

# Technical efficiency and technology gap of the manufacturing industry in China: Does firm ownership matter?

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## **Abstract**

China's manufacturing industry has undergone intense structural change during the enterprise reform. The waxing of private and foreign-owned firms and the waning of state-owned and collective firms are accompanied by dramatic technological upgrading and productivity growth. We study how ownership type affects technical efficiency and technological advancement in China's industrial sectors using detailed firm-level data. By employing a metafrontier-based technique, we are able to account for technology heterogeneity in ascertaining four types of firm ownership in 30 manufacturing sectors. The robust data envelopment analysis offers estimation flexibility and enables us to mitigate data problems. Our results confirm that firm ownership is important in explaining technical efficiency and technology gap among Chinese firms. We show that foreign-owned firms set the standard for technical efficiency and are technology leaders. Private ownership is found to dominate state as well as collective ownership in both technical efficiency and technology gap. Over time, foreign-owned firms take the lead in efficiency improvement and private firms contribute to technology advancement. We also find that China has successfully revitalized state-owned firms, although room for improvement remains. Lastly, we find evidence that China has successfully stimulated technology progress in almost all industrial sectors. We contribute to the literature by using a nonparametric estimation method that assumes technology heterogeneity when firms are partitioned into hierarchical categories. Our study also has rich policy implications on China and other transit economies.

**Key words:** technical efficiency; technology gap; metafrontier; data envelopment analysis; manufacturing industry.

## Highlights

- We find that private ownership is superior to state and collective ownership in technical efficiency and technology level.
- We demonstrate that foreign ownership has the best technical efficiency and the highest technology level.
- Foreign-owned firms achieve substantive improvement in technical efficiency, whereas technological progress is strongest in private firms.
- China's enterprise reform stimulates efficiency improvement among state-owned firms, but we find no evidence of technological progress among them.
- We observe widespread technological progress among Chinese firms in almost all industrial sectors.

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# 1 Introduction

In the past 40 years, researchers witnessed profound structural transformations in China’s manufacturing industry. Prior to 1978, China was an absolute planned economy dominated by state-owned enterprises (SOEs). From the 1980s to the early 2000s, a series of policy interventions transformed the ownership structure of the industry, resulting in a hybrid structure that distinguishes China from any other major economy. Indigenous private firms have overtaken SOEs in industrial output and R&D activity (Boeing, Mueller, & Sandner, 2016; Brandt, Van Biesebroeck, & Zhang, 2012); foreign-owned firms play a critical role in technology transfer and economic growth (Holmes, McGrattan, & Prescott, 2015; Whalley & Xian, 2010). Although outnumbered, state-owned firms (as well as collective firms) still constitute a large fraction of industrial employment and output (Hsieh & Song, 2015).

China’s experience provides researchers a unique opportunity to inquire into the role of ownership in firm performance. In this study, we investigate the technical efficiency and technology gap of different ownership types using firm-level data for 1999–2007 on 30 industrial sectors. In particular, we employ data envelopment analysis (DEA) to construct our measures of efficiency and technology gap. DEA, first presented by Charnes, Cooper, and Rhodes (1978), has the advantage of disentangling (in)efficiency from technology potential (Bos, Economidou, & Koetter, 2010; Bos, Economidou, Koetter, & Kolari, 2010). Compared with conventional parametric methods, DEA is attractive because it does not assume *a priori* any functional form for the technology, which is usually restrictive.<sup>1</sup> For these reasons, DEA is widely used to compare the efficiency of decision making units (DMUs) under the common-technology assumption.<sup>2</sup> A second strand of the DEA literature, pioneered by Färe, Grosskopf, Norris, and Zhang (1994) and Chambers, Färe, and Grosskopf (1996), extends the basic DEA methodology to decompose productivity growth into efficiency change and technological progress. In particular, panel data are used to construct a production frontier that is common to all DMUs but shifts over time.<sup>3</sup> Following these traditions, we compare the performance of different ownership types in the cross-section, and we also study the way their performance evolves over time.

The main distinguishing feature of our empirical study is recognizing heterogeneity in technology. Given their unique operation modes, firms of each ownership type arguably possess a distinct technology, and hence, a uniform treatment may not be appropriate.<sup>4</sup> A similar problem exists for industrial sectors. Unfortu-

nately, existing empirical studies, such as those of A. Zhang, Zhang, and Zhao (2001), Boeing et al. (2016), and Berkowitz, Ma, and Nishioka (2017) generally ignore the potential differences in the technologies employed by different ownership types or industrial sectors in assessing their relative performance. As a major departure from the extant literature, our analysis employs the concept of metafrontier developed by Battese and Rao (2002).<sup>5</sup> The concept of metafrontier has been suggested when firms are split into different groups. In the present study’s context, the metafrontier enables us to construct efficiency and technology measures that are comparable across ownership types and industrial sectors while controlling for technology heterogeneity. Metafrontier-based techniques have been widely used in the context of China. Recent studies include those of K.-H. Chen and Yang (2011) and T.-T. Fu, Juo, Chiang, Yu, and Huang (2016) on the banking sector; K. Du, Lu, and Yu (2014) and N. Zhang and Wei (2015) on CO2 emission; Lin and Zhao (2016) on the textile sector; and Fei and Lin (2017) on the agricultural sector. These studies generally use macro-level data and employ a single criterion to define groups. In contrast, our study employs firm-level data and partitions firms according to two criteria.

To date, metafrontier-based techniques have not been defined when partitioning firms into hierarchical categories (for this empirical study, into different ownership types within each industrial sector). Since we investigate the technical efficiency and technology gap of firms in every sector when distinguishing between ownership types, we extend the concept of metafrontier in that direction. This extension is particularly relevant when firms are further divided into subgroups within every group, as in our empirical study. Attractively, this option is introduced by a simple modification of the initial concept of metafrontier as defined by Battese and Rao (2002). Thus, our extension, while remaining consistent with previous works, offers the extra advantage of taking additional heterogeneity of the firms into account. Thus, we also contribute to the literature on metafrontier methods.

The rest of the paper is organized as follows. The next two subsections introduce the background of China’s industrial reform and review the literature on the ownership–efficiency linkage. In Section 2, we define our concepts of technical efficiency and technology gap by considering ownership type and sectoral difference. In Section 3, we evaluate the technical efficiency and technology gap of the manufacturing sectors in China. In Section 4, we present our conclusions.

## 1.1 Background

The first stage of China’s industrial reform was launched in the early 1980s. The contract responsibility system and dual price system are regarded as the two major institutional innovations of this period (Jefferson & Rawski, 1994). Under the former, the manager, the managerial group, and sometimes the entire work force signed a contract with the State over a specific output or profit target. In exchange, the firms gained greater sovereignty over operational decisions; in addition, they were allowed to retain excess outputs or profits. The dual price system allowed firms to exchange a portion of their outputs and inputs at market prices. With these measures, managers were given more autonomy even though the state withheld ownership rights. This period also witnessed the proliferation of collective firms, which were “quasi-state-owned” firms under the control of local government officials (Putterman, 1995, p. 1052). Their entry resulted in fierce competition that eroded SOE profits (Naughton, 1994). However, at this stage, the size of the private sector, including foreign ownership, was very small (Jefferson & Rawski, 1994).

The landmark event of the second-stage reform was Deng Xiaoping’s south tour in 1992, during which he encouraged the development of private ownership and the market economy. Foreign direct investment (FDI) surged, and the *Company Law* was passed in 1993, establishing the legal status of private firms. This period witnessed unprecedented growth of private and foreign-owned firms.<sup>6</sup> In an effort to revitalize SOEs, in 1997, the 15th Congress of the Communist Party enacted the policy known as “grasp the large and let go of the small” (Hsieh & Song, 2015, p. 299), which means to corporatize large SOEs and to privatize or shut down small and loss-making SOEs. From 1998 to 2007, more than 83% of SOEs were shut down or privatized, with a greater numbers of smaller ones shut down than larger SOEs (Hsieh & Song, 2015). Meanwhile, most collective firms underwent a similar privatization movement (Kung & Lin, 2007; Xia, Li, & Long, 2009). The waxing of private and foreign-owned firms and the waning of state-owned and collective firms is the major characteristic of the second-stage industrial reform.

The third-stage enterprise reform aimed to centralize state ownership among large SOEs. Until the early 2000s, multiple government agencies controlled each SOE.<sup>7</sup> These government agencies sometimes had conflicting interests, resulting in low management efficiency. To break through the multiple-management framework, the State-Owned Asset Supervision and Administration Commission (SASAC) was established in 2003. The SASAC has two objectives: to exercise

state ownership rights and to maintain and improve the value of state assets. As of 2003, a total of 196 central SOEs were affiliated to the central SASAC, amounting to 29% of state industrial employment and 43% of total industrial assets (Naughton, 2006). As Naughton (2006) points out, the mission of SASAC is to improve the governance, transparency, and ultimately, the performance of major SOEs.

Thirty years of continuous reform left China with hybrid ownership of industry: a state sector that is under firm control by the SASAC, a downsized collective sector, and flourishing private and foreign-owned sectors. As of 2007, the output shares were 17.9% (state), 6.8% (collective), 41.0% (private) and 34.3% (foreign).<sup>8</sup>

In addition to SOE reforms, Chinese policymakers have pursued various industrial development plans to enhance the technology content of the manufacturing industry. In 2009, the State Council (SC) decreed the Restructuring and Revitalization Plans for 10 “mainstay” sectors, nine of which belong to manufacturing.<sup>9</sup> Other pilot plans compiled by the SC and the National Development and Reform Commission (NDRC) include the *National Industrial Policy Outline of the 1990s* (1994 by SC), the *Catalog of Industries, Products, and Technologies That Are Currently Particularly Encouraged by the State* (2000 by NDRC), and subsequently the *Catalog for Guiding Industrial Restructuring* (2005, 2011, and 2013 by NDRC). These pilot plans target either large industrial sectors or sectors of high technology content.

## 1.2 Theory and empirical evidence

The choice between public and private provision of goods and services is always under debate. Arguments for government intervention include the need to regulate monopolies, to deal with externalities, and to provide public goods. Under these market failures, state ownership will increase efficiency over private ownership (Megginson & Netter, 2001).

Sappington and Stiglitz (1987) highlight that private ownership and state ownership are quite similar in the sense that they both involve significant delegation of authority. They propose a fundamental privatization theorem stating that under ideal conditions, the government can achieve the same objectives (i.e., efficiency, equity, and rent extraction) by contracting production to private firms. They discuss several conditions under which these objectives may not be achieved, some with unambiguous implications on the public–private choice debate: That is, government provision (state ownership) is superior if the government is more

tolerant to risk than private producers, if the government has superior knowledge of the production process, if the contracting cost is high, or if the knowledge about the government's benefit is limited; conversely, private provision is preferred if the government's commitment ability with private firms is stronger than with state-owned firms, or if state-owned firms face hierarchical controls. Shleifer and Vishny's (1997) interpretation is based on the agency problem. They point out that a firm's management, whether state-owned or private, inevitably has substantial residual control rights because of incomplete contract; failing to align management behavior with stakeholder interests (i.e., the public or the shareholders) results in efficiency loss. They acknowledge that state ownership is better than concentrated private ownership in the case of monopoly power, externalities, or distributional issues because the concentrated private shareholder will be overly focused on profit maximization, leaving too few rents for other stakeholders (i.e., managers, workers, and consumers). However, they also express deep concern about state ownership. They point out that state-owned firms are controlled by bureaucrats with extremely concentrated control rights but very little cash flow rights; to make things worse, these bureaucrats typically have goals that are very different from promoting social welfare. Such a combination results in highly inefficient outcomes. Bai, Li, Tao, and Wang (2000) attack this problem from a different angle. They highlight that Chinese SOEs engage in multitasking because they must provide social welfare (employment) apart from meeting profit objectives. Consequently, their financial performance must be poorer than that of private firms. Although their argument is focused on profits, their model shows that state-owned firms must be less efficient since they hire extra labor. To summarize, the choice between state and private ownership is so controversial that Laffont and Tirole (1993) conclude, "theory alone is thus unlikely to be conclusive in this aspect" (p. 654).

In this regard, empirical studies find mixed results. Early studies focusing on productivity or profitability generally find that private ownership outperforms state ownership; these include studies by Boardman and Vining (1989) on the productivity of manufacturing and mining firms; Ehrlich, Gallais-Hamonno, Liu, and Lutter (1994) on the productivity of airlines; and Dewenter and Malatesta (2001) on the profitability of industrial companies. However, using a sample of 17 state-owned firms, Kole and Mulherin (1997) find that state ownership does not affect firms' accounting performance. When the sample is expanded to include more sectors, and when more efficiency measurements are introduced, empirical studies generate conflicting results. For example, Barbetta, Turati, and Zago

(2007) analyze technical efficiency of Italian hospitals and find that public hospitals are, on average, less efficient than private ones; but neither Alexander and Lee (2006) nor Bøgh Andersen and Blegvad (2006) find significant differences in cost efficiency between public and private health care facilities. As regards the water supply industry, many early studies based on US data (Bhattacharyya, Harris, Narayanan, & Raffiee, 1995; Bhattacharyya, Parker, & Raffiee, 1994; Lambert, Dichev, & Raffiee, 1993) find that public provision is more efficient than private provision, whereas more recent studies based on extended data sources (Da Silva e Souza, De Faria, & Moreira, 2007; Estache & Rossi, 2002; García-Sánchez, 2006) find no systematic difference in efficiency.

China's state-owned firms and collective firms fit Shleifer and Vishny's (1997) description quite well—they were under the control of bureaucrats with extremely concentrated control rights but limited cash flow rights. Therefore, we expect the state-owned firms to be less efficient than private firms. The 2003 reform centralized state ownership of large SOEs under the SASAC, which is more concerned about economic objectives. According to Sappington and Stiglitz (1987) and Bai et al. (2000), we should expect an efficiency boost among these state-owned firms after the reform. Therefore, we have our first two hypotheses:

**Hypothesis 1** *State-owned firms and collective firms are less efficient than private firms.*

**Hypothesis 2** *After the third-stage enterprise reform in 2003, there is a boost in the efficiency of some state-owned firms but not of collective firms.*

The debate regarding foreign ownership is much less. First, according to the traditional theory of multinational enterprises (Dunning, 1981; Helpman, Melitz, & Yeaple, 2004; Markusen, 2004), factors such as the language barrier and lack of local business networks put foreign firms at a disadvantage. To compete with local firms, multinationals must have an ownership advantage: a product or a production process or a management technique that can be shared with its foreign affiliates and that gives them some market power advantage in foreign markets. Therefore, foreign-owned firms are expected to be more productive than domestic firms. Using data from developed countries as well as developing countries, empirical findings generally support this view (Aitken & Harrison, 1999; Doms & Jensen, 1998; Harris & Robinson, 2003). Second, multinationals may systematically choose more productive domestic firms for acquisition, resulting in more productive affiliations (Criscuolo & Martin, 2009). Third, even if domestic firms

are mediocre prior to acquisition, after the acquisition the multinationals may introduce new technology or production restructuring to the affiliates; the multinationals may also provide access to the export market, which enables the affiliates to explore economies of scale, resulting in productivity gains (Aitken & Harrison, 1999; Girma & Görg, 2007). The latter two forces are often found to play at the same time (Arnold & Javorcik, 2009; Guadalupe, Kuzmina, & Thomas, 2012). In the long run, the productivity advantage of foreign-owned firms established earlier may subside because domestic firms may improve their productivity through imitation, labor market exchange, and general spillover effects. However, in a dynamic setting, continuing FDI may maintain the productivity advantage of the foreign-owned firms, on average (Harris & Robinson, 2003). Based on these arguments, we have our third hypothesis:

**Hypothesis 3** *Foreign-owned firms are more efficient than indigenous private firms.*

Recent empirical studies on China's industry document strong productivity growth (e.g., Berkowitz et al., 2017; Brandt et al., 2012; Hu, Xu, & Yashiro, 2015). This growth could be the result of efficiency improvement, or technological progress, or both. Hsieh and Klenow (2009) suggest that efficiency improvement can be achieved by resource reallocation from less efficient firms to more efficient ones. Based on the fact that state and collective firms were overtaken by private and foreign-owned firms in industrial output and employment, this argument can be indirectly tested by Hypotheses 1–3. However, technological progress remains to be verified. Empirical evidence is limited on this aspect. Based on provincial aggregate data, Henderson, Tochkov, and Badunenko (2007) estimate that China's average annual technical change rate was 5.5% during 1978–2000. Using similar data, Badunenko and Tochkov (2010) report that this rate was 6.82% in 1998–2003. X. Fu and Gong (2011) estimate the average annual technical change rate for China's industry during 2001–2005 using firm-level data, and their estimate is 5.1%. These findings motivate us to posit the following hypothesis:

**Hypothesis 4** *China's industrial sectors experienced net technological progress during the study period.*

Although Hypothesis 4 is not our main interest, we note that technological progress combined with efficiency improvement implies productivity growth.

## 2 Method

We assume that we observe firms from  $I$  industrial sectors. Moreover, we assume that each sector is composed of  $K_i$  groups, for  $i = 1, \dots, I$ . Note that we do not impose the condition that the sectors—or even the groups—should contain the same number of firms; that is, we consider unbalanced panels, as in our empirical investigation in Section 3. In every sector  $i = 1, \dots, I$  and group  $k = 1, \dots, K_i$ , firms use  $P$  production factors, captured by  $\mathbf{x}_{ik}$ , to produce one output, captured by  $y_{ik}$ . As discussed in the Introduction, our aim is to define measurements of technical efficiency and technology gap at two levels: between sectors and when discriminating between firm ownership types in each sector. Typically, technical efficiency and technology gap can be defined in two ways: input or output orientation. Given this study’s context, we believe that using output orientation is more natural. By doing so, we recognize that the aim of the firms or sectors is to reach the highest output or economic growth for a fixed amount of inputs.<sup>10</sup> Thus, we define our concepts in terms of potential output or potential economic growth.

We start by defining the technology and the notion of potential outputs. Next, we define the technical efficiency and technology gap indicators. Finally, we show how our different indicators can be computed by means of linear programs. For the sake of compactness and to improve the readability of our exposition, we do not explicitly add a subscript for the period for the concepts defined below, but a point to note is that these are all time dependent.

### 2.1 Define the technology

We define the technology in terms of output requirement sets for every period. Given our setting, we distinguish between three levels: each group in every sector; each sector; and when considering all sectors. The output requirement set for group  $k$  in sector  $i$  is defined as follows:

$$P_{ik}(\mathbf{x}_{ik}) = \{y \mid \mathbf{x}_{ik} \text{ can produce } y \text{ in group } k \text{ and sector } i\}. \quad (1)$$

The set  $P_{ik}(\mathbf{x}_{ik})$  contains the output quantities that can be produced by inputs  $\mathbf{x}_{ik}$  for a specific period. We label this set the sector-group technology set of group  $k$  and sector  $i$ . Next, the output requirement set in sector  $i$  is given by:

$$\begin{aligned} P_i(\mathbf{x}_{ik}) &= \{y \mid \mathbf{x}_{ik} \text{ can produce } y \text{ in sector } i\} \\ &= P_{i1}(\mathbf{x}_{ik}) \cup \dots \cup P_{iK}(\mathbf{x}_{ik}). \end{aligned} \quad (2)$$

$P_i(\mathbf{x}_{ik})$  represents the sector-specific technology set. We can also view this set as the envelopment of the sector-group technology sets in sector  $i$ . In other words,  $P_i(\mathbf{x}_{ik})$  defines the metafrontier of the sector-group technology sets in sector  $i$ . Finally, the output requirement set when considering all sectors is given by:

$$\begin{aligned} P(\mathbf{x}_{ik}) &= \{y \mid \mathbf{x}_{ik} \text{ can produce } y\} \\ &= P_1(\mathbf{x}_{ik}) \cup \dots \cup P_I(\mathbf{x}_{ik}) \\ &= \{P_{11}(\mathbf{x}_{ik}) \cup \dots \cup P_{1K}(\mathbf{x}_{ik})\} \cup \dots \cup \{P_{I1}(\mathbf{x}_{ik}) \cup \dots \cup P_{IK}(\mathbf{x}_{ik})\}. \end{aligned} \quad (3)$$

$P(\mathbf{x}_{ik})$  represents the overall technology set, that is, when considering all sectors (and thus all groups). It turns out that it is also the envelopment or the metafrontier of the sector-specific technology sets. In other words,  $P(\mathbf{x}_{ik})$  could be seen as a metafrontier of metafrontiers. Note that, by construction, we have  $P_{ik}(\mathbf{x}_{ik}) \subseteq P_i(\mathbf{x}_{ik}) \subseteq P(\mathbf{x}_{ik})$ , for all  $i$  and  $k$ .

In Figure 1, we present an illustration of the technology sets for a case with three sectors that each contains three groups for a specific period. In that case, two inputs (e.g., capital and labor, as in our empirical study) are used to produce one output (e.g., value added, as in our empirical study).

[Figure 1 here]

The technology set for sector 1,  $P_1(\mathbf{x}_{ik})$ , is defined as the envelopment of the three sector-group technology sets  $P_{11}(\mathbf{x}_{ik})$ ,  $P_{12}(\mathbf{x}_{ik})$ , and  $P_{13}(\mathbf{x}_{ik})$ . A similar result applies for the other two sectors. The overall technology set  $P(\mathbf{x}_{ik})$  is defined as the envelopment of the three sector-specific technology sets  $P_1(\mathbf{x}_{ik})$ ,  $P_2(\mathbf{x}_{ik})$ , and  $P_3(\mathbf{x}_{ik})$ .

## 2.2 Potential outputs

Based on the previous concepts of output requirement sets for the three levels, we can define the potential outputs as follows:

$$y_{ik}(\mathbf{x}_{ik}) = \max \{y \mid y \in P_{ik}(\mathbf{x}_{ik})\}, \quad (4)$$

$$y_i(\mathbf{x}_{ik}) = \max \{y \mid y \in P_i(\mathbf{x}_{ik})\}, \quad (5)$$

$$y(\mathbf{x}_{ik}) = \max \{y \mid y \in P(\mathbf{x}_{ik})\}. \quad (6)$$

Intuitively, the actual value cannot exceed the potential values, implying that  $y_{ik}(\mathbf{x}_{ik}) \geq y_{ik}$ ,  $y_i(\mathbf{x}_{ik}) \geq y_{ik}$ , and  $y(\mathbf{x}_{ik}) \geq y_{ik}$ . If they coincide, it reveals that the

output is at its optimal value (with respect to the referent technology). Moreover, we have, by construction, that  $y(\mathbf{x}_{ik}) \geq y_i(\mathbf{x}_{ik}) \geq y_{ik}(\mathbf{x}_{ik})$ . In words, potential output with respect to the sector-group technologies cannot exceed potential output with respect to the sector-specific technologies, which cannot exceed potential output with respect to the overall technology. Intuitively, this reflects that the group-specific technologies are included in the sector-specific technologies, which are themselves included in the overall technology (see our discussion of Equation [3]).

### 2.3 Technical efficiency

We can now define our concepts of technical efficiency by means of the following ratios:

$$TER_{ik}(\mathbf{x}_{ik}) = \frac{y_{ik}(\mathbf{x}_{ik})}{y_{ik}}, \quad (7)$$

$$TER_i(\mathbf{x}_{ik}) = \frac{y_i(\mathbf{x}_{ik})}{y_{ik}}, \quad (8)$$

$$TER(\mathbf{x}_{ik}) = \frac{y(\mathbf{x}_{ik})}{y_{ik}}. \quad (9)$$

These three ratios provide three different levels of technical efficiency:  $TER_{ik}(\mathbf{x}_{ik})$  is the sector-group technical efficiency when considering group  $k$  in sector  $i$  for the technology,  $TER_i(\mathbf{x}_{ik})$  is the sector-specific technical efficiency when considering sector  $i$ , and  $TER(\mathbf{x}_{ik})$  is the overall technical efficiency. As discussed previously, actual output cannot exceed potential outputs, making the technical efficiency ratios greater or equal to unity. When the ratio equals one, it reveals that output is at its maximal value with respect to the referent technology set. When the ratio is larger than one, output can, in principle, be increased without increasing the production factors. Moreover, we also have that  $TER(\mathbf{x}_{ik}) \geq TER_i(\mathbf{x}_{ik}) \geq TER_{ik}(\mathbf{x}_{ik})$ , given the ranking between the potential outputs discussed previously.

Of the three ratios, the sector-group technical efficiency  $TER_{ik}(\mathbf{x}_{ik})$  measures the distance of actual output  $y_{ik}$  to the sector-group potential output  $y_{ik}(\mathbf{x}_{ik})$ . Intuitively, it measures the efficiency level of each firm compared with the best practice determined by the sector-group technology. Therefore, this measure of technical efficiency is comparable across industrial sectors and ownership types because technology heterogeneity has been controlled for. This variable is our main interest in the empirical study. Based on Hypotheses 1–3, we have:

**Hypothesis 1a** *The average sector-group technical efficiency ratio is greater (less efficient) for state-owned firms and collective firms than for private firms.*

**Hypothesis 2a** *After the third-stage enterprise reform in 2003, the sector-group technical efficiency ratio decreases (more efficient) among some state-owned firms but not among collective firms.*

**Hypothesis 3a** *The average sector-group technical efficiency ratio is smaller (more efficient) for foreign-owned firms than for indigenous private firms.*

## 2.4 Technology gap

Technology gaps are captured by the following ratios:

$$TGR_{ik}(\mathbf{x}_{ik}) = \frac{y_{ik}(\mathbf{x}_{ik})}{y_i(\mathbf{x}_{ik})}, \quad (10)$$

$$TGR_i(\mathbf{x}_{ik}) = \frac{y_i(\mathbf{x}_{ik})}{y(\mathbf{x}_{ik})}. \quad (11)$$

$TGR_{ik}(\mathbf{x}_{ik})$  is our measure of sector-group technology gap, and  $TGR_i(\mathbf{x}_{ik})$  of sector-specific technology gap. That is,  $TGR_{ik}(\mathbf{x}_{ik})$  captures the technology gap in group  $k$  and sector  $i$ , and  $TGR_i(\mathbf{x}_{ik})$  captures the technology gap in sector  $i$ . Both ratios are smaller than one. This can also be noted from the relationship between the potential outputs (i.e.,  $y(\mathbf{x}_{ik}) \geq y_i(\mathbf{x}_{ik}) \geq y_{ik}(\mathbf{x}_{ik})$ ). A value of one reveals no technology gap, whereas a smaller value implies more gaps.

Intuitively, the sector-group technology gap ratio  $TGR_{ik}(\mathbf{x}_{ik})$  measures the distance of the sector-group potential output  $y_{ik}(\mathbf{x}_{ik})$  to the sector-specific potential output  $y_i(\mathbf{x}_{ik})$ . Within the same sector, a comparison of this ratio across groups reveals their differences in technology level or technology advancement. Alternatively, it can be interpreted as an efficiency measure for the technology that is specific to group  $k \in K_i$  relative to the technology of sector  $i$ . It follows from Equations (7), (8), and (10) that  $TER_i(\mathbf{x}_{ik}) = TER_{ik}(\mathbf{x}_{ik})/TGR_{ik}(\mathbf{x}_{ik})$ . That is, the technical efficiency with respect to the technology available to the sector, which is a commonly adopted efficiency measure, can be decomposed into two components: the sector-group technical efficiency and sector-group technology gap. Thus, Hypotheses 1–3 also imply:

**Hypothesis 1b** *The average sector-group technology gap ratio is smaller (less advanced in technology) for state-owned firms and collective firms than for private firms.*

**Hypothesis 2b** *After the third-stage enterprise reform in 2003, the sector-group technology gap ratio increases (technology improves) among some state-owned firms but not among collective firms.*

**Hypothesis 3b** *The average sector-group technology gap ratio is greater (more advanced in technology) for foreign-owned firms than for indigenous private firms.*

## 2.5 Estimation

Assume that in a specific period we observe  $N_{ik}$  firms in each sector  $i = 1, \dots, I$  and group  $k = 1, \dots, K_i$ . Attractively, it suffices to estimate, for each firm  $n$ , three potential output values to define all our technical efficiency and technology gap ratios:  $y_{ik}(\mathbf{x}_{ikn})$ ,  $y_i(\mathbf{x}_{ikn})$ , and  $y(\mathbf{x}_{ikn})$ . Different methods could be used at this stage. We prefer, given the study context, to make use of a nonparametric estimation method. Indeed, no guideline is available to define the technology (captured here by output requirement sets) for multiple group and sector contexts. Moreover, assuming a specific technology structure could bias the results of our study.

Therefore, we estimate the potential outputs using a DEA-based methodology. DEA, introduced by Charnes et al. (1978), does not assume any functional form for the technology, but rather, reconstructs the technology using the data. Nevertheless, to avoid a trivial reconstruction and to match the common practice, we impose some regularity conditions on the technology.<sup>11</sup> Clearly, stochastic methods could be used as an alternative at this stage, when a parametric form is specified (Amsler, O'Donnell, & Schmidt, 2017).

In fact, the three potential outputs can be obtained by means of linear programs. The only difference between the three definitions of potential output is the referent technology set, captured, in practice, by a set of comparison partners. Let us define  $S_{ik}$  as the set that contains all firms in sector  $i$  and group  $k$ . In a similar vein, we define  $S_i$  as the set that contains all firms in sector  $i$  and  $S$  as the set that contains all the firms.

For every firm  $n_0 \in (1, \dots, N_{ik})$  in group  $k_0 \in (1, \dots, K_i)$  and sector  $i_0 \in$

$(1, \dots, I)$ ;  $y(\mathbf{x}_{i_0k_0n_0})$  is obtained using the following linear program:

$$\begin{aligned}
y(\mathbf{x}_{i_0k_0n_0}) &= \max_{\lambda_{ikn} (\forall n \in D)} y \\
\text{(C-1)} \quad y &\leq \sum_{n \in D} \lambda_{ikn} y_{ikn}, \\
\text{(C-2)} \quad \mathbf{x}_{i_0k_0n_0} &\geq \sum_{n \in D} \lambda_{ikn} \mathbf{x}_{ikn}, \\
\text{(C-3)} \quad \sum_{n \in D} \lambda_{ikn} &= 1, \\
\text{(C-4)} \quad \forall n \in D: \lambda_{ikn} &\geq 0, \\
\text{(C-5)} \quad y &\geq 0.
\end{aligned} \tag{12}$$

It suffices to replace  $D$  by  $S_{ik}$ ,  $S_i$ , or  $S$  to obtain the estimator of the potential output for the three levels. The estimators for technical efficiency and technology gap are obtained by replacing the theoretical potential outputs by their estimated values in Equations (7)–(11), respectively. Clearly, these estimators have to be interpreted as their theoretical counterparts.

As a final remark, we point out that, in general, linear programs are very sensitive to the presence of outliers. This problem arises because all the peers are used to construct the frontier (potential outputs) in Equation (12). Fortunately, it is possible to make the linear programs robust to this issue. In this study, we adopt Daraio and Simar’s (2007) order- $m$  estimator to compute the potential outputs. This estimator benchmarks each firm against the expected maximum output among  $m$  peers randomly drawn from set  $D$ . Practically, the sampling procedure is repeated many ( $B$ ) times to obtain the expected maximum output.<sup>12</sup> Because the order- $m$  estimator does not envelope all the data at the same time, it is much more robust to outliers and extreme values; simultaneously, it remains consistent.

### 3 Application

We question the ownership–efficiency linkage in China’s manufacturing industry, while distinguishing between different sectors. We start by presenting the data and contextualizing our study by showing some key descriptive statistics. Next, we provide our results for the technical efficiency and technology gap. Finally, we present a summary and discuss policy implications.

### 3.1 Data and descriptive statistics

Our study uses a firm-level dataset issued by the National Bureau of Statistics (NBS) of China: the China Industry Survey (CIS).<sup>13</sup> The survey covers all state-owned firms and “above-scale” (annual sales revenue greater than 5 million RMB) non-state firms in the manufacturing industry over the years 1999–2007, comprising over two million observations from more than 555,000 distinct firms. The dataset provides rich information about each firm, including industrial classification, ownership structure, inputs and outputs, and key variables from the financial statements. Because of its comprehensiveness and high quality, this dataset has been widely used to study China’s industry.<sup>14</sup>

The CIS dataset assigns a four-digit industry classification code to each firm. The corresponding national standard of economic classification (GB/T 4754) defines manufacturing sectors as those in the code range 1300–4400. That is, we finally have 30 sectors; see Table S1 in the supplementary material for more details, in which we also specify the technology intensity of the sectors, as defined by the Organisation for Economic Co-operation and Development (OECD).<sup>15</sup>

We classify all firms into four ownership types: state-owned, collective, private, and foreign-owned. We determine a firm’s ownership type based on two separate sources of information: registration type and registered capital. Because neither offers a complete characterization of ownership type for all firms, we adopt a two-step procedure that combines the information from these two variables. In step one, a firm is defined as state- (or collective-, private-, or foreign-) owned if the registered capital owned by the state (or collective organization, private persons, or foreigners) outweighs the shares of the other owners. If step one is indeterminate, we move on to step two. There, ownership is well defined only if the registration information is unambiguous about the control rights.<sup>16</sup>

We consider a very simple setting with two production factors: capital and labor. In this case, value added becomes the output variable. This setting, although simple, is the most used one in empirical macroeconomics, and dates to Solow (1956).<sup>17</sup> The CIS dataset does not report real capital stock, which means that it must be estimated. In this study, we use Brandt et al.’s (2012) algorithm to convert capital values at original purchasing prices into real values that are comparable over time and across sectors.<sup>18</sup> Value added is reported as a nominal value in the CIS dataset, which is converted into real value using the sector-specific output deflator of Brandt et al. (2012). Finally, labor input is measured by annual average employed persons.<sup>19</sup>

It is well known that DEA is sensitive to outliers. In this study, we follow the procedures of Brandt et al. (2012), M. Chen and Guariglia (2013), and Guariglia, Liu, and Song (2011) to clean the data. Briefly speaking, we remove the observations with abnormal values in key financial variables and those with extreme values in the input–output variables.<sup>20</sup>

After these procedures, we have a total of 1,628,700 observations. We present the relative importance of the four ownership categories in China’s manufacturing industry in Table 1. It can be observed that the percentage of state-owned firms declined rapidly from 26.0% in 1999 to 3.7% in 2007; that of collective firms also experienced a similar decline, from 28.3% to 6.4%. Private firms registered vibrant growth, from 26.4% to 68.0%. The percentage of foreign-owned firms grew slowly from 19.3% to 21.9%. The shrinking state and collective ownership types and the burgeoning private ownership coincide with China’s second-stage enterprise reform launched in 1997, during which private ownership was advocated, while many state-owned and collective firms were either shut down or privatized.

[Table 1 here]

Table S2 in the supplementary material shows the capital (real capital stock), labor (employment), and output (real value added and real industrial output) shares of the four ownership categories. We observe a similar downward trend for state and collective ownership in input and output shares, and an upward trend for private and foreign ownership. According to their input (especially capital) and output shares, state-owned firms are generally much larger, whereas collective and private firms are smaller in size.

In the supplementary material, we present the proportions of firm number, inputs, and output per sector. In 1999, the presence of domestic firms (Table S3) was most prominent in sectors 13 (agri-processing), 26 (chemicals), 31 (mineral-processing), and 35 (general equipment). Indeed, 37.9% of state-owned firms, 34.6% of collective firms, and 33.3% of private firms were operating in these four sectors, which are typically low-tech sectors. More foreign-owned firms were found to operate in sectors 17 and 18 (clothing), 39 (electric apparatus), and 40 (telecoms and computer). These four sectors together accounted for 31.1% of all foreign-owned firms. The first two sectors are typically labor-intensive and low-tech sectors, but the next two are medium-high-tech or high-tech sectors. Therefore, it seems that foreign-owned firms are either labor-driven or technology-driven. By 2007, this pattern was barely altered (Table S4), except that state-owned firms increased their presence in sectors 35–37. Judging by their input shares, sectors

17, 26, 31, 32, and 37 were particularly large in 1999. In 2007, sectors 39 and 40 recorded considerable growth and sectors 17, 26, and 31 became less important. These suggest that more resources were allocated to technologically advanced sectors.

## 3.2 Hypotheses and results

We start by presenting our results for the estimated technical efficiency and technology gap. These estimates are computed for every firm using the procedure explained in Section 2. Next, we make use of statistical tests to formally verify whether our observations hold true.

### 3.2.1 Technical efficiency

Figure 2 presents the box plots for our three estimators of technical efficiency: the overall technical efficiency, sector-specific technical efficiency, and sector-group technical efficiency, when grouping all firms. We choose to rely on the box plots given their easy interpretation and because they provide a better view of the distribution than relying on the average, for example. Of note, the (meta)frontiers are re-generated every year so that these technical efficiencies measure a firm's efficiency level relative to the (meta)frontiers of that year. Moreover, it is important to remark that only a few firms are declared as outliers by the box plots. This result is owing to our robust estimation method, as explained in Section 2.

[Figure 2 here]

We observe a much greater variation for the overall technical efficiency than for the sector-specific technical efficiency. The sector-group technical efficiency exhibits the smallest variation. Therefore, we observe two layers of heterogeneity in technical efficiency: between sectors, and between ownership types. Failing to control for either one may obscure firm-level technical efficiency (compared with the sector-group metafrontier) with between-sector or between-group variations of technology. Thus, it seems reasonable for us to concentrate on the sector-group technical efficiency when we study technical efficiency in all 30 sectors together.

The median for the sector-group technical efficiency is rather constant over time, indicating that the distance of an average firm to the sector-group frontier is relatively stable. A possible explanation is that the change in efficiency is not balanced across sectors or ownership types. Some ownership types or sectors may experience efficiency gains, whereas some others may experience efficiency losses;

when aggregating, these effects cancel out each other. Later, when we study Table 2, we show that it is indeed the case: Foreign-owned firms and state-owned firms experience efficiency gains, whereas private firms experience significant efficiency losses. Overall, these results suggest that, in general, there is still room for potential output improvements without modifying the capital and labor quantities.

Next, we discriminate our analysis with respect to firm ownership. The box plots per ownership type are shown in Figure 3. The three quartiles clearly indicate that foreign-owned firms are the winners in terms of technical efficiency (lower technical efficiency ratio), whereas collective firms are the least efficient, lending support to Hypotheses 3a. Figures 3a and 3c reveal rich information about the state–private dichotomy studied in the literature. It can be observed that during 1999–2004, private firms clearly outperformed state-owned firms (and also collective firms) in technical efficiency, as reflected by the three quartiles. This observation suggests that the majority of state-owned firms are less efficient than private firms, supporting Hypothesis 1a. However, from 2005, although private firms continue to have a smaller third quartile (more efficient), state-owned firms have a lower first quartile and median. This observation suggests that the most productive state-owned firms began gaining efficiency relative to private firms in the third stage of China’s enterprise reform, which supports Hypothesis 2a. This finding is consistent with the conclusions of Hsieh and Song (2015) and Berkowitz et al. (2017).

[Figure 3 here]

In Table 2, we summarize the sector-group technical efficiency for each sector-group and study its evolution. Using the 1999–2007 average technical efficiency values (in columns “all year average”), we run a “horse race” between the four ownership types. Foreign-owned firms win (most efficient) in 17 sectors and lose (least efficient) in only one. The situation for collective firms is almost the opposite: They have two wins but 17 losses. The win–loss ratios are 7:8 for state ownership and 4:3 for private ownership. This comparison echoes previous findings that foreign-owned firms are the most efficient, whereas state-owned and collective firms are the least efficient (Hypotheses 1a and 3a; also see Figure 3). It is interesting to observe that foreign ownership and private ownership are the absolute winners in all high-tech sectors (27, 40, and 41), and in almost all medium-high-tech sectors (26, and 35–37). Moreover, they also win in many low-tech or medium-low-tech sectors, such as sectors 14–17 and 28–34. Therefore, we feel it safe to claim that foreign-owned and private firms demonstrate the highest technical efficiency

in China's manufacturing industry; their efficiency advantage prevails over many sectors.

[Table 2 here]

Over the years, foreign-owned firms have exhibited considerable improvement of their technical efficiencies, which pushes the median technical efficiency close to unity in most sectors. Only in sectors 17 (textile), 25 (petroleum processing), and 29 (rubber) do we observe efficiency degradation. The situation is similar for state-owned firms. Except for nine sectors (16, 18, 20, 22, 25, 30, and 33–35), state-owned firms are able to increase their technical efficiencies (decreasing technical efficiency ratios) over time. We might attribute this change to the third-stage enterprise reform (Hypothesis 2a). Turning to private firms, we observe declining technical efficiency in many sectors. A few sectors (including 18, 25, and 27–29) experience pronounced drops. These observations suggest that while foreign and many state-owned firms achieve efficiency gains over time, private firms in many sectors are becoming less efficient. The latter may result from the emergence of new private firms that are technologically more advanced than the majority of incumbent firms. Consequently, the explosion of the sector-group frontier makes incumbent firms less efficient. As an alternative explanation, private firms are usually found to be financially constrained because of the unfavorable credit policy of state-owned banks (Guariglia et al., 2011; Poncet, Steingress, & Vandebussche, 2010); such financial constraints may cause them to become less efficient. Although we cannot directly test the second hypothesis using our method, we can assess the validity of the first statement by studying the change of technology gap among private firms. We return to this point in Section 3.2.2.

### 3.2.2 Technology gap

Figure 4 presents the box plots for the sector-specific technology gap ratios and sector-group technology gap ratios computed for each annual sample. Both panels demonstrate large technology gaps (small ratios) in the lower quartile, revealing that (segments of) the frontiers of some sectors or some ownership types are very far away from the upper-level metafrontier. The situation shown in Figure 4a is far worse. We also observe large variations in technology gap ratios. These observations tell us that China's overall technology is shaped by a few sectors. Noticeably, the situation improves over time, suggesting that more sectors are able to reduce their technology gaps and catch up with others.

[Figure 4 here]

To further investigate the relationship between ownership and technology gap, we plot Figure 5 for each ownership type. Foreign ownership is undoubtedly the most technologically advanced of all ownership types. In most years, the median technology gap ratio is 0.9 or higher, and the third quartile is always close to one. Clearly, it is the foreign-owned firms who shape the sector-specific technology sets and the corresponding metafrontiers. This result unambiguously supports Hypothesis 3b. The median sector-group technology gap ratio of state ownership is relatively stable over time; the third quartile is usually close to 0.8. Thus, the box plots do not demonstrate the technology improvement predicted by Hypothesis 2b. Judging by the box plots, the technology gap ratios of collective ownership are similar, but slightly lower than those of state ownership. Two aspects of private ownership are worth mentioning. First, during 1999–2002, the technology gap ratios of private firms appear similar to those of state-owned and collective firms. Thus, it is difficult to evaluate Hypothesis 1b based on the box plots. Second, the technology gap ratios of private firms increase substantially later, suggesting technological progress among private firms. The expansion of the sector-group frontiers coincides with the deterioration of efficiency among private firms in many sectors (Table 2). As we mentioned previously, the entry of highly productive new private firms is likely the common cause of both observations.

[Figure 5 here]

We report the sector-specific technological gap ratios per sector-year in Table 3. Similar to its sector-group counterpart, this ratio measures the efficiency of the sector-specific technology relative to the overall technology. It can be used to compare the technology level across industrial sectors, and its rate of change is a relative measure of technological progress. Notably, a few sectors exhibit high technology levels: 16 (tobacco), 26 (chemicals), 27 (pharmaceuticals), 32 (ferrous metal), 37 (transport equip.), 40 (communication equip.) and 41 (meters). They are China's most advanced sectors in terms of technology level. The annual change rates reveal considerable technological progress in all sectors except for sector 27 (pharmaceuticals). That is, the improvement of technology we observe in Figure 4a applies to almost all manufacturing sectors. In the last column of the table, we report the average annual technical change rate, which measures the year-over-year expansion rate of the sector-specific metafrontier. Thus, it is an absolute measure of technological progress.<sup>21</sup> The numbers confirm our previous finding:

In virtually all sectors, we observe technological progress during the period of study, justifying Hypothesis 4.

[Table 3 here]

We report the sector-group technology gap ratios per sector-year for each ownership type in Table 4. This table reveals more information than Figure 5 about the technology advantage of the ownership types. In a similar manner as earlier, we ran another “horse race” using the 1999–2007 average levels of the sector-group technology gap ratios. Foreign ownership wins (greatest ratio) in 19 sectors and never loses (smallest ratio). Clearly, foreign-owned firms are not only the most efficient (Table 2), but also the most technologically advanced. Roughly speaking, they shape the technology metafrontier for 19 out of the 29 sectors studied here. This observation corroborates the previous finding shown in Figure 5 and supports Hypothesis 3b. Private ownership wins in three sectors and loses in eight sectors. State ownership and collective ownership combined yield an outcome of 6:20. Therefore, we find weak evidence that private ownership is more technologically advanced than state ownership and collective ownership (Hypothesis 1b). Although the technology gap ratio of state ownership is the lowest in 14 sectors, it is quite high in a few sectors, including sector 16 (tobacco), 25 (fossil fuel), and 31–33 (non-metallic mineral and metal). These sectors, unsurprisingly, are dominated by state-owned firms.

[Table 4 here]

Inspecting the annual change rates of technology gap ratios, we find clear evidence of technological progress among private firms. They are able to increase their technology gap ratios in 19 sectors, and the increase is substantive in sectors 13, 18, 20–23, 25–31, 34, 37, and 42. This observation is consistent with Figure 5c. In contrast, only nine sectors experience technological progress for foreign ownership, eight sectors for state ownership, and 12 sectors for collective ownership. Note that in the latter cases, the growth rates are often small. Therefore, although foreign-owned firms take the lead in technical efficiency improvement (Table 2), the explosion of sectoral metafrontiers we observe in Table 3 is largely driven by the technological progress among private firms. Finally, we find little support for Hypothesis 2b, because state-owned firms experience technology degradation (decreasing technology gap ratio) in 18 out of 29 sectors.

### 3.2.3 Statistical tests

Our previous analyses are based only on box plots, averages, and medians and thus suffer from a lack of statistical foundation. To formally verify our previous findings and to provide more evidence, we rely on a version of the Li test adapted to the DEA context by Simar and Zelenyuk (2006). The DEA version of the Li test is a nonparametric test that checks whether the distributions of two samples are equal or not. We use the test in two different ways. One, we verify whether improvements have occurred over time. Two, we check whether a certain ownership type possesses a better performance than another. Both tests use one-sided alternatives.

The  $p$ -values are available in Table 5, where we study how technical efficiency and technology gap ratios change over time, and in Tables 6 and 7, where we compare technical efficiency and technology gap ratios across ownership types. Note that, in Tables 6 and 7, we test whether the row group has better performance than the column group.

[Table 5 here]

The  $p$ -values reported in column 3 of Table 5 confirm our previous finding of no significant improvement in the sector-group technical efficiency in the long run (Figure 2c). Indeed, these  $p$ -values are too large to claim a performance increase has occurred. The result is similar when we switch to the  $p$ -values for the sector-specific technical efficiency in column 2. However, it becomes highly significant in column 1, when we study the overall technical efficiency. These results are because foreign- and state-owned firms are able to improve their technical efficiencies in most sectors, whereas private firms experience declining technical efficiency in many sectors (Table 2). Thus, the net effect on the sector-group technical efficiency is ambiguous. Note that our conclusion will be completely different if the inference is based on the overall technical efficiency, which is not comparable across industrial sectors or ownership types. Column 4 highlights the improvement in sector-specific technology gap ratios, which we identify with Figure 4a and Table 3. Finally, because private firms are able to increase their technology gap ratios in many sectors (Table 4), the improvement in the sector-group technology gap is marginally significant in column 5.

[Table 6 here]

[Table 7 here]

Tables 6 and 7 highlight the absolute advantage of foreign-owned firms in technical efficiency and technology gap. In all binary comparisons, the  $p$ -values confirm the dominance of this ownership type over the other three. Thus, the tests reaffirm Hypotheses 3a and 3b. Private ownership also outperforms state ownership and collective ownership in technical efficiency (Hypothesis 1a). This clear-cut finding is consistent with what we observe in Figure 3 and Table 2. Finally, despite the fact that Figure 5 is inconclusive about Hypothesis 1b and Table 4 provides weak support, the tests in Table 7 clearly indicate that private ownership is advantageous over state ownership and collective ownership in terms of technology gap. Thus, these tests lend support to Hypothesis 1b.

As a final remark, we report that these results are also confirmed when performing tests for every sector separately. We do not report these tests here for the sake of compactness.

### 3.3 Sensitivity analyses

Lastly, we modify our modeling and variable selection to verify that our findings remain valid. In particular, we re-estimate the technology efficiency and technology gap ratios with which we regenerate Tables 2–7. Note that the presence of outliers and potential data issues are tackled in the same way as we explained in Sections 2.5 and 3.1.

The first sensitivity analysis consists of adding a third production factor in our modeling of technology. Previous empirical works have suggested using intermediate inputs (Berkowitz et al., 2017; Li, Liao, & Zhao, 2018). In that case, real industrial output is the appropriate output variable.<sup>22</sup> The new results are presented in Tables S5–S10 of the supplementary material. Next, we also express our concern over data manipulation or systematic measurement error. Although this problem is seldom addressed in relevant studies, Brandt, Van Biesebroeck, and Zhang (2014) point out that the expenditure approach adopted by NBS is likely to overstate the industrial value added reported by the CIS data. They propose an alternative measure of industrial value added that is based on the income approach. Following their definition, we compute the income-approach real value added and update our results in the main analysis.<sup>23</sup> These results are presented in Tables S11–S16 of the supplementary material.

In both scenarios, we observe high levels of similarity between the new results and those presented in Section 3.2. These include the comparisons of average technical efficiency and technology gap ratios among ownership types (Tables 2 and

4), the patterns of efficiency change and technological progress among ownership types (Tables 2 and 4), the pattern of sectoral technology change (Table 3), and the statistical inferences drawn from the Li tests (Tables 5–7). The only change is in the tests for the differences in technology gap ratios (Table 7). With the new estimates, the differences among ownership types are less significant.

Overall, we conclude that our main findings are valid even when modifications to our modeling or variable measure are made.

### 3.4 Summary and policy implications

We summarize our findings in five main points:

- Our results support the hypotheses that foreign-owned firms are the most efficient and state-owned and collective firms the least in terms of technical efficiency. Foreign ownership is the clear winner in terms of technical efficiency, followed by private ownership; together they take the lead in all high-tech and almost all medium-high-tech manufacturing sectors.
- We find that China’s enterprise reform successfully boosted technical efficiency among state-owned firms in many sectors. Consequently, the most efficient state-owned firms began to gain efficiency relative to private firms in the third stage of the enterprise reform. Meanwhile, foreign ownership takes the lead in efficiency improvement in almost all sectors.
- The analysis demonstrates that foreign-owned firms are the most technologically advanced and state-owned and collective firms the least. The technology advantage of foreign ownership is manifested in a wide range of sectors, and such advantage is stable over time. Although state-owned firms are technologically constrained in many sectors, they are found to be technologically advanced in a few sectors dominated by the state.
- We fail to find evidence in support of the hypothesis that state-owned firms improved their technology level during the enterprise reform, but we find that private firms registered the most prominent technological progress during the period of study, *albeit* they suffer efficiency losses in quite a few sectors.
- Technological improvement is observed in almost all manufacturing sectors. This is justified by the relative measure of technological progress as well as the absolute measure.

Many of the above results corroborate the findings in the literature. Our conclusion is similar to those of Jefferson, Rawski, and Zhang (2008) and Berkowitz et al. (2017), who find that state-owned firms are, on average, less productive than private and foreign-owned firms. They also support the view that foreign-owned firms constitute an important source of technology transfer and innovation (Cheung & Ping, 2004; Xu & Sheng, 2012). Next, the efficiency gain and technological progress demonstrated by this study is conceptually similar to the productivity growth documented in the literature (Berkowitz et al., 2017; Curtis, 2016). Finally, we corroborate the finding of Berkowitz et al. (2017) that a selected group of state-owned firms have become as productive as private and foreign-owned firms.

Despite these similarities, a major departure of our methodology from the conventional treatment (total factor productivity) is that we disentangle technical efficiency from technology gap, which are both determinants of productivity. Our results reveal the dual advantage of foreign-owned and private firms: They not only are more efficient but also more technologically advanced. We are able to assess separately the efficiency gains and technological progress (relative to sectoral technologies) achieved by the same type of firms. We demonstrate strong technological progress yet marked efficiency loss among private firms; we also observe strong efficiency gains among state-owned firms in the upper quartile. Finally, our method allows us to study the technological progress of sector-specific technologies. To our knowledge, no extant studies have presented similar results in their pursuit of such research questions.

These findings have rich policy implications. First, our results indicate that China's enterprise reform successfully revitalized state-owned firms, some of which are operating at high levels of efficiency (relative to their technology potential). Although the effect of privatization has been thoroughly studied, little attention has been paid to surviving state-owned firms. Therefore, our finding is an important complement to the literature. Interestingly, Abramov, Radygin, and Chernova (2017) make the same observation about Russia's large state-owned companies over the 2006–2014 period. Although such empirical evidence is scant, it is important to recognize that the efficiency of state-owned firms can be improved with properly designed government intervention.<sup>24</sup>

Second, our results pinpoint the advantage of private ownership over state ownership in terms of efficiency and technology level. Although empirical studies in developed and middle-income countries generate conflicting results (Section 1.2), evidence from transition economies is usually consistent with our finding. These include countries in Eastern Europe (Bonin, Hasan, & Wachtel, 2005; Brown,

Earle, & Telegdy, 2016), Russia (Abramov et al., 2017), and Asia-Pacific and Latin America (Boubakri, Cosset, & Saffar, 2017). Given China’s sheer size, it is thus safe to argue that private superiority over state is a prevailing rule among transit economies. Following the argument of Hsieh and Klenow (2009), transit economies could continuously improve their overall economic performance through privatization, that is, the reallocation of resources from the state sector to the private sector.

Third, our findings indicate that foreign ownership is the driving force of efficiency improvement, which affirms China’s FDI-friendly industrial policy. Although we do not have direct evidence, the literature suggests that foreign-owned firms create technology spillovers to indigenous Chinese firms (Tanaka & Hashiguchi, 2015; Xu & Sheng, 2012), causing the industry-wide technological progress observed in our empirical study. Thus, our results demonstrate the importance of China staying with her “opening-up” policy in the future.

Finally, a profound shift has occurred in China’s enterprise reform strategy recently. Since the launch of the 2009 stimulus package, the Chinese government has adopted a new policy that is described as “the state advances as the private sector retreats” (Hsieh & Song, 2015, p. 297), which means that the government is ready to support the expansion of the state sector at the cost of the non-state sector. A similar re-nationalization strategy is also observed in Russia (Chernykh, 2011). Given our findings, these policies are likely to undermine the efficiency in China and Russia. Indeed, recent studies confirm our worries (J. Du, Liu, & Zhou, 2014; Johansson & Feng, 2016). Thus, these findings cast serious doubt on the re-nationalization policies in the former Socialist Bloc.

## 4 Conclusion

In China, the manufacturing industry is playing the most important role in boosting economic growth, and various policies have been designed to improve its efficiency and technological performance. In this study, we identify the ownership effect on firm efficiency during 1999–2007, which provides valuable information in the context of policy implementations. The main distinguishing feature of our empirical analysis is to properly control for technology heterogeneity across industrial sectors and ownership types using an extended nonparametric estimation method.

Our results suggest that firm ownership is important in explaining the technical efficiency and technology gap among Chinese manufacturing firms. Foreign-owned

firms not only shape the sectoral technology metafrontier, but also set the standard for technical efficiency. Hence, it is important for China to stay open to industrial FDI to further receive technology and improve efficiency. Our results reveal a marked state-private sector gap in efficiency and technology level. Thus, further privatization will improve the overall performance of China and other transit economies. Our results also corroborate others' finding that efficiency improvement among state-owned firms is possible with government intervention. In addition, we find evidence that China's industrial development plans have been successful in stimulating technological progress in most sectors. Finally, our findings suggest that re-nationalization policies may undermine technical efficiency and slow down technological progress in the manufacturing industry.

However, we point out some limitations of our empirical study that may be considered for further research. First, we focus on two performance measures, technical efficiency and technology gap, but leave scale efficiency untreated. Given the fact that state- and foreign-owned firms are, on average, larger in size (M. Chen & Guariglia, 2013), it would be interesting to assess the extent of dis-economies of scale and to analyze whether the optimal size differs among ownership types. Second, the current study does not account for the moderation effects of environmental factors, such as transportation infrastructure, human capital, and environmental regulations. Special statistical methods are required to tackle this issue (Fried, Lovell, Schmidt, & Yaisawarng, 2002; Fried, Schmidt, & Yaisawarng, 1999), and thus, it deserves a separate study. Third, we remark that value added and employment reported by the CIS dataset are subject to measurement error, as for the income-approach value added (Brandt et al., 2014). Therefore, the results presented in this study should be interpreted with caution.

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## Notes

<sup>1</sup>Choosing a particular functional form may have an important impact on the results. See, for example, Hsieh and Klenow (2009), Choi, Lee, and Williams (2011), and Van Beveren (2012) for related discussions.

<sup>2</sup>See Liu, Lu, Lu, and Lin (2013) for a thorough review of the five major fields of DEA applications.

<sup>3</sup>This extension is popular in economic growth studies. See Ang and Kerstens (2017) and Walheer (2018c) for recent applications and the references therein.

<sup>4</sup>This is especially true for state-owned firms, on which social and political objectives are often imposed (Bai et al., 2000; Bai, Lu, & Tao, 2006). Bozec, Dia, and Breton (2006) provide evidence that technical efficiency is superior to profitability measures in assessing the relative performance of state-owned firms.

<sup>5</sup>The concept of metafrontiere is based on the notion of meta production function of Hayami and Ruttan (1970). See Battese, Rao, and O'Donnell (2004), O'Donnell, Rao, and Battese (2008), and Walheer (2018a) for more detail about the concept of metafrontier.

<sup>6</sup>Nationwide, their combined output share quickly increased from 13.9% in 1992 to 44.3% in 1999 (China Statistical Yearbook).

<sup>7</sup>Most of the administrative functions were practiced by the Central Working Committee for Enterprises, the State Economic and Trade Commission, and the Ministry of Finance.

<sup>8</sup>Source: the authors' own calculations based on the *China Industry Survey* dataset.

<sup>9</sup>Source: [http://www.gov.cn/jrzq/2009-02/26/content\\_1244190.htm](http://www.gov.cn/jrzq/2009-02/26/content_1244190.htm).

<sup>10</sup>See, for example, Kumar and Russell (2002), Henderson and Russell (2005), Badunenko, Henderson, and Russell (2013), and Walheer (2016a, 2016b, 2018a, 2018b, 2019) for the output-oriented approach to economic growth.

<sup>11</sup>In particular, we assume that the output requirement sets satisfy free disposal of outputs, and are compact (Färe & Primont, 1995). In addition, see O'Donnell et al. (2008) and Huang, Ting, Lin, and Lin (2013) for more details about the estimation of technology gap ratios. Finally, we point out that imposing regularity conditions is weaker than relying on a parametric specification for the technology/production function.

<sup>12</sup>In this study, we set  $B = 1,000$ , and  $m = 25$  or  $50$  or  $100$  depending on the size of  $D$ .

<sup>13</sup>Database: doi: 10.17632/mxmdmwszy6r.2. The data package also includes MATLAB programs that replicate the results presented in Sections 3.2 and 3.3.

<sup>14</sup>See Brandt et al. (2014) for an in-depth exposition of the features of this dataset. This dataset has incubated quite a few influential studies, including Brandt et al. (2012), M. Chen and Guariglia (2013), Guariglia et al. (2011), Hsieh and Klenow (2009), Hsieh and Song (2015), and Yu (2015).

<sup>15</sup>See <http://www.oecd.org/sti/ind/48350231.pdf> for more details.

<sup>16</sup>Firms registered as state-owned enterprises, state-owned partnerships, and state-owned limited liability companies are defined as state-owned; firms registered as collective enterprises and collective partnerships are defined as collective-owned; firms registered as sole proprietorships, private partnerships, private limited liability companies, and private joint-stock companies are defined as private-owned; and firms registered as (wholly) foreign-owned are defined as foreign-owned.

<sup>17</sup>See, for example, Brandt et al. (2012), M. Chen and Guariglia (2013), Hsieh and Song (2015), Kumar and Russell (2002), and Walheer (2019). At this point, we remark that some authors include extra production factors (e.g., human capital and energy) or consider pollution. We prefer to stay with the simple specification for three main reasons. One, although there is a theoretical consensus on including labor and capital, it is not true for other production factors. For example, energy is often modeled as an intermediate obtained via technological combinations of labor and capital, and human capital is usually modeled as an augmentation of labor instead of as a separate factor. Two, although data for capital and labor are available in the CIS dataset, it is not true for the other factors mentioned above. Finally, including pollution is beyond the scope of this study, because it would require modification of the method (see, e.g., Cherchye, De Rock, and Walheer [2015] for more discussion).

<sup>18</sup>Basically, their procedure consists of three steps: First, estimate the initial nominal capital stock of a firm when it was established; second, estimate the real capital stock of the firm when it is first observed in the data; and finally, estimate the real capital stock of the firm in subsequent years. Stages two and three employ the perpetual inventory method, using the investment deflator provided by Brandt et al. (2012), and 0.09 for the depreciation rate. See Brandt et al. (2014) for more details.

<sup>19</sup>In their introduction to the CIS data, Brandt et al. (2014) identify two issues with data quality. One, employment is very likely to be under-reported. Two, the value added is overstated. The exact impact of these measurement errors on our estimates is difficult to assess. In the extreme case, if the output or an input is inflated or deflated by the same proportion in the sample, then estimates of technical efficiency and technology gap will not be affected at all. Although no solution has been offered to improve the employment measure, Brandt et al. (2014) do suggest an alternative measure of the value added, which can be derived from the financial variables provided by the CIS dataset. We return to this point in Section 3.3.

<sup>20</sup>Specifically, we remove observations satisfying the following conditions: (1) negative sales revenue; (2) total assets smaller than current assets or fixed assets; (3) accumulated depreciation smaller than current depreciation; (4) negative or missing value in any of the input–output variables (i.e., real value added, real industrial output, real fixed assets, employment, and real intermediate inputs); (5) firms with less than eight employees (they follow a different accounting practice [Jefferson et al., 2008]); and (6) the lower and upper 1% tail of the input–output variables.

<sup>21</sup>Technical change is defined as the quotient of two technical efficiency ratios of the same input–output mix evaluated using the technologies that belong to two different periods. In practice, to evaluate technical change between two consecutive periods  $t$  and  $t + 1$  using firm-level data, one has to compute four technical efficiency ratios: First, the technical efficiency ratios actually observed in  $t$  and  $t + 1$ ; second, two counterfactual technical efficiency ratios. One counterfactual uses the input–output mix in period  $t$  and the technology in period  $t + 1$ , and the other one uses the input–output mix in period  $t + 1$  and the technology in period  $t$ . These counterfactuals can also be computed using our linear program (12). The technical change quotient can be based on either the input–output mix in  $t$  or that in  $t + 1$ . To avoid arbitrary selection, the geometric mean of the two quotients is commonly taken (Färe et al., 1994).

<sup>22</sup>Both intermediate inputs and industrial output are reported in nominal values by the CIS dataset. We convert them into real values using the sector-specific input and output deflators

provided by Brandt et al. (2012).

<sup>23</sup>The income-approach value added is defined as the sum of labor compensation, net indirect taxes, profit, and depreciation. Labor compensation consists of wage, unemployment insurance, welfare expenses, retirement pension and medical insurance, and housing subsidy. Net indirect taxes can be expressed as sales tax plus value added tax, plus taxes under general and administrative expenses, and minus government subsidies. All the necessary financial variables are available in the CIS dataset. When we aggregate the income-approach value added by year, we find that our numbers are very close to those reported by Brandt et al. (2014). Comparing the annual aggregates, the income-approach value added is 70–77% of the expenditure-approach value added reported by the CIS dataset. We use the sector-specific output deflator provided by Brandt et al. (2012) to convert the nominal values into real ones.

<sup>24</sup>Some of these interventions may not be feasible in the long run. For example, the efficiency improvement may be the result of state support during economic recession (Abramov et al., 2017).

Table 1: Descriptive statistics by firm type and year

<b>Year</b>	<b>State (%)</b>	<b>Collective (%)</b>	<b>Private (%)</b>	<b>Foreign (%)</b>	<b>Total</b>
2007	3.74	6.35	68.00	21.91	295,085
2006	5.11	7.43	65.04	22.42	261,824
2005	6.12	8.57	62.38	22.93	236,699
2004	9.67	12.25	52.84	25.24	122,124
2003	11.34	14.81	51.64	22.22	167,159
2002	14.74	17.91	46.16	21.19	151,323
2001	17.51	21.20	40.56	20.73	133,401
2000	22.40	25.53	31.78	20.28	131,740
1999	26.09	28.28	26.37	19.26	129,345

Notes: For each year, we report the percentage shares of the ownership types in firm number. The last column reports the total number of firms for each annual sample.

Table 2: Sector-group technical efficiency

Sector	State				Collective				Private				Foreign			
	1999	2007	All year average	Annual change rate (%)	1999	2007	All year average	Annual change rate (%)	1999	2007	All year average	Annual change rate (%)	1999	2007	All year average	Annual change rate (%)
	1.38	1.23	1.34	-1.46	2.36	1.37	1.94	-6.57	1.09	1.45	1.50	3.57	2.90	1.27	1.51	-9.84
13	1.38	1.23	1.34	-1.46	2.36	1.37	1.94	-6.57	1.09	1.45	1.50	3.57	2.90	1.27	1.51	-9.84
14	2.12	1.00	1.27	-8.95	2.62	1.86	2.35	-4.22	1.87	1.20	1.31	-4.22	1.43	1.00	1.11	-4.35
15	1.94	1.95	1.84	0.06	1.97	1.67	2.31	-2.06	1.07	1.23	1.29	1.79	1.00	1.00	1.03	0.00
16	2.43	3.14	2.70	3.24	1.00	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00	1.00	1.02	0.00
17	1.98	1.01	1.38	-8.15	1.40	1.62	1.80	1.86	1.00	1.67	1.58	6.63	1.18	1.30	1.34	1.20
18	1.02	1.33	1.06	3.44	2.01	2.45	2.82	2.49	1.62	3.08	2.08	8.35	1.92	1.00	1.50	-7.84
19	1.00	1.00	1.00	0.00	1.99	2.80	2.24	4.37	1.34	1.57	1.61	2.05	1.20	1.19	1.22	-0.16
20	1.22	1.82	1.84	5.08	1.81	1.80	1.75	-0.03	1.28	1.66	1.88	3.24	1.24	1.00	1.26	-2.65
21	1.00	1.00	1.00	0.00	2.14	2.04	2.59	-0.59	1.49	1.97	1.53	3.52	1.61	1.00	1.38	-5.81
22	1.52	1.64	1.63	0.94	1.23	2.91	2.51	11.43	1.29	1.73	1.56	3.75	1.69	1.09	1.26	-5.37
23	1.23	1.22	1.30	-0.03	1.96	2.12	2.38	0.98	1.08	1.28	1.75	2.19	1.01	1.00	1.15	-0.12
24	1.36	1.00	1.04	-3.74	4.15	2.39	2.79	-6.68	1.56	1.09	1.39	-4.41	1.37	1.00	1.36	-3.83
25	2.09	2.41	2.50	1.83	1.00	1.37	1.12	4.03	1.00	1.85	1.41	8.02	1.07	1.40	1.14	3.43
26	2.49	1.35	1.94	-7.41	1.58	1.42	1.84	-1.30	1.00	1.63	1.39	6.27	1.00	1.00	1.00	0.00
27	2.17	1.79	1.94	-2.40	2.72	2.02	2.46	-3.68	1.52	3.11	2.23	9.34	1.76	1.00	1.56	-6.85
28	2.12	1.05	1.70	-8.41	1.65	2.09	1.65	2.98	1.11	2.30	1.97	9.60	1.38	1.00	1.29	-3.93
29	2.05	1.30	1.88	-5.53	1.10	1.65	1.58	5.21	1.20	2.65	1.49	10.36	1.50	2.85	2.26	8.34
30	1.00	1.15	1.27	1.73	2.09	1.63	2.04	-3.05	1.08	1.65	1.61	5.40	1.35	1.00	1.26	-3.72
31	3.07	1.00	1.95	-13.10	1.21	1.38	1.56	1.71	1.12	1.77	1.56	5.91	1.28	1.24	1.27	-0.47
32	2.11	1.84	2.13	-1.68	1.00	1.52	1.30	5.42	1.00	1.55	1.47	5.66	1.00	1.00	1.14	0.00
33	1.59	1.94	2.02	2.47	1.13	1.55	1.55	4.04	1.46	1.04	1.45	-4.11	2.94	1.00	1.49	-12.60
34	1.00	1.99	1.32	8.98	1.32	1.91	1.70	4.70	1.19	1.96	1.76	6.46	1.43	1.00	1.15	-4.35
35	1.77	2.62	1.91	5.00	1.69	2.04	1.87	2.34	1.52	1.68	1.38	1.28	1.15	1.00	1.12	-1.77
36	3.69	1.59	2.72	-9.98	1.61	1.61	2.06	0.00	2.53	1.63	1.69	-5.37	1.99	1.00	1.31	-8.19
37	2.19	1.86	2.55	-2.03	1.60	2.43	2.81	5.36	1.00	1.21	1.09	2.39	1.00	1.00	1.10	0.00
39	1.74	1.24	1.35	-4.16	2.77	1.43	2.53	-7.91	3.06	1.21	1.78	-10.91	1.66	1.56	1.54	-0.71
40	1.51	1.27	1.55	-2.12	2.77	3.35	3.80	2.40	1.00	1.00	1.11	0.00	1.00	1.00	1.00	0.00
41	2.93	1.00	1.63	-12.56	3.24	3.11	3.12	-0.51	1.00	1.27	1.36	3.02	1.00	1.00	1.02	0.00
42	1.27	1.33	1.26	0.59	2.35	3.50	4.81	5.08	3.80	5.70	3.64	5.20	1.75	1.37	1.86	-3.07

Notes: For years 1999 and 2007, we report the median technical efficiency of each sector-group. We compute the median technical efficiency for each year between 1999 and 2007 and report their average in the column "All year average." The annual change rate is the compound year-over-year change rate of the median sector-group technical efficiency between 1999 and 2007.

Table 3: Sector-specific technology gap and technical change per sector

Sector	Technology gap			Annual change rate (%)	Annual technical change rate (%)
	1999	2007	All year average		
13	0.64	0.71	0.65	1.19	2.33
14	0.47	0.66	0.58	4.43	1.44
15	0.58	0.72	0.62	2.66	1.78
16	0.58	0.91	0.69	5.95	1.23
17	0.47	0.62	0.54	3.56	2.52
18	0.44	0.74	0.61	6.67	1.66
19	0.48	0.68	0.56	4.49	0.99
20	0.41	0.61	0.50	5.28	1.15
21	0.40	0.64	0.51	5.99	1.52
22	0.43	0.64	0.53	5.02	2.65
23	0.43	0.58	0.51	3.79	0.92
24	0.45	0.66	0.52	4.85	3.44
25	0.48	0.81	0.67	6.77	1.76
26	0.59	0.95	0.72	6.26	2.05
27	0.75	0.73	0.68	-0.38	2.47
28	0.46	0.64	0.53	4.27	1.49
29	0.42	0.70	0.55	6.74	4.50
30	0.46	0.62	0.53	3.85	1.16
31	0.48	0.63	0.53	3.43	1.72
32	0.59	0.81	0.69	4.08	2.19
33	0.50	0.80	0.58	6.04	3.68
34	0.47	0.69	0.56	4.99	1.08
35	0.52	0.77	0.61	5.06	3.97
36	0.57	0.68	0.61	2.21	1.58
37	0.67	0.97	0.71	4.77	0.91
39	0.30	0.50	0.40	6.59	1.48
40	0.50	0.76	0.69	5.35	2.44
41	0.86	0.90	0.95	0.54	2.22
42	0.58	0.76	0.66	3.29	1.34

Notes: For years 1999 and 2007, we report the median technology gap ratio of each sector. We compute the median technology gap ratio for each year between 1999 and 2007 and report their average in the column "All year average." The annual change rate is the compound year-over-year change rate of the median sector-specific technology gap ratio between 1999 and 2007. The annual technical change rate is the average year-over-year technical change rate for all firms in the sector.

Table 4: Sector-group technology gap

Sector	State			Collective			Private			Foreign			
	1999	2007	All year average	1999	2007	All year average	1999	2007	All year average	1999	2007	All year average	Annual change rate (%)
13	0.68	0.62	0.65	-1.17	0.91	0.60	0.74	-5.11	0.62	0.92	0.74	5.18	0.96
14	0.72	0.54	0.65	-3.61	0.78	0.56	0.67	-4.05	0.74	0.67	0.68	-1.21	0.97
15	0.62	0.96	0.77	5.64	0.62	0.77	0.65	2.85	0.65	0.57	0.64	-1.93	0.98
16	1.00	1.00	1.00	0.00	0.56	0.43	0.43	-3.35	0.30	0.30	0.38	0.00	0.54
17	0.86	0.59	0.71	-4.71	0.78	0.82	0.78	0.75	0.74	0.79	0.86	0.88	0.91
18	0.65	0.65	0.55	0.00	0.93	0.50	0.68	-7.47	0.62	0.95	0.72	5.37	0.96
19	0.47	0.30	0.50	-5.44	0.58	0.69	0.68	2.14	0.85	0.80	0.89	-0.69	0.79
20	0.78	0.79	0.72	0.11	0.82	0.78	0.74	-0.74	0.73	1.00	0.86	4.03	0.82
21	0.62	0.30	0.43	-8.70	0.98	0.87	0.79	-1.48	0.58	0.74	0.69	3.05	0.95
22	0.62	0.75	0.66	2.33	0.81	0.62	0.71	-3.19	0.69	0.91	0.70	3.47	1.00
23	0.92	0.88	0.84	-0.59	0.79	0.74	0.70	-0.75	0.51	0.67	0.67	3.55	0.99
24	0.67	0.65	0.70	-0.54	0.84	0.97	0.81	1.86	0.62	0.57	0.68	-0.97	0.92
25	0.99	0.86	0.95	-1.64	0.68	0.53	0.66	-3.07	0.73	0.83	0.69	1.59	0.89
26	0.61	0.52	0.57	-2.02	0.65	0.59	0.67	-1.22	0.51	0.63	0.65	2.60	0.91
27	0.79	0.77	0.66	-0.40	0.75	0.52	0.62	-4.40	0.65	0.96	0.74	4.88	1.00
28	0.80	0.62	0.65	-3.02	0.59	0.72	0.68	2.55	0.70	0.99	0.85	4.56	0.89
29	0.70	0.58	0.69	-2.20	0.96	1.00	0.96	0.52	0.58	0.79	0.65	3.89	0.81
30	0.55	0.59	0.68	1.01	0.66	0.61	0.74	-0.93	0.67	0.84	0.78	2.90	0.70
31	1.00	0.66	0.87	-5.07	0.59	0.52	0.67	-1.46	0.70	1.00	0.86	4.47	1.00
32	0.74	0.94	0.93	3.06	0.69	0.70	0.67	0.11	1.00	0.90	0.77	-1.28	0.88
33	0.65	0.93	0.86	4.66	0.98	0.59	0.73	-6.10	0.50	0.53	0.68	0.77	0.73
34	1.00	0.79	0.75	-2.95	0.65	0.75	0.66	1.84	0.62	0.89	0.79	4.55	0.84
35	0.64	0.97	0.73	5.45	0.61	0.68	0.72	1.32	0.83	0.57	0.67	-4.66	0.85
36	0.80	0.70	0.85	-1.69	0.77	0.69	0.74	-1.32	0.89	1.00	0.75	1.40	0.81
37	0.73	0.72	0.70	-0.13	0.64	0.71	0.64	1.19	0.54	0.82	0.62	5.39	0.87
39	0.30	0.30	0.30	0.00	0.30	0.30	0.30	0.00	0.30	0.30	0.30	0.00	0.94
40	0.57	0.57	0.62	-0.09	0.63	0.93	0.76	5.07	0.83	0.72	0.70	-1.82	0.30
41	0.57	0.61	0.62	0.95	1.00	0.79	0.79	-2.97	0.99	0.71	0.66	-4.14	0.97
42	0.79	0.69	0.60	-1.67	0.47	0.50	0.63	0.81	0.57	0.73	0.68	3.32	1.00
													0.98
													1.11

Notes: For years 1999 and 2007, we report the median technology gap ratio of each sector-group. We compute the median technology gap ratio for each year between 1999 and 2007 and report their average in the column "All year average." The annual change rate is the compound year-over-year change rate of the median sector-group technology gap ratio between 1999 and 2007.

Table 5:  $p$ -values per year

Years	Overall technical efficiency	Sector-specific technical efficiency	Sector-group technical efficiency	Sector-specific technology gap	Sector-group technology gap
2007 > 1999	0.01	0.33	0.51	0.01	0.10
2007 > 2006	0.69	0.79	0.41	0.07	0.10
2006 > 2005	0.56	0.52	0.04	0.46	0.06
2005 > 2004	0.81	0.45	0.54	0.05	0.58
2004 > 2003	0.48	0.04	0.08	0.32	0.03
2003 > 2002	0.10	0.04	0.08	0.00	0.28
2002 > 2001	0.33	0.15	0.35	0.01	0.24
2001 > 2000	0.05	0.06	0.02	0.74	0.93
2000 > 1999	0.03	0.07	0.55	0.57	0.02

Note: We test the null hypothesis  $F_{t+1} = F_t$ , where  $F_t$  and  $F_{t+1}$  denote the cumulative distribution functions of the variable under study in period  $t$  and  $t+1$ , respectively. The alternative hypothesis is  $F_{t+1} > F_t$  for technical efficiency and  $F_{t+1} < F_t$  for technology gap.

Table 6:  $p$ -values per ownership type: sector-group technical efficiency

Sector-group technical efficiency	State	Collective	Private	Foreign
State	1.00	0.11	0.95	0.99
Collective	0.36	1.00	0.69	0.98
Private	0.02	0.04	1.00	0.79
Foreign	0.00	0.01	0.00	1.00

Note: We test the null hypothesis  $F_r = F_c$  against the alternative  $F_r > F_c$ , where  $F_r$  and  $F_c$  denote the cumulative distribution functions of the row sample and the column sample, respectively.

Table 7:  $p$ -values per ownership type: sector-group technology gap

Sector-group technology gap	State	Collective	Private	Foreign
State	1.00	0.31	0.74	1.00
Collective	0.21	1.00	0.61	0.97
Private	0.02	0.07	1.00	1.00
Foreign	0.00	0.00	0.01	1.00

Note: We test the null hypothesis  $F_r = F_c$  against the alternative  $F_r < F_c$ , where  $F_r$  and  $F_c$  denote the cumulative distribution functions of the row sample and the column sample, respectively.

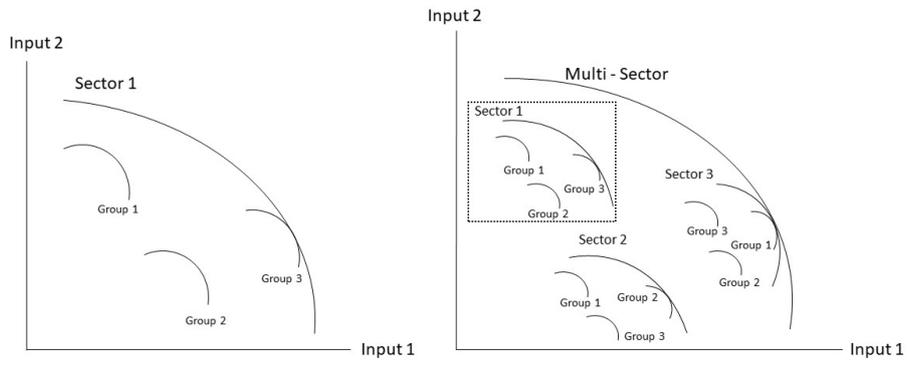
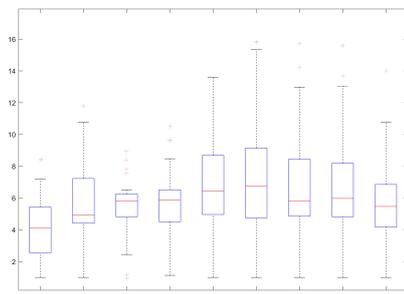
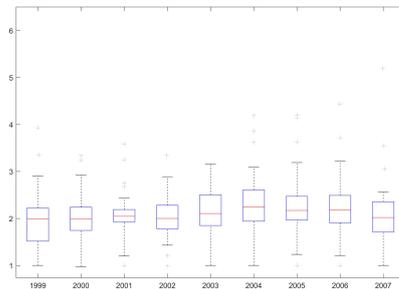


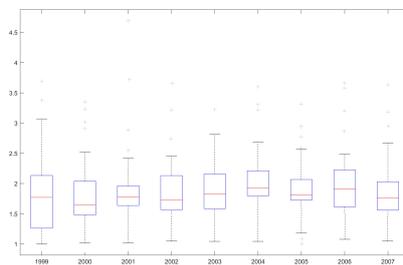
Figure 1: Multi-sector setting



(a) Overall technical efficiency

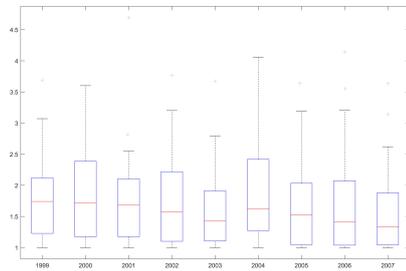


(b) Sector-specific technical efficiency

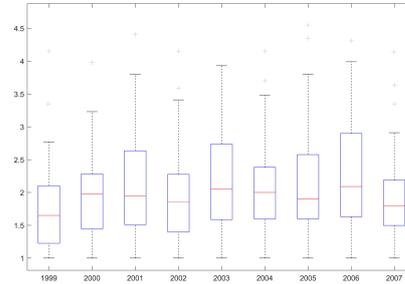


(c) Sector-group technical efficiency

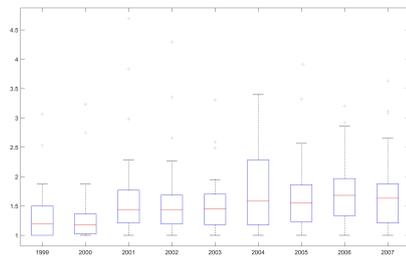
Figure 2: Technical efficiency, all firms



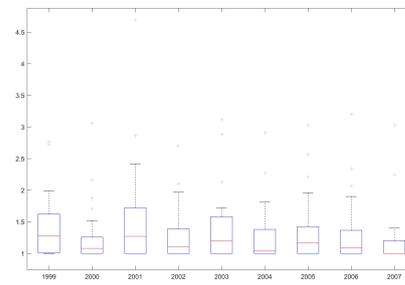
(a) State



(b) Collective

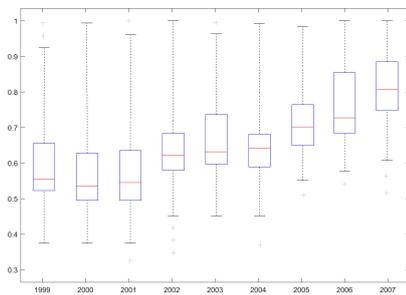


(c) Private

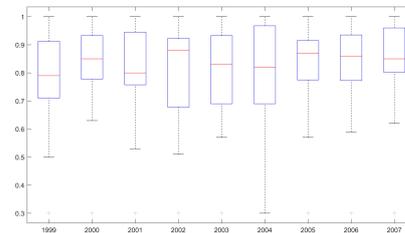


(d) Foreign

Figure 3: Sector-group technical efficiency by ownership type

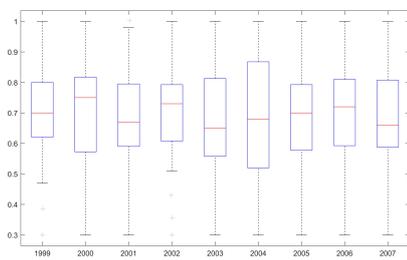


(a) Sector-specific technology gap

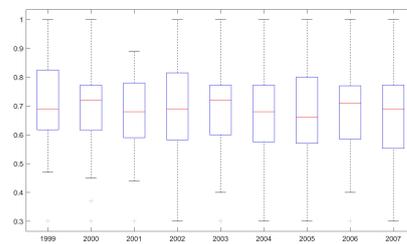


(b) Sector-group technology gap

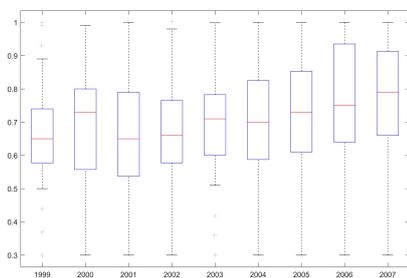
Figure 4: Technology gap, all firms



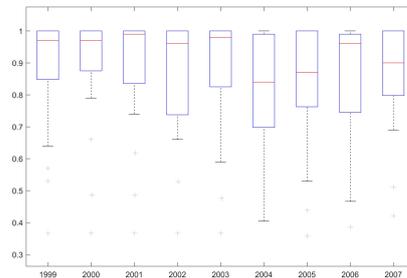
(a) State



(b) Collective



(c) Private



(d) Foreign

Figure 5: Sector-group technology gap by ownership type