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Medium and long-term impact of SARS on total factor productivity (TFP): Empirical evidence from Chinese industrial enterprises

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\textbf{ABSTRACT}

This study examines the impact of the 2003 SARS epidemic on the total factor productivity (TFP) of Chinese industrial enterprises using a difference-in-differences (DID) approach. The results exhibit that SARS significantly reduces TFP by 3.12–5.81%, lasting for three to five years. Further, this impact is heterogeneous across industries. A significantly negative impact is found in labor intensive industries, while capital and technology intensive industries is less affected. Contrarily, a significantly positive impact is observed in those industries necessary for life and production. Mechanism tests show that the impact on TFP is caused by a reduction in labour productivity and a decrease in innovation investment after SARS outbreak. This study highlights the importance of more targeted policy on Covid-19 and similar epidemics both in industrial, national and international level.

1. Introduction

As is well known that the COVID-19 pandemic has spread globally, causing significant economic losses and a global economic downturn in the short and long run. Wang (2020) believes the COVID-19 pandemic is a once-in-a-century crisis, causing economic losses comparable to the Spanish flu in 1918, the global economic crisis in 1929, and the US financial crisis in 2008.\textsuperscript{1} Major financial institutions, such as the IMF, the Institute of International Finance, Moody’s Investors Service, and Nomura Securities, have lowered their global economic forecasts for 2020, 2021 and 2022.\textsuperscript{2} According to economic theory, exogenous shock can be divided into demand shock or supply shock. Keynesianism and monetarism both explain the economic fluctuations from the perspective of demand side, arguing that economic fluctuations are mainly short-term ones. In contrast, the real business cycle theory maintains that economic fluctuations are mainly driven by real factors on the supply side, such as technological progress or natural disasters, therefore the economic fluctuations usually last for some time (Kydland & Prescott, 1982). The COVID-19 pandemic has witnessed a great macroeconomic shock that simultaneously impacted supply side, demand side and productivity in short and long run. However, most current research on the COVID-19 pandemic is focused more on the short-term impact on companies, industries, and employment rather than long term impact (Walmsley et al., 2021; Eggers & Woodside, 2020).

This study investigates the medium and long-term economic impact of the severe acute respiratory syndrome (SARS) epidemic,
which is very similar to the COVID-19 pandemic in several dimensions. First, given current data of COVID-19, it is very difficult to provide profound insights and make accurate judgments regarding the medium and long-term impact of COVID-19 on economy. However, research on the medium and long-term economic impact of the SARS epidemic based on rich historical data can provide a useful policy implication. Second, the SARS epidemic impacted China and some east Asian countries (Fig. 1) but not the rest of the world. In contrast, the current Covid-19 pandemic has spread worldwide. Therefore, research on the medium and long-term economic impact of SARS in China can provide more targeted and useful recommendations to the world on how to fight against COVID-19.

Based on an extensive sample data of industrial enterprises in China from 2001 to 2007, this study employs the difference-in-differences (DID) approach and its dynamic extension. We find that the SARS epidemic has a significantly negative impact on TFP of Chinese industrial enterprises. Moreover, the impact of SARS lasted for approximately three to four years after the outbreak. Notably, this dynamic impact is not linear, showing negative in the year of the outbreak, turning positive in the second year, increasing again from 2005 to 2006, and decreasing thereafter. Regarding heterogeneity across industries, we find that SARS has a significantly negative impact on labor intensive industries, while has less negative impact on capital and technology intensive industries. In contrast, it has a positive impact on industries necessary for life and production. In terms of mechanism, we find that a reduction in labour productivity and a decrease in innovation investment by firms are responsible for the reduction in TFP. Our placebo tests and propensity score matching (PSM) test both show that our result is robust.

Compared to the existing literature, this study makes several contributions. First, non-Chinese researchers mostly focused on the basic theory and international empirics of the economic impact of epidemics however rarely discussed evidence from China. In contrast, this study chooses SARS, the first large epidemic after the founding of the People’s Republic of China as a quasi-experiment and provides more implications to the impact of COVID-19 and how to fight against COVID-19 more effectively. Second, most studies by Chinese researchers investigated the short-term impact of SARS on various industries, but rarely examined the impact on medium and long-term development while this study illustrates the findings of medium and long-term impacts of SARS on enterprise. Third, this study analyzes the impact of SARS based on enterprise TFP, which is a classical approach in the economics scholarship. Thus, this study is more comprehensive than those examining the impact of SARS on a single indicator, such as production, cost, or profit.

The rest of this paper is organized as follows. Section 2 presents a literature review on the impact of epidemics on medium and long-term economic development. Section 3 introduces the historical background of the SARS epidemic and proposes hypotheses. Section 4 presents the model specification, variables, and data sources. Section 5 presents the empirical analysis. Section 6 concludes and draws some policy recommendations.

Fig. 1. Countries or areas with reported confirmed cases of SARS, 31 July 2003. Data Source: World Health Organization.
2. Literature review

Relevant studies on the impact of epidemics on economic development can be divided into two categories: studies that examine the medium and long-term economic impact of related outbreaks (including Black Death, cholera and Spanish flu) in other countries and those that focus on the economic effect of SARS on the Chinese economy.

In the first strand of literature, two contrary perspectives are present in the relevant studies of other countries. One viewpoint is that an epidemic may have a positive impact on a country’s economic development. For example, Capasso and Malanima (2007) and Malanima (2002) believe that the mortality rate during an epidemic may cause a shortage of labor supply and thus rising wages, thereby improving living standards and promoting long-term growth. Although Voigtlander and Voth (2013) do not directly study the long-term impact of epidemics, their findings somewhat support the view that wars, epidemic and germs have a long-term positive economic impact before the industrial revolution because an epidemic such as the Black Death, and frequent wars cause a significant decrease in population, which lead to increasing per capita income of the remaining population.

The contrary view is that epidemics have a long-term negative economic impact. For example, based on the history of Italy in the 17th century, Alfani (2010, 2013) find that the epidemic has a severe impact on property distribution, income inequality, and economic decline. Almond (2006) uses the 1918 influenza pandemic as a natural experiment to examine its long-term impact in the United States and finds that pregnant women during the influenza outbreak are negatively affected. Their children have lower education, higher disability rates, lower income levels, and lower economic and social status in next several years. Forbes (2000) assesses how the Asian flu and the Russian virus negatively impact the world economy based on firm-level data. Karlsson et al. (2014) examines the negative effects of the Spanish flu pandemic of 1918 on capital income to be approximately 5% in the short term and 6% in the medium term. Moreover, the flu pandemic contributes to an 11% increase in the poverty rate in that population.

Research in recent years has increasingly shown that the epidemic has a long-term negative impact on economic development. For example, Alfani and Percoco (2019) argue that the Black Death causes damage to long-term population growth, urban population size, and urbanization rates by reducing productivity in Italy. Ambrus, Field, and Gonzalez (2020) suggests that the 1854 London cholera epidemic has a significant negative economic impact which lasts for more than 100 years because it causes a decrease in population and housing prices in the epidemic area. Jordà, Singh, and Taylor (2020) believe that significant macroeconomic after-effects of pandemics persist for decades and real rates of return to assets are greatly reduced.

In the second strand of literature, most studies examine the short-term impact of SARS on macroeconomic and industrial economy while limited attention has been given to medium and long-term economic effects of SARS. For example, Hanna and Huang (2006) estimate that the total costs of the SARS would be about 1.5% of GDP for China in that year. Chou et al. (2004) assert that SARS could have significant short-run macroeconomic effects by analyzing the SARS shock to Taiwan services and manufacturing sectors. Zhu et al. (2003) and Xue and Sun (2008) demonstrate the severe impact of the SARS epidemic on domestic and inbound tourism in China. Wu and Cheng (2003) reveal that the SARS epidemic has a severe impact on all transportation sectors in the short term, as compared to the same period in subsequent years. Yang (2004) discusses the short-term impact on the retail industry. Zhen (2003) and Xia (2003) investigate the impact of SARS on the livestock products and feed industry and the export of agricultural and animal by-products.

As for the medium and long-term impact of the SARS epidemic on China’s economy, some scholars have made extensive thinking at the theoretical level. For example, San (2003) suggests that the SARS epidemic not only has a serious short-term impact on the Chinese economy but also might sharpen the long-term and deep-seated contradictions in investment, consumption, employment, and real income of rural residents. Li (2003) believes that the SARS epidemic would lead to changes in formal and informal institutions and would promote reform and increase resource allocation efficiency in China via comparative analysis with the East Asian financial crisis.

In summary, extensive high-quality studies have been conducted outside China to evaluate the medium and long-term economic impact of epidemics, mostly based on rich data or empirical evidence. However, they rarely examine the effects of SARS due to data unavailability. Conversely, many studies have been conducted by Chinese researchers on the impact of the SARS epidemic, mostly focusing on the short-term or industrial impact, and not presenting sound empirical evidences. Therefore, investigating the medium and long-term effects of SARS is significant in theoretical exploration and is of practical significance concerning the COVID-19 pandemic.

3. Historical background and hypotheses

3.1. Historical background

SARS emerged in Guangdong Province at the end of 2002 and spread slowly throughout the country after February 2003. On March 6, the first imported SARS case appeared in Beijing. In April, the Chinese government began to take public prevention and treatment measures due to its significant impact across the country. The epidemic reached its peak at the end of April and declined quickly afterward in May, ending in July 2003.

Fig. 2 shows the changes in the number of confirmed SARS cases in the 70 days after April 21, 2003, which is considered the starting time of the epidemic, based on the data released by the State Council Information Office of the People’s Republic of China. The

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3 Extensive data are available from the China Internet Network Information Center: http://www.china.com.cn/chinese/zhuanli/feiyian/325381.htm. The data were organized for this study.
epidemic reached its peak on days 25–30 and declined dramatically after days 45–47. This trend is attributed to the Chinese government’s launch of nationwide SARS prevention and treatment measures in April, thereafter, the epidemic came under control on day 55.

Fig. 3 shows the changes in the number of confirmed SARS cases in severely affected provinces or municipalities (i.e., Beijing, Guangdong, Hebei, Inner Mongolia, Shanxi, and Tianjin). Each of them reported more than 150 cases and accounted for 96.73% of the national total, of which five of them are located in North China, and one in South China (i.e., Guangdong Province). This observation is consistent with the depiction from other literature (e.g., Fan & Ying, 2005).

The changes in the number of cases in less affected provinces or municipalities are shown in Fig. 4 for comparison. Fig. 4 shows that each province reported less than 40 cases. Thus, the classification of severely affected and less affected areas in this study is reasonable. This classification is used in our following empirical study as an identification approach to divide our treatment group and control group in DID model.

### 3.2. Hypotheses

According to WHO and many national laboratories, SARS is caused by a new coronavirus. SARS can be quickly transmitted from person to person via droplets, hands, eyes, mouth, nose, and conjunctiva. Due to its high infectivity, sanitary and quarantine inspection were enhanced at ports, communities, factories, and mines across China, which inevitably affected production, daily life, trade, investment, travel, and other societal aspects. Thus, the SARS epidemic had a direct, multipath, and extensive impact on Chinese industrial enterprises. Furthermore, given the duration and severity of the outbreak, we believe that the epidemic has a medium to long term effect on enterprise TFP. In our paper, medium-term effect is defined as 1 year, and long-term effects is defined as 2 years or more.

The SARS epidemic affects the TFP of industrial firms in China through several different channels. The most direct channel, is that more employees take time off work and capital productivity will be reduced. Specifically, during the outbreak, person-to-person activities such as business trips, conferences, trade fairs, etc., were reduced to a large extent therefore the frequency and effectiveness of communication between business partners, collaborators, investors etc., are reduced accordingly. Given this, we usually expect an increase in operating costs and a reduction in enterprise profits. The issue of credit constraints might exist. When firms face liquidity shortages, employees may be retrenched beyond a certain threshold with much of an impact on productivity (Céspedes et al., 2020).

Furthermore, capital productivity can be reduced by the limits of social distancing between people. If commercial premises must operate with very few customers and staff, then labor input and value added per square meter will be reduced (Bloom et al., 2020). This can be seen as a reduction in the productivity of capital, and therefore TFP will suffer.

In addition to its direct impact on the TFP of industrial firms, SARS also has larger number of indirect effects of the TFP. From the

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A similar identification is used in Ren (2003).
perspective of enterprises, reduction in labor productivity and less innovation are the possible mechanisms through which SARS affects the TFP of industrial firms in China.

First, changes in working environment and way of working will affect employees’ productivity. Once a virus hits, employers or employees have to face problems such as tighter traffic, cancellations and postponing of important meetings and events, travel restrictions, teleworking and physical unavailability, impaired manager-employee relationships and difficulty building trust with co-workers, which will negatively affect their ability and willingness to perform the existing tasks and new tasks, leading to reduction of enterprise productivity (Naraynamurthy & Tortorella, 2021).

Second, behavioral changes introduced by epidemic interventions can affect employees’ emotional, mental health and cognitive functions, which can ultimately impact their labor efficiency (Shin et al., 2019; United Nations Sustainable Development Group, 2020). In addition, some studies have shown that infection diseases may contribute to cognitive impairment (Katan et al., 2013), which may lead to the loss of human capital through impaired mental health and reduce the marginal work efficiency of labor, thereby reducing firm TFP.

Third, a pandemic influenza will also lead to a large reduction in R&D expenditure by firms and divert senior management time spent on dealing with the pandemic, resulting in the misallocation of enterprises’ capital and the decline of TFP (Bloom et al., 2020). During the SARS epidemic, the company has increased the welfare of employees, providing them with face masks, disinfectants,
medicines, and certain cash subsidies. In order to ensure the stability of the internal production management, the enterprise has set up special organizations and special funds to deal with SARS (China Enterprise Confederation and China Enterprise Directors Association, 2003). Under the constraints of limited liquidity, enterprise R&D funds and production activities will be reduced to a large extent. Furthermore, if senior managers focus on responding to the pandemic, the productivity-enhancing activities will be reduced. Bloom et al. (2019) show that the time UK businesses spent preparing for Brexit significantly reduced productivity. In addition, most studies show that the weakening of independent research and development ability can directly reduce the total productivity of enterprises (Amable et al., 2016; Baumann & Kritikos, 2016). Therefore, enterprises’ TFP will suffer.

We also expect the existence of lag effects, mainly in the indirect channels by which SARS affects the TFP of industrial firms operate with a variety of lags. On the one hand, some of the effects on worker productivity operate with a long lag. SARS infected person might produce the long-term sequelae, including a significant impairment of pulmonary function, exercise capacity and health status (Ngai et al., 2010). Control of infectious SARS will also eliminate the lower productivity due to this condition with a very long-time lag. On the other hand, the impact on TFP has a long lag, because the improvement of TFP may be through technological innovation and technological research and development, which is characterized by more investment and long cycle (Anh, 2015; Bansal & Hunter, 2003).

However, the shock also has asymmetric effects across industries, with labor-intensive sectors bearing the brunt because these industries are dependent on large numbers of workers and a lower degree of automation (such as food manufacturing, furniture manufacturing, textile, handicraft and others) and there face great challenges and higher uncertainty due to traffic restrictions and restrictions on mobility and density of people. However, capital and technology intensive industries or enterprises with very low demands for manpower, such as electric equipment and machinery, transportation equipment manufacturing, chemical raw materials and chemical products, metal products, etc., are not so heavily affected by the outbreak. In contrast, some industries such as water supply, waste resources and materials recycling industries do not suffer, and receive some benefit because these industries are financed by the government and government have taken some measures to stabilize urban life and public utility.

Based on the above discussion, an analytic framework of the impact of the SARS epidemic on the TFP of Chinese industrial enterprises is shown in Fig. 5.

According to this framework, we propose the following hypotheses:

**Hypothesis 1.** Given the high infectivity and broad impact of SARS, it might negatively affect the TFP of Chinese industrial enterprises.

**Hypothesis 2.** The negative impact of the SARS epidemic on TFP might last for a specific period.

**Hypothesis 3.** The negative impact of the SARS epidemic on TFP might exhibit significant heterogeneity across industries, depending on labor-intensive or capital and technology intensive or not, low or high degree of automation.

**Hypothesis 4.** The negative impact of the SARS epidemic on TFP was caused by a reduction in labour productivity and a decrease in innovation after the outbreak.

### 4. Model specification, variables, and data sources

#### 4.1. Model specification

The following DID model is employed to examine the impact of the SARS epidemic on TFP:

\[
\ln \text{tfp}_{p,t} = \beta_0 + \beta_1 \text{time}_t + \text{treat}_p + \delta X + \varphi_p + \gamma_k + \eta_i + \epsilon_{pkt} \\
\]

where \(\ln \text{tfp}_{p,t}\) is the logarithm of the TFP of firm in industry from province \(p\) in year \(t\), and \(\text{time}_t\) is a dummy variable with values of 0 and 1. According to the WHO, SARS first surfaced in Guangdong on November 16, 2002; the epidemic in Guangdong reached its peak in February 2003. Thereafter, it spread to Beijing and North China after March-April then peaked in May-June (Fan & Ying, 2005). As of July 13, 2003, there were no new confirmed cases in China for a long time, indicating the end of the epidemic. Therefore, the value of \(\text{time}_t\) is set to 1 for 2003 and later years; otherwise, it is 0. The value of \(\text{treat}_p\) is 1 when the enterprise is in a severely affected area and 0 when it is in a non-affected or mildly affected area. According to the China Internet Network Information Center, which was authorized by the Ministry of Public Health of the PRC to release SARS epidemic information, the provincial and municipal governments reported more than 150 cumulative confirmed cases, accounting for 96.73% of the national total. Therefore, these six provinces or municipalities are identified as severely affected by the SARS epidemic, and the remaining as less affected ones. Moreover, \(X\) is a group of control variables that affect TFP, \(\varphi_p\) is a province fixed effect, \(\gamma_k\) is an industry fixed effect, \(\eta_i\) is a year fixed effect and \(\epsilon_{pkt}\) is the random error term. The coefficient \(\beta_1\) captures the impact of the SARS epidemic on TFP.

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5 No confirmed SARS cases have been reported in Hainan, Yunnan, Xizang, Qinghai, Guizhou, Heilongjiang and Xinjiang provinces.

6 The influence of SARS on Chinese enterprises’ management and countermeasures [N]. China Enterprise News, 2003/06/05.

7 See http://www.china.com.cn/chinese/zhuanti/feiyan/325381.htm. Accessed on February 1, 2020.
4.2. Variables and data sources

4.2.1. Dependent variable

The dependent variable is TFP. From the existing literature, TFP can be estimated using ordinary least squares (OLS), linear programming (LP) (Levinsohn & Petrin, 2003), ordered probit (OP) (Olley & Pakes, 1996), and generalized method of moments (GMM) (Blundell & Bond, 1998). The OP approach requires that the investment of an enterprise in each year must be greater than 0, which will cause the loss of many samples during the estimation. Therefore, TFP was estimated using the semi-parametric LP approach, following Lu and Lian (2012). Moreover, a robustness test was performed using OLS and GMM.

4.2.2. Control variables

We control for a variety of factors that the existing literature have found to influence enterprise TFP. First, following Chen et al. (2020), we include wages of employees (sa) and asset-liability ratio (loar) in control. Following Yuan and Gao (2019), Xiao and Xue (2019) and Jiang et al. (2020), we also control the age of the enterprise (age), financial expense ratio (fin_lev), fixed investment (inv) and subsidy income (lnsub_in) in regressions. The share of ownership matters, therefore we include the shares of government capital (soe_cap); the capital of Hong Kong, Macao, and Taiwan (for_cap); collective capital (coe_cap); and corporate and personal capital (pri_cap) in control (Yu et al., 2017).

In addition, to control the differences in local economic development, openness, human resources, infrastructure and industrial development, some provincial-level variables such as the natural log of GDP per capita (lnpgdp), adjusted for purchasing power parity (Jiang et al., 2020), trade openness (open), percentage of students in school (nustu), total length of inland waterways (riv) and proportion of the secondary industry in GDP (indse) (Wang & Yao, 2021) are added as controls which are sourced by the National Bureau of Statistics of China.

Considering the impact of China’s accession into the WTO since 2001, the financial crisis since 2008 and the comparable observation, the China Industrial Enterprise Dataset from 2001 to 2007 was employed in this study. We use the method of Brandt et al. (2012) to match balanced panel data by applying sequence recognition method. However, given that some key original indicators are missing or incorrect (Nie et al., 2012), the study adopts the following strategy. First, missing industrial added values in some years are calculated using the following formula: industrial added value = sales revenue + ending inventory – opening inventory + value-added tax – intermediate input (Liu & Li, 2008). Second, abnormal observed values, including total liabilities, sales revenue, and total assets less than 0, as well as the number of employees less than 8, are excluded from the dataset. Third, industrial added value, sales output, sales, and intermediate input are all deflated by the producer price index in 2001 to ensure the comparability of indicators in the sample. The producer price index comes from the China Statistical Yearbook. Finally, approximately 440,000 sample data were collected for this empirical analysis. Table 1 shows the statistics of the variables in the empirical analysis.

5. Empirical results

5.1. Benchmark regression

Table 2 reports the benchmark regression results of the impact of the SARS epidemic on the TFP of Chinese industrial enterprises based on Eq. (1). Columns (1) and (2) are the results from the OLS model. Columns (3) and (4) represent the results with fixed effects model.

Columns 2 and 4 of Table 2 show that the SARS epidemic has a highly significant impact on TFP, with a coefficient ranging from –3.12% to –5.81%. When control variables are not included (columns 1 and 3 of Table 2), the SARS epidemic still has a significantly negative impact on TFP. To be brief, these results confirm Hypothesis 1.

5.2. Dynamic impact over time

The analysis in Section 5.1 shows that the SARS epidemic significantly reduced the TFP of Chinese industrial enterprises during the
### Table 1
Descriptive statistics of variables.

| Variable | Definition | Observation | Mean      | S.D.    | Min      | Max      |
|----------|------------|-------------|-----------|---------|----------|----------|
| **Firm-level variables** |            |             |           |         |          |          |
| lntfp | Logarithm of TFP | 435,061 | 5.3249 | 1.1334 | -10.8635 | 13.5075  |
| fin_lev | The ratio of financial expense to total industrial output | 441,959 | 0.0234 | 0.6626 | -161.5542 | 284.9474 |
| lnsa | Logarithm of wages of employees | 443,768 | 7.4410 | 1.7495 | 0.0000 | 15.6234 |
| lnage | Logarithm of the age of the enterprise | 443,772 | 2.4535 | 0.7431 | 0.0000 | 6.0113 |
| lnar | The ratio of total assets to total liabilities | 443,529 | 0.5855 | 0.3257 | 0.0000 | 48.4623 |
| lninv | Logarithm of fixed investment | 443,763 | 9.0190 | 1.8038 | 0.0000 | 18.3392 |
| lnsub_in | Logarithm of subsidy income | 443,768 | 1.0207 | 2.3650 | -11.96 | 14.0224 |
| soe_cap | The ratio of government capital to paid-in capital | 441,509 | 0.1250 | 0.31552 | -3.1065 | 5.1876 |
| forcap | The ratio of Hong Kong, Macao, and Taiwan to paid-in capital | 441,509 | 0.1086 | 0.2887 | -0.4048 | 1.9725 |
| coe_cap | The ratio of collective capital to paid-in capital | 441,509 | 0.5611 | 0.4644 | -4.1876 | 7.2816 |
| pricap | The ratio of corporate and personal capital to paid-in capital | 441,509 | 0.1065 | 0.2884 | -0.9322 | 5.7827 |
| **provincial-level variables** |            |             |           |         |          |          |
| lnpgdp | Logarithm of GDP per capita | 443,772 | 9.7669 | 0.6070 | 8.0067 | 11.0078 |
| lnriv | Logarithm of the total length of sea network | 431,004 | 8.3559 | 1.3901 | 3.2591 | 10.1186 |
| lnspsu | The percentage of students in school | 443,772 | 13.2053 | 0.5768 | 8.8248 | 14.2024 |
| indse | The ratio of secondary industry in GDP | 443,772 | 49.2818 | 6.2422 | 20.2000 | 57.6000 |
| open | The ratio of total trade of GDP | 443,772 | 0.6545 | 0.5256 | 0.0418 | 1.6984 |

### Table 2
Impact of the SARS epidemic on TFP.

| Equation (1) | (2) | (3) | (4) |
|--------------|-----|-----|-----|
| Method | OLS | OLS | Fixed effect |
| time*treat | -0.0322*** | -0.0312*** | -0.0328*** |
| (0.00918) | (0.00873) | (0.00900) |
| fin_lev | -0.0522** | -0.0401*** |
| (0.0188) | (0.0153) |
| lnsa | 0.181*** | 0.116*** |
| (0.00212) | (0.00176) |
| lnage | 0.450*** | -0.421*** |
| (0.0714) | (0.109) |
| lnage2 | -0.255*** | 0.277*** |
| (0.0371) | (0.0614) |
| lnar | -0.216*** | -0.132*** |
| (0.0280) | (0.0256) |
| lninv | 0.0508*** | -0.0397*** |
| (0.00229) | (0.00256) |
| Soe_cap | -0.607*** | -0.601*** |
| (0.0142) | (0.0149) |
| Coe_cap | -0.136*** | -0.176 ***|
| (0.0126) | (0.0135) |
| pricap | -0.134*** | -0.204*** |
| (0.0105) | (0.0118) |
| For_cap | -0.205*** | -0.138*** |
| (0.0112) | (0.0112) |
| lnsub_in | 0.0271*** | 0.0206*** |
| (0.000980) | (0.000886) |
| lnpgdp | -0.0206 | 0.0807*** |
| (0.0208) | (0.0211) |
| lnriv | 0.0248*** | 0.0411*** |
| (0.00867) | (0.00933) |
| lnspsu | -0.0521 | -0.0816** |
| (0.0317) | (0.0381) |
| indse | 0.0308*** | 0.0337*** |
| (0.00126) | (0.00132) |
| open | -0.00814 | -0.0527*** |
| (0.0205) | (0.0223) |
| Constant | 5.248*** | 3.140*** |
| (0.0317) | (0.346) |
| Province fixed | YES | YES | YES |
| Time fixed | YES | YES | YES |
| Industry fixed | YES | YES | YES |
| N | 435061 | 419061 | 435061 |
| R² | 0.088 | 0.225 | 0.062 |

Note: *** *, **, and * indicate significance at the 1 %, 5 %, and 10 % levels, respectively. Numbers in brackets are clustered robust standard errors.
study period. However, we do not have any idea of the dynamic impact of SARS from 2003 to 2007. Following Chen et al. (2021), we employ Eq. (2) to test the dynamic impact of SARS on TFP.

\[
\ln \text{tfp}_{pt} = \beta_0 + \sum_{t=0}^{5} \beta_t \text{time}_t \cdot \text{treat}_p + \lambda X + \phi p + \gamma_k + \eta_t + \epsilon_{pt}
\]

where \(\text{time}_t\) is the dummy variable defined for a specific period after the event date, and therefore the coefficient \(\beta_t\) captures the impact on TFP during the corresponding post-SARS period.

Table 3 shows the result. In columns (1) to (5), the interaction terms between each the year dummy variable and the dummy variable of severely affected areas are put into regression in order to reduce the possible multiple-collinearity of them, while the standard dynamic DID model in Eq. (2) is shown in column (6).

Column (1)-(6) of Table 3 show that the impact of the SARS epidemic on TFP is significantly negative in 2003 but becomes significantly positive in 2004. It turns negative again and increases in magnitude from 2005 to 2006, decreasing after 2007.

Regarding the positive coefficient in 2004, we believe that this is a natural result in China because after the outbreak of SARS, the Chinese government rolled out several fiscal and monetary policies for enterprises in seriously affected by SARS. For example, the State Council issued a policy on 9 May 2003 that exempted and reduced administrative institutional fees for certain industries until September 30, 2003. Meanwhile, the Ministry of Finance also reduced and exempted businesses in service industries from the urban utility surtax, the urban and local educational surtax from May 1 to September 30, 2003. However, those one-time policies did not offset 100% the side impact of SARS on TFP. Therefore, we still see significant negative impacts of SARS on TFP in 2005–2007. This indicates that the SARS epidemic had a non-linear long-run impact on TFP even though SARS was a once in a lifetime shock for the economic system.

In addition, we test dynamic effects using another approach by Kerr and Nanda (2009). To do so, we first create a new dummy “years since SARS” which is equal to zero before 2003, and equal to 1,2,3,4,5 since 2003. Then, we multiply it with “treat”. The new result in Column (7) of Table 3 shows that the SARS has a lasting negative impact on firms’ TFP.

In brief, the above findings confirm Hypothesis 2.

5.3. Cross-industry heterogeneity

Regarding industrial heterogeneity, our data is divided into labor intensive, capital intensive and life necessary industries by two-digit industry codes. We find the following interesting information from Table 4. First, the SARS epidemic has a significantly negative impact on labor intensive industries, such as food manufacturing, textile, furniture manufacturing, printing and record medium reproduction, paper-making and paper products, with a coefficient of approximately –8.35% to –25.1%.

Second, most of the capital and technology intensive industries with high automation level are negatively affected by SARS, however the impacts are slightly lower than labor intensive industries. For example, the coefficients for chemical raw materials and chemical products, rubber products, plastic products, non-metallic mineral products, metal products, general equipment manufacturing, transportation equipment manufacturing and electric equipment and machinery range from –6.89% to –19.6%.

Third, the SARS epidemic also has a significantly positive impact on the tobacco industry. One possible reason is that there was

| Table 3 |
| Temporal dynamic of the impact of the SARS epidemic. |
| Equation | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Method | Treat* 2003 | -0.0474 * ** (0.00805) | 0.0900 * ** (0.00999) | -0.0301 * ** (0.00836) | -0.0519 * ** (0.00699) | 0.0460 * ** (0.00732) | 0.0274 * ** (0.00299) |
| Treat* 2004 | Treat* 2005 | Treat* 2006 | Treat* 2007 |
| Treat* 2007 | Treat *Years since SARS |
| Constant | 4.909 * ** (1.210) | 4.677 * ** (1.212) | 4.491 * ** (1.211) | 4.335 * ** (1.211) | 4.478 * ** (1.210) | 4.239 * ** (1.225) |
| Control variables | YES | YES | YES | YES | YES | YES | YES |
| Province fixed | YES | YES | YES | YES | YES | YES | YES |
| Time fixed | YES | YES | YES | YES | YES | YES | YES |
| Industry fixed | YES | YES | YES | YES | YES | YES | YES |
| N | 419061 | 419061 | 419061 | 419061 | 419061 | 419061 | 419061 |
| R2 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 |

Note: (1)***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. (2) Numbers in brackets are clustered robust standard errors (3) Control variables are the same as in Table 2.
hearsay that smoking helps prevent SARS (Chen et al., 2003). Another reason is that when crises affect people’s lives and communities, people may engage in different negative coping strategies, including using tobacco. In addition, some industries necessary for production and life such as water industries and waste resources and materials recycling industries do not suffer but receive some benefit. Their coefficients are positive though their significance is not that strong. We believe that this is because these industries are financed by the government and Chinese government took some measures to stabilize urban life and public utility. For example, Ministry of Housing and Urban-Rural Development of the PRC has issued a national notice that water supply and drainage enterprises must ensure the disinfection of water plant production areas and water supply facilities, strengthen the prevention and control management of domestic sewage and pay high attention to the operation of water supply system and the stability of urban water supply during SARS epidemic. In short, the above results support Hypothesis 3.

5.4. Mechanism test

In this section, we use the per capita industrial added value (\(\ln lnapro\)) to measure labor productivity, and use the output value of new products (\(\ln newp\)) to measure the innovation capability of enterprises for mechanism test.

The regression results based on mediating variables are shown in Table 5. Column (1) reports the same results in columns (2) of Table 2. The results from Column (2) and (3) reveal that the SARS epidemic cause a significant reduction in labor productivity by 8.47% and the output value of new products by 31.5% at the 1% statistical level. Column (4) shows that when the labor productivity and the output value of new products are considered simultaneously, the SARS impact coefficient still has the same direction, with a decrease in magnitude, and an increase in \(R^2\). It indicates that reduction in labor productivity and less technological innovation partially mediated the impact of SARS on TFP, thus confirming Hypothesis 4.

Note: (1) *, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. (2) Numbers in brackets are clustered robust standard errors. (3) Control variables are the same as in Table 2.

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### Table 5

| Industry Description | time*treat | Control variables | Province fixed | Time fixed | Industry fixed | Constant | \(N\) | \(R^2\) |
|-----------------------|-------------|-------------------|----------------|-------------|---------------|----------|------|------|
| Labor Intensive Industries | Food manufacturing | -0.135 * | YES | YES | YES | NO | 2.399 | 8724 | 0.126 |
| | Textile | -0.0835 * | YES | YES | YES | NO | 1.996 | 32380 | 0.128 |
| | Furniture manufacturing | -0.147 * | YES | YES | YES | NO | 0.634 | 3915 | 0.124 |
| | Printing and record medium reproduction | -0.251 ** | YES | YES | YES | NO | -0.656 | 7700 | 0.094 |
| | Handicraft and others | -0.249 ** | YES | YES | YES | NO | 5.125 | 8584 | 0.105 |
| | Plastic products | -0.103 ** | YES | YES | YES | NO | -1.260 | 18295 | 0.097 |
| | Rubber products | -0.118 * | YES | YES | YES | NO | -1.656 | 5138 | 0.110 |
| Capital and technology intensive industries | Metal products | -0.0885 * | YES | YES | YES | NO | 0.830 | 20149 | 0.120 |
| | Chemical raw materials and chemical products | -0.0690 * | YES | YES | YES | NO | -1.442 | 30179 | 0.162 |
| | Non-metallic mineral products | -0.105 ** | YES | YES | YES | NO | -2.921 * | 34552 | 0.114 |
| | General equipment manufacturing | -0.196 ** | YES | YES | YES | NO | 5.210 * | 30392 | 0.141 |
| | Transportation equipment manufacturing | -0.0990 * | YES | YES | YES | NO | -0.247 | 19157 | 0.152 |
| | Electric equipment and machinery | -0.0689 * | YES | YES | YES | NO | 3.950 * | 26087 | 0.156 |
| Industries necessary for production and life | Tobacco products | 0.375 * | YES | YES | YES | NO | 6.041 | 485 | 0.637 |
| | Water production and supply | 0.104 * | YES | YES | YES | NO | 2.836 | 6789 | 0.200 |
| | Waste resources and materials recycling | 1.195 ** | YES | YES | YES | NO | 1.372 | 220 | 0.376 |

Note: (1) *, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. (2) Numbers in brackets are clustered robust standard errors. (3) Control variables are the same as in Table 2.

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8 See https://www.h2o-china.com/news/17233.html. Accessed on May 14, 2003.
5.5. Robustness test

5.5.1. Parallel trend test

The parallel trend assumption is an identifying requirement for running DID. To prove the parallel trend, we employ two different methods. Firstly, following Schnabl (2012) and Fu et al. (2015), samples before the SARS outbreak were retained while samples after the SARS were cancelled, it can be seen from the results in column (1) in Tables 6 and 7 that the coefficient of the SARS epidemic is not significant, indicating that there is no difference between the treatment group and the control group in years before the SARS epidemic. Secondly, a more formal approach is to draw dynamic impact analysis based on Cornaggia, Mao, and Tian (2015). Column (2) of Table 6 show that the coefficient of the interaction item is not statistically significant in 2001 but becomes significantly positive in 2002 and 2004, and become significantly negative after 2005. The reason behind the positiveness may be the positive impact brought by China’s WTO accession. Fig. 6 shows a drastic falling-down trend of the average import tariffs for all products in China since 2002. Upon this tariff reduction, new foreign firms with high productivity have entered into Chinese market, at the same time the competition among Chinese and foreign firms also forms a positive productivity spillover on Chinese industrial enterprises (Brandt et al., 2012; Jian et al., 2014). Anyway, the SARS epidemic in 2003 was indeed an important time cutoff for the positive and negative

### Table 5
Mechanisms mediating the impact of SARS on TFP.

| Equation | Dependent variable | (1) | (2) | (3) | (4) |
|----------|--------------------|-----|-----|-----|-----|
| lntfp    | Time*treat        | -0.0581*** | -0.0847*** | -0.315*** | -0.0215*** |
|          |                   | (0.00875)  | (0.00833)  | (0.0235)  | (0.00540)  |
| lnlapro  |                   | 0.851***  | 0.0188***  | 0.00231   | 0.000481   |
|          |                   | (0.00041)  | (0.00048)  | (0.00041) | (0.00048)  |
| lnnewp   |                   | 4.069*** | 4.847*** | 5.176*** | -0.689*** |
|          |                   | (1.205)  | (1.422)  | (1.548)  | (0.258)   |
| Control variables | YES | YES | YES | YES | YES |
| Province fixed | YES | YES | YES | YES | YES |
| Time fixed | YES | YES | YES | YES | YES |
| Industry fixed | YES | YES | YES | YES | YES |
| N        | 419061            | 419598 | 365849 | 361376 |
| R²       | 0.125             | 0.113  | 0.047  | 0.728  |

Note: (1) * **, * *, and * indicate significance at the 1%, 5%, and 10% levels, respectively. (2) Numbers in brackets are clustered robust standard errors. (3) Control variables are the same as in Table 2.

### Table 6
Parallel trend test and Robustness analysis of TFP.

| Equation | (1) | (2) | (3) | (4) | (5) |
|----------|-----|-----|-----|-----|-----|
| Method   | Parallel trend test | Parallel trend test1 | Add WTO | OLS | GMM |
| Time*treat | 0.0170 | 0.0170 | -0.0581*** | -0.0601*** | -0.0572*** |
|          | (0.0187) | (0.0187) | (0.00875) | (0.00740) | (0.00878) |
| Treat* 2001 | 0.0221 | 0.0221 | 0.110*** | 0.110*** | 0.110*** |
|          | (0.0144) | (0.0144) | (0.00794) | (0.00794) | (0.00794) |
| Treat* 2002 | 0.108*** | 0.108*** | 0.0109 | 0.0109 | 0.0109 |
|          | (0.0074) | (0.0074) | (0.0166) | (0.0166) | (0.0166) |
| Treat* 2005 | -0.110*** | -0.110*** | -0.125*** | -0.125*** | -0.125*** |
|          | (0.0166) | (0.0166) | (0.0161) | (0.0161) | (0.0161) |
| Treat* 2006 | -0.117*** | -0.117*** | -0.117*** | -0.117*** | -0.117*** |
|          | (0.0157) | (0.0157) | (0.0157) | (0.0157) | (0.0157) |
| Constant | -5.767 | -5.767 | 4.419*** | 2.807 * | 4.057*** |
|          | (5.514) | (5.514) | (1.217) | (1.478) | (1.201) |
| Control variables | YES | YES | YES | YES | YES |
| Province fixed | YES | YES | YES | YES | YES |
| Time fixed | YES | YES | YES | YES | YES |
| Industry fixed | YES | YES | YES | YES | YES |
| N        | 120369 | 120369 | 419061 | 419061 | 419061 |
| R²       | 0.122 | 0.122 | 0.125 | 0.125 | 0.125 |

Note: (1) * **, * *, and * indicate significance at the 1%, 5%, and 10% levels, respectively. (2) Numbers in brackets are clustered robust standard errors. (3) Control variables are the same as in Table 2. (4) WTO accession measures: the value of is set to 1 for 2002 and later years; otherwise, it is 0.
changes of TFP in Chinese industrial enterprises. In addition, a potential concern could be that our finding is driven by the effect of WTO accession. Therefore, we perform one more robust test, in which we add the WTO accession dummy into our main regression. As shown in column (3) of Table 6, the impact of the SARS epidemic on TFP are still robust. The results of previous regressions in Tables 2, 3, 4 and 5 are also very consistent even considering the WTO accession impact.

5.5.2. Estimation of TFP by OLS and GMM

Except for parallel test, Table 6 reports the regression results with TFP estimated by OLS and GMM method. We find that the coefficients of our core explanatory variable in Table 6 are still very consistent with the benchmark regression in Table 2, which indicates that the use of a different method for estimating the dependent variable does not affect the estimation results.

5.5.3. Placebo test

Furthermore, we use two placebo tests to do our robust checks. First, we assume that the SARS epidemic occurred in 2002 instead of 2003. The result in column (2) shows that the coefficient of SARS is insignificant as expected.

Second, 10 provinces or municipalities of less affected areas are randomly selected and falsely considered as severely affected areas. The results are shown in Tables 8a and 8b. We find that the coefficients in these cases are also not significant, which confirms our finding in Table 2 again.

5.5.4. PSM

Except for the above robust checks, we also employ the propensity score matching (PSM) to eliminate possible bias from confounding variables in the original observed data. First, we choose all variables representing firm characteristic as covariates. Second, we use the nearest-collor matching technique to match the pairs according to the standard of 1:1 to assess whether the values of the covariates are significantly different between the treatment and the control group. This situation results in a 2.98% loss of sample size. Our result is shown in Fig. 7 which shows that the deviations of each variable between the two groups are significantly reduced. Table 9 shows the regression results with TFP estimated by OLS and GMM method. We find that the coefficients of our core explanatory variable in Table 6 are still very consistent with the benchmark regression in Table 2, which indicates that the use of a different method for estimating the dependent variable does not affect the estimation results.

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PSM

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shows results using a paired sample. The coefficients still have the same direction and comparable significance level. This confirms our empirical findings again.

6. Conclusion and policy recommendations

In summary, the study reached the following conclusions: (1) The SARS epidemic has a significantly negative impact on the TFP of Chinese industrial enterprises, resulting in approximately a 3.12–5.81 % reduction. (2) This impact of SARS is non-linear and lasts for some years. The impact of SARS is negative in the first year, turns positive in the second year, and repeatedly negative in the third, fourth, and fifth years. (3) Regarding cross-industry heterogeneity, the SARS epidemic has a significantly negative impact in labor-intensive industries, with a coefficient of approximately 8.35 % to 25.1 %. However, capital and technology intensive industries was less affected, with a coefficient ranging from 6.89 % to 19.6 %. Contrarily, the SARS epidemic had a significant positive impact on TFP in industries necessary for production and life. (4) Regarding the mechanism, we find that the SARS epidemic might lead to a reduction in labor productivity and a decrease in innovation, where both play a significant role in stunting TFP. (5) The robustness tests demonstrate that our conclusions are not affected by the TFP methodology or the degree of sample matching. The counterfactual placebo tests also indicate that the time setting and classification of severely affected and less affected areas in this study are reasonable.

Similar to SARS, COVID-19 is a major public health crisis which has already been the largest most severe shock to the world. The number of COVID-19 infections and deaths is much higher than that of SARS, and the duration of the COVID-19 outbreak is also longer than that of SARS. More importantly, the COVID-19 is more contagious than SARS. Undoubtedly, examining the impact of the SARS epidemic could be a big help to the world in many dimensions.

First, the government is the important player in dealing with the economic difficulties caused by the crisis. Short- and long-term policy response should be equally addressed. In the short term, tax reduction and exemptions, financial support, employment and production stabilization should be the focus of the government’s response. More targeted responses should be used in country practices since equal responses and measures will not work effectively in severely affected and less severely affected areas. In the long term, the government should protect and even improve the innovation capacity of enterprises through targeted subsidies, R&D subsidies and tax incentives in crisis.

Second, enterprises should strengthen their awareness of the epidemic response and rationally arrange capital allocation to avoid reducing necessary R&D investment due to additional costs. In addition, enterprises can also appropriately increase their compensation or additional welfare to encourage employee to improve productivity. Finally, as individuals, we should tame the anxiety caused by the epidemic and build up own personal resilience and maintain good relationships with colleagues in pandemic.

Declaration of Interest

No interests to declare.

Table 8

| Equation | (1) | (2) | (3) | (4) | (5) |
|----------|-----|-----|-----|-----|-----|
| Dependent variable | lntfp | lntfp | lntfp | lntfp | lntfp |
| Time*Treat | 0.0221 | 0.0105 | 0.0227 | 0.0137 | 0.0134 |
| Constant | 4.461*** | 4.567*** | 4.435*** | 4.565*** | 4.505*** |
| Control variables | YES | YES | YES | YES | YES |
| Province fixed | YES | YES | YES | YES | YES |
| Time fixed | YES | YES | YES | YES | YES |
| Industry fixed | YES | YES | YES | YES | YES |
| N | 419061 | 419061 | 419061 | 419061 | 419061 |
| $R^2$ | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 |

Note: (1)* ** *, * *, and * indicate significance at the 1 %, 5 %, and 10 % levels, respectively. (2)Numbers in brackets are clustered robust standard errors. (3) Control variables are the same as in Table 2.
Data Availability

Data will be made available on request.

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