RESEARCH ARTICLE

The impact of smart city pilots on corporate total factor productivity

Pengyu Chen[1]

Abstract

The existing literature on smart city pilots mainly focuses on the city level and rarely addresses the firm level. This paper assesses the impact of smart city pilot policy (SCP) on firms' total factor productivity (TFP) and explores the impact of SCP under different heterogeneities as well as the mechanisms of action of the SCP. The LP approach is used in this paper to measure firms' TFP, and the impact of SCP is analyzed by the DID model with firms' panel data from 2009 to 2019 as research objects. First, it was found that the SCP can significantly increase the TFP of firms (0.041). Second, through heterogeneity analysis, we found that SCP can strengthen the monopoly position of monopolistic firms and state-owned enterprises. Moreover, the SCP can also alleviate the development imbalance of TFP between firms in coastal and non-coastal areas. In addition, SCP can significantly improve TFP of heavy polluting enterprises. Finally, we find that the important ways for SCP to improve firms' TFP is increasing investment in technological innovation, talent agglomeration, attracting financing, improving resource allocation efficiency, and digital transformation. The study provides unique insights for policy makers and business managers in China and other emerging countries to enhance TFP and achieve corporate sustainable development.

Keywords The smart city pilot policy · Firms' total factor productivity · Heterogeneity · Mechanism analysis

Introduction

Since the twenty-first century, urbanization has led to high economic growth (Sun et al. 2022); however, this urban development model is largely dependent on industrialization (Lydon and Garcia 2015). Nevertheless, industrialization development brings various disadvantages, such as greenhouse gas emissions, shortage of public resources, traffic congestion, haze, and degradation of green spaces (Dong et al. 2019; Işik et al. 2017). With the awakening of public, media, and social awareness of environmental protection, green and high-quality living environment is demanded (Khan et al. 2020). In 2008, the International Business Machines Corporation (IBM) formally introduced the concept of "smart cities" to encourage countries around the world to adopt smart city policies that incorporate digitization, low carbon, ecology, and recycling into urban

management systems to achieve the goals of economic, social, and environmental sustainability.

Early researches on smart city mainly focused on the basic connotations and developed countries (Yigitcanlar and Kamruzzaman, 2018). For example, Zygiaris (2013) considers smart cities as a combination of green, connection, openness, integration, intelligence, and innovation. The cited authors examined smart cities such as Barcelona, Edinburgh, and Amsterdam in developed countries to assess the effectiveness of smart cities. However, as environmental problems become increasingly serious, urban environment governance in developing countries with crude economic development model has become a new concern (carbon reduction plans such as the Paris Climate Agreement and carbon trading pilots). Compared with developed countries, smart cities in developing countries were relatively built late and have poor infrastructure, leading to policy uncertainty. Therefore, there is value in exploring the practice of smart cities in developing countries. China released its first smart city pilot policy in 2012 to improve the efficiency of resource utilization, optimize urban management and services, and improve the quality of life of its citizens.

Some scholars have started to explore the impact of smart city policy using econometric methods and mostly focused

✉ Pengyu Chen
cpy702018@163.com

1 Department of Economics, College of Business and Economics, Dankook University, Yongin-si, South Korea

on the macro level, such as, innovation, carbon emissions (Guo et al. 2022), green total factor productivity (Wang et al. 2022), ecological total factor productivity (Dong et al. 2022), and environmental pollution (Xu and Yang 2022), but on the micro-firm level, effects have not yet been explored. On the one hand, firms are the medium that regulates the relationship between residents and the city, and changes in firms respond positively to the individual and city levels (Kim et al. 2019). Namely, firms are producers of product markets and providers of labor markets (Ulas 2007; McCollum and Findlay 2018), which can directly affect the economic situation of residents and the stability of economic markets. It can also indirectly increase government financial revenue (Bournakis and Mallick, 2018) and to conduct pollution control with these more revenue (Işık et al. 2021a; Ongan et al. 2022). On the other hand, many problems such as "urban diseases" are mainly due to industrialization (Xiao et al. 2006), such as traffic chaos and environmental degradation (Aziz et al. 2020; Sharif et al. 2020a); industrialization is responsible for 37% of greenhouse gas emissions and 80% of total energy consumption (Anwar et al. 2020). The emission of various pollutants not only deteriorates the living environment of the residents but also poses a threat to their health (Konteh 2009). In addition, companies continue to attract an influx of labor, which continues to exacerbate these problems (Cerna 2016). Total factor productivity (TFP) is one of the main indicators of sustainable development, and an increase in TFP means an optimization of internal structures and an increase in resource utilization ratio, which in turn will improve the economic and living environment of the city and its inhabitants (Zhang et al. 2020). Therefore, it is significant to study the impact of smart city pilot policies on the total factor productivity of enterprises.

China's smart city pilot is being pushed forward in four phases, and we regard this policy as a quasi-natural experiment. Constructed based on the China Stock Market and Accounting Research Database (CSMAR) and the City Statistics Yearbook for listed companies from 2009 to 2019, we use the difference in difference (DID) method, and the propensity score matching-difference in difference (PSM-DID) method accurately estimates the impacts of the policy. The potential contributions of this paper are as follows. (1) To our knowledge, there is no literature investigating the impact of SCP on firms' TFP. The TFP is measured using the LP method to avoid the problem of sample loss due to the OP method. (2) While most studies have examined city heterogeneity, this paper examines the effects of smart city policies under firm heterogeneity. Micro-firm-level data can give us insights in-depth into how policies change at the micro-level. It can provide more comprehensive information to policy makers and business managers. (3) The stability of the SCP is empirically verified through a variety of robustness tests. (4) The role of mechanisms at the micro-level is

further explored to test the Porter hypothesis and provide new evidence for the application of Porter's hypothesis in emerging developing countries.

The rest of the paper is presented below. The "Policy background and mechanisms analysis" section provides the policy background and the mechanisms analysis. The "Methods and data" section describes the methodology and sample. The "Empirical results" section presents the empirical results and discussion, and the "Conclusions, suggestions, and limitations" section provides conclusions, policy recommendations, and limitations.

Policy background and mechanisms analysis

Policy background

Since IBM proposed the concept of "smart cities" in 2008, developed countries in Europe and the USA have first put forward their own smart city policies. For example, in 2009, BYD and IBM established the first smart city in the USA, the UK launched the "Digital Britain" programs in 2009, Singapore launched the "Smart Nation 2015" programs in 2006, and South Korea proposed the "Smart Seoul 2015" programs in 2012. These programs aim to mitigate or curb environmental degradation through a series of complementary policies and maintain a low ecological footprint to achieve urban sustainable development (Işık et al. 2021b). Specifically, smart city construction is the integration of various resources through emerging technologies such as robotics, big data, artificial intelligence, the Internet of Things, and blockchain to achieve City 2.0 Innovation. China is a late developer in the area of building smart cities, having issued the first batch of 90 smart city pilots in 2012, among which there are 37 prefecture-level cities, 50 counties (districts), and 3 towns. The scope of smart cities was then gradually expanded in 2013 and 2014, with more and more cities in the central and western regions being approved as smart cities. By 2020, the number of smart city pilots reached 290.

Mechanism analysis

Innovation process

Innovation is an important tool for achieving sustainable development (Kadeev et al. 2020). Smart city construction affects the innovation process, including innovation inputs, outputs, human capital, and knowledge flows (Caragliu et al. 2013). Therefore, SCP increases the TFP of firms by changing the innovation process. First, smart cities are based on a variety of digital technologies that facilitate the information exchange between individuals, between organizations, and between organizations and individuals, reducing the cost of

information exploration and promoting innovation (Gupta and Bose 2019). Digital technologies facilitate knowledge sharing, reduce knowledge storage costs, and make knowledge flow more fluid (Lin et al. 2002). In addition, pilot cities focus on harmony between humanity and the natural environment, which means that pilot cities focus more on the use of clean energy, and the development of green technology (Vázquez et al. 2018; Chien et al. 2022). For example, Shahzad et al. (2021) took 29 developed countries from 1994 to 2018 as the research objects and found that environment-related technologies can promote renewable energy generation and thus reduce carbon emissions (Aziz et al. 2021; Işık et al.2019a; Sharif et al. 2021). At the same time, factors have a trend to move to regions with a better economic and political environment, according to the "vote with your feet" effect mechanism, and leading to an influx of skilled people and knowledge (Lööf and Heshmati 2002). Furthermore, as the knowledge bearers, technicians are the necessary human capital to achieve innovative outputs. Based on the above analysis, we propose that:

> H1: SCP has a positive impact on R&D inputs, innovation outputs, knowledge flows, and talent agglomeration, which in turn enhances TFP

Financing constraints

The pilot cities have well information platform so that information about the enterprises can be disclosed to society promptly. Based on signaling theory, as an external stakeholder of the enterprise, creditors will actively adjust their strategies under the change of access to enterprise information. In other words, the pilot city provides a perfect information release platform for enterprises, for stakeholders to understand the dynamic changes of enterprises on time, which can reduce the information asymmetry between enterprises and stakeholders (Chen et al. 2014). The inflow of social capital can reduce the burden of enterprises, which in turn can enhance TFP. For example, Sinha et al. (2021) mentions that the government can complement existing policies by implementing green financing channels to achieve sustainable development. Based on the above analysis, we propose that:

> H2: SCP reduces the financing constraint, thereby enhancing TFP

Resource allocation efficiency

Smart cities enable the development of green economies in cities by integrating resources from various sectors. On the one hand, the application of a large number of digital technologies can reduce the costs of enterprises, reduce the waste of non-essential resources, and increase the efficiency

of resource allocation (Caballero-Morales 2021). On the other hand, based on institutional theory, business managers will adjust their decisions to respond positively to external pressures (Weaver et al. 1999). In other words, to achieve the goals of a smart city, companies may be forced to transform and upgrade to cope with such pressures. In addition, higher resource allocation efficiency allows resources to be fully utilized and contributes to higher firm TFP (Cui et al. 2022). Based on the above analysis, we propose that:

> H3: SCP improves the resource allocation efficiency, thereby enhancing TFP

Corporate digital transformation

Smart cities imply the application and accumulation of a large number of new technologies. On the one hand, pilot cities use these technologies to accelerate smart cities for high-quality development (Selim et al. 2018). And enterprises will use these advantages as a basis for improving their digitalization processes and achievements (Kar et al. 2019), to improve corporate TFP (Tulchynska et al., 2021). On the other hand, these technologies will increase the economic market dynamism (Park 2017), which will lead to a positive flow of factors, and reduce firms' concerns about digital transformation (Mukherjee and Roy 2016). Based on the above analysis, we propose that.

> H4: SCP improves the corporate digital transformation, thereby enhancing TFP

Methods and data

Baseline model

To test the impact of the smart city pilot policy on firms' TFP, the DID model was constructed as follows:

$$Y_{i,t} = \alpha_0 + \beta SCP_{i,t} + \sum_{i=1}^{9} \gamma_i X + \alpha_i + \delta_t + \epsilon_{i,t} \qquad (1)$$

where Y_{it} is a variable for firm i's TFP in year t. The variable of interest is SCP_{it}, a dummy variable that equals 1 when firm i is domiciled in a smart city and 0 otherwise, and the corresponding coefficient β shows the net effect of SCP policy. α_i and δ_t are vectors of city and year dummy variables that account for firm and year fixed effects. The $\epsilon_{i,t}$ is the error term. We used regression models with firm and year fixed effects and control variables to estimate policy effects to allow for unobserved time-invariant heterogeneity.

Calculation of TFP

Total factor productivity is one of the key indicators of sustainable development (Ocak and Fındık 2019). Existing measures of total factor productivity are mainly based on the OP and LP methods (Olley and Pakes 1992; Levinsohn and Petrin 2003). However, the OP method leads to sample loss (Xiao et al. 2021), which is caused by the fact that actual investment by firms is not always positive (Olley and Pakes 1992). In contrast, the LP method can address these issues well, which uses intermediate inputs as a proxy variable. And considering the possible "labor and intermediate input correlation" problem in the LP method, this paper adopts the method of Ackerberg et al. (2015) to revise the model.

The model for estimating TFP is as follows (Wang et al. 2021):

$$LnY_{it} = \beta_0 + \beta_1 LnK_{it} + \beta_2 LnL_{it} + \beta_3 LnM_{it} + \varepsilon_{it} \qquad (2)$$

where Y_{it} is the output of firm i at year t, measured by the natural logarithm of operating revenue; LnL_{it} is labor, measured by the natural logarithm of firm i's total number of employees at year t; LnK_{it} is capital, measured by the logarithm of firm i's net fixed assets at year t; and LnM_{it} is the firm's intermediate inputs, measured by the logarithm of cash paid to purchase goods and services. ε_{it} represents the total factor productivity.

Independent variable

The treatment variable is defined as a dummy variable indicating the status of the city of registration of the firm. The treatment variable indicates that the city is approved as a smart city with a treatment variable (SCP) of 1 and 0 if it has never been approved as a smart city.

Control variables

Based on the existing literature, we selected the control variables at three levels: firm financial, board, and city. Data on firm financial and board characteristics are taken from China Stock Market and Accounting Research Database (CSMAR) and include age, operating income growth rate, debt ratio, size, number of board members, proportion of board women, and average annual board salary. Data on city characteristics were extracted from the China City Statistical Yearbook 2009–2019. Population size is used to measure city size, and the share of tertiary industry in local GDP is used to measure industrial structure. Descriptive statistics are shown in Table 1.

Sample select

This paper uses a sample of Chinese A-share listed manufacturing companies from 2009 to 2019 from CSMAR. The sample study year of this paper starts from 2009; on the one hand, key data are disclosed from 2009 onwards, and on the other hand, it allows us to capture the pre-policy firm and city characteristics. We excluded unreliable sample observations and manually reviewed financial annual reports to compensate for some missing data. We ended up with 14,969 firm-year observations.

Table 1 Descriptive statistics

Variable	Treated			Control		
	Obs	Mean	SD	Obs	Mean	SD
TFP_LP	12,065	14.598	0.926	2,901	14.520	0.904
Growth	12,067	0.145	0.234	2,901	0.140	0.237
Age	12,068	2.706	0.353	2,901	2.717	0.341
Size	12,067	21.907	1.074	2,901	21.857	1.041
Lev	12,068	0.390	0.191	2,901	0.399	0.196
BM	12,068	2.761	0.206	2,901	2.761	0.191
BF	12,068	0.177	0.111	2,901	0.169	0.108
BW	12,046	15.128	0.733	2,897	15.019	0.708
Pop	12,068	6695.798	3381.087	2,901	6466.8	2818.146
IS	12,068	52.613	12.790	2,901	44.085	9.831

TFP_LP represents the total factor productivity of the firm, Growth represents the rate of increase in the firm's turnover, Age represents the logarithm of the firm's age, Size represents the logarithm of the firm's total assets, Lev represents the ratio of the firm's liabilities to total assets, BM represents the logarithm of the firm's board of directors, BF represents the proportion of women on the firm's board of directors, BW represents the logarithm of the firm board average annual wage, Pop represents the population of the city (unit: 10,000 people), and IS represents the share of the tertiary sector in the local GDP

Empirical results

Baseline regression

Table 2 shows the regression results of the SCP on firms' TFP. Columns (1) to (5) progressively fix the time effect and add firm characteristics, board characteristics, and city characteristics. The results show that the coefficient of the SCP is 0.340 at the 1% significant level. These results suggest that for every 1% increase in SCP policy, the firm's TFP increases by 0.34%. Columns (2) to (5) show that regardless of the fixed time effect or the addition of different characteristics, the SCP significantly increases the TFP of firms in the pilot city.

In addition, the use of the DID model requires the parallel trend hypothesis to be met for a more rigorous assessment. The test coefficients for parallel trends are shown in Fig. 1. The coefficients on the dummy variables do not deviate significantly from zero in the years prior to the implementation of the SCP, indicating that the two groups met the parallel trend hypothesis prior to the implementation of the SCP.

Robustness test

Placebo test

A placebo test was conducted to eliminate the effect of other unobserved variables on the regression results of SCP and to improve the robustness of the estimates (Dong et al. 2022). Figure 2 shows the estimated coefficients and p values for a random sample of 500, with the estimates after random sampling distributed mainly near 0. It can be inferred that the other omitted coefficients are 0. This suggests that the regression results are not influenced by unobserved variables.

Table 2 The impact of SCP on TFP

Variables	(1) TFP_LP	(2) TFP_LP	(3) TFP_LP	(4) TFP_LP	(5) TFP_LP
SCP	0.340***	0.038*	0.037**	0.040***	0.041***
	(0.009)	(0.015)	(0.012)	(0.012)	(0.012)
Growth			0.380***	0.373***	0.374***
			(0.012)	(0.012)	(0.012)
Age			−0.012	0.002	0.004
			(0.042)	(0.041)	(0.041)
Size			0.505***	0.456***	0.455***
			(0.007)	(0.008)	(0.008)
Lev			−0.130***	−0.074*	−0.081**
			(0.28)	(0.028)	(0.028)
BM				−0.040	−0.039
				(0.028)	(0.028)
BF				−0.066	−0.069*
				(0.042)	(0.042)
BW				0.159***	0.159***
				(0.008)	(0.008)
POP					0.00003*
					(0.00001)
IS					−0.0003
					(0.001)
C	14.370***	14.087***	3.431***	2.223***	2.097***
	(0.007)	(0.014)	(0.178)	(0.189)	(0.211)
Firm	Yes	Yes	Yes	Yes	Yes
Year	No	Yes	Yes	Yes	Yes
Obs	14,966	14,966	14,964	14,939	14,939
R-sq	0.834	0.865	0.911	0.913	0.913

*** indicates significance at the $p < 0.01$, ** indicates significance at the $p < 0.05$, * indicates significance at the $p < 0.1$

Fig. 1 Years relative to policy implemented
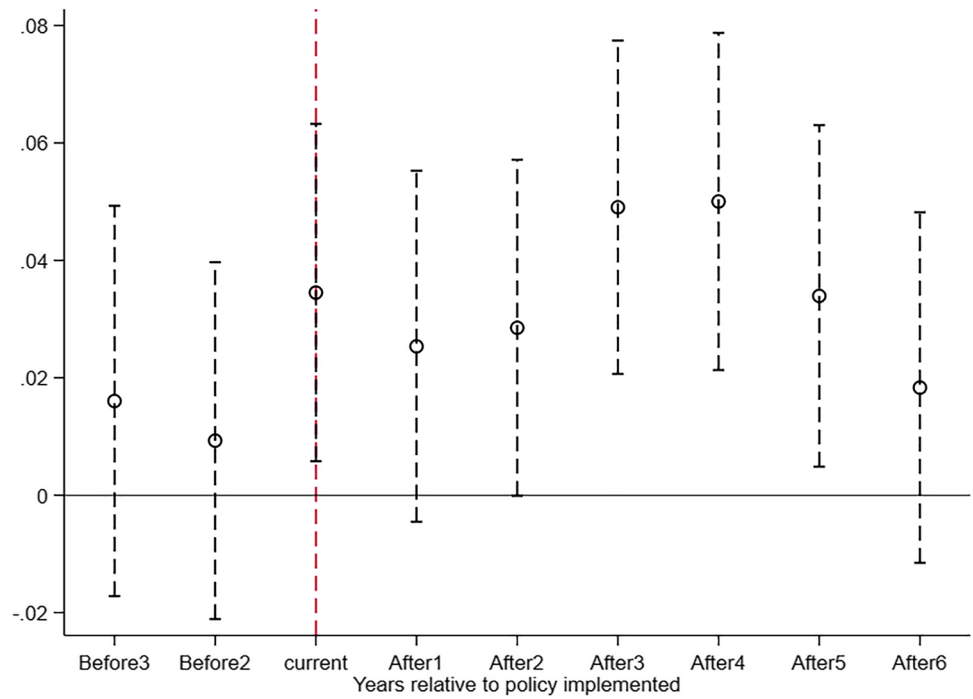
Fig. 2 Placebo test
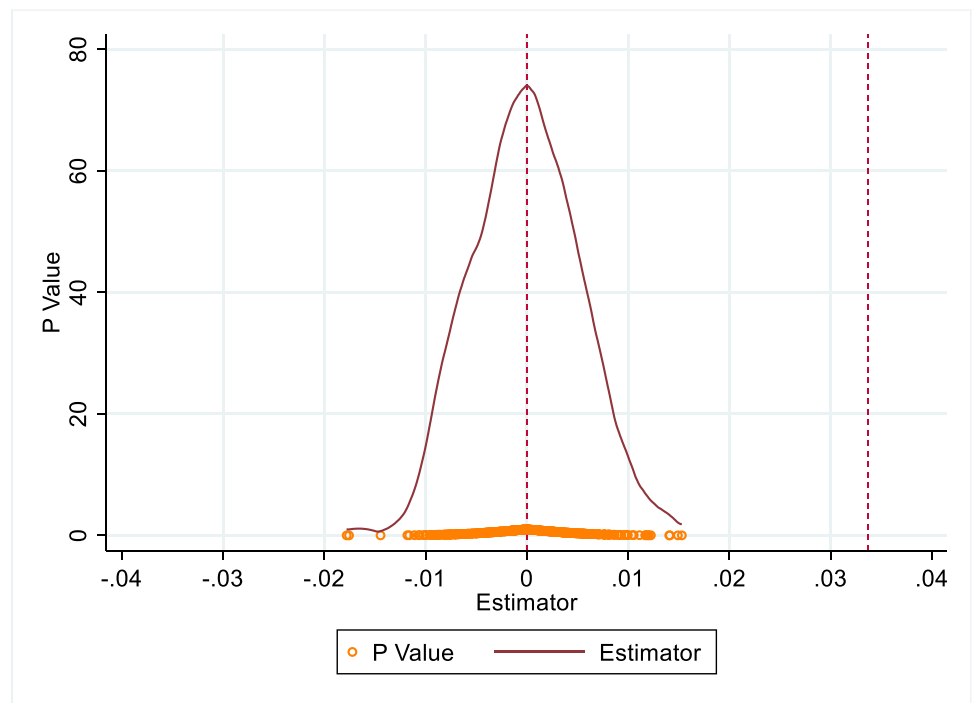
Replace the dependent variable

To improve the stability of the model, we again measure the TFP using the MrEst method (Mollisi and Rovigatti, 2017). Wooldridge (2009) mentions that the GMM estimation method not only solves the potential identification problem of the ACF method in the first step, but also takes into account serial correlation and heteroskedasticity, whereas Wooldridge estimation can lead to sample loss due to the inclusion of lagged terms, the MrEst method used in this paper addresses the problem of sample loss. The conclusions are found to be consistent with the previous ones, verifying the stability of the regression findings in Table 3.

Table 3 The impact of SCP on TFP_Mr

Variables	(1) TFP_Mr	(2) TFP_Mr	(3) TFP_Mr	(4) TFP_Mr	(5) TFP_Mr
SCP	0.342***	0.038***	0.037**	0.040**	0.041**
	(0.009)	(0.015)	(0.012)	(0.012)	(0.012)
Firm control	No	No	Yes	Yes	Yes
Board control	No	No	No	Yes	Yes
City control	No	No	No	No	Yes
Firm	Yes	Yes	Yes	Yes	Yes
Year	No	Yes	Yes	Yes	Yes
Other policies	Yes	Yes	Yes	Yes	Yes
C	14.409***	14.125***	3.410***	2.200***	2.073***
	(0.007)	(0.014)	(0.178)	(0.189)	(0.211)
Obs	14,966	14,966	14,964	14,939	14,939
R-sq	0.835	0.866	0.911	0.914	0.914

*** indicates significance at the $p < 0.01$, ** indicates significance at the $p < 0.05$, * indicates significance at the $p < 0.1$

Table 4 The impact of SCP on TFP with removing other policies

Variables	(1) TFP_LP	(2) TFP_LP	(3) TFP_LP	(4) TFP_LP	(5) TFP_LP
SCP	0.417***	0.048***	0.039**	0.042**	0.042**
	(0.011)	(0.016)	(0.013)	(0.013)	(0.013)
Firm control	No	No	Yes	Yes	Yes
Board control	No	No	No	Yes	Yes
City control	No	No	No	No	Yes
Firm	Yes	Yes	Yes	Yes	Yes
Year	No	Yes	Yes	Yes	Yes
Other policies	Yes	Yes	Yes	Yes	Yes
C	14.384***	14.087***	3.431***	2.222***	2.087***
	(0.007)	(0.014)	(0.178)	(0.189)	(0.211)
Obs	14,966	14,966	14,964	14,939	14,939
R-sq	0.836	0.866	0.911	0.913	0.913

*** indicates significance at the $p < 0.01$, ** indicates significance at the $p < 0.05$, * indicates significance at the $p < 0.1$

Remove the impact of other policies

SCP aims to achieve sustainable urban development and are susceptible to the impacts of other environment-related policies, such as low-carbon city pilots and carbon emission trading policy. This paper excludes the impacts of these policies to examine the net effect of SCP. The coefficients of SCP are found to be significantly positive despite slight variations, which indicates that our regression findings are stable (Table 4).

Removing selection bias issues

Firms may choose to take into account the economic and other characteristics of their place of incorporation, which can lead to selection bias, and we use the propensity score matching(PSM) to eliminate the selection bias problem (Dehejia and Wahba 2002). Namely, we first use firm characteristics from the year prior to the policy to match the control and treatment groups. Nearest neighbor matching was used and the results are shown in Table 5. As can be seen, after matching, the standardized bias between the treatment and control group observations is significantly reduced and "Balancing" is achieved.

Table 6 provides the regression result based on the PSM-DID method. The results are consistent with Table 2, which suggests that our findings are plausible.

Heterogeneity analysis

Studies of smart city pilots have mainly examined urban heterogeneity, ignoring enterprise heterogeneity. This paper classifies state-owned enterprises (SOE) and non-state-owned enterprises (non-SOE) according to ownership. According to the classification of heavily polluting enterprises in "The Environmental Information Disclosure Guidelines for Listed Companies" published by the Chinese Ministry of Environmental Protection in 2010, enterprises are classified into heavily polluting and non-heavily polluting enterprises (PE and non-PE). Enterprises are classified into coastal and non-coastal enterprises (CE and Non-CE) based on whether the enterprise is registered in a coastal area. Market share is calculated based on the enterprise's operating revenue and divided into monopolistic and non-monopolistic enterprises(ME and non-ME).

Table 7 shows the regression results based on firm heterogeneity. Columns (1) and (2) show the results of the ownership regressions; coefficients of SCP are 0.042 and 0.041 at the 10% significant level, indicating that SCP has a greater positive impact on TFP for SOE than that for non-SOE. (3) and (4) are regression results for heavy polluting industries; the coefficients of SCP are 0.045 and 0.043 at the 5% and 10% significance levels, indicating that the positive impact of SCP on TFP is greater for PE than that for non-PE. (5) and (6) are the results of the regressions on the place of incorporation of firms; the coefficients of SCP are 0.043 and 0.047 at 5% and 10% significant levels, which indicates that

Table 5 Balancing test

Variable	Sample	Mean		Bias (%)	Reduct |bias|(%)	t-test	
		Treated	Control			t	p>|t|
Age	Unmatched	2.508	2.534	−5.9	85.1	−0.99	0.325
	Matched	2.507	2.503	0.9		0.22	0.823
Size	Unmatched	21.475	21.375	9.4	92.0	1.55	0.121
	Matched	21.433	21.441	−0.7		−0.20	0.842
Growth	Unmatched	0.217	0.222	−0.9	−11.1	−0.14	0.893
	Matched	0.216	0.210	1.0		0.26	0.791
Lev	Unmatched	0.358	0.350	2.6	98.8	0.38	0.701
	Matched	0.244	0.345	−0.00		−0.01	0.990
Board	Unmatched	2.753	2.740	6.3	37.6	1.05	0.294
	Matched	2.746	2.738	4.0		1.05	0.295
Female	Unmatched	0.171	0.168	3.0	54.8	0.50	0.619
	Matched	0.171	0.173	-1.3		−0.33	0.741
Wage	Unmatched	14.962	14.813	21.3	96.1	3.59	0.000
	Matched	14.936	14.93	0.8		0.24	0.808

All covariates were measured at pre-treatment period

Table 6 The impact of SCP on TFP within PSM-DID

Variables	(1) TFP_LP	(2) TFP_LP	(3) TFP_LP	(4) TFP_LP	(5) TFP_LP
SCP	0.332***	0.027*	0.022*	0.026**	0.027**
	(0.009)	(0.016)	(0.013)	(0.013)	(0.013)
Firm Control	No	No	Yes	Yes	Yes
Board Control	No	No	No	Yes	Yes
City Control	No	No	No	No	Yes
Firm	Yes	Yes	Yes	Yes	Yes
Year	No	Yes	Yes	Yes	Yes
C	14.37***	14.08***	3.313***	2.231***	2.057***
	(0.00669)	(0.0139)	(0.152)	(0.169)	(0.190)
Obs	13,542	13,542	13,540	13,529	13,529
R-sq	0.828	0.862	0.907	0.909	0.909

*** indicates significance at the $p < 0.01$, ** indicates significance at the $p < 0.05$, * indicates significance at the $p < 0.1$

the positive impact of SCP policy is greater for the non-CE than that for CE. (7) and (8) are the regression results of market concentration; the coefficients of SCP are 0.039 and 0.037 at 10% significant level, which indicates that the positive impact of SCP is greater for ME than that for non-ME.

Mechanism testing

Table 8 reports the results of the mechanism test. The results of the mechanistic tests are reported in Table 5. Column (1) shows that SCP can increase the R&D investment of firms. (2) The coefficient of SCP is 12.188 at the 10% significant level, indicating that SCP can enhance patent output. Column (3) shows that SCP can enhance the knowledge flow. Regression result (4) indicates that SCP can help firms attract talent inflow. In regression result (5), SCP can reduce financing constraints and help firms to access social capital more easily. In regression result (6), for every 1% increase in SCP, investment efficiency decreases by 0.002. The lower the investment efficiency, the more efficient the firm's resource allocation. In regression result (7), SCP can facilitate the digital transformation. This verifies hypothesis H1, H2, H3, and H4.

Discussion

The following are contributions of this study: it is found that smart city pilots can increase the total factor productivity of firms, which is similar to the findings of Jiang et al. (2021) who find that SCP can improve GTFP at the city level, and this paper extends this finding to the micro-firm level. One possible explanation is that SCP increases the construction of digital infrastructure, indirectly accelerating firms' transition to Industry 4.0, which in turn improves firms' TFP. In control variables of board, we find that the large number of women directors on the board will inhibit the increase in firms' TFP, which is in line with the role congruity theory of prejudice against female leaders proposed by Eagly and Karau (2002), which states that it is difficult for women to be leaders and is negative for firm operations. A possible explanation for this is that board gender differentiation can disrupt organizational stability (Dezsö and Ross 2012). The larger the city size in the city control variable, the larger the firm's TFP, which is consistent with the findings of Ding et al (2016). This implies that the larger the city size, the

Table 7 The regression results based on firm heterogeneity

Variables	SOE (1) TFP_LP	Non-SOE (2) TFP_LP	PE (3) TFP_LP	Non-PE (4) TFP_LP	CE (5) TFP_LP	Non-CE (6) TFP_LP	ME (7) TFP_LP	Non-ME (8) TFP_LP
SCP	0.042*	0.041*	0.052**	0.045*	0.043**	0.047*	0.039*	0.037*
	(0.020)	(0.016)	(0.017)	(0.018)	(0.015)	(0.022)	(0,021)	(0.017)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
C	2.098***	2.173***	3.775***	1.145***	2.604***	2.293***	2.743***	2.288***
	(0.351)	(0.270)	(0.338)	(0.270)	(0.248)	(0.476)	(0.275)	(0.378)
Obs	5,546	9,393	5,782	9,157	9,584	5,355	8,101	6,838
R-sq	0.916	0.904	0.909	0.917	0.925	0.899	0.945	0.907

*** indicates significance at the $p < 0.01$, ** indicates significance at the $p < 0.05$, * indicates significance at the $p < 0.1$

Table 8 Mechanism testing

Variables	(1) RTI	(2) PA	(3) KL	(4) TW	(5) FC	(6) IE	(7) DT
SCP	0.001*	12.188*	0.088***	0.063**	−0.017***	−0.002*	0.094*
	(0.001)	(7.266)	(0.018)	(0.022)	(0.005)	(0.001)	(0.052)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
C	0.002	−579.937***	−6.644***	−11.685***	4.278***	0.141***	−9.674***
	(0.011)	(124.266)	(0.304)	(0.377)	(0.081)	(0.020)	(0.884)
Obs	14,941	14,941	14,941	14,941	14,941	10,793	14,941
R-sq	0.805	0.707	0.942	0.853	0.867	0.152	0.663

*** indicates significance at the $p < 0.01$, ** indicates significance at the $p < 0.05$, * indicates significance at the $p < 0.1$. RTI represents the firm's R&D investment intensity (compared to operating income). PA represents the number of patents filed. KL represents a firm's knowledge flow, measured by the logarithm of patent citations. TW is the logarithm of technical staff. FC refers to financing constraints. IE represents resource allocation efficiency, measured by Richardson's (2006) investment efficiency. DT represents a firm's digital transformation, using text analysis to retrieve the frequency of occurrence of keywords related to digitalization (Rha and Lee, 2022)

more mobile the people, the more active the economy, and the better various infrastructures, the more positive the effect on firm TFP (Howell et al. 2018).

We explored the impacts of SCP under different heterogeneities. First, we find that the impact of SCP is greater for SOEs than for non-SOEs, which is similar to the findings of Chen et al. (2021), who found that low-carbon city policies have a greater impact on SOEs; we extend this finding to SCP aspect. On the one hand, SOEs hold a dominant position in the economic market and can better improve their TFP under the effect of SCP (Szarzec and Nowara 2017). On the other hand, this is also consistent with institutional theory, namely, SOEs have a special political status and are more sensitive to policies, which requires SOE management to actively and quickly adjust their strategies (Wong 2018). Second, we find that SCP enhances TFP more for PE than

for non-PE, which is somewhat different from the study by Chu et al. (2021), whose exploration focuses on the city level. One possible explanation is that SCP emphasizes sustainable urban development; as major emitters of pollution, heavy polluters are under more policy pressure. This forces themselves to upgrade or innovate, which can boost its total factor productivity (Arenhardt et al. 2016). Third, we find that SCP has a greater impact on non-CE than on CE. It is possible that the economic status of coastal areas is better than that of non-coastal areas (Fleisher et al. 2010), and that SCP improves non-coastal areas more, which in turn can boost the TFP of local firms. In other words, smart city pilot policies can compensate for the disadvantages of non-coastal areas by making it easier for them to access various resources and information. Fourth, SCP has a greater impact on ME than on non-ME. The reason is that ME has a strong

risk tolerance (Murugkar et al. 2007), and smart city pilots may change the organizational and operational structure (Evans et al. 2021), which poses certain risks. ME can offset these uncertainty risks to improve their resource allocation. On the other hand, non-ME, which are more focused on short-term benefits due to fierce market competition (Villanueva et al. 2007), are likely to settle for the status quo.

We also tested the mechanisms by which smart city pilot policies work at the enterprise level. First, the SCP has a positive impact on innovation input and output. Secondly, we find that SCP can aggregate talents and accelerate knowledge flows, which is consistent with the findings of Wang and Deng (2022) based on the city level. This is also consistent with the Porter hypothesis that external environmental pressures will stimulate firms to innovate, validating the validity of the Porter hypothesis at smart city policy and micro level in China. In other words, firms will actively respond to the pilot policy to improve their TFP through technological innovation. Or it can be described that firms will have easier access to information on intellectual and human capital through information channels to improve their own innovation environment, which in turn will improve TFP. Third, smart city pilot policies can reduce firms' financing difficulties, which is consistent with signaling theory (Connelly et al. 2011). Information asymmetry between firms and external stakeholders often leads to financing difficulties for firms (Cassar 2004). Smart cities have robust information channels which help firms to disseminate information to the community on time and keep external stakeholders informed about the situation of the firm. It makes it further difficult for firms to access social capital. Fourth, we mentioned in the previous section that SCP would increase the efficiency of resource allocation for firms. We tested this claim and found that SCP has a negative impact on investment efficiency (a positive impact on resource allocation efficiency), which is consistent with the findings of Oueida et al. (2019). This implies that companies can take advantage of the SCP to improve their degree of digitization and transform themselves from industrial companies to Industry 4.0 smart companies. Finally, it is also demonstrated that SCP can enhance the digital transformation of companies.

Conclusions, suggestions, and limitations

In this paper, we take the SCP as a quasi-natural experiment. We constructed firm data from 2009 to 2019 using the CSMAR database and the City Statistics Yearbook to examine the impact of SCP on firm TFP. The conclusions are as follows: (1) SCP significantly increases TFP based on the LP method. (2) SCP increases firm monopoly, both in terms of market competitiveness and firm ownership. In terms of

firm location, the SCP will alleviate regional imbalances. In addition, enterprises in the heavy pollution industry are more sensitive to the policy. (3) We find that strengthening firms' investment in technological innovation, talent aggregation, attracting financing, improving resource allocation efficiency, and digital transformation are important ways for SCP to advance firms' TFP. Smart cities are a common way for developed countries in Europe and the USA to achieve sustainable development, while for developing countries such as China they face various problems.

The research in this paper provides recommendations for policy makers and business managers. For policy makers, first, the government should expand the scope of the smart city pilot and increase the construction of related facilities, for example, by increasing the popularity of Internet and 5G technology, training digital professionals, and establishing network-based transportation methods to strengthen the effect of smart city policy. Considering the unbalanced distribution of smart city pilots, the government should increase the policy tilt to the central and western regions, for example, by one-to-one supporting the development of the western regions by the central and eastern regions and expanding the western development scope to establish a sound market economy in order to achieve nationwide coordinated development(Adebayo et al. 2022). Second, the results of heterogeneity tell us that smart cities will strengthen the monopoly of companies with market advantages, which requires the government to develop flexible incentive policies to mitigate these imbalances. Supervise the development of enterprises through a series of rewards and fine mechanisms. Third, the results of the mechanism test show that factors such as R&D investment, knowledge flow, talent aggregation, resource allocation efficiency, financing capability, and digital transformation enhancement are important ways to improve total factor productivity. The government should encourage technological innovation to promote the use of renewable energy and thus achieve sustainable development (Chien et al. 2021; Sun et al. 2021). The government should improve regulations on knowledge protection and develop a positive talent introduction policy. An information platform should be established to disclose information to the outside world in a timely manner. And appropriate incentive and subsidy policies should be formulated to reduce the burden of digital transformation for enterprises. For business managers, they should recognize the advantages of smart city policies and actively align corporate strategies to achieve sustainable growth with smart city policies, such as transformation and upgrading, innovation strategies, and digital transformation strategies. Second, business managers focus on the importance of R&D, talent, resource allocation, and digital transformation, and they should timely release information to the society and establish a perfect promotion mechanism to attract external capital, technology and

talents. In addition, they should utilize high technology such as blockchain, cloud computing, robotics, and digitalization to change the traditional business model to reduce the waste of resources and achieve high quality development.

There are still limitations in this paper. First, policy formulation and effects are often influenced by the external environment (Praharaj et al. 2018), such as economic policy uncertainty (Sharif et al. 2020b), political uncertainty (Sohail et al. 2022), and COVID-19 pandemic (Işık et al. 2020). Existing studies have found that these external environmental changes may affect policy strategies and corporate strategies (Ahmad et al. 2021). Therefore, these external factors also need to be considered. Second, there are a variety of factors that affect total factor productivity, but only nine control variables are taken in this paper. The effects of other factors should also be considered, such as economic development (Isik et al. 2021c; Isik et al. 2019b), globalization (Sharif et al. 2019), and financial development (Godil et al. 2020). The object of this paper is listed companies from 2009 to 2019, which leads to a limited time period for the study and makes it difficult to explore the long-term effects of SCP policies. Third, apart from firm heterogeneity, it is also necessary to consider industry heterogeneity, such as IT industry, biopharmaceuticals industry, and insurance industry (Li et al. 2022), for they have different sensitivities to external policies. Finally, policies are not only influenced by the government but also driven by the market, and the effects of policies driven by both need to be subdivided. In future research, the effects of SCP policy will be further explored.

Declarations

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Consent to participate Not applicable.

Consent for publication Not applicable.

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