converted from US dollar to RMB at year-end prices published by the People's Bank of China each year. Figure 1 shows total factor productivity TFP by year for each municipality, with statistical descriptions of the variables listed in Table 1.

4 Analysis of Empirical Results

4.1 Univariate Analysis

Univariate analysis was first conducted to gain a preliminary understanding of the effect of the Guangzhou-Foshan cities' synchronization, and the results are presented in Table 2.

Total factor productivity (TFP) changes before and after the Guangzhou-Foshan cities' synchronization. Before Guangzhou-Foshan cities' synchronization, the difference in TFP between the control and treatment groups was 0.891 and 1.308, respectively, with a difference of 0.417 and significant at the 1% level, showing that the control group's TFP was slightly lower than the treatment group's before Guangzhou-Foshan cities' synchronization. The TFP in the control and treatment groups after cities' synchronization were 1.009 and 2.368, respectively, with a difference of 1.359, and their values were significant at the 1% level. TFP grew in both the control and treatment groups over time, with the treatment group's growth being slightly faster than the control group's. A difference in difference score of 0.942 was obtained for TFP by subtracting the difference between the two groups after Guangzhou-Foshan cities' synchronization from the difference between the two groups before Guangzhou-Foshan cities' synchronization, which was significant at the 1% level, indicating that TFP increased significantly after Guangzhou-Foshan cities' synchronization.

Changes in technological advancement (TC). Before Guangzhou-Foshan cities' synchronization, the TCs of the control and treatment groups were 0.832 and 0.967, respectively, with a difference of 0.135, and their values were significant at the 5% level. The difference between the control and treatment groups after Guangzhou-Foshan cities' synchronization was 0.445 1.099 and 1.544, respectively, and their values were significant at the 1% level. A difference in difference value of 0.31 was obtained for TC by subtracting the difference between the two groups after Guangzhou-Foshan cities'

Table 2. Univariate analysis.

	Before			After			DID value
	Control group	*Treatment group*	*Difference*	*Control group*	*Treatment group*	*Difference*	*Diff-in-Diff*
TFP	0.891	1.308	0.417	1.009	2.368	1.359	0.942
S.D.	–	–	0.116	–	–	0.116	0.165
P-value	–	–	0	–	–	0	0
TC	0.832	0.967	0.135	1.099	1.544	0.445	0.310
S.D.	–	–	0.055	–	–	0.055	0.078
P-value	–	–	0.015	–	–	0	0
EC	1.084	1.348	0.264	0.895	1.491	0.595	0.331
S.D.	–	–	0.077	–	–	0.077	0.108
P-value	–	–	0.001	–	–	0	0.002

synchronization from the difference between the two groups before Guangzhou-Foshan cities' synchronization, which was significant at the percent level, indicating that there was a boosting effect on TC for technological progress after Guangzhou-Foshan cities' synchronization.

Changes in technical efficiency (EC). Before Guangzhou-Foshan cities' synchronization, the EC of the control and treatment groups were 1.084 and 1.348, respectively, with a difference of 0.264 at the 1% level of significance. After Guangzhou-Foshan cities' synchronization, the EC of the control and treatment groups were 0.895 and 1.491, respectively, which were significant at the 1% level, with a decline in the control group. After deriving the difference between the two groups after Guangzhou-Foshan cities' synchronization from the difference between the two groups before Guangzhou-Foshan cities' synchronization, a difference in difference value of 0.331 for EC was acquired, which was significant at the 1% level, indicating that technical efficiency EC increased after Guangzhou-Foshan cities' synchronization.

4.2 Model Regression Analysis

4.2.1. Impact on Total Factor Productivity TFP

Using stata14.0, the impact of the Guangzhou-Foshan cities' synchronization effect on total factor productivity (TFP) was calculated by adding *NSE*, *RDR*, *ROAD*, *FDI*, *IO*, *IU* in turn. The variables pass the unit root LLC test. And the variables' logarithms are used to decrease volatility. The model 1-model17 in Table 3 gives the regression results for a sample of 21 cities in Guangdong Province. The time factor t was significantly positive at the 1% statistical level before any control variables were included. After gradually adding control variables, the significance level of the time factor tended to decline, but it was still positive and significant at the 10% statistical level. It shows that the total factor productivity TFP of cities in Guangdong Province tends to rise over time, which is consistent with the analysis of the total factor productivity development trend in Guangdong Province from 1990 to 2016 [13].

The region factor w is significantly positive at the 1% significance level without the control factors. It remains positive and stable at the 1% significance level after the control variables are included. When the influence of Guangzhou-Foshan cities' synchronization is removed, the treatment group's total factor productivity TFP is higher than the control group's, which is consistent with Guangzhou and Foshan's economic status as the first and third largest cities in Guangdong Province.

The cross-products of the time and area factors $w \times t$ is stable and significantly positive at the 1% level both before and after the addition of the control variables, indicating that the Guangzhou-Foshan cities' synchronization significantly increases total factor productivity in the treatment cities. The addition of the control variables has no significant effect on this value, which is very close to the difference- in –difference value in the univariate analysis. Increases or decreases in the control variables had no effect on the stability of the findings.

In the other control variables, the most significant effect on total factor productivity TFP is R&D investment, which is significantly positive at the 5% level. Increased R&D investment, particularly in large and medium-sized industrial enterprises, helps to

Table 3. Impact of cities' synchronization on total factor productivity.

Explanatory variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	0.118*** (0.029)	0.163*** (0.041)	0.098** (0.047)	0.083* (0.046)	0.082* (0.047)	0.087* (0.048)	0.096* (0.048)
w	1.122*** (0.141)	1.274*** (0.151)	1.249*** (0.149)	1.214*** (0.153)	1.216*** (0.153)	1.195*** (0.153)	1.228*** (0.15)
$w \times t$	0.941*** (0.154)	0.915*** (0.159)	0.929*** (0.157)	0.935*** (0.156)	0.938*** (0.158)	0.94*** (0.158)	0.936*** (0.157)
$\ln NSE$		−0.03 (0.029)	−0.045 (0.03)	−0.059* (0.338)	−0.059* (0.034)	−0.054 (0.034)	−0.054 (0.034)
$\ln RDR$			0.033** (0.014)	0.029** (0.014)	0.03** (0.013)	0.031** (0.013)	0.036** (0.146)
$\ln ROAD$				0.081 (0.068)	0.079 (0.067)	0.09 (0.073)	0.104 (0.076)
$\ln FDI$					−0.009 (0.039)	−0.009 (0.038)	−0.015 (0.039)
$\ln IO$						−0.019 (0.041)	−0.0002 (0.044)
$\ln IU$							−0.032 (0.029)
N	336	329	329	329	329	329	329
R2	0.752	0.758	0.76	0.76	0.76	0.76	0.76

Note: 1. Values in brackets are standard deviations; 2. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively; 3. All individual fixed models were employed; 4. All models considered heteroscedasticity, and robust standard errors were used for statistical inference

increase the regional level of total factor productivity, which is consistent with the prior findings [3]. In models 4 and 5, the effect of non-state economy employment on total factor productivity is negative and significant at the 10% statistical level, but insignificant in the other models. The effect of road mileage on total factor productivity is positive but minor, implying that urban transportation expansion has a catalytic influence on total factor productivity to some extent. The driving effect of highway and secondary road infrastructure on TFP is most obvious in the study by Liu and Wu [12], with the effect of highways being persistent and other classes of roads not exhibiting consistent significance. The utilization of foreign capital, as well as import and export, had a negative but not significant impact on TFP. The findings of Liu [15] reveal that foreign direct investment boosts TFP in the short term but erodes it in the long run, implying that there is a long-term causal relationship between TFP decline and foreign direct investment. Using Guangdong Province as an example, Liao and Wang [13] discovered that the marginal effects of FDI, imports, and exports on TFP were declining, and the interval of positive effects of both on TFP was shrinking. The number of internet users has a negative but insignificant effect on TFP. Guo and Luo [5] found that the internet has a significant facilitating effect on China's technological progress and an inhibiting effect on China's technical efficiency. Therefore, the negative effect of this variable in the model could be due to the inhibiting effect on technical efficiency over the facilitating effect on technological progress, as supported by the subsequent model results in this paper.

4.2.2. Impact on Technological Advancement (TC)

After the gradual inclusion of control variables, Table 4 shows the results of the empirical investigation of the impact of the Guangzhou-Foshan cities' synchronization on technological progress.

The time factor t was significantly positive at the 1% level before the inclusion of control variables. It remained significantly positive at the 1% level after the inclusion of other control variables, indicating that there was a trend for technological progress to improve across Guangdong cities from 2001 to 2016.

The area factor w was stable and significantly positive at the 1% level both before and after the inclusion of the control variables, indicating that in the absence of the Guangzhou-Foshan cities' synchronization factor, the treatment group's technical progress was higher than the control group's.

Table 4. Impact of cities' synchronization on technological progress.

Explanatory variables	Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
t	0,.267*** (0.016)	0.299*** (0.023)	0.188*** (0.031)	0.165*** (0.031)	0.166*** (0.031)	0.162*** (0.032)	0.156*** (0.031)
w	0.473*** (0.067)	0.525*** (0.068)	0.482*** (0.066)	0.427*** (0.066)	0.422*** (0.066)	0.439*** (0.068)	0.419*** (0.069)
$w \times t$	0.309*** (0.081)	0.298*** (0.082)	0.323*** (0.795)	0.332*** (0.079)	0.325*** (0.079)	0.323*** (0.079)	0.325*** (0.079)
$\ln NSE$		−0.036** (0.017)	−0.062*** (0.017)	−0.084*** (0.018)	−0.085*** (0.018)	−0.089*** (0.018)	−0.089*** (0.018)
$\ln RDR$			0.056*** (0.104)	0.051*** (0.101)	0.051*** (0.01)	0.05*** (0.01)	0.046*** (0.01)
$\ln ROAD$				0.127*** (0.037)	0.132*** (0.037)	0.123*** (0.04)	0.114*** (0.04)
$\ln FDI$					0.02 (0.021)	0.02 (0.021)	0.02 (0.021)
$\ln IO$						0.016 (0.228)	0.004 (0.023)
$\ln IU$							0.019 (0.01)
N	336	329	329	329	329	329	329
R2	0.703	0.710	0.735	0.741	0.742	0.743	0.745

The cross-products of the time and area factors $w \times t$ remained stable and significantly positive at the 1% level both before and after the addition of the control variables, indicating that when the time and area factors were removed, cities' synchronization had a significant positive enhancing effect on the treatment group's technological progress, and that this finding remained stable with the addition of the control variables.

Other control variables that have a significant impact on technological progress include the number of people employed in the non-state economy, R&D investment, and road mileage. The number of people employed in the non-state economy is significantly negative at the 1% level, most likely because the non-state economy, while growing and expanding, is primarily composed of a large number of small and micro enterprises that are constrained by their own circumstances and lack the ability to invest in and contribute to the development of new technologies. R&D investment and road mileage are both significantly positive at the 1% level, indicating that R&D investment and infrastructure development, such as roads, can effectively promote technological progress. The impact of real utilized foreign investment, total value of imports and exports, and the number of internet users on technological progress are positive but not significant.

4.2.3. Impact on Technical Efficiency (EC)

The Table 5 presents the results of the empirical analysis of the impact of Guangzhou-Foshan cities' synchronization on technical efficiency after the gradual addition of control variables.

Before the control variables were included, the time factor t was significantly negative at the 1% statistical level. After the control variables were gradually included, the time factor remained stable and significantly negative at the 1% level. It indicates a decreasing trend in technical efficiency in Guangdong Province between 2001 and 2016.

The area factor w was stable and significantly positive at the 1% level both before and after the inclusion of the control variables, indicating that the treatment group's technical efficiency was higher than the control group in the absence of the effect of the Guangzhou-Foshan cities' synchronization factor.

The cross-products of the time and area factors $w \times t$ remained stable at a significant positive level at the 1% level both before and after the addition of the control variables, indicating that when the time and area factors were removed, cities' synchronization had a significant positive effect on the technical efficiency of the treatment group, a finding that remained stable after the addition of the control variables.

After the gradual inclusion of the variables, the number of people employed in the non-state economy is significantly positive at the 5% level, indicating that the non-state economy contributes to technical efficiency. The technical efficiency of private enterprises in Guangdong Province in Fan [4]'s study is the highest among all ownership systems in the province, which supports the above model results to some extent. R&D investment, road mileage, real utilized foreign capital, total value of imports and exports, and internet user population all have a negative impact on technical efficiency. The effect of road mileage on technical efficiency is significantly negative, and its significance decreases with the inclusion of other control variables, which may be due to blind construction or over-construction in some cities, which do not effectively play the role of infrastructure and operate less efficiently. According to Li [16]'s findings, the effect of actual use of foreign capital on technical efficiency is negative and tends to increase

Table 5. Impact of cities' synchronization on technical efficiency

Explanatory variables	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21
t	−0.188*** (0.021)	−0.185*** (0.026)	−0.150*** (0.031)	−0.127*** (0.031)	−0.130*** (0.030)	−0.124*** (0.031)	−0.109*** (0.033)
w	0.575*** (0.091)	0.554*** (0.100)	0.567*** (0.101)	0.624*** (0.107)	0.639*** (0.108)	0.608*** (0.111)	0.660*** (0.108)
$w \times t$	0.331*** (0.071)	0.315*** (0.069)	0.307*** (0.070)	0.298*** (0.072)	0.321*** (0.074)	0.324*** (0.074)	0.318*** (0.071)
ln *NSE*		0.023 (0.023)	0.031 (0.025)	0.053** (0.026)	0.056** (0.026)	0.063** (0.027)	0.063** (0.026)
ln *RDR*			−0.018 (0.012)	−0.013 (0.011)	−0.010 (0.011)	−0.009 (0.010)	−0.001 (0.017)
ln *ROAD*				−0.129** (0.052)	−0.144** (0.052)	−0.127** (0.055)	−0.104* (0.057)
ln *FDI*					−0.066** (0.026)	−0.066** (0.026)	−0.076*** (0.026)
ln *IO*						−0.029 (0.034)	−0.001 (0.036)
ln *IU*							−0.051** (0.023)
N	336	329	329	329	329	329	329
R2	0.684	0.710	0.712	0.717	0.723	0.724	

in significance level. The effect of internet users on technical efficiency is significantly negative at the 5% level, confirming Guo and Luo [5]'s findings. R&D investment and gross import and export value have a negative but insignificant impact on technical efficiency.

5 Conclusion

As the Chinese economy develops, cities' synchronization will become a future trend in urban organization, contributing to synergistic development between cities. This article examines the impact of cities' synchronization on total factor productivity using a double difference model on data from 21 cities in Guangdong Province from 2001 to 2016, while breaking total factor productivity down into technical progress and technical efficiency to better understand its sources of influence. The article uses a difference in difference DID model to derive the following conclusions from the main factors affecting total factor productivity, such as R&D investment, road mileage, and real utilization of foreign capital.

First, cities' synchronization significantly increases total factor productivity in co-located cities, with the path of influence coming from both the promotion of technological progress and the enhancement of technological efficiency by cities' synchronization, with the weight of the influence of these two factors being close in magnitude. This implies that by shortening the spatial and temporal distances between neighboring cities, inter-city resources are integrated, economic ties are strengthened, resource mobility is improved for sharing, and the competitiveness of co-located cities is increased.

Second, total factor productivity in 21 cities in Guangdong Province increased overall from 2001 to 2016, and technological progress has similarly remained on an upward trend, but technical efficiency has tended to decline over the study period. Innovation and the promotion of technological development through increased R&D investment, improved infrastructure development, and the rational use of foreign investment have moved the production possibility frontier outwards, but the relatively slow diffusion and use of technology, as well as the mismatch of other resources, have caused the internal point of production possibility to move slower than the outward movement of the production possibility frontier, resulting in a decline in technical efficiency.

At the same time, research has shown that there is a reasonable range for the contribution of some resource inputs to total factor productivity. For example, a moderate intensity of R&D inputs can have a maximum contribution to total factor productivity, whereas too high or too low can weaken this effect. Some resource factors, such as foreign direct investment, total exports and imports, have a marginal impact on total factor productivity in the long run. Some factors have a 'double-edged' impact on total factor productivity, i.e. they can only contribute to one side of technological progress while inhibiting the other, such as internet use.

Cities' synchronization allows for the free flow of resources and the allocation of resources on a larger spatial scale. Because the impact of each resource factor on total factor productivity varies, cities' synchronization at a lower level can avoid the negative effects of cities' synchronization at a higher level, thereby increasing total factor productivity. However, administrative boundaries are still maintained, and cities remain independent decision-makers, so the impact of cities' synchronization is dependent on whether institutional design and systematic planning can facilitate the division of labor and complementary strengths to achieve the optimal allocation of resources.

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