NEW PERSPECTIVES ON CHINESE MANUFACTURING INDUSTRIES USING MICRODATA

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This dissertation consists of three essays that study the industrial organization of China's manufacturing sector from an empirical perspective. It uses structural estimation to look into the performance of China's manufacturing sector with a particular emphasis on the steel industry - a key sector in China that produces half of the world's steel. This dissertation also examines the financial constraints that manufacturing firms face.

Chapter 1 documents the development of the steel industry in the past two decades. Chapter 2 studies productivity differences in vertically-integrated Chinese steel facilities, using a unique dataset that provides equipment-level information on inputs and output in physical units for each of the three main stages in the steel value chain, i.e., sintering, iron-making and steel making. We find that private integrated facilities are more productive than provincial state-owned facilities, followed by central state-owned facilities. This ranking lines up with our productivity estimates in the two downstream production stages, but central state-owned facilities outperform in sintering, most likely because of their superior access to high-quality raw materials. The productivity differential favoring private facilities declines with the size of integrated facilities, turning negative for facilities larger than the median. We attribute this pattern to differences in the internal configuration of integrated facilities, which reflect the greater constraints confronting expanding private facilities. Increasing returns to scale within each stage of production partially offset these costs, and rationalize choices of larger facilities.

Chapter 3 draws on the Chinese Industrial Survey Data from 1998 to 2007 to examine financing constraints in the manufacturing sector. Building on the Euler Equation approach and applying the dynamic GMM estimation, we find that on average private firms face more obstacles in accessing credit than state-owned enterprises (SOEs). Contrary to the widely accepted view that China's private sector is largely excluded from formal credit allocation, we find that large firms, both state-owned and private, are not credit constrained. Medium and small SOEs are financially constrained, although to an extent less than their private counterparts of similar size. Moreover, the capabilities of firms in accessing external finance differ by economic region and across industries.

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This dissertation is dedicated to my beloved parents in China for their unconditional love and sacrifice.

1.0 DEVELOPMENT OF THE CHINESE STEEL INDUSTRY

1.1 MASSIVE EXPANSION

The Chinese steel industry has expanded dramatically due to development policies that promote strong domestic demand for steel products. China has led the world in steel production since 1996. Major products in the steel industry skyrocketed as Figure 1 illustrates. Crude steel grew at 11.5 percent per annum in China over the period 1996 to 2015 whereas the world's production grew at 4.1 percent annually. China peaked in steel production in 2014, producing 822.3 million tons of crude steel.[1] Although 2015 witnessed a drop in steel production (803.8 million tons), China alone accounted for 49.6 percent of the world's total production. Along with the rapid expansion in production, China has become the world's largest importer of iron ore as well. The share of Chinese import in world's total iron ore import rose steadily over time and reached 65 percent in 2015 (see Figure 2).

With dramatic output expansion, the value of industrial output in the steel industry shot from 388.32 billion RMB to 6,406.70 billion RMB from 1998 to 2011 (see Table 1).[2] The period 2003 to 2008 witnessed the strongest growth. Despite the dramatic increase in the value of steel output, its share in the total industrial output enjoyed a modest increase.

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[1] All data come from China Steel Yearbook (various years) unless otherwise indicated. And the figures presented are from the author's calculations.

[2] To keep consistency with the Chinese National Bureau of Statistics (hereafter NBS), Table 1 covers above-scale firms in the 2-digit smelting and pressing of ferrous metals industries including iron smelting, steel smelting, steel pressing and smelting of ferroalloy. The NBS stopped reporting gross value of industrial output and employment at industry-level since 2013.

The value of the steel output made up 5.7 percent of the total industrial output in 2002, and the share reached its peak value of 8.8 percent in 2008, after which a slight fall occurred, bringing down the share to 7.6 percent in 2011.

The number of firms in the steel industry also experienced a pronounced increase (see Table 1). While the number of steel firms dropped slightly between 1998 and 2000, it increased steadily over the period 2000 to 2008. The number began to decline from 2009 on to 6,742 firms. Even so, compared to 1998, the total number of firms more than doubled. On the other hand, employment dropped significantly between 1998 and 2002, during which the industry shook off 4.6 million workers, or 16 percent, largely due to restructuring in China's state sector. Even though the number of firms picked up from 2001 on, another two years went by before employment began to go up. With the number of steel firms more than doubling, employment increased by merely 2 percent to 34 million by 2011. Therefore, the annual output per worker enjoyed a remarkable increase, jumping from 40.2 tons to 206.5 tons of crude steel per worker from 1998 to 2011.

1.2 INDUSTRIAL UPGRADING

1.2.1 Product Quality Upgrading

In addition to the significant expansion in production, the quality of the Chinese steel products improved as well. Even though the majority of the finished steel products supplied by the Chinese steel firms are low value-added products, the past decade witnessed an improvement in quality of domestically-produced steel. A number of Chinese firms stepped into the high-end market to produce materials for autos, electric appliances and delicate machines, Figure 3 indicates that the high value-added steel products (including cold-rolled sheet and strip, clad and coated sheet and electro-sheet) rose from 23.2 million tons to 166.33 million tons between 2004 and 2015. Over the same period, while total finished steel products in 2015 were 3.8 times as much as 2004, high value-added steel experienced a seven-fold increase. The share of high value-added steel in total steel products went up from 7.6 percent to 14.8 percent.

A question thus arises: Who contributed to the production of high value-added products? In 2004, the 71 key vertically-integrated steel firms (among which 17 are private) produced 65.5 percent of the high value-added steel, and in 2011 the 82 (among which 49 are private) key firms produced about half of the high value-added steel.[3] Noteworthily, private steel firms increased their share in high value-added products over time, and in 2011, produced more than half of the high value-added steel. Regarding small private firms, in 2004, on average 8.3 percent of the products were high value-added while the share rose to 17.2 percent in 2011. This suggests that the large number of small private firms - mostly rolling mills - also experienced quality upgrading over time. Even though the private sector has been playing an increasingly important role in the Chinese steel industry, except for a couple of big private firms, the importance of an average single private firm in China, if not negligible, is limited compared to the SOEs.

In addition, there is significant variation across the key firms in their capacity to produce high value-added products. The central SOEs displayed the highest capability to produce high value-added products. For example, the high value-added products took up a proportion of nearly 29.9 percent and 21.2 percent in the total finished steel products at Baosteel and Wuhan Steel respectively - China's top steel producers. The share for Hebei steel - a provincial SOE - in contrast, was 8.14 percent, which is 4.7 percentage points lower than the industry average.

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[3] The key (hereafter) firms are member firms of the Chinese Iron and Steel Association that includes all SOEs and big private steel firms with annual production over 1 million tons. The steel firms excluded by the Chinese Iron and Steel Association are small-scale private firms.

1.2.2 Technology Upgrading

The Chinese steel industry has experienced rapid technological upgrading since the early 1990s. Figure 4 shows the share of steel produced through continuous casting, an advanced technique in steel casting as opposed to ingot casting.[4] In 1990, 25.1 percent of crude steel was produced by continuous casting, and in 1998, the share reached 70 percent. In the subsequent 8 years, almost all steel makers in China upgraded to the continuous casting technique. In 2015, 98.3 percent of the steel was made by continuous casting. On the other hand, in terms of steel making, the energy-consuming open hearth furnace (OHF) process was completely eliminated in the late 1990s (see Figure 5). Even though China was not at the industry's technology frontier, it caught up with the advanced technology rapidly.[5]

1.3 INTERNATIONAL TRADE

China began to export steel products since 1990 but remained a net importer for over a decade. As the world's largest steel producer, China has been unsurprisingly playing a big part in the international market for steel products. Figure 6 presents the imports and exports of finished steel products (rolled steel) from 1998 to 2015. Despite substantial expansion in steel production, steel imports grew steadily until 2003, when it reached a peak amount with net imports mounting to 30.2 million tons. The year 2004 saw a decline in imports whereas exports started to take off, resulting in a 50 percent decrease in net imports. The sharp rise in steel exports eventually made China a net exporter in 2006, and the net exports climbed to 45.8 million tons in 2007. Although the exports plummeted in 2009 by 58.4 percent due to the Great Recession, China remained a net exporter. The year

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[4] Continuous casting is the process whereby molten metal is solidified into a "semifinished" steel for subsequent rolling in the finishing mills. Prior to the introduction of continuous casting in the 1950s, steel was poured into stationary molds to form ingots. Since then, "continuous casting" has evolved to achieve improved yield, quality, productivity and cost efficiency. https://en.wikipedia.org/wiki/Continuous-casting

[5] Data in this section are from the World Steel Association.

2010 witnessed an immediate recovery in exports by 73 percent, which guaranteed China's role of a net exporter of steel products. Steel export increased by 50 percent in 2014 and continued to rise notably in 2015. The net exports continued to expand since then. On the whole, the steel imports fell steadily since 2006, the steel exports on the other hand displayed significant volatility.

Figure 7 illustrates the structure of steel imports/exports by presenting information on low value-added and high value-added products.[6] Two major findings emerge. First, the net imports of high value-added steel fell substantially over time, enabling China to become a net exporter of high value-added steel in 2012. While the share of high value-added steel in total exports grew gradually from 11 percent to 22.3 percent, which translates into an increase of 23.5 million tons of high value-added steel from 2004 to 2015; the share of the high value-added imports remained stable between 50-60 percent, with tonnage down sharply by 57.4 percent. Second, China remained a net exporter of low value-added steel. The exports of low value-added steel were volatile, and its share in total exports fell from 39.3 percent in 2003, to 17 percent in 2009, and rose significantly afterwards, ending up with 44.4 percent in 2015. The imports of low value-added steel dropped by 40 percent in volume between 2004 and 2015 but its share increased slightly by 3.1 percentage points. To conclude, the change in trade structure illustrates the structural change in Chinese steel production.

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[6] Long products are key examples of low value-added steel that include rail, section, bar, rebar and wire rod, which mainly serve the construction sector. High value-added products include cold-rolled sheet and strip, clad and coated sheet and electro-sheet. Cold-rolled sheets and strips are key examples of high value-added steel that are crucial components for automobile and electric appliances. Note that the examples of high and low value-added products illustrated in Figure 7 do not add up to the total imports/exports.

1.4 EXCESS CAPACITY

Rapid industrialization in China stimulated strong domestic demand for steel and therefore massive investment in the steel industry. Investment in fixed assets accelerated between 2001 and 2005, growing at 43 percent per annum. It slowed down massively in the subsequent two years and sped up again afterwards at an average annual rate of 14.6 percent over the period 2008 - 2012 (see Figure 8). The investment began to drop since 2013, nonetheless, the level in 2015 remained higher than 2011 by 3.4 percent. Consequently, China's steel capacity expanded massively from 134.2 million tons to 1.13 billion tons between 1998 to 2015 (see Figure 9). Despite Beijing's repeated directive to cut capacity, the total steel capacity climbed steadily. Key firms took a significant proportion of steel capacity in the industry, and its average share reached 82 percent over the period 1999 - 2015.[7] Steel capacity of China's key firms rose steadily whereas that of small firms fell in several years. Figure 10 illustrates that the capacity growth rate of the small steel firms was more cyclical than that of the key firms. In contrast, the key firms raised capacity more smoothly, and contributed 76.6 percent of the increased capacity (981.4 million tons) from 1999 to 2015.

Questions thus arise: What results in the distinct patterns of capacity expansion between the two groups of firms? Why was the cyclical pattern more salient for the small steel firms? Several channels could explain the observed patterns. First and foremost, the preferential government treatment provides big firms with cheaper raw materials (iron ore), finance, land and electricity, etc. As a result, they are able to expand even when steel prices are low and industrial policy aims to limit steel development.[8] Support from the central government largely enhances the central SOEs' capability to expand. As to key

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[7] The key (hereafter) firms are member firms of the Chinese Iron and Steel Association that includes all SOEs and big private steel firms with annual production over 1 million tons. The steel firms excluded by the Chinese Iron and Steel Association are small-scale private firms.

[8] For example, during my interview with an engineer at Wuhan Steel, he mentioned that Wuhan Steel was able to carry out almost any projects before getting the central government's approval, because it was only a matter of time for the firm to get official permission from the NDRC.

provincial-level firms, despite Beijing's directive to harness capacity, they keep expanding under local governments' tacit permission, as these firms are important contributors of local tax and employment.

The small private firms, on the contrary, mostly rely on their own resources to finance investment, hence are profit-driven and are more likely to respond to market conditions, such as steel prices and demand. Moreover, the small firms are also more likely to become targets of local governments when the central government strengthens regulation and demands reductions in steel capacity.

Rapid expansion has produced unintended consequences, notably massive excess capacity, which has aroused heated debate among researchers and policy makers. The capacity utilization rate of crude steel was 85.4 percent in 1998 and declined by 14 percentage points over the next two decades.[9][10] Overall, the capacity utilization rate of the key firms was above the industry average(see Figure 11), nonetheless, the difference from the average utilization rate at industry-level narrowed down over time and began to increase since 2013.

Total excess capacity attained 323 million tons in 2015, 15 times the 1999 figure (see figure Figure 12). Even though the small firms on average made up approximately 18 percent of total capacity, their share in excess capacity was significantly higher, averaging at 33 percent (see Figure 13). For example, in 2007, 63.4 percent of excess capacity was generated by the small steel firms while they merely accounted 26.6 percent of total capacity. Therefore the small firms generated disproportionately higher excess capacity. In addition, Figure 14 shows that the share of excess capacity generated by the small firms is largely consistent with the cyclical pattern of the capacity growth rate. 2002 and 2004 are exceptional in that the growth rate of capacity was low whereas the excess capacity remained high. The drastic surge of steel capacity in 2001 and 2003, which led

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[9] According to my interview with some steel employees, the actual utilization rate is lower than 70 percent.

[10] Note that the U.S. utilization rate was averaged around 81 percent in the 10-year period dating back from 2011. Data source: 2011 Annual Statistical Report. American Iron and Steel Institute.

to considerable excess capacity in the subsequent years. Capacity began to fall since 2014, during which the small firms generated approximately 40 percent of total excess capacity.

1.5 LOW CONCENTRATION

The Chinese steel industry displays low concentration. The production share of the four largest steel producers (CR4 hereafter) in China is less than 30% (see Figure 15), whereas the corresponding shares in the U.S. and Japan are 75% and 53%.[11] CR4 began to decline in the early 2000s and reached a historic low in 2005 at 17.9 percent. Between 2006 and 2010, CR4 slightly recovered. It declined again since 2011, ending up with 19.7 percent in 2013, 8 percentage points lower than the 1998 level.

The Chinese central government sees the emerging private steel firms as trouble and has struggled to make structural changes since the mid-90s. Merger and acquisition ($M\&A$) is one of the key policies that the center imposes to shake out small steel firms and restructure the industry around a few state-owned giants subject to its direct supervision. Regulation and resource allocation would be more effective in a concentrated industry from the center's viewpoint. In the 10th Metallurgy Five Year Plan, the State Economic and Trade Commission, for the first time, brought up the initiative of $M\&A$ in the steel industry. The Plan emphasized that large vertically-integrated groups should be established, and that small firms should mainly aim at realizing production specialization and serving local markets. However, the document did not lay out specific consolidation plans. However, before 2005, only a limited number of $M\&A$ transactions took place in the steel industry, most notably was the acquisition carried out by Baosteel.

Since the National Development and Reform Commission (NDRC hereafter) launched the Steel Industry Development Policy in 2005, the central government has put in great

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[11] Data source: Bin Qi. 资本市场将决定中国改革的成败(Capital Market Will Determine the Fate of China's Transformation). www.ftchinese.com, 07/26/2013.

efforts to promote consolidation in the steel industry. In the 11th Five Year Plan, the NDRC encouraged large and competitive steel firms to conduct $M\&A$ transactions both within and across provinces, and even across ownership as well. Additionally, the NDRC instructed that the Ministry of Finance, Social Security and Treasury support $M\&A$ transactions in the steel industry.In the Steel Industry Adjustment and Revitalization Plan for 2009-2011 and the 12th Five Year Plan, $M\&A$ was again set as one of the top policy priorities.[12]

The past decade witnessed a large number of $M\&A$ transactions in the steel industry, mainly including five types of $M\&A$: first, within-province between central and provincial SOEs; second, within-province between provincial SOEs; third, cross-province primarily between central and provincial SOEs; fourth, between private firms; last, between SOEs and private firms.[13][14] Notably among all the $M\&A$ transactions, most prevailing were the first three types, while the cross-ownership transactions were rarely successful.

1.6 DYNAMICS OF THE STEEL INDUSTRY

This section exploits the Chinese Industrial Survey Data to provide evidence on the dynamic features of the Chinese steel industry over the period 1998 - 2007. It particularly focuses on the changing roles of the SOEs and the emergence of the private sector.[15][16]

In 1998, SOEs played a dominant role in the steel industry, contributing 66.3 percent

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[12] See Table A1 and Table A2 for the detailed description of the $M\&A$ policies.

[13] Central SOEs are under the direct supervision of the State-owned Assets Supervision and Administration Commission of the State Council (SASAC). Provincial SOEs are under the direction of provincial or regional SASACs.

[14] See Table A3 and Table A4 in the appendix for $M\&A$ the major transactions over the period 1998 - 2012.

[15] In this section and Chapter 3, SOEs refer to firms that are registered as state-owned enterprises, state-owned jointly operated enterprises and wholly state-owned companies. This definition differs from the one used in Chapter 2, in which shareholding limited and other limited liability companies controlled by the state are also categorized as SOEs. I present more details in Appendix A.3.1.

[16] In this section, the steel industry includes iron smelting, steel smelting and steel smelting but excludes smelting of ferroalloy.

of the gross value of industrial output (GVIO), 65 percent of profit and 74.4 percent of employment. In 2007, the shares of the GVIO, profit and employment declined to 23.7 percent, 24.3 percent and 29.2 percent, respectively. In terms of large SOEs, firm number fell from 72 to 48 over 1998 to 2007, and the GVIO share from 58.1 percent to 22.6 percent.[17] Correspondingly, the employment share dropped from 61.4 percent to 28.1 percent. Over the same period, profit share of the large SOEs declined significantly as well. In 1998, the profits realized by the large SOEs exceeded the total profits in the steel industry, which suggests that the rest of the industry was loss-making. However, in 2007, the large SOEs only contributed to 24.0 percent of the total profits in the industry. Despite the shrinkage of the state sector, the SOEs are still playing an important role in the steel industry.

In sharp contrast with the shrinkage of the state sector's share, private steel firms expanded rapidly in the past decade. In 1998, 12.4 percent of firms were private and the share in firm number climbed to 63.0 percent in 2007. The private steel firms only accounted for 1.8 percent of the total industrial output in 1998, however, the share rose to 20.1 percent in 2007. As to employment, the private sector absorbed 23.2 percent of total steel employment in 2007, whereas private steel firms merely made up 1.6 percent of the steel employment in 1998. The share of profit realized by private firms also soared from 5.3% to 15.4%. Notably, a number of large private firms even gained a leading role in the steel industry. For example, the leading private firm - Sha steel - is ranked among China's top-five by tonnage, and the firm expanded dramatically in the last decade, with its share of crude steel output rising from 2.8 percent to 4.55 percent between 2004 and 2011. And the firm is widely considered as the leading producer of construction steel thus its pricing of rebar is closely watched by its competitors.[18] As part of its expansion strategy, Sha steel also took an active part in $M\&A$ from 2006 to 2010.

The private firms gradually gained recognition of the Chinese government given their

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[17] Detailed size classification is presented in section 3.3.1.2.

[18] FACTBOX-China's 10 biggest steel mills in 2012. http://www.reuters.com/article/2013/01/31/china-steel-output-idUSL4N0B02B020130131.

important role in the steel industry. The Ministry of Industry and Information Technology (MIIT hereafter) entitled the private steel firms with the legal standing. For instance, in 2012, MIIT endorsed entry of 45 plants industry-wide, two thirds of which were private firms.

2.0 OWNERSHIP AND PRODUCTIVITY IN VERTICALLY-INTEGRATED FIRMS: EVIDENCE FROM THE CHINESE STEEL INDUSTRY

2.1 INTRODUCTION

Increases in productivity are an important source of economic growth for firms, industries and countries. Researchers have documented sizeable and persistent productivity differences between producers – even within narrowly-defined industries – and identified their elimination as a potentially important source of productivity growth.[1] Understanding the sources of these differences requires accurate measures of productivity, a task often hindered by issues of endogeneity and measurement.[2] But even if these problems can be addressed, identifying the sources of these differences is handicapped by the fact that productivity analysis is usually carried out at the aggregate firm level. In sharp contrast, production activity of individual firms often involves vertically-integrated operations carried out in multiple production units. Technologies and productivity likely differ by stage of production. Aggregate data and analysis miss this dimension, leaving as important research questions how firms configure their production operations and then their link with performance.

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[1] See for example, Syverson (2004) and Hsieh and Klenow (2009).

[2] De Loecker and Goldberg (2014) show how the absence of producer-level input and output prices, for example, leads to the estimation of revenue-based productivity measures that can reflect aspects other than the true efficiency of the producer.

Unlike prior productivity studies that focus on the firm level, to the best of our knowledge, this chapter is one of the first to investigate the underlying sources of productivity differences between production facilities through the lens of facilities' internal structure. In particular, this chapter studies vertically-integrated steel producers in China. By fact of its size - the sector now produces half of the world's steel - China's steel industry is important both domestically and internationally. The sector also remains heavily state-dominated. A recent literature has documented sizeable productivity differences between firms and sectors in China that appear tied to ownership and the regulatory environment.[3] State-owned enterprises (SOEs) often have better access to capital, technology, inputs and human resources, differences that may not be easily captured by available data (e.g. Haggard and Huang (2008)).

Drawing on a unique data set that provides equipment (hereafter interchangeable with machines/furnaces) level input and output information in physical terms by stage of production, we estimate production functions separately for the three main stages in steel's value chain (sintering, pig-iron making and steel making).[4] Following Domar (1961), we then integrate our productivity estimates within each stage into estimates for integrated facilities, using as weights either the estimated elasticities of material inputs in pig-iron making and steel making or the ratio of the value of sinter and pig-iron to steel. The richness of our data allow us to measure the efficiency of producers at integrated facility level, and more important, to decompose differences in performance by ownership type into process (stage) and equipment level differences, thereby providing new insight into the internal dimensions of complex industrial operations.

We find that private facilities are on average 6.2 percent more productive than central state-owned facilities, and 2.3 percent higher relative to provincial state-owned facilities. With value-added in the steel industry 25 to 30 percent of the gross output, these modest

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[3] See for example Hsieh and Klenow (2009), Hsieh and Song (2015), Brandt (2015), Berkowitz et al. (2016).

[4] Our estimation builds on the control function approach introduced by Olley and Pakes (1996) and Levinsohn and Petrin (2003), and developed further by Ackerberg et al. (2015) and Gandhi et al. (2016).

productivity differences translate into sizeable differences in profitability.

These differences do not capture the full story however. First, productivity advantages enjoyed by private facilities in downstream production stages (iron-making and steel making) are partially offset by nearly 9 percent lower productivity upstream in sintering. Likely underlying this gap is central state-owned facilities' superior access to higher quality raw material. With better access to iron ore, the productivity advantage of private facilities would be even larger. Second, we find that the productivity premium of private facilities declines with their size, and actually turns negative for facilities larger than the median. Private facilities smaller than the median size are 20.7 percent more productive than central state-owned facilities, and 5.7 percent more than provincial state-owned facilities.

This pattern is linked with how private firms internally configure their production facilities as they expand their steel production: They install more machines/furnaces of larger sizes, but machines/furnaces that are systematically smaller in size on average than those in state-owned facilities. The expansion path of private facilities drives down their relative productivity through two distinct channels: First, scarce managerial resources of private facilities key to the coordination of production across stages are now spread more thinly. Second, within each stage of production, relative equipment-level productivity of private facilities declines sharply with size as a result of fewer years experience with these newer technologies. Difficulties in hiring more capable workers and managers may also delay the realization of experience and learning effects associated with these new technologies.

Underlying the decision of private firms to build relatively smaller machines/furnaces as they expand are several factors including tighter restrictions on equipment size and investment, difficulty in accessing higher quality raw materials, and possibly credit constraints. Our study suggests that in the context of increasing returns to scale at the stage and facility level, the productivity premium of private facilities would be significantly higher if these constraints as well as those associated with accessing better human capital were removed.

The remainder of the chapter is organized as follows. Section 2.2 describes the data and presents key facts that help guide the empirical analysis. We provide an empirical approach to identify multi-stage productivity in section 2.3, followed by a discussion on productivity differences and the underlying sources in section 2.4. We discuss potential biases resulting from measurement errors in section 2.5 and conclude in section 2.6.

2.2 DATA AND DESCRIPTIVE EVIDENCE

2.2.1 Steel Production Technology

Vertically-integrated steel production involves a complex series of individual processes that use coal as the primary energy source and iron ore as the basic raw material (Ahlbrandt et al. (1996)). A steel facility integrates production in four major links along the production chain: sintering, pig-iron making, steel making and steel rolling (see Figure 16).[5] The process of sintering is basically a pre-treatment to transform iron ore fines into a high quality burden called sinter for use in the iron-making facility - the blast furnace. The principle of sintering involves the heating of iron ore fines along with flux and coke fines or coal to produce a semi-molten mass that solidifies into porous pieces of sinter with the size and strength characteristics necessary for feeding into the blast furnace. It is basically an agglomeration process achieved through combustion.[6] Sinter, together with coke, pulverized coal and limestone are then fed into the top of a blast furnace, while hot air is blown into the lower section of the furnace through a series of pipes, setting off a chemical reaction throughout the furnace as the material moves downward.[7] The molten pig-iron from the blast furnace along with oxygen and fuel are then fed into a basic oxygen furnace to produce steel, which is called primary steel making. Modern steel making can also incorporate a secondary steel making process, which involves refining of the crude

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[5] We provide a detailed description of steel technology in appendix A.2.

[6] http://ispatguru.com/the-sintering-process-of-iron-ore-fines-2/

[7] https://en.wikipedia.org/wiki/Blast-furnace

steel.[8] The semi-finished steel produced in vertically integrated firms is finally shaped into sheets, bars, wire, and tube steel of desired thickness and uniformity through a metal forming process in rolling mills.[9]

Technologically, larger blast furnaces incur smaller heat losses and enable more efficient heat recovery.[10] However, larger furnaces require higher-grade iron ore. The use of low-grade ore in larger blast furnaces increases energy intensity, generates more waste, and may even shorten the life expectancy of the blast furnaces.

2.2.2 Data

We construct a unique monthly-level data set on the facilities of vertically-integrated firms in the Chinese steel industry from January 2009 to October 2011.[11] Over this period, production of reporting firms in our sample represents sixty percent of the total steel output in China.[12] The reported data are in the form of equipment-level information on inputs and outputs in physical units for each of the three major stages of production (sintering, pig iron making and steel making). Input information includes key material inputs, standardized energy consumption, number of workers, size of equipment (capacity) and utilization rates.[13] These data are supplemented by information on ownership, year of establishment and location.

Our analysis centers on the first three major stages of production, i.e. sintering, pig-

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[8] In this process, alloying agents are added, the level of dissolved gases in the steel is lowered, and inclusions are removed or altered chemically to ensure that high-quality steel is produced. See Wikipedia http://en.wikipedia.org/wiki/Steelmaking

[9] https://en.wikipedia.org/wiki/Rolling-(metalworking)

[10] http://ietd.iipnetwork.org/content/blast-furnace-system

[11] The underlying data are collected by the Chinese Iron and Steel Association (CISA) as part of regular data collection efforts from all firms with annual steel production over 1 million tons.

[12] Three-quarters of the output not covered is production by private firms. This includes the production of smaller non-member private firms, and more important, the output of some member private firms. Notable omissions include Shandong Rizhao Steel, with an annual production capacity of 10 million tons. Also excluded are facilities ran by the headquarters of Baosteel, a central SOE that is generally acknowledged to be the most technically advanced steel firm in China.

[13] For steel rolling, we only have aggregate firm level information.

iron making and steel making, and excludes steel rolling. We do so for several reasons. First, finished rolled steel products can be highly differentiated, and differ in value added, final usage, and price. Output however is only reported in physical terms. Second, we only have data on total production of rolled products at the firm level rather than the product or the plant level. The input information is similarly aggregated across products and plants. And third, while the main purpose of sintering and pig-iron making is to meet the immediate consumption needs of the next stage in the production chain, firms often sell or hold inventory in semi-finished steel for later use. Therefore, between steel making and rolling, there is a dynamic dimension to decision-making that our data cannot capture. Despite this omission, we still capture a high percentage of the activity in the sector. In an average steel firm, the total value-added generated by the three stages under our consideration is more than double that of the rolling stage, or nearly seventy percent overall.[14]

Steel production in China is a highly vertically-integrated activity. Out of total of 81 firms for which we have production data, 70 undertake sintering, 71 are involved in pig-iron production and 68 make steel. An individual firm may also operate more than one integrated facilities. At the sinter-iron-steel level, we compiled data on 136 fully vertically-integrated facilities, operated by 59 firms.[15] Figure 17 provides an illustration of the typical make-up of a firm in our sample. Each firm may operate multiple integrated facilities; each facility houses a sintering plant, a pig iron making plant and a steel making plant; each plant in the value chain link may involve production in multiple production units, i.e. sintering machines, blast furnaces or basic oxygen furnaces, respectively.

2.2.2.1 Ownership

We categorize firms by three basic types of ownership: central SOEs, provincial SOEs and private firms. Central SOEs are under the direct supervision

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[14] We base these calculations on a 2015 report by the China Mingsheng Bank: Research on the Steel Industry and Suggestions on Development Strategy.

[15] See appendix A.2.1 for the detailed methodology that we used to link the machines/furnaces across stages. We lose observations from a small number of firms and integrated facilities because of missing data.

of the State-owned Assets Supervision and Administration Commission of the State Council (SASAC). We also define firms that have been merged into central SOEs as central state-owned. Provincial SOEs are under the direction of provincial or regional SASACs. Private firms in our sample include joint-ventures (JVs), wholly owned foreign firms and privatized SOEs.[16]

China's steel industry continues to be state dominated. Although their role has declined significantly the last decade, data at the national level for 2014 suggest that nearly half of steel production still comes from state-owned firms. Table 2 provides a breakdown of ownership for our sample, which is skewed in favor of state-owned firms, at the equipment level by stage of production and by integrated facility. In each of the three stages of production, between seventy and eighty percent of machines/furnaces are state-owned. State-owned firms are also consistently the source of eighty percent of total production, with the remainder coming from private firms. Within the state sector, provincial SOEs dominate.

2.2.2.2 Size Steel firms span a wide range of sizes at both the equipment and integrated facility level. By industry convention, we measure the size of a sintering machine by its effective area; size of a blast furnace as its effective volume; and the size of basic oxygen furnace as its tonnage. We define the size of an integrated facility as the total size of basic oxygen furnaces within the facility. These size measures directly reflect production capacity.

Table 3 provides summary data on equipment size for each stage of production by ownership. A clear ranking emerges: On average, machines/furnaces of central state-owned facilities are the largest, followed by those of provincial state-owned and then private facilities. A typical private machine/furnace is only 60 percent of the size of a central state-owned machine/furnace. The average size of a private pig-iron furnace, for example, is 698

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[16] Privatized SOEs were the product of restructuring efforts in the state sector in the late 1990s and early 2000s.

cubic meters compared to 1230 for a furnace of a central state-owned facility. Note also in columns (4) and (5) the wide range of equipment sizes within each ownership group. Table 4 provides comparable information at the integrated facility level. Central SOEs operate the largest facilities, which on average are more than twice as large as those of the private facilities (301 tons versus 131 tons), and a third larger than the facilities of provincial SOEs (301 tons versus 227 tons).

In Table 5, we break down integrated facilities into size quartiles and report for each quartile the total number of facilities by ownership and their respective shares of total steel production. Almost half of the facilities in central SOEs are in the largest size quartile: they produce 13.3 percent of total steel, and make up the largest share of total production by central state-owned facilities. The number of facilities of provincial SOEs is fairly evenly distributed throughout the quartiles, but those in the largest size quartile play a dominant role in total steel production. In sharp contrast with the state-owned facilities, only a single private integrated facility lies in the largest size group. Most private facilities are smaller in size than the sample median. In terms of the total production of private facilities however, the integrated facilities in the third quartile are the most important, and produce 37 percent of the steel by private facilities.

2.2.2.3 Internal Structure of Integrated Facilities As part of a single integrated facility, firms will typically operate multiple production units, e.g. sintering machines, blast furnaces or basic oxygen furnaces, in each stage of production. In Table 6 we report the average number of machines/furnaces and their average size for each stage of production by ownership and facility size. As before, we break down integrated facilities into size quartiles. As a general rule, the number of machines/furnaces used in each stage increases with the facility quartile. The increase however is less than proportional to the increase in the facility size, implying an increase in average machine/furnace size with the size of the integrated facility. For central state-owned facilities, the number of sintering machines and blast furnaces actually falls with facility size. For steel, they increase, but less rapidly than they do in either provincial state-owned or private facilities. This behavior gives rise to systematic differences in the number of machines/furnaces and their size in each stage of production as the size of the integrated facility increases. In particular, central state-owned facilities consistently operate the smallest number and largest machines/furnaces in each size category, followed by provincial state-owned and then private facilities. Alternatively, as private firms expand their integrated facilities, they do so using more machines/furnaces of smaller average size compared to SOEs.

2.3 ESTIMATING TOTAL FACTOR PRODUCTIVITY OF INTEGRATED FACILITIES

This section describes a framework to estimate total factor productivity of multiple stage production systems. Section 2.3.1 discusses the timeline of firms' decision. Section 2.3.2 presents the theoretical framework and the methodology to construct productivity for integrated facilities. Section 2.3.3 explains the details of our estimation procedure.

2.3.1 Description of Decision-Making

Firms make choices regarding investment and production. At the beginning of each year, a firm observes its state, which includes observable variables that affect their input access, output market and borrowing/regulatory constraints. Based on its initial state, the firm chooses its targeted level of total production to maximize current profit. This production must then be allocated among integrated facilities and machines/furnaces in each stage to minimize its total production cost. After observing production, the firm learns its productivity. At the end of the year, the firm decides on investment, which depends on the current state and productivity. Moreover, the choice of investment (i.e., the size of the facility, and its internal configuration) is limited by current regulations (mostly on the minimum size of the equipment) and has dynamic implications: first, larger machines/furnaces are less flexible on input choice and potentially more costly to maintain, which affects the expected payoff when there is uncertainty in the input market; and second, larger machines/furnaces enjoy the benefits of increasing returns to scale.

Since we have short panel data, we leave the investigation of the full industry dynamics for future research.[17] To reconcile with the monthly frequency of our data at facility level, we focus on the monthly production instead of yearly production at each facility and assume that production decision is made independently by each facility. At the beginning of each month, each facility observes its stock of capital and labor and then its individual productivity of machines/furnaces. Based on these observables, the facility chooses its intermediate input for each equipment in the last stage. Note that the facility obtains its last-stage intermediate input through a second-to-last stage production. Moving backward, the facility chooses its intermediate input for each equipment in the second-to-last stage. The process continues in this manner until the first stage of production. Following convention, we assume that intermediate input choices are monotone with respect to productivity in each corresponding stage. At the end of this month, the facility decides on hiring/firing employees and maintaining/utilizing certain machines/furnaces in the next month.

2.3.2 A Model of Multiple-Stage Production

In each period t, an integrated facility (facility "i") engages in three major stages of production, i.e. sintering (stage "1"), pig iron making (stage "2") and steel making (stage "3"). Along this production chain, output in each stage serves as the key material input for the production of subsequent downstream. For simplicity, we assume that each stage

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[17] Note that this paper centers on productivity differences by facility ownership related to facilities' internal configuration. We lay out a heuristic model in the appendix A.2.3 to illustrate the nature of the choices on equipment size and equipment number subject to various constraints facilities may face.

(plant) involves a single machine/furnace.[18] A complete production process is described as below:

$$Y_{i1t} = \min\{e^{\omega_{i1t}} L_{i1t}^{\alpha_1} K_{i1t}^{\beta_1}, \gamma_1 R_{i1t}\} e^{\epsilon_{i1t}}, \tag{2.1}$$

$$Y_{i2t} = e^{\omega_{i2t}+\epsilon_{i2t}} L_{i2t}^{\alpha_2} K_{i2t}^{\beta_2} R_{i2t}^{\gamma_2}, \tag{2.2}$$

$$Y_{i3t} = e^{\omega_{i3t}+\epsilon_{i3t}} L_{i3t}^{\alpha_3} K_{i3t}^{\beta_3} R_{i3t}^{\gamma_3} \tag{2.3}$$

where

$$Y_{i1t} = R_{i2t},$$

$$Y_{i2t} = R_{i3t}$$

and R_{i1t} represents crude iron ore fine, Y_{i1t} and R_{i2t} denote sinter, Y_{i2t} and R_{i3t} pig iron, and Y_{i3t} denotes the final product steel. Our measurement of capital $K_{i\cdot t}$ is the capacity of the equipment in this stage, and $L_{i\cdot t}$ is the corresponding number of employees. Productivity ω_{it} is Hicks-neutral. While each stage uses a different technology, $Y_{i1t} = R_{i2t}$ and $Y_{i2t} = R_{i3t}$ reflect the intrinsic linkage of multiple-stage steel production. As sintering is an agglomeration process that reshapes iron ore to the size and strength necessary for pig-iron making, this stage of production is assumed Leontief in materials.[19]

Applying the Leontief first order condition for sintering, we proceed with the following

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[18] We will deal with multiple-equipment production later.

[19] Substitutability may exist between raw iron ore and labor (capital), mostly likely due to the quality of iron ores. However, we do not have information on the raw iron ores used in sintering.

(log) production system:

$$
\begin{aligned}
y_{i1t} &= \alpha_1 l_{i1t} + \beta_1 k_{i1t} + \omega_{i1t} + \epsilon_{i1t}, \\
y_{i2t} &= \alpha_2 l_{i2t} + \beta_2 k_{i2t} + \gamma_2 r_{i2t} + \omega_{i2t} + \epsilon_{i2t}, \\
y_{i3t} &= \alpha_3 l_{i3t} + \beta_3 k_{i3t} + \gamma_3 r_{i3t} + \omega_{i3t} + \epsilon_{i3t}, \\
y_{i1t} &= r_{i2t}, \\
y_{i2t} &= r_{i3t}
\end{aligned}
$$

One advantage of the above production system is that it allows intuitive aggregation of stage productivity. In particular, we obtain such an aggregate for each integrated facility by combining the above (log) production functions for the three stages following Domar (1961):

$$y_{i3t} = \omega_{it} + \alpha_1\gamma_2\gamma_3 l_{i1t} + \alpha_2\gamma_3 l_{i2t} + \alpha_3 l_{i3t} + \beta_1\gamma_2\gamma_3 k_{i1t} + \beta_2\gamma_3 k_{i2t} + \beta_3 k_{i3t} + \epsilon_{it}$$

where $\omega_{it} \equiv \omega_{i3t} + \gamma_3\omega_{i2t} + \gamma_2\gamma_3\omega_{i1t}$ and $\epsilon_{it} \equiv \epsilon_{i3t} + \gamma_3\epsilon_{i2t} + \gamma_2\gamma_3\epsilon_{i1t}$ are facility-level productivity and facility-level noise, respectively. Intuitively, the facility-level productivity ω_{it} reflects the sum of productivity in each stage of production weighted by its importance in the production chain using elasticities.

Alternatively, we can use the value shares of pig iron and sinter out of the total value of steel as the corresponding weights. We assume that producers face perfect competition for sinter, pig iron and steel, the price of which are P_1, P_2 and P_3, respectively. We omit the facility subscript and time subscript t in the following illustration. Iron making (steel making) plants choose labor $L_2(L_3)$ and intermediate material $R_2(R_3)$ to maximize profits, while capital $K_2(K_3)$ is predetermined.[20] The first order conditions with respect to material R_2 and R_3 and the inter-linkage equality equations $Y_1 = R_2$ and $Y_2 = R_3$ imply:

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[20] Labor could be a dynamic choice too. We examine this more fully in our discussion of the estimation approach.

$$\gamma_2 = \frac{P_1 Y_1}{P_2 Y_2}$$
$$\gamma_3 = \frac{P_2 Y_2}{P_3 Y_3}$$

Hence we obtain the alternative weights:

$$\gamma_3 = \frac{P_2 Y_2}{P_3 Y_3} \tag{2.4}$$
$$\gamma_2 \gamma_3 = \frac{P_1 Y_1}{P_3 Y_3} \tag{2.5}$$

In addition, for the integrated facilities that have multiple machines/furnaces in each link of the production chain, before aggregation, we first construct a weighted average stage productivity measure using as the weight either the share of deterministic components of production ($K^\alpha L^\beta R^\gamma$) or the share of machine/furnace size.

2.3.3 Estimation Approach

For estimation, we adopt the control function approach developed by Olley and Pakes (1996) and rely on a production unit's choice on intermediate inputs to control for unobserved productivity (Levinsohn and Petrin (2003)). A major advantage of our data is that it contains equipment-level information on inputs and output, which allows estimating production functions by stage and the calculation of equipment-level productivity estimates. A standard procedure has two steps.[21]

In the first step, we use energy input e_{ist} to control for unobserved TFP ω_{ist}. For stage $s \in \{2, 3\}$, the energy input is determined by predetermined capital and labor, as well as

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[21] We abstract from firms' entry/exit decisions since they are not prominent in the data. At this stage, we do not take into account monthly entry/exit decisions on machines/furnaces, but this could be dealt with in a manner similar to Olley and Pakes (1996). Effectively, we can estimate the probability a machine/furnace shuts down and use it as a control in our estimation.

TFP:

$$e_{ist} = \phi_{st}(k_{ist}, l_{ist}, \omega_{ist}).$$

Following Ackerberg et al. (2015), we assume that $\phi_{st}(\cdot)$ is strictly monotone in ω_{ist} conditioning on (k_{ist}, l_{ist}). This implies that the above relationship can be inverted:

$$\omega_{ist} = \phi_{st}^{-1}(k_{ist}, l_{ist}, e_{ist}).$$

Therefore, we obtain our first step estimating equation in which the output y is a semi-parametric function of inputs $(k_{ist}, l_{ist}, e_{ist}, r_{ist})$

$$y_{ist} = \alpha_s l_{ist} + \beta_s k_{ist} + \gamma_s r_{ist} + \phi_{st}^{-1}(k_{ist}, l_{ist}, e_{ist}) + \epsilon_{ist}$$

As usual, we collect the deterministic terms and denote them as $\Phi_{st}(k_{ist}, l_{ist}, e_{ist}, r_{ist}) \equiv \alpha_s l_{ist} + \beta_s k_{ist} + \gamma_s r_{ist} + \phi_{st}^{-1}(k_{ist}, l_{ist}, e_{ist})$. Note that for stage $s = 1$, the same analysis follows by leaving out r_{i1t} due to the Leontief technology.

Ackerberg et al. (2015) argue that it may take longer to optimally adjust capital and labor input use than intermediate inputs, which include materials and energy. Since our data are on a monthly basis and include large SOEs that face larger hiring and firing costs, labor is likely to be fixed or quasi-fixed. Therefore, it is reasonable to assume that the demand for intermediate inputs depends on productivity and the predetermined capital and labor input. The advantage of using energy inputs as control variables is two-fold: first, energy input is measured in terms of standardized coal, which addresses the issue of potential bias resulting from quality differences in inputs; and second, using energy input for the control function throughout all three stages keeps our estimation consistent. We approximate $\Phi_t(k_{it}, l_{it}, e_{it}, r_{it})$ by a high order polynomial and use OLS regression for estimation.[22] We also include ownership dummies ($Downership$), time dummies (Dt) and province dummies ($Dprovince$) in the regression. In pig-iron making, we adjust material input r by the percentage of pure ore content to control for quality variation. Basic oxygen

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[22] To simplify illustration, the subsequent analysis abstracts from stage subscript s.

furnaces (steel making) differ significantly in the share of steel that goes through secondary refining. One of the major goals of secondary refining is to remove impurities from the molten steel, so the intensity of secondary refining potentially reflects the quality of pig iron used in steel making. To control for input quality in steel making, we also include in the first stage a dummy to capture whether furnaces carry out secondary refining ($Dsecond_{it}$) and then the share of steel that goes through secondary refining ($second_{it}$).

In the second step, we estimate the parameters $\theta \equiv (\alpha, \beta, \gamma) \in \Theta$ by GMM, which exploits a Markov assumption on the TFP and the timing of input choices. Θ denotes parameter space. In particular, we assume that TFP follows a first-order Markov process:

$$\omega_{it} = g(\omega_{i,t-1}) + \xi_{it}$$

which says that the current productivity shock consists of an expected term predicted by productivity at $t-1$ ($\omega_{i,t-1}$) plus a deviation from the expectation, often referred to as the "innovation" component (ξ_{ist}). Note that ω_{it} is identified up to θ from the first step after taking out measurement error and unanticipated shocks from output. We regress ω_{it} on a linear function of $\omega_{i,t-1}$ to obtain $g(\omega_{i,t-1})$.[23] Denote $\omega_{it}(\theta) \equiv \hat{\Phi}_t(k_{it}, l_{it}, e_{it}, r_{it}) - \alpha l_{it} - \beta k_{it} - \gamma r_{it}$. For a given θ, $g(\cdot)$ can be estimated and thus ξ_{ist} (up to θ) is obtained. The latter is used to construct the moment conditions:

$$E[(\xi_{it}(\theta) + \epsilon_{it}) \begin{pmatrix} l_{i,t-1} \\ l_{it} \\ k_{it} \\ r_{i,t-1} \\ \Phi_{i,t-1}(k_{i,t-1}, l_{i,t-1}, r_{i,t-1}) \end{pmatrix}] = 0.$$

Since the capital stock is a state variable at t, it should be orthogonal to the innovation shock on productivity at t. We use current labor (l_{it}) as an instrument for itself because of its dynamic feature. We also include labor at $t-1$ as an additional instrument. And we

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[23] The results are robust to higher order polynomials.

use lagged material input $r_{i,t-1}$ as an instrument for r_{it}. As pointed out by Gandhi et al. (2016), the use of $\xi_{it} + \epsilon_{it}$ rather than ξ_{it} alone in the moment condition is more general. We search over the parameter space Θ to find $\hat{\alpha}$, $\hat{\beta}$ and $\hat{\gamma}$ that minimize the above moment conditions.

We use the GMM procedure to identify separately production function coefficients for each individual stage s, $s = \{1, 2, 3\}$. As is commonly done, we also add firms' age to the production function to control for potential systematic differences in technology resulting from the learning-by-doing process.[24] In steel making, we allow the status of secondary refining ($Dsecond_{i,t-1}$) and the share of secondary refining ($second_{i,t-1}$) to enter the productivity evolution process since secondary refining technology may potentially impact the law of motion of productivity.

Our use of measures of output and inputs in physical units introduces measurement errors, which can bias our estimates. We do not capture potential quality differences in output, or in the facility's human capital. The number of employees that we use to measure labor abstracts from differences in workers' skill level. Similar issues arise in our use of equipment capacity as our measures for capital stock. In Section 2.5, we return to these issues and provide several robustness checks for differences in input and output quality.

2.4 MAIN RESULTS

2.4.1 Production Function Coefficients and Returns to Scale

Table 7 presents estimates of the production functions for sintering, iron making and steel making, the three major production stages along the value chain for steel. For each stage of production, we report results using both OLS and GMM. For sintering, the coefficients are

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[24] Ideally we want to use a machine/furnace's age to capture this process. Lacking this information, we use the firm's age.

only provided for labor and capital, and not for materials, reflecting the assumed Leontief technology. The use of input and output in physical units eliminates price biases. Our GMM estimates correct for any endogeneity bias due to the potential relation between input usage and unobserved productivity. In addition, disaggregated input information allows us to estimate production functions at each individual stage, without imposing any assumptions on input expenditure allocation.[25]

For individual production parameters, the differences between the OLS and GMM results are relatively small. The elasticities are largest for materials, followed by capital and labor. Of the three stages, sintering is the most capital intensive, followed by pig-iron and steel making. More important differences emerge with respect to estimates of returns to scale. Most notably, our GMM estimates imply increasing returns to scale, and thus falling long-run average costs, in each stage of production.[26] The sum of the input elasticity is largest for sintering (1.12), followed by steel making (1.06), and iron making (1.03).

Increasing returns to scale prevails in all three stages of production, and we now take a look at the increasing returns to scale at the facility level. As discussed before, the facility-level production function can be expressed as:

$$y_{i3t} = \omega_{it} + \alpha_1\gamma_2\gamma_3 l_{i1t} + \alpha_2\gamma_3 l_{i2t} + \alpha_3 l_{i3t} + \beta_1\gamma_2\gamma_3 k_{i1t} + \beta_2\gamma_3 k_{i2t} + \beta_3 k_{i3t} + \epsilon_{it}$$

This facility-level production function in our setup reflects the nature of production. First, inputs in different stages are not perfect substitutes, an assumption that is implicitly imposed in the traditional firm-level production function. Workers may specialize in individual stages of production, making them less than perfectly mobile across stages. Second, upstream inputs, namely, labor and capital, contribute to the entire production chain through

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[25] The bias in production function coefficients from a commonly used revenue production functions arises from several sources. First, relying on sales and expenditure data will not deliver the vector of production. Second, even with no input and output price variation, the OLS estimation could generate biased estimates due to the well-know simultaneity and selection biases. In addition, input information at the firm level forces one to estimate an aggregate production function for a multi-product firm unless one imposes assumptions on input expenditure allocation (De Loecker and Goldberg (2014)).

[26] We replicate the OLS and GMM estimation for a thousand bootstrapped samples, and find that the mean of the returns to scale from GMM is statistically larger than the returns to scale from the OLS.

their role as intermediate material providers. Therefore, the facility-level increasing returns to scale is characterized by the sum of the capital and labor elasticities in each stage of production weighted by the material input elasticities, i.e., $(\alpha_1+\beta_1)\gamma_2\gamma_3+(\alpha_2+\beta_2)\gamma_3+(\alpha_3+\beta_3)$. By plugging in the estimated elasticities, we obtain a degree of increasing returns to scale 1.14.

The degree of increasing returns to scale at the facility level is larger than the returns to scale in the individual stages, suggesting that the three stages contribute to overall increasing returns in a mutually reinforcing way. Our estimates are also larger than several recent estimates for the industry, notably, an estimate of 1.03 by Collard-Wexler and De Loecker (2015) for the US, and 1.07 for China by Sheng and Song (2012). [27]

2.4.2 Dispersion of Productivity

We derive TFP (Total Factor Productivity) estimates for each stage of production using the production function estimates above. In Table 8, we report two measures of equipment-level dispersion for productivity: the standard deviation of TFP, and the ratio of TFP of machines/furnaces at the 90th percentile to those at 10th percentile.[28] Several things are noteworthy. First, dispersion declines as production moves downstream. While sintering machines at the 90th percentile are more than twice as productive as the machines at the 10 percentile, in pig-iron the ratio is 30 percent, and in steel making, the 90th percentile furnaces are 25 percent more productive than the 10th percentile furnaces. At the level of integrated facilities, the 90:10 ratio is 1.91. Second, these differences are much smaller

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[27] Possibly underlying these differences is some combination of the estimation of an aggregate production function, and in the case of Sheng and Song (2012), a revenue production function. The latter is necessary because of the lack of firm-level price information. De Loecker and Goldberg (2014) point out that variation in both output and input prices in a revenue production function likely results in a downward bias in production function coefficients and therefore a lower returns to scale. Collard-Wexler and De Loecker (2015) construct firm-level input and output deflators, and thus effectively estimate a production function in physical terms.

[28] The 90:10 ratios for sintering, iron making and steel making are based on the average productivity of machines/furnaces over time.The ratio for integrated facility is based on the average productivity of integrated facilities over time.

than estimates for Chinese manufacturing in 2005 by Hsieh and Klenow (2009), who find a 90-10 ratio of 11.5, or six times our estimates at the facility level.[29]

2.4.3 Productivity Differences by Ownership at Equipment Level

We are interested in the effect of ownership on equipment-level productivity. In Table 9, we report estimates of productivity by ownership for each stage of production. Estimates are obtained from simple OLS regressions of the log of equipment-level TFP on ownership dummies that also control for the effect of seasonality with the use of monthly dummies. In these regressions, equipment of central state-owned facilities are our omitted category. In both pig-iron making and steel-making, private facilities have a productivity advantage over central state-owned facilities, 5.2 percent and 5.8 percent, respectively. Differentials favoring private facilities in both stages are slightly smaller in comparison with provincial state-owned facilities. In sharp contrast, the productivity ordering by ownership is reversed for sintering: Sintering machines of central state-owned facilities are 8.6 percent more productive than private facilities, and 10.2 percent more productive than provincial state-owned facilities.

Estimates in Table 3 suggest important differences in the size distribution of equipment, with central state-owned facilities consistently running the largest machines/furnaces, followed by provincial state-owned facilities, and then private facilities. To identify the role of equipment size in explaining productivity differences by ownership, we add to the previous regressions an interaction term between equipment size and our ownership dummies and report the estimates in Table 10.[30] Three findings emerge: First, the coefficient on size suggests a decline in TFP as size expands in central state-owned facilities, our ref-

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[29] There are a number of possible explanations for these differences. First, Hsieh and Klenow (2009)'s estimates also reflect productivity differences within industries, but their estimate is calculated over all industries. Second, their estimates are based on a value-added rather than gross aggregate production function. As they point out in the paper, the measure of productivity should reflect the quality and variety of a plant's products, not just its physical productivity.

[30] Note that in these regression we may be picking up the systematic (and unobserved) correlation between the size of the equipment and overall number of equipment the firm is running.

erence group, in all three stages. Second, TFP of private equipment declines relative to central state-owned facilities as size expands in all three production stages, with the effect more pronounced (and statistically significant) in iron-making and steel production. These results imply that for larger machines/furnaces, the TFP advantage of private over state-owned facilities disappears and turns negative. Finally, for provincial state-owned facilities, the productivity gap with central state-owned facilities narrows in sintering and iron-making as equipment size expands, but widens in steel.

What might help to explain the reversal in the productivity ranking in the case of sintering? A regular supply of iron ore is critical to the running of sintering machines. SOEs, especially central SOEs, typically enjoy privileged access to iron ore.[31] Central SOEs source imported iron ore through long-term contracts directly with the importers, which enable them to build up inventories of iron ore when prices are relatively low. In principle, sourcing difficulties might force private facilities to operate their sintering machines at lower rates of capacity utilization, which then show up as lower productivity. Data on capacity utilization however reveal only modest differences by ownership in the case of sintering.[32] Nonetheless, sourcing difficulties related to private facilities' more limited access to higher quality iron ore might hold the key to the differences we observe in productivity.[33]

In general, the quality of domestic iron ore is much lower than that of imported ore. This is reflected, for example, in the ore's percentage of silica, a chemical substance that lowers the quality of sinter and also adversely affects the production process. For domestic iron ore, the silica content ranges from 6.5 to 12 percent. By contrast, imported iron ore is more homogeneous in pure ore content, and contains only 4 percent silica.[34] Over the three-year period between 2009 and 2011, steel firms of all ownership in China relied heavily

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[31] Interview with a steel consultant at Shanghai Securities Research Institute in December, 2014.

[32] Capacity utilization is measured here as the ratio of operating days to total calendar days minus scheduled maintenance days. Private facilities actually operate slightly more intensively than central state-owned facilities by 1.8 percentage points.

[33] Factors influencing sintering process. July 8, 2013. http://ispatguru.com/factors-influencing-sintering-process/

[34] The information on iron ore fines is extracted from Yu (2004).

on imported ore, however private firms used two-thirds more domestic iron ore than did SOEs: 33.3 percent versus 20 percent.[35] Data for 2012 reported in Table 11 indicate that rich ore fines - a measure of the quality of crude ore used in sintering - account for 56.1 percent of total crude iron ore processed in central SOEs, while the proportion of rich ore fines in private firms is lower by 14.3 percentage points, or 25 percent. This difference is statistically significant.

Sintering is positioned at the very beginning of the value chain and entails the production of high quality burden out of crude iron ore fines. The use of lower grade domestic iron ores by private facilities necessitates additional processing in order to produce the iron ore of the desired quality for pig-iron production. This ties up the processing equipment longer and requires additional labor inputs, both of which translate directly into the lower equipment productivity we observe.[36]

2.4.4 Productivity Differences in Integrated Facilities by Ownership

Recall that we can use either elasticities of material inputs or value shares to integrate estimates of stage TFP into an aggregate TFP at facility level. In Table 12 we report these two sets of weights for each stage of production. Two main messages emerge. First, the contribution of production to overall facility-level efficiency increases as we move downstream. The weight on sintering productivity is 0.48 compared to weights of 0.8 and 1.0 on iron-making and steel production, respectively. Second, the two alternative weights are similar in magnitude, which provides additional validation for our estimated elasticities. As a result, the two sets of weights deliver similar estimates of TFP. The subsequent analysis is based on the TFP estimates weighted by the elasticities.

We present estimates of facility-level productivity differentials by ownership in Table 13.

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[35] Data on iron ore are reported on an annual basis and cover two-thirds of the firms in the production data.

[36] In iron- and steel-making, however, our production function estimation already factors in the quality of the key material inputs. In fact, controlling for input quality changes only slightly the magnitudes of productivity differentials.

Column (1) shows that private integrated facilities are on average 6.2 percent more productive than the facilities in central SOEs, and are 2.3 percent more productive relative to provincial SOEs. Two main messages emerge. First, the ordering of productivity by ownership at the facility level follows that found in pig-iron making and steel making. This implies that the sizeable productivity disadvantage of private facilities in sintering is more than offset by their superiority in the two downstream stages of production. Second, the magnitude of the private ownership premium in steel seems small by comparison with Hsieh and Song (2015)'s recent estimate of 33 percent for 2007 for the manufacturing sector, but more in line with Berkowitz et al. (2016), who find an average 8.2 percent productivity premium of private firms relative to SOEs between 2003 and 2007.[37]

Care must be taken in interpreting our estimates however. First, in addition to the likely productivity losses in sintering linked with sourcing difficulties in high-quality iron ores, private facilities may face other constraints that impact their productivity relative to state-owned facilities.[38] Below, we examine the possible role of restrictions on how private facilities expand. In a less constrained environment, the premium favoring private facilities might be even larger. Second, with value added in the steel sector 25-30 percent of gross output, even modest productivity differences of the sort we have estimated translate into significant differences in profitability by ownership, which have wider implications.

2.4.5 The Larger, the Better?

We documented systematic differences in the size of integrated facilities by ownership: SOEs in general operate much larger facilities. The scatter plot of TFP against facility

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[37] Differences in these estimates may come from several sources: First, estimation of a value-added versus gross-output production function. Although both value-added and gross-output based TFP indices provide a measure of technological change, the two will not necessarily be the same (Balk (2009)). Second, differences in assumptions relating to the underlying production technology, e.g. Cobb-Douglas versus CES versus translog, may result in differences in estimated TFP and our productivity ranking. And third, some estimates may only reflect within-sector variation, while others capture both within and between sector differences.

[38] Rough calculations suggest that eliminating the premium of central state-owned facilities in sintering would raise the premium of private facilities at the facility level by an additional 2-3 percentage points.

size in Figure 18 demonstrates a negative relationship between the two for the full sample, with the slope much steeper for private than state-owned facilities. To examine how TFP differs systematically with facility size by ownership, we run regressions of TFP on facility size that also include interaction terms of ownership dummies with facility size. Results are provided in Table 13 column (2) and confirm the results of Figure 18. For central state-owned facilities, size appears to have no significant effect on TFP. In sharp contrast, for private facilities, and slightly less so for provincial state-owned facilities, productivity of integrated facilities declines with size. The coefficient on the interaction term for private facilities implies that with a doubling in size, their productivity declines by 13.6 percent relative to central state-owned facilities.[39] This has the effect of reducing the productivity premium of these firms relative to central state-owned facilities at larger sizes.

To further illustrate how the productivity premium differs by size, and explore any potential nonlinear relationships, we once again divide our sample into size quartiles and estimate productivity differentials by ownership for each of the subsamples. Table 14 confirms that the productivity advantage of private integrated facilities declines remarkably with size. Private facilities outperform central state-owned facilities by 32.7 percent and provincial state-owned facilities by 7.9 percent when the facility size is below the 25th percentile. These premiums are huge relative to the average premiums of 6.2 percent and 2.3 percent that we presented earlier. Clearly, a pooled-sample regression conceals any heterogeneity that might be linked with the size of integrated facilities. The productivity premium of private facilities remains positive but declines considerably in the second quartile. For facilities between the median and 75th percentile, the ranking of TFP completely flips: Central state-owned facilities demonstrate an absolute advantage in this quartile of 19.8 and 5.2 percent relative to private and provincial state-owned facilities, respectively. In the largest quartile, private facilities once again exhibit a significant advantage in TFP over the state-owned facilities, however this is tied to the operations of a single private in-

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[39] Since the productivity of central state-owned facilities is not systematically related to size, this also implies an absolute decline.

tegrated facility. With output in the third size quartile nearly forty percent of the private sector's total steel production, the low relative productivity of these facilities drags down considerably the private sector's overall premium relative to the state-owned facilities.

2.4.5.1 The Internal Configuration of Integrated Facilities An integrated facility consists of sets of sintering machines, blast furnaces (pig-iron making) and basic oxygen furnaces (steel making). As firms expand existing facilities, or build new ones, they can manage the size of the equipment they use in each stage to obtain their desired output capacity. In pig-iron, for example, they may decide to use two 400 m^3 blast furnaces rather than a single 800 m^3 blast furnace. Similar options are available in the choice of sintering machines for sintering and basic oxygen furnaces for steel making. Differences in the internal configuration of integrated facilities of private firms and SOEs may help explain the systematic relationship between size and productivity of these two types of facilities.

To examine this relationship more fully, we first regress the number of equipment in an integrated facility on log size and log size interacted with our ownership dummies for each individual stage. Since the number of equipment is a count variable, we report results in Table 15 using Poisson regression. Two findings emerge. First, when central state-owned facilities expand, the absolute number of equipment drops in sintering and pig-iron making, but increases in steel making. Second, doubling the size of private facilities is associated with more machines/furnaces in all stages of production, both absolutely and relative to state-owned facilities that expand at the same rate. In Table 16, we report related results from the perspective of average equipment size. They tell a complementary story. As the size of the integrated facility doubles, the average size of equipment in private facilities in each stage of production increases, but increases less rapidly relative to central state-owned facilities by 13.3 percentage points in sintering, 27.4 percentages points in pig-iron making and 17 percentage points in steel making.

In short, as private firms try to expand their capacity, they install larger machines/furnaces, but more of them since their average machine/furnace size is smaller than SOEs. From the perspective of Table 6, this difference is especially sharp in the third quartile for pig-iron making, exactly the quartile in which private facilities do most poorly relative to the state-owned facilities. And this pattern of internal organization helps to explain the falling productivity premium of private integrated facilities.

2.4.5.2 Larger Equipment Size As suggested by Table 10, equipment-level TFP declines with equipment size. In particular, equipment-level TFP in private facilities declines relative to state-owned facilities as equipment size expands in all three production stages, with the effect more pronounced (and statistically significant) in pig-iron and steel making.

Three channels combined may help to explain the falling equipment-level productivity in private facilities in both absolute terms and relative to state-owned facilities when equipment size increases. First, because of learning-by-doing effects associated with the use of new technologies, larger furnaces may only achieve full production efficiency with added years of operational experience. Li (2011) documents this phenomenon for Baosteel, widely accepted as China's most advanced steel maker. The decline in TFP with equipment size in all ownership categories may reflect the learning-by-doing process required to master fully the newly installed larger machines/furnaces in the industry.[40]

Second, rising equipment size requires better human capital both on the shop floor and in management. Ahlbrandt et al. (1996) argue in the context of the US steel industry that for any given level of technology, the best performing plants are those with the most capable production workers. More generally, new technology and human capital are highly complementary. Li (2011) points out, for example, that by design larger blast furnaces are more advanced in their technology (e.g. energy saving and environmental friendly), and also more demanding in the role of advanced management systems.[41] In larger furnaces,

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[40] However, our short panel cannot effectively show such learning-by-doing effect.

[41] Larger blast furnaces require managers to adopt modern management procedures, such as "PDCA", i.e. Plan, Do, Check and Action. As large blast furnaces also generate huge amounts of data, management and analysis of data are critical for operating and control of large and modern blast furnace. See "High

for example, workers must control the size, shape and temperature of the burdens fed into furnaces within much finer tolerances, thereby putting a premium on higher quality shop-floor workers.[42] Last, large furnaces require additional care and maintenance: A temporary breakdown lasting a single minute can result in substantial costs.

Third, much lower levels of human capital in private facilities may lead to the more rapid drop-off in TFP as equipment size rises. In China's steel sector 18.7 percent of SOE employees had a college degree or higher compared to only 7.2 percent in private firms. The percentage of skilled labor in SOEs was almost two and a half times larger than in private firms (4.7 versus 2 percent).[43] In general, SOEs provide better wage and non-wage benefits (housing, pensions, child care and health care, etc) than private firms, and thus are more attractive for more highly skilled workers. A vast literature documents the earning gap between SOEs and non-state firms in urban China.[44] Even though the earnings premium of SOEs over private firms has declined over time, the premium was still 24 percent in 2007 (Démurger et al. (2012)). The decomposition of earnings suggests that observed differences in human capital, hours worked, etc. are only a small part of the picture and that ownership differences unrelated to productivity are far more important.[45] Lower levels of human capital in private firms likely increase the time needed to digest new technology and prevent private facilities from fully exploiting the potential of such technology. Hence, the lack of highly skilled managers and qualified workers could be one explanation for the sharply falling TFP in larger private facilities.

Capacity Iron Making with Large, Modern Blast Furnaces", International Conference on Emerging Trends in Metals & Minerals Sector. New Delhi, 5 September 2014.

[42] In addition, in larger furnaces, the production process must be more carefully monitored to ensure that slag is removed almost immediately because of the greater risk that it might clog the furnace as pressure inside the furnace increases (Yao (2014)).

[43] The figures are based on the authors' calculation using the 2004 Industrial Survey Data.

[44] See for example, Zhao (2002), Chen et al. (2005), Démurger et al. (2007), Démurger et al. (2012), Ge and Yang (2010), Xia et al. (2013).

[45] The earning variable covers both wage and non-wage benefits and is adjusted to reflect differences in regional cost of living.

2.4.5.3 Coordination To operate integrated facilities, firms have to coordinate multiple machines/furnaces both within the same stage and across stages. Ahlbrandt et al. (1996) point out that integrated plants incorporate a series of processes, which must be compatible and coordinated in order to achieve maximum efficiency and quality. However, coordinating changes in the work environment can be challenged by a series of practices including training and team building, motivation and communication, and conflict resolution. Better management practices and more capable managers facilitate coordination and thereby reduce coordination costs. We saw in the previous section that private facilities in general face constraints on human capital. This situation may apply to managerial talent as well. The lack of skilled managers likely induces additional coordination cost at the expense of efficiency. Even if private facilities have as good managers as state-owned facilities, the rising number of machines/furnaces as they expand spreads managerial resources more thinly in private facilities, posing more challenges for coordination in multi-process production.

To investigate how well the production stages are coordinated, we construct TFP correlations between consecutive links along the production chain for each integrated facility. In Table 17 we present TFP correlations by ownership and by facility size. Private facilities display the highest TFP correlation across stages when facility size is below median. However, when integrated facilities get larger, TFP correlation drops steadily in private facilities. In sharp contrast, TFP tends to align much better across stages in larger state-owned facilities. In short, the failure of the private facilities to align production efficiencies across stages when they expand translates into a loss in facility-level TFP.

2.4.6 Why Are Private Facilities Smaller?

Over the period we analyze, the demand for steel grew rapidly, and steel firms of all ownership types had strong incentives to expand. With steel production exhibiting strong increasing returns to scale at both the equipment- and facility-level, we expect expansion to be achieved through larger scales because of the falling long-run average cost. However, our data show that private facilities are on average much smaller than state-owned facilities, as are their machines/furnaces throughout the value chain. The internal configuration of private facilities likely reflects a variety of constraints private firms face as they make expansion plans. For private firms subject to constraints on expansion approval, finance, human capital and iron ore quality, private firms are better off expanding in small scales with relatively small machine/furnace size. A further reason to partially offset the expectation for increasing equipment size is the added production flexibility afforded by having smaller machines/furnaces.

2.4.6.1 Regulatory Constraints Rapid expansion of China's steel sector in the last two decades has been accompanied by an unexpected and unwelcomed outcome: massive excess capacity. A major objective of the Chinese central government is to limit excessive capacity, and more important, to restructure the industry around a few giant SOEs under its direct supervision. This policy direction incentivizes firms that want to be significant players in the industry to expand in order to avoid being acquired or possibly shut down. However, government permission is essential for capacity expansion, approval that is much harder for private firms than for SOEs. The regulatory constraints may prevent private firms from expanding to a larger size.

Despite the central directive to limit capacity, there are cases in which firms expand with cooperational support from local governments who are interested in promoting local investment to improve their tax base and growth prospects. Nevertheless, private firms that undergo large-scale expansion risk drawing public attention and becoming a target of upper-level regulatory agencies. A well-known example is Tieban Steel, a private firm in the province of Jiangsu. The firm's owner was imprisoned for carrying out a large-scale project that expanded the firm's capacity by 8 million tons against the wishes of the central government. To avoid detection, Tieben took advantage of a regulatory loophole and split the expansion into several smaller projects that installed smaller machines/furances in several phases. Although Tieben ultimately failed, its case illustrates the role of regulatory constraints in limiting the size of facilities built by private firms.

2.4.6.2 Capital Constraints Capital constraints could also result in smaller scales for private firms. A sizeable investment is required to install an integrated facility. The investment cost of a single large machine/furnace is also substantially larger than multiple smaller machines/furnaces with equal total capacity. In Table 18, we report the investment cost per unit of capacity by furnace size. Using blast furnaces for iron-making as an example, installing two $500m^3$ furnaces rather than a single furnace of $1000m^3$ saves approximately 4.5 million US dollars, or 7-8% of total investment.[46] In theory, the increasing returns to scale should provide a strong motive for firms to install larger machines/furnaces. However, it is widely documented that private firms in China are discriminated against in the credit market.[47] Hence, private firms face a trade-off between enjoying lower long-run average costs by bearing the immediate higher investment cost and making less-costly investments. The financing constraints likely steer private firms towards smaller machines/furnaces.

2.4.6.3 Human Capital Constraints A growing body of literature and stylized facts demonstrate the effect of firm ownership on firms' capability in accessing resources and capital. Drawing on a sample of private enterprises in China, Garnaut et al. (2012) argue that private firms are not only financially constrained, but are also constrained in other areas such as human capital.[48] Iskandar (2015) uses the World Bank 2012 survey data to provide evidence that private firms are human capital constrained in terms of skilled and trained labor force. The steel industry is no exception. As we described earlier, compared

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[46] The figures are based on an internal report prepared by the Chinese Metallurgy Planning Institute in August 2016 for the authors.

[47] Among many others, Brandt and Li (2003); Poncet et al. (2010); Guariglia et al. (2011); Cull et al. (2015).

[48] The four surveyed cities include Beijing, Chengdu, Chengde and Wenzhou.

to private firms, SOEs had a larger fraction of employees with college degree and above, and more skilled labor as well. Thus, smaller machines/furnaces are more compatible with the managerial talent, organizational capabilities and skill sets that private firms have, and private firms are better off with smaller machines/furnaces conditional on the available resources of human capital. On the other hand, larger machines/furnaces require more talented and experienced managers as well as higher skill workers, which SOEs likely have in more abundance.[49]

2.4.6.4 Raw Material Constraints As is evidenced in Figure 19, the iron ore that smaller furnaces use covers a much wide range of grades than larger furnaces which only use high grade ore. Larger furnaces are substantially more demanding in the quality of raw materials due to their structural features. As to private firms, access to only lower grade iron ores and greater flexibility of smaller furnaces with respect to iron ore choice may predispose them towards smaller units, which are a better fit for private firms in terms of the raw materials that they are able to obtain.

2.4.6.5 Production Flexibility Even in the context of a long-run increase in the demand for steel, short-run fluctuations are likely. To take full advantage of the opportunities in a booming market, firms need to be able to expand capacity quickly, and fully utilize existing capacity. In contrast, in periods of contraction, firms need to be able to adjust production and shut down plants quickly.

Larger furnaces take longer to build. This introduces additional uncertainties and may even pull down expected returns as firms run the risk of missing out on a boom market. In addition, the time (and therefore costs) it takes to start up or shut down a furnace also increases with size. This makes it much more difficult for a large furnace to adjust to demand shocks in the short run. By contrast, firms with several smaller furnaces can adjust

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[49] Several studies have also shown that state-owned firms in China hold aside large human resource inventories (e.g. Peng and Heath (1996); Tan (2003)).

productions more gradually and in a more timely way by simply suspending operations in a subset of their furnaces. Similarly, as the market recovers and steel prices increases, small furnaces can respond more quickly.

Since January 2016, steel prices have recovered from their lows in 2015. By April 2016, 40-50 million tons of steel capacity–mostly in private firms–were estimated to have resumed production, which represents more than 70% of the idle capacity in 2015.[50] Big SOEs, on the other hand, were not able to ramp up production using idle capacity in time to take advantage of the rising prices. Larger blast furnaces require more thorough inspections and replacement of key components before they can be safely restarted. The entire process not only takes two to four weeks, but entails sizable costs, which keeps the big SOEs from adjusting production flexibly.

2.5 DISCUSSION

2.5.1 Measurement Error in Capital

Capacity alone may not fully capture the variations in capital, which could result in a bias in our productivity estimates. Investment cost per unit capacity, which we assume as fixed cost, for example, increases with equipment size.[51] The potential bias results from two sources. First, the positive correlation between capacity and unit investment cost leads to an upward bias in capital coefficients. Second, estimated productivity contains the unit price of capacity. Other things equal, the overestimate of the capital stock in private facilities would lead to a downward bias in the productivity differentials that we found in pig-iron and steel making.

The following proof formalizes our argument. To simplify the exposition, we omit

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[50] http://news.cqcoal.com/a/xinwenzixun/jinriguanzhu/2016/0427/65557.html

[51] We extract the information on investment costs of steel plants from an internal report prepared by the Chinese Metallurgy Planning Institute in August 2016 per the authors' request.

stage subscript s and time subscript t. Let us rewrite the production function using price-adjusted capital k^*, consisting of unit capacity price p and capacity k, the capital measure that we use in our baseline estimation.

$$\begin{aligned} y_i &= \alpha l_i + \beta k_i^* + \gamma r_i + \omega_i + \epsilon_i \\ &= \alpha l_i + \beta k_i + \gamma r_i + \beta p_i + \omega_i + \epsilon_i \end{aligned}$$

In our baseline model, we treat unit capacity price p as measurement error, so our estimated productivity is equal to $\hat{\beta} p_i + \hat{\omega}_i$. First, unit capacity price p is positively correlated with capacity k, which will lead to a potential upward bias in the estimated parameter on capital β. Second, our measure of productivity $(\hat{\beta} p_i + \hat{\omega}_i)$ includes the unobserved unit capacity price, which would potentially bias the ownership differentials in productivity. Let us consider the estimated productivity differential between equipment in private and central state-owned facilities, i.e., $\hat{\beta}(p_i^{private} - p_i^{central}) + (\hat{\omega}_i^{private} - \hat{\omega}_i^{central})$. The first term reflects capacity price difference, and the second measures the true difference in productivity. As private facilities systematically operate smaller equipment than central state-owned facilities, unit capacity price of private machines/furnaces is generally lower. Consequently, the first term of the productivity differential is negative, which gives rise to a downward bias in the estimated productivity premium of private equipment as opposed to equipment at central state-owned facilities.

We use the price information on investment of basic oxygen furnaces (steel making) in Table 18 to adjust capital, and re-estimate the production function for steel using this adjusted capital measure. The estimated coefficients are reported in Table 19. Compared to the baseline estimation, using the adjusted capital generates a lower coefficient for capital, as predicted. We report the corresponding productivity differentials in Table 20. The productivity premium of private furnaces relative to central state-owned furnaces rises from 5.8 percent to 7.5 percent when we base our estimates on the price-adjusted capital, an increase in relative TFP of nearly thirty percent.

Independent of furnace size, systematic differences may also exist in the costs per unit of capacity between private and state-owned facilities. In general, we expect private firms to be more cost sensitive, and for them to be successful in finding ways to build furnaces of any size at lower cost, and thus enjoy lower per unit cost of capacity relative to SOEs. This source of measurement error would further underestimate productivity premiums of private facilities. Similar to our discussion about the bias generated by ignoring the increasing unit cost of capacity with equipment size, there will be an effect coming through our estimate of the elasticity for capital, and our estimate of the capital stock of these private facilities. Additional information on capacity cost by ownership is needed to estimate the magnitude of this bias.

2.5.2 Measurement Error in Output

From Table 21 we know that private facilities produce consistently lower quality output in each production stage. As to output quality, we observe qualification rates of sinter, pig-iron and steel. In addition, stability rates of sinter and shares of premium iron are reported. Shares of secondary steel making provides additional evidence on the quality of steel. Output is measured in physical units in our data set, obscuring output quality differences between facilities, which could bias the productivity estimates. To simplify the exposition, we omit stage and time subscripts.

$$y_i^*(y_i, X_i) = f(l_i, k_i, r_i) + \omega_i + \epsilon_i \tag{2.6}$$

where y^* measures the quality-adjusted output, defined as a function of the observed output y and X, a vector of output quality measures. f is a general production function and is stage-specific but time-invariant. Assume that y and the quality components are additively separable.

$$y_i^* = y_i + \delta(X_i) \tag{2.7}$$

Substitute (Equation 2.7) into (Equation 2.6) generates the baseline production function that we estimated.

$$y_i = f(l_i, k_i, r_i) + (\omega_i - \delta(X_i)) + \epsilon_i \tag{2.8}$$

Hence the estimated productivity $\omega_i - \hat{\delta}(X_i)$ also incorporates output quality.

To see how output quality affects productivity differentials by ownership, we re-estimate the facility-level productivity differentials by controlling the quality of each output. Table 22 shows that productivity premium of private facilities relative to central state-owned facilities drops slightly when we control for output quality, from 6.2 percent to 5.7 percent. And the premium relative to provincial state-owned facilities experiences a more pronounced change, declining from 2.3 percent to less than 1 percent. The shrinking premiums suggest that state-owned facilities produce higher quality output at the expense of productivity.

2.6 CONCLUSION

Prior productivity studies often focus on firm level due to data limitations. This chapter is one of the first to study the underlying sources of productivity differences by production facilities' ownership structure through the lens of facilities' internal configuration. The new data set that we construct provides equipment-level information on inputs and output in physical units for each link in the value chain of vertically-integrated facilities. The richness of our data allow us to measure the physical efficiency of producers at integrated facility level, and more important, to decompose differences in performance by ownership type into process (stage) and equipment level differences, thereby providing new insight into the internal dimensions of complex industrial operations.

We find that private facilities are on average 6.2 percent more productive than central state-owned facilities, and 2.3 percent relative to provincial state-owned facilities. Adjusting for capital cost and product quality differences lead to minor changes in productivity premiums. The magnitude of the private ownership premium in steel seems small by comparison with prior studies on the productivity differences by ownership in China's manufacturing industries. Among others, the gaps leave a caveat for future research on productivity that one needs to interpret more carefully productivity estimates which may pick up serious measurement errors. Breaking down the facility level productivity, we find that this ranking lines up with our productivity estimates in the two downstream production stages, but central state-owned facilities outperform in sintering, which may be linked with their superior access to higher quality raw materials.

The internal configuration of the integrated facilities provide further sources to understand the productivity differences between facilities. Private facilities expand by adding more but smaller machines/furnaces, which potentially reflects various constraints that they are facing. As a result, the productivity advantage of private facilities declines with their size, turning negative for facilities larger than the median. Underlying the decision of private firms to build relatively smaller machines/furnaces as they expand are several factors including tighter restrictions on equipment size and investment, difficulty in accessing higher quality raw materials and human capital, and possibly credit constraints. Our analysis suggests that the productivity advantage of private facilities would be significantly higher if the constraints were removed. For example, rough calculations suggest that eliminating the premium of central state-owned facilities in sintering would raise the premium of private facilities by an additional 2 to 3 percentage points.

In this chapter we have focused largely on the constraints facing private firms in their choice of machine/furnace size. As discussed in section 2.4.6.3, there are also likely some advantages to having a portfolio of machines/furnaces with smaller average size. In order to examine these trade-offs more carefully, we need to build and estimate a structural dynamic model that looks at the role of both demand and supply side considerations in the firm's choices. This will entail incorporating into a dynamic model of investment the various constraints that we identified facing firms of different ownership type. We will also need to model the demand side, the fluctuations of which also likely play an important role in shaping firms' decisions on internal configuration. Access to several more years of firm-level data will facilitate model identification by providing data that spans both booms and contractions in China's steel market.

3.0 FINANCING CONSTRAINTS IN CHINA: EVIDENCE FROM THE MANUFACTURING SECTOR

3.1 INTRODUCTION

Finance sector plays an important role in economic growth (e.g., Schumpeter (1961), King and Levine (1993) and Rajan and Zingales (1998)). The presence of financing constraints hampers the development of an economy through resource misallocation across firms. The extent of financing constraints and its impact on firms' investment decisions are heated topics in the corporate finance literature.[1] Financing constraints are considered as one of the primary obstacles to firms' investment.

Developing countries in general bear more institutional imperfections than developed countries; with weaker financial systems, their firms face more severe financing constraints. To what extent are firms financially constrained in China, the world's largest transition economy? Does the preferential treatment for state-owned enterprises (SOEs) still exclude China's private sector from formal credit allocation?

China has enjoyed impressive growth for over thirty years since the launch of the Economic Reform and Opening Policy in the late 1970s. The reform era witnessed a dramatic decline of the state sector and a rise of the non-state sector. The share of SOEs in industrial output and industrial employment amounted to 78% and 76% respectively in 1978,

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[1] To list a few, Fazzari et al. (1988), Whited (1992), Bond and Meghir (1994), Love (2003), Harrison and McMillan (2003), and Harrison et al. (2004), etc.

and the state sector absorbed 84% of investment during 1975-1980.[2] However, the shares in industrial output and employment plummeted to 12.2% and 10.3% in 2010 for the state sector, whereas the corresponding shares of the private sector shot up to 30.5% and 34.7% in the same year.[3] The swift emergence of the private sector is largely due to the entry permission rendered by the reform to firms of all ownerships in many different sectors that had been exclusive for SOEs. Furthermore, the political support of privatization of small SOEs and ownership restructuring of large SOEs in the 1990s deepened the economic reform to a great extent (Büchelhofer (2008)). Consequently, the number of industrial enterprises soared from 936,000 in 1980 to 7.34 million in 1995 (Brandt and Rawski (2008)) and 7.93 million in 1999 (China Statistical Year Book, 2000).[4]

Despite an increasingly important role the private sector plays in the Chinese economy, the preferential treatment for SOEs still prevails in various aspects and hampers the growth of the economy. That private firms are discriminated against SOEs in China in terms of credit allocation dates back to the extremely repressed financial system in the central planning era. Despite a structural change in the financial sector that took place between 1978 and 1984 (Allen et al. (2008)), a price ceiling was imposed on both lending and deposit rates to keep interest rates at a low level to direct capital into the state-owned sector (Chan et al. (2012)). Lending quotas issued by the four state-owned commercial banks were distributed among state-owned firms based on the investment plans and funding requests they submitted.[5] Private firms, nonetheless, were excluded from lending quotas. Furthermore, there was a legal bias against private firms which made assets collateralization harder, thereby banks found it riskier to lend to private firms (Huang (2002)). Even though the financial liberalization took place in the late 1990s, the “political pecking order” of firms continues as a major obstacle to channeling resources to the most efficient firms.

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[2] Data source: Fifty years, 2000, p.18,21,58, cited by Brandt et al. (2008).

[3] The calculation is based on data reported in China Statistical Year Book 2011.

[4] From 2001 on, China Statistical Year Book only reports numbers of above-scale industrial firms.

[5] The Bank of China, China Construction Bank, the Industrial and Commercial bank of China, and the Agricultural Bank of China.

In spite of a market-oriented financial reform, it is widely accepted that the private sector is still subject to tremendous constraints compared to its state counterpart. Based on a survey that covers over 10,000 firms in eighty-one countries, Batra et al. (2003) find that private firms in China are the most constrained in the world with respect to their access to capital. Brandt and Li (2003) examine bank discrimination against private firms in China and find that access to working capital is difficult for private firms, which results in an inefficient allocation of credits. Haggard and Huang (2008) provide survey evidence suggesting that restrictive access to formal financial credits makes Chinese private firms resort to informal funds. Héricourt and Poncet (2009) illustrate that as financial reform deepens in China, the FDI inflow alleviates financing constraint for private firms. Poncet et al. (2010) find that Chinese private firms are credit constrained while state-owned firms are not.

Furthermore, the presence of foreign capital alleviates the level of constraints faced by private firms. Chan et al. (2012) investigate the impact of recent financial reforms in China on the financing constraints and investment behaviors of size-dependent publicly-listed Chinese firms. They find that large firms are not financing constrained but small firms display significant constraints. However, as financial reform takes place, large firms - mostly state-owned - become more financing constrained since their preferential treatment is gradually eliminated; little change has been witnessed for the small firms.

So far, existing studies have relied on information of either publicly-listed firms or surveys of certain geographic region covering short time periods; evidence based on the small coverage of firms would reveal a partial picture therefore could lead to biased conclusions. Unlike earlier studies, I use the Chinese Industrial Survey Data that cover all the above-scale manufacturing firms from 1998 to 2007 to measure the level of financing constraints in China's state and private sectors.[6] In addition, this chapter breaks down the analyses to different economic regions and industries. The empirical framework builds on an Euler

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[6] The above scale firms refer to all the SOEs and non-state firms with annual sales above 5 million RMB.

equation approach where the level of financing constraints is captured by the stochastic ratio of shadow costs of external finance tomorrow to today. Particularly, two firm-level financial factors are introduced to explicitly proxy the level of financing constraints, i.e. interest coverage and debt to asset ratios.

Applying dynamic GMM estimation, I find that SOEs, overall, are slightly financing constrained whereas private firms do face much greater obstacles in accessing credit. However, contrary to the widely accepted view that China's private sector is largely excluded from formal credit allocation, I find that large firms are not credit constrained even if they are privately owned. Since firm size is positively correlated with firm performance in the private sector, this result sheds light on the transition of the Chinese banking system and provides evidence of increasingly commercial bank behavior.

Another possible explanation relates to the origins of large private firms. The recent astonishing emergence of the private sector, especially large-scale private firms, implies that these firms have high likelihood to possess political connections, which facilitate easy access to credit. With regard to medium and small firms, SOEs are financially constrained, although to an extent less than their private counterparts. Therefore, over the course of development, not only ownership but firm size shapes the structure of credit allocation.

Furthermore, this chapter illustrates that there is cross-regional variation in accessing external finance. The east and coastal region is the most financially constrained region among the four (east and coastal, northeast, middle and west) regions, which is largely due to the constrained private firms in the region. In addition, cross-sector analysis demonstrates that high-tech firms do not display any financing constraints at all, whereas in other industries, medium and small firms suffer from credit distortion with private firms being constrained to a greater degree than SOEs. The tilt toward the high-tech sector is largely in line with the economic policy on industrial upgrading launched by the Chinese central government. This finding partly demonstrates policy-makers' recognition of the role the private sector plays in the economy in transition.

This chapter proceeds as follows. Section 3.2 presents a structural investment model based on firm's dynamic optimization problem, characterizes the econometric specification, and discusses estimation issues. Section 3.3 provides a detailed data description followed by an illustration of main results in section 3.4. Section 3.5 is devoted to limitations and extensions, and section 3.6 draws conclusions.

3.2 METHODOLOGY

3.2.1 Euler Equation Approach

In this section, following Whited (1992), Bond and Meghir (1994), Love (2003) and Harrison and McMillan (2003), I lay out a dynamic structural model of investment to describe firms' optimization problem. In this model, together with an equity constraint, I also introduce a debt constraint to take into account a complete scope of financing constraints firms face.

A firm i is assumed to maximize the present market value of its expected net dividend streams by choosing variable inputs N_{it} and investments I_{it} at the beginning of every period t. Without loss of generality, I_{it} is assumed to be immediately productive. However, a strictly convex adjustment cost is incurred when firms add new capital. At the same time, firms realize borrowing B_{it} while paying back previous period's debt $B_{i,t-1}$ at the interest rate $i_{i,t-1}$. Inflation rate is denoted as π_t, depreciation rate δ, and $\beta^t_{i,t+j}$ is the discount factor for period t+j. $F(K_{it}, N_{it})$ is the production function for gross output, where K_{it} represents capital stock at period t. $G(K_{it}, I_{it})$ characterizes the adjustment cost of investment, which reflects, for example, the installation cost of a new machine. Furthermore, let p_{it} denote firm specific output price, p^I_{it} the price of investment goods, w_t the price of variable inputs. $\bar{D}_{it}$ is the firm- and time-varying lower limit on dividends, and $\bar{B}_{it}$ represents the firm- and time-varying borrowing constraint the firm faces. For simplicity assume there is no imposition of tax in the economy. Under these assumptions, the firm's objective function becomes:

$$MaxE_t[\sum_{j=0}^{\infty}\beta_{i,t+j}^{t}D_{i,t+j}(K_{i,t+j},N_{i,t+j},I_{i,t+j})] \tag{3.1}$$

subjects to four constraints below:

- Capital stock evolution

$$K_{it}=(1-\delta)K_{i,t-1}+I_{it} \tag{3.2}$$

- Definition of firm's dividend

$$D_{it}=p_{it}F(K_{it},N_{it})-p_{it}^{I}I_{it}-w_tN_{it}-p_{it}G(K_{it},I_{it})+B_{it}- \\ i_{t-1}B_{i,t-1}-(1-\pi_t)B_{i,t-1} \tag{3.3}$$

- Borrowing constraint

$$B_{it}\leq\bar{B}_{it} \tag{3.4}$$

- Dividend constraint

$$D_{it}\geq\bar{D}_{it} \tag{3.5}$$

Note that equations (3.4) and (3.5) capture the constraints the firm faces on external finance. First order conditions with respect to K_{it}, I_{it} and B_{it} generate the following equations, where the Lagrangian multipliers θ_{it}, γ_{it}, λ_{it} are associated with constraints (3.2), (3.4) and (3.5) respectively. In particular, λ_{it} can be interpreted as the shadow cost of raising new equity.

$$K_{it}:(1+\lambda_{it})(\frac{\partial D}{\partial K})_{it}=\theta_{it}-(1-\delta)\beta_{i,t+1}^{t}E_t(\theta_{i,t+1}) \tag{3.6}$$

$$I_{it}:(\frac{\partial D}{\partial K})_{it}+\lambda_{it}(\frac{\partial D}{\partial I})_{it}+\theta_{it}=0 \tag{3.7}$$

$$B_{it} : -\gamma_{it} + (1+\lambda_{it}) + \beta^t_{i,t+1} E_t[(\pi_t - 1 - i_t)(1+\lambda_{i,t+1})] = 0 \tag{3.8}$$

Combining equation (3.6) and (3.7) delivers the Euler equation:

$$(\frac{\partial D}{\partial K})_{it} + (\frac{\partial D}{\partial I})_{it} = (1-\delta)\beta^t_{i,t+1} E_t[\frac{1+\lambda_{i,t+1}}{1+\lambda_{it}}(\frac{\partial D}{\partial I})_{i,t+1}] \tag{3.9}$$

Equation (3.8) indicates that a binding debt constraint will affect the expected intertemporal transfer of resources. However, as debt enters the dividend function separately, the debt constraint does not affect the Euler equation (3.9) (Whited and Wu (2006)). Furthermore, since both λ_{it} and γ_{it} are unobservable and are likely to be affected by the same set of observable variables, it is difficult to identify the two separately. To address this issue, I follow the approach of Whited and Wu (2006) to focus on the identification of the Lagrange multiplier λ_{it} associated with dividend constraint via the Euler equation (3.9). The left-hand side of the Euler equation represents marginal cost of investment today net of marginal increase in output; the right-hand side reads as the present value of expected marginal cost of postponing investment till tomorrow. When the constraint (3.8) doesn't bind, no wedge would appear between the opportunity costs of investment today and tomorrow, i.e. $\frac{1+\lambda_{i,t+1}}{1+\lambda_{it}} = 1$. Under circumstances of financing constraints, however, a higher shadow cost of today $\lambda_{i,t}$ will drive up the opportunity cost of investing today, therefore generate a lower $\frac{1+\lambda_{i,t+1}}{1+\lambda_{it}}$. Firms then would rather substitute tomorrow's investment for today's. Therefore, the term $\frac{1+\lambda_{i,t+1}}{1+\lambda_{it}}$ in Euler equation (3.9) captures the level of financing constraints. Define $\Lambda_{it} \equiv 1 - \frac{1+\lambda_{i,t+1}}{1+\lambda_{it}}$: the more financially constrained, the higher Λ_{it} the firm carries. Equation (3.10) is written as below:

$$(1-\delta)\beta^t_{i,t+1} E_t[(1-\Lambda_{it})(\frac{\partial D}{\partial I})_{i,t+1}] = (\frac{\partial D}{\partial K})_{it} + (\frac{\partial D}{\partial I})_{it} \tag{3.10}$$

3.2.2 Parameterization

3.2.2.1 Adjustment Costs I follow Bond and Meghir (1994) in applying a symmetric adjustment cost function which is linearly homogenous in investment and capital, $G(I_{it}, K_{it}) = \frac{1}{2}bK_{it}[I_{it}/K_{it} - c]^2$. Therefore the derivatives of dividends with respect to I and K are presented as below:

$$(\frac{\partial D}{\partial I})_{it} = -b\alpha p_{it}(\frac{I}{K})_{it} + bc\alpha p_{it} - p^I_{it} \tag{3.11}$$

$$(\frac{\partial D}{\partial K})_{it} = \alpha p_{it}(\frac{Y}{K})_{it} - \alpha p_{it}(\frac{\partial F}{\partial N}\frac{N}{K})_{it} + b\alpha p_{it}(\frac{I}{K})^2_{it} - bc\alpha p_{it}(\frac{I}{K})_{it} \tag{3.12}$$

where $Y_{it} = F_{it} - G_{it}$ denotes net output and $\alpha = 1 - (1/\epsilon) > 0$, where ϵ is the constant price elasticity of demand under the assumption of imperfect competition. Y is further assumed to be linearly homogeneous in K and L. Moreover, without explicitly specifying a production function form, the marginal product of variable costs $\frac{\partial F}{\partial N}$ is assumed to be replaced by $w_t/\alpha p_{it}$.

3.2.2.2 Linearization Following Love (2003), I linearize the term $(1 - \Lambda_{it})(\frac{\partial D}{\partial I})_{i,t+1}$ around mean values, yielding the following approximation:

$$(1 - \Lambda_{it})(\frac{\partial D}{\partial I})_{i,t+1} \approx -\phi\Lambda_{it} + a(\frac{\partial D}{\partial I})_{i,t+1} + \phi(1 - a) \tag{3.13}$$

where by assumption a refers to the mean of $(1 - \Lambda_{it})$, ϕ is the mean of $(\frac{\partial D}{\partial I})_{i,t+1}$ across firms over time. Furthermore, under the assumption of rational expectations, the stochastic term on the left-hand side of equation (3.10) is replaced with realized future values plus an error term v_{it}, which is assumed to be orthogonal to all the current-period variables. Substituting (3.11), (3.12) and (3.13) into (3.10) generates the following form:

$$
\begin{aligned}
(\frac{I}{K})_{i,t+1} = \frac{(1+c)\Phi_{t+1}}{a}(\frac{I}{K})_{it} - \frac{\Phi_{t+1}}{a}(\frac{I}{K})^2_{it} - \frac{\Phi_{i,t+1}(\alpha-1)}{ab\alpha}(\frac{Y}{K})_{it} - \frac{\Phi_{i,t+1}}{ba\alpha}(\frac{CF}{K})_{it} + \frac{\Phi_{i,t+1}}{b\alpha}U_{it} \\
- \frac{\phi}{ab\alpha p_{i,t+1}}\Lambda_{it} + (1 - \frac{\Phi_{i,t+1}}{a})c + \frac{1-a}{\alpha a p_{i,t+1}} + v_{it}
\end{aligned}
\tag{3.14}
$$

where $\Phi_{i,t+1} = \frac{p_{it}}{p_{i,t+1}} \frac{1}{\beta^t_{i,t+1}(1-\delta)}$, $(\frac{CF}{K})_{it} = \frac{p_{it}Y_{it} - w_t N_{it}}{p_{it}K_{it}}$ is the ratio of real cash flow to capital stock. The $U_{it} = \frac{p^I_t}{p_t}[1/a - \frac{p^I_{t+1}\beta^t_{t+1}(1-\delta)}{p^I_t}]$ is defined as user cost of capital. In particular, we impose ϕ to be non-positive, which implies the average $(\frac{\partial \Pi}{\partial I})_t$ is driven negative due to the existence of capital adjustment cost and the unit cost of investment. The positive correlation between financial factors and future investment simply justifies the argument that the more financially constrained, the more likely firms would postpone their investment till tomorrow.

3.2.2.3 Financing Constraints

I follow Whited (1992) to measure Λ_{it} with two firm-level financial factors, the ratio of total debt to total assets (DAR) and the ratio of interest to the sum of interest and cash flow, which is referred to as interest coverage (COV). Under the constrained circumstance, these financial factors would have a positive impact on future investment, since firms substitute investment tomorrow for today. In a word, the more constrained are firms today, the more likely they are willing to postpone their investment activities till tomorrow. The function of Λ_t adopts the linear form:

$$
\Lambda_{it} = c(DAR_{it}, COV_{it}) \approx c_0 + c_1 DAR_{it} + c_2 COV_{it} \tag{3.15}
$$

Moreover, the sensitivity of investment on cash flow can be drawn on as a complementary but rather indirect indicator of how difficult firms obtain external finance (e.g.,Bond and Meghir (1994)).

3.2.3 Empirical Model and Identification

I follow Bond and Meghir (1994) by assuming the real discount rate term Φ_{it}, price p_{it} and the coefficients on the right-hand side terms to be constant across firms and over time. Furthermore, I introduce time fixed effects and firm fixed effects to control for the variation in the user cost of capital term and the potential yearly macroeconomic shocks that hit the firm. Substituting equation (3.15) into (3.14), I arrive at the empirical specification:

$$
\begin{aligned}
(\frac{I}{K})_{it} = \beta_1(\frac{I}{K})_{i,t-1} + \beta_2(\frac{I}{K})^2_{i,t-1} + \beta_3(\frac{Y}{K})_{i,t-1} + \beta_4(\frac{CF}{K})_{i,t-1} + \\
\beta_5 COV_{i,t-1} + \beta_6 DAR_{i,t-1} + d_t + \epsilon_{it} \quad (3.16)
\end{aligned}
$$

where $\epsilon_{it} = s_i + v_{it}$, CF = cash flow, Y = sales, d_t = time fixed effects, s_i = firm fixed effects and $v_{i,t}$ = error term. We expect the signs of β_5, β_6 and (or) β_4 to be positive for the financially constrained firms.

3.2.3.1 Identification Issues The first issue in estimation concerns the presence of firm fixed effects. Since the lagged variable $(\frac{I}{K})_{i,t-1}$ is correlated with the firm fixed effects s_i, which gives rise to dynamic panel bias (Nickell (1981)), OLS would generate inconsistent estimators. One prevalent way to work out this endogeneity problem is to conduct first-difference transformation to take out the fixed effects. However, the endogeneity problem still remains since $E[\Delta(\frac{I}{K})_{i,t-1}\Delta\epsilon_{it}] \neq 0$. To further resolve the issue, one way could be applying the GMM estimator developed by Arellano and Bond (1991) where differenced lagged dependent variable $\Delta(\frac{I}{K})_{i,t-1}$ is instrumented with t-2 and further lags, assuming no presence of autocorrelation among the error terms. If there's AR(q) in ϵ_{it}, levels of endogenous variables dated at t-q-2 and further are taken as instruments. As Roodman (2006) points out, compared to the one-step GMM estimator, the two-step estimator is efficient and robust to whatever patterns of heteroskedasticity. As the data I use cover large numbers of firms over ten years and across thirty 2-digit industries, it is likely to have the presence of heteroskedasticity among observations. Therefore, I resort to the two-step estimator.

As demonstrated by Blundell and Bond (1998), if the dependent variable I/K is close to a random walk, then Arellano-Bond first-difference GMM estimator performs poorly because past levels shed little light on future changes, therefore untransformed lags are weak instruments for transformed variables. Blundell and Bond (1998) prove that under the assumption that changes in any instrumenting variable are uncorrelated with the fixed effects, i.e.,$E[\Delta(\frac{I}{K})_{i,t-1}\epsilon_{it}] \neq 0$, $\Delta(\frac{I}{K})_{i,t-1}$ is a valid instrument for $(\frac{I}{K})_{i,t-1}$. Again, if there's AR(q) in ϵ_{it}, $\Delta(\frac{I}{K})_{i,t-q-1}$ are taken as the instruments. I apply Blundell and Bond (1998) two-step system GMM estimator. In particular, because of serial correlation mentioned above, levels of I/K and $(I/K)^2$ dated at t-3 are used as instruments for first-difference equations and first differences of I/K and $(I/K)^2$ dated at t-2 are for level equations.[7]

While I/K is inevitably correlated with the firm fixed effects, CF/K, Y/K, COV, DAR can be potentially correlated with s_i as well (Bond and Meghir (1994)). On the other hand, the rational expectation error v_{it} is orthogonal to any information at the time when the investment decision is made. I assume that all the regressors other than $(I/K)_{i,t-1}$ in the Euler equation are not predetermined. In so doing, the strict exogeneity enables $(CF/K)_{i,t-1}$, $(Y/K)_{i,t-1}$, $COV_{i,t-1}$ and $DAR_{i,t-1}$ to be standard instruments for the first difference equation. I also include industry dummies and time dummies as additional instruments.

To test overidentification restrictions of the model, I use Hansen J statistics. In terms of standard errors, the standard formula for the variance of linear GMM estimates can produce downward-biased results when the number of instruments is large, which makes two-step GMM useless for inference (Arellano and Bond (1991)). Windmeijer (2005) devises a finite-sample correction to the two-step covariance matrix that generates more accurate

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[7] I report Arellano and Bond AR(1) and AR(2) tests statistics to show that AR(1) is present in all the regressions while AR(2) do not exist.

inferences.

3.3 DATA ON CHINESE MANUFACTURING SECTOR

3.3.1 Data

I use panel data from the Annual Surveys of Industrial Production that span 1998 to 2007 for all the above-scale industrial firms in China.[8] The surveys are conducted by the Chinese National Bureau of Statistics.[9] The data form an unbalanced panel, with firms entering and exiting every year. The survey includes mining, manufacturing and public utilities. My study focuses on the manufacturing sector mainly for two reasons. First, the manufacturing sector plays an influential role in the Chinese economy. During the period 2005 to 2009, the sector accounted for 33.03% of national GDP per annum; during 2005 to 2010, the average share of manufacturing goods in merchandise exports amounted to 93%.[10] Second, the focus on the manufacturing sector allows a more accurate assessment of financing constraints across state-owned firms and private firms. This is because the excluded industries (petroleum and natural gas extraction, electricity and heating production and supply, water production and supply, etc) are mostly government controlled oligopolies that possess strong power over resources, including financial resources. Consequently, incorporating the entire industries are very likely to bias the true levels of financing constraints.

3.3.1.1 Industry Classification The manufacturing sector consists of thirty 2-digit industries in the data. Each firm is classified into an industry following the 4-digit Chinese Industry Classification System that resembles the old U.S. SIC system. In the empirical

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[8] Each survey round covers all the state-owned firms plus non-state firms with annual sales above 5 million RMB ($ 728,000), which are referred to as above-scale firms.

[9] Hereafter, I shall refer to the Chinese National Bureau of Statistics as NBS.

[10] Data source: World Deveopment Indicators(database), World Bank, DC (accessed 2010), http://data.worldbank.org/data-catalog/world-development-indicators.

analysis, I follow the 2-digit industry classification to reduce the number of industries to a tractable level. In 2003, the classification system was revised to merge some sectors while incorporating more details for other sectors. I follow Brandt et al. (2012) to construct a consistent classification for years prior and post 2003. I provide detailed information on the industry classification in the Appendix Table A7.

3.3.1.2 Ownership and Size Classification I follow Jefferson et al. (2003) and Brandt et al. (2012) to utilize information on a firm's registration type to categorize ownership. Specifically, there are 23 registration types, which are regrouped into six types in my study: state-owned, collective, private, HMT (Hong Kong, Macau and Taiwan) and others.[11][12] A sector-wide criterion set up by the NBS is used to classify firm size. Firms with annual sales above 400 million RMB and total employment no less than 1,000 are characterized as large; those with annual sales between 20 million RMB and 400 million, employment between 300 and 1,000 are classified as medium (see Table 23). Failure to meet either the annual sales or employment criteria would push the firm into a lower category.

3.3.1.3 Capital Stock and Investment Firms do not report fixed investment directly. Rather, each firm reports the value of fixed assets at original purchase prices as well as their fixed assets at original purchase prices less accumulated depreciation, defined as net value of fixed assets in the data set. The value of fixed assets include all the undepreciated capital stock at original purchase prices, therefore the net value of fixed assets is not an ideal measure for capital stock. Following Brandt et al. (2012), I implement the perpetual inventory method to construct capital stock. In addition, annual investment is measured as changes of fixed assets at original purchase prices between years.

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[11] Collective-owned firms are referred to as economic units where the assets are owned collectively.

[12] One limitation associated with the provided classification is that as long as a firm is kept track of by the same ID, changes in ownership can not be captured. Considering that the ownership classification criterion set by the NBS involves several ambiguous elements that can hardly be identified by the available information in the data set, I stick to previous literature using the same data set to carry out ownership classification. Detailed information is provided in the Appendix A.3.1.

3.3.2 Performance of Chinese Manufacturing Sector

3.3.2.1 Size and Ownership Distribution With the launch of the economic reform in China, the entry threshold was significantly lowered for the non-state sector, which led to a pronounced increase in firm numbers. On the whole, active firms in the manufacturing sector rose from 149,693 to 312,930 over ten years. Figure 20 illustrates that firm number increases steadily from 1998 to 2003 while the following year witnesses a significant jump. A slight drop follows afterwards, which is ended immediately by an upsurge in the last two years in the sample at a higher rate than that from 1998 to 2003. The evolution varies by ownership, however. In contrast to a nationwide boom, the state sector suffers a decline in the number of active firms.

Table 24 reports firm distribution by size and ownership in 1998 and 2007 respectively. First, small firms stand out in terms of firm number across ownerships and over time. Second, the number state-owned firms shrank in all size over 1998-2007, whereas the number private firms grew significantly. The most striking change occurs in small firms: there were only 7.9 percent private firms in 1998, and the share reached 55.4 percent in 2007.

3.3.2.2 Aggregate Efficiency and Firm Performance Figure 21 illustrates the evolution of capital productivity over 1998 and 2007, i.e. output per unit of capital. Output(Q) is measured as value added and capital stock as net value of fixed assets.[13] Figure 21 reports full sample results as well as the patterns for state and private firms separately. Overall, the manufacturing sector experienced a steady gain in efficiency over the ten years. The capital efficiency more than doubled from 1998 to 2007. By ownership, the capital efficiency of private firms was three folds that of SOEs in 1998. While the capital efficiency grew at an average rate of 6.40% per annum in the private sector, it grew

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[13] All the values that I use in my calculation and the following regressions are deflated by treating 1998 as the base year. I extracted the output and input deflators from NBS and used the capital goods deflators constructed by Loren Brandt and Thomas Rawski, downloaded at http://feb.kuleuven.be/public/N07057/CHINA/appendix/.

more rapidly in the state sector at 11.43%.[14] Even so, private firms remained more efficient than their state-owned counterparts in 2007.

With respect to firm-level performance, I follow Jefferson et al. (2003) to present profitability and export intensity across firm ownership (see Table 25).[15] Profitability experienced a rise on the whole regardless of firm size and ownership. A striking feature is that negative profitability prevailed among state-owned medium and small firms. Clearly, state-owned firms do not necessarily shut down even though they are not profitable anymore. Export intensity reveals that private firms are more export oriented than state-owned firms regardless of firm size.[16] Overall, private firms perform better than state-owned ones.

3.3.3 Summary Statistics

Table 26 provides descriptive statistics for the key variables in the empirical analysis. Column (1) (3) and (5) report the full sample summary statistics, and column (2) (4) and (6) are for the trimmed sample at 1 percentile level at both tails. First, standard deviations for all the variables in the full sample are extremely high. For example, the absolute value of mean investment-to-capital ratio (I/K) in the pooled sample of SOEs and private firms (column (1)) is 0.56. However, the corresponding standard deviation explodes to 75.96, which implies the presence of observations with extreme values. The other variables exhibit the same patterns. Considering that the outliers would potentially lead to noise and flaws for the data, the empirical analysis is based on the trimmed sample.[17] Note that standard deviations in column (2), (4) and (6) drop remarkably to a reasonable

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[14] Upon the author's calculation.

[15] Profitability refers to the ratio of profit to revenue and export intensity is defined as the ratio of export values to industrial sales in the data.

[16] Note that figures in the parentheses represent performance of firms with positive export values. The pattern maintains.

[17] Throughout the paper, the data set is truncated at both tails at 1 percentile level. Considering wide coverage of the entire manufacturing sector, truncating the data set to 1 percentile level won't induce the data to lose its main characteristics. Furthermore, I carried out the same regressions for samples trimmed at distinct levels as the benchmark case (1 percentile), i.e. 0.5% as well as every consecutive 1 percentile level from 2 up to 5. The main conclusion holds.

range. Another noteworthy feature of the data is the negative investment-to-capital ratio, which results from the fact that around 25% of firm-year observations in the data carry out negative investment. The negative investment is interpreted as fixed asset resale and transfer and can also be reflective of lumpy investment. On the whole, private firms have higher investment intensity (I/K) (0.092) than SOEs (-0.032), which is also true for sales-to-capital (Y/K) ratio. Turning to financing sources, private firms hold a cash flow ratio four times as high as that of SOEs.[18] In contrast, SOEs (0.71) have higher debt-to-asset ratios (DAR) than private firms (0.57). The financial situation provides some evidence that private firms rely more on internal resources to finance their investment activities, whereas SOEs are more likely to turn to external sources.

3.4 EMPIRICAL RESULTS

3.4.1 Financing Constraints by Firm Ownership and Size

Table 27 reports the results from estimating Equation 3.16 for the pooled sample and sub-samples of private firms and SOEs respectively. Arellano and Bond AR(1) tests show that there are first-order autocorrelation for the error terms among all three samples, which verifies the invalidity of using second lags to instrument the endogenous variables. The tests of AR(2) do not demonstrate second-order autocorrelation, therefore endogenous variables dated at t-3 are used as instruments for the first difference equation estimation; in addition, first differences of endogenous variables dated at t-2 are used for the level equation.

The focus of this chapter is the coefficients on the explicit proxies of financing constraint indicator Λ_{it}, i.e. coefficients on the ratio of lagged debt to assets (DAR) and the lagged interest coverage ratio (COV). With regard to the pooled-sample, both coefficients are

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[18] The CF variables is constructed by summing operating profit and current depreciation, as previous literature does.

positive and significant at 1% level, which holds for the private firms too. The magnitudes of both coefficients are higher for private firms though, equal to 0.0304 (COV) and 0.0830 (DAR) respectively. For SOEs, however, the coefficient on COV becomes insignificant and the one on DAR (0.0343) is of much smaller magnitude. This evidence suggests that Chinese manufacturing firms on the whole are financially constrained, and that private firms are more constrained than SOEs. This result is highly consistent with previous findings (e.g., Poncet et al. (2010)) that the presence of "political pecking order" of firms provides more favorable environment for SOEs in the allocation of credits whereas private firms are facing more barriers. While Poncet et al. (2010) argue that SOEs are not financing constrained at all, my results illustrate that even SOEs are slightly constrained in the Chinese manufacturing sector. This difference arises partly in that a broader coverage of firms in my analysis contains more exhaustive information that delivers a more general picture.

To make a further investigation within each ownership sub-sample, firm size is utilized as a classification. Table 28 presents results for large- and medium/small-sized firms separately. Comparison among different samples in Table 28 suggests that the most financing constrained firms in the manufacturing sector are the medium/small private firms, with positive and significant coefficients on both COV and DAR in column (4), the magnitudes of which are 0.0199 and 0.0900 respectively.

It is worth noting there is no evidence of financing constraints facing large private firms. After a transition of over 30 years, the private sector is playing an increasingly important role in boosting Chinese economic growth. As described in section 3.3.2.2, large private firms outperform all other types of firms. Furthermore, some industries are even largely led by private firms, for example, the solar photovoltaic equipment industry. In fact, several large private solar PV firms like Yingli in Baoding (Hebei province) have become pillar enterprises in the local economy. Local governments, thereby have launched facilitating policies to channel more resources into these firms in order to maintain employment and to foster local economic growth. Easy access to credits are one facet of such policies. At the national level, in the late 1990s Chinese constitution acknowledged that private sector is an indispensable and integral part of the economy (Héricourt and Poncet (2009)). With both law and policy support, it is not surprising that frictions in the financial market are gradually eliminated for the private firms, mostly the large ones.

Another striking finding is that medium/small state-owned firms are facing financing constraints to some extent, which is reflected by the positive and significant coefficient on DAR (equal to 0.0941). While the coefficient on DAR of SOEs is roughly the same level as their private counterparts, the coefficient on COV is negative and insignificant, suggesting that medium/small SOEs are less financing constrained than private firms of similar size. Taken into consideration of the relatively poor profitability of medium/small SOEs, as Table 25 illustrates, this result suggests that firm efficiency has gain more importance in the Chinese economy even though the "political pecking order" of firms still exists to a certain degree. Now that large SOEs are politically assigned with the highest priority, they are facing no credit friction at all. Even though medium/small private firms absorb a growing share of the labor force and provide relatively good performance, obtaining external credits is still costly which therefore hinders their development. This conclusion largely corresponds with what is found by Chan et al. (2012), that is, large firms are generally not credit constrained whereas the smaller ones do encounter financial friction. Love (2003) and Schiantarelli (1996) argue that small firms are more likely to subject to asymmetric information problems and transaction costs. Large firms, on the contrary, may enjoy preferential credit access through political connection or directed-credit policies (Chan et al. (2012)).

3.4.2 Financing Constraints by Economic Region

There is remarkable variation in economic development across different regions. As a whole, there are thirty-one provinces, municipalities and autonomous regions, excluding

Hong Kong, Macau and Taiwan. Following the NBS criterion, I divide China into four economic regions: east and coastal, northeast, middle and west.[19] The east and coastal region includes 10 provinces and municipalities located in the east and coastal areas, like Beijing, Shanghai and Guangdong, etc. This region is the most developed area in China, with the highest population density and highest per capita GDP as well as investment. Moreover, this region attracts the largest volumes of FDI and human resources. In contrast, the western region is the least developed due to its disadvantage in geography, lack of technology and human resources as well as relatively poor infrastructure. The northeast and the middle regions fall in between. Overall, the level of development decreases from the east and coastal to the west. The relationship between financial and real sides of the economy has long attracted attention.

Table 29 shows the financing constraints across economic regions and reports financing constraints facing SOEs and private firms within each region. First of all, as illustrated by column (1), (4), (7) and (10), firms in the east and coastal region are on average more constrained than the remaining three regions. Coefficients on both financial factors COV and DAR are positive and significant at 1 percent level, and they are the largest among the four regions. When we break down firms by ownership, three more interesting findings emerge. First, private firms display higher financing constraints than SOEs in each region. Second, as to SOEs, comparison among the four regions indicates that no financing constraints are detected in the west, whereas SOEs in the east and coastal region are less constrained than SOEs in the northeast and the middle regions. In addition, private firms in the east and coastal region are more financing constrained than the middle and the west regions. The by-ownership evidence suggests that the highest financing constraints in the east and coastal region result mostly from the constrained private firms in the region.

It is widely accepted that countries and areas with higher levels of economic development also enjoy healthier financial systems, thus are subject less to capital market imper-

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[19] The detailed classification method is presented in the appendix Table A9.

fection and credit misallocation. Our results suggest the opposite. That private firms - the most competitive group - in China's most developed economic region face more financing constraints can add evidence to the growing literature of resource misallocation in China.[20] Care must be taken in interpreting the results, however. Local informal financial institutions have been well developed in the east and coastal region and are playing a critical role in financing private firms in the region.[21] However, it is highly possible that official data released by the NBS fails to incorporate informal sources of credits. Consequently, our results may only hold for formal credits.

3.4.3 Financing Constraints by High-Tech/Non-High-Tech Industries

In the recent years, high-tech industries have witnessed pronounced growth in the whole manufacturing sector in China.[22] Between 2000 and 2005, high-tech industries enjoyed an annual growth rate of 27.5% in value added. In 2005, the annual sales in high-tech industries amounted to 3,400 billion RMB, and the value added accounted for 4.4% in GDP. Additionally, high-tech products took up 28.6% of overall exports in 2005, with an absolute volume of 218.3 billion dollars, which was six times that of the late 1990s (11th Five-year Plan for High-tech Industry, p.5).[23] High-tech industries have played a critical role in prompting technology development, which serves as a driving force for economic growth. To encourage the development of high-tech industries, policies were laid out to strengthen financial support for related industries. Therefore, other things equal, access to credit should be easier and less costly for high-tech industries in the manufacturing sector.

Table 30 reports results for high-tech and non high-tech manufacturing firms separately. Column (1) shows the pool-sample regression result, which indicates that as a whole the manufacturing sector is financing constrained. This finding is highly consistent with what

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[20] For example, Hsieh and Klenow (2009).

[21] Like areas in Wenzhou (Zhejiang province), Quanzhou(Fujian province). See Tsai (2004).

[22] See the Appendix Table A8 for the detailed high-tech industry classification.

[23] www.sdpc.gov.cn/zcfb/zcfbtz/2007tongzhi/W020070514615556997089.pdf

Table 27 column (1) reflects and the magnitudes of estimates are quite similar between the two. Thus in the pooled sample, whether to include high-tech industry dummy or 2-digit industry dummies only leads to minor quantitative changes for the results. As shown by the rest of Table 30, while high-tech industries face no financing constraints, other industries suffer greatly from capital market imperfection. In particular, not only private firms have difficulty in accessing credits, state-owned firms are not able to access credits freely as well. When I further divide firms by size, the pattern persists. Regardless of size distinction, all the coefficients on financial variables are statistically insignificant for high-tech industries(Table 31), implying that they are free of financing constraints. Outside the high-tech industries, only large firms are free of financing constraints while medium/small firms - state-owned and private - are constrained from obtaining external credits. However, for medium/small SOEs, the coefficient on DAR is positive and significant but the magnitude (0.0560) is roughly 80 percent of that for the private firms (0.0714). In addition, the coefficient on COV of medium/small SOEs is negative and insignificant whereas the coefficient of private medium/small firms is positive (0.0154) and statistically significant at 1 percent level. Hence, in the industries outside the high-tech, medium/small private firms are more constrained than their state-owned counterparts.

3.5 DISCUSSION

3.5.1 Nonlinearity

Linearization of the Euler equation plays a crucial role of the whole analysis. On the one hand, the linearized reduced form specification highly simplifies the estimation. However, the associated cost of doing so is losing nonlinear features the data may exhibit. There are two streams of existing literature that conduct investment Euler equation estimation: one originating from Whited (1992) estimates the nonlinear Euler equation directly through

GMM, the other following Love (2003) estimates the linearized version via dynamic linear panel data GMM estimator. Now that the whole paper has been built on the linearization method, it is worthwhile to conduct the nonlinear estimation to check how much robustness the results could demonstrate.

3.5.2 Entry and Exit

Brandt et al. (2012) find that the manufacturing sector during years 1998 to 2007 experienced substantial entry and exit of firms.[24] So far, most of the existing literature that studies investment and financing constraints has neglected this particular aspect, which may be partially due to data structures or model simplification. Nonetheless, financing constraint is closely related to how well a firm can grow and stay active. Intuitively, ignoring the elements of entry and exit would lead to downward biased estimates of financing constraints presuming that there is net exit. As such, it is of significant importance to introduce entry and exit dimension into the traditional investment model. Schündeln (2005) models firm dynamics by incorporating entry and exit to identify the cost of financing constraint in Ghanaian Manufacturing. This work certainly sheds light on the extension I plan to make.

3.6 CONCLUSION

In this paper, I use the Chinese Industrial Survey Data spanning from 1998 to 2007 to examine the level of financing constraints. Unlike earlier studies, the dataset I utilize contains all the above-scale manufacturing firms and thus has a broader platform than either listed firms or survey data confined to certain geographic regions. Building on the

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[24] Brandt et al. (2012) matched firms that changed IDs spanning 1998-2007 to avoid counting the incumbent firms as either exit or entry.

Euler equation approach and through dynamic GMM estimation, I find that SOEs, overall, are slightly financing constrained whereas private firms face much greater obstacles in accessing credits. Moreover, the analysis of financing constraints level by firm size within each ownership category suggests that large firms are not credit constrained regardless of ownership. Among medium/small firms, SOEs are less financially constrained than their private counterparts. Further, there is cross-region variation in accessing external finance. The east and coastal region is the most financially constrained region among the four (east and coastal, northeast, middle and west), which is largely due to the constrained private firms in the region. Last, high-tech firms exhibit no financing constraints at all whereas in other industries, medium and small firms suffer from credit distortion with private firms being constrained to a greater degree.

Several extensions can be made in the future. First, in contrast with linear estimation, it is worthwhile to conduct nonlinear estimation as so to check how much robustness the results could demonstrate. Second, extending the model by incorporating entry and exit could generate a more precise estimate of financing constraint level.

4.0 FUTURE WORK

The core of this dissertation is to exploit the new micro data to provide a new perspective on productivity differences of vertically-integrated manufacturing firms in China. In particular, it is the first work to decompose firm productivity into stage- and plant (equipment)-level and explain productivity differences through the lens of firms' internal organization.

We see this dissertation as the start of a research agenda that may encompass several further projects. In chapter 2, we impose the assumption that in a vertically-integrated operation, each production unit (i.e., equipment) operates independently both within and across stages. In an immediate extension, we are working to relax this assumption by allowing for productivity shocks to be correlated within and across stages. This full-fledged description of productivity goes one step further to characterize the links of vertically-integrated firms' internal activities. We will jointly estimate production functions for the three stages in the value chain. This extension will make an important contribution in methodology to the production function literature.

The second project focuses on China's industrial policy in the steel industry. Beijing has been struggling to restructure the industry around a few giant national champions through two major policy tools: capacity reduction and $M\&A$ (merger and acquisition). We are working to examine the consequences of these two aspects of policy. In one paper, we focus on firms' decision-making on investment under the policy influence of capacity reduction. On one hand, firms have strong incentives to expand ex-ante to remain a significant player so as to avoid being shuttered or downsized. On the other hand, as suggested by the current paper, the government would likely cut private firms, which are nevertheless the most efficient segments of the industry. Therefore, the policy on capacity reduction may lead to unintended consequences.

To understand the dynamic implication of this policy, we will construct a dynamic structural model of firm investment in steel capacity where SOEs and private firms expand under different borrowing/hiring/input constraints. We will estimate the model using annual firm-level information originating from the Chinese Iron and Steel Association that we assembled on output, steel capacity (capital), employees, wages, intermediate inputs and profits over 2000-2013. With the estimated model, we plan to run counterfactual experiments of various capacity reduction schemes and study their impacts on efficiency and welfare.

In addition, we will explore the impact of $M\&A$ on firm efficiency and market power. The central government has constantly promoted (and often imposed) consolidation during the last 15 years. We have constructed a timeline with details of annual $M\&A$ transactions from 2000 to 2013 in the steel industry. A particularly nice feature of our data is that firms report information separately for subsidiary units both before and after such reorganizations. Therefore, the inputs and detailed disaggregated output data by final product enable us to examine firms' performance with regard to productivity, product mix and markups before and after $M\&A$.

We anticipate a series of papers that will generate policy implications to a globally important industry at the center of China's proposals for rebalancing of the economy. In addition, the implication of our work is not restricted to China's steel industry. The analytic frameworks that we propose should provide broad insights into future research on the performance of complex industrial operations, and in particular, the industries under government regulation.

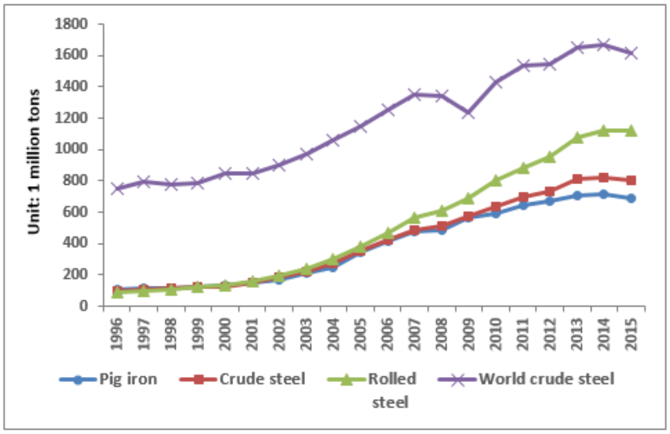

Figure 1: Output of Major Steel Products Between 1996 and 2015

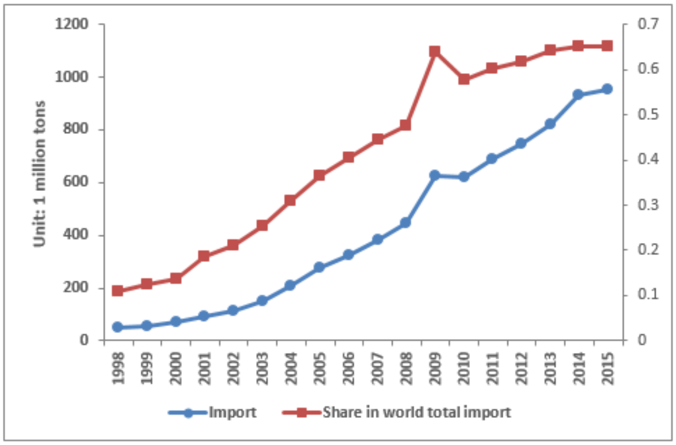

Figure 2: Import of Iron Ore

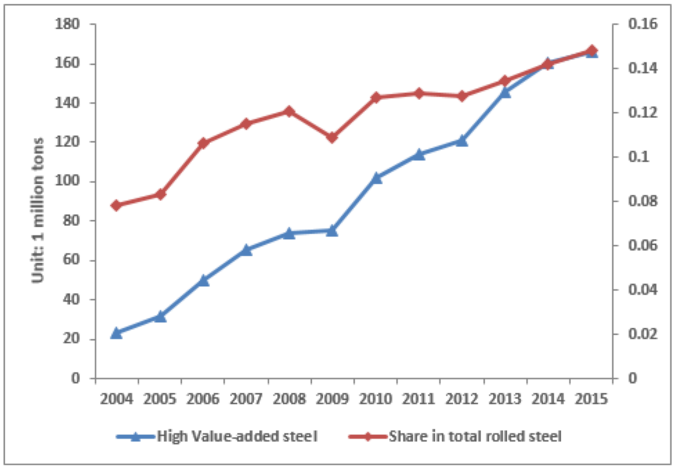

Figure 3: High Value-Added Steel Products

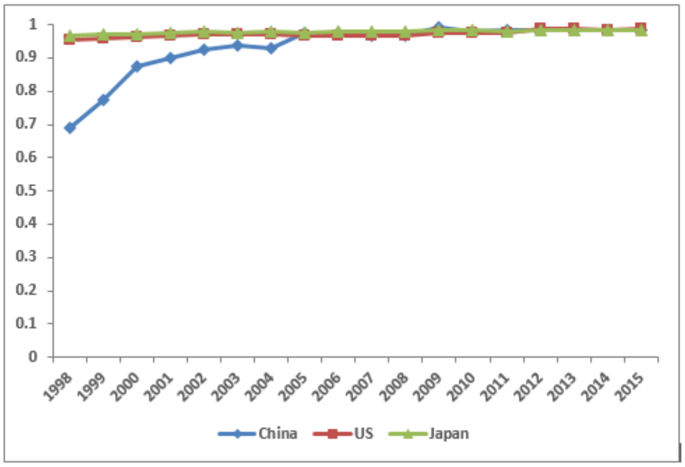

Figure 4: Continuous Casting Ratio

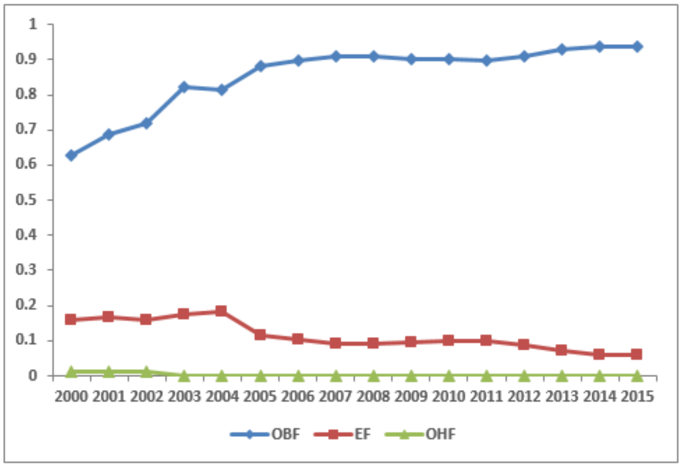

Figure 5: Crude Steel by Production Technique

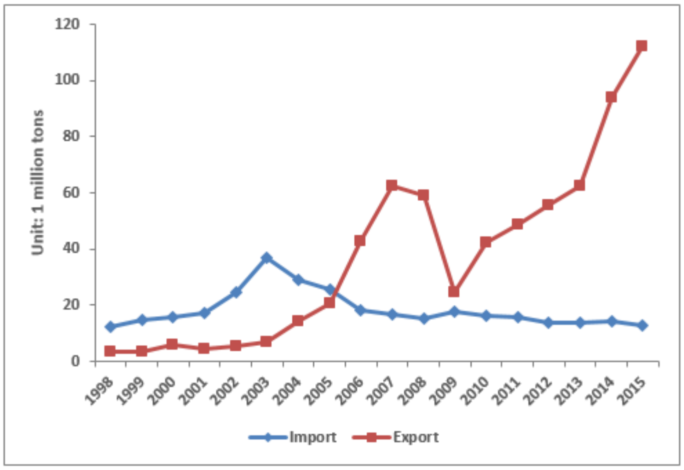

Figure 6: Import and Export of Rolled Steel

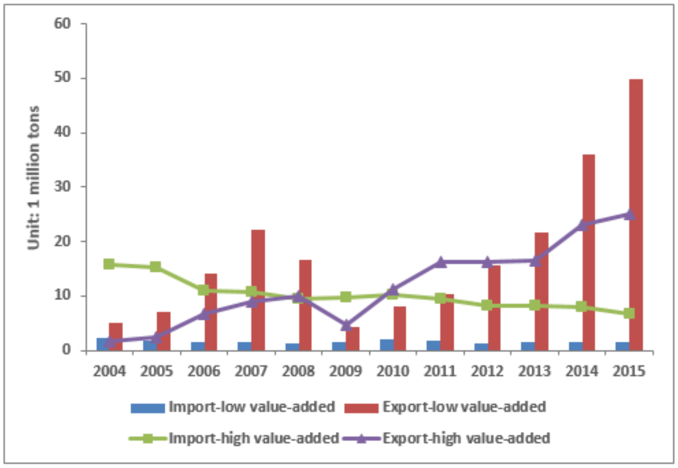

Figure 7: Import and Export of High Value-Added Rolled Steel

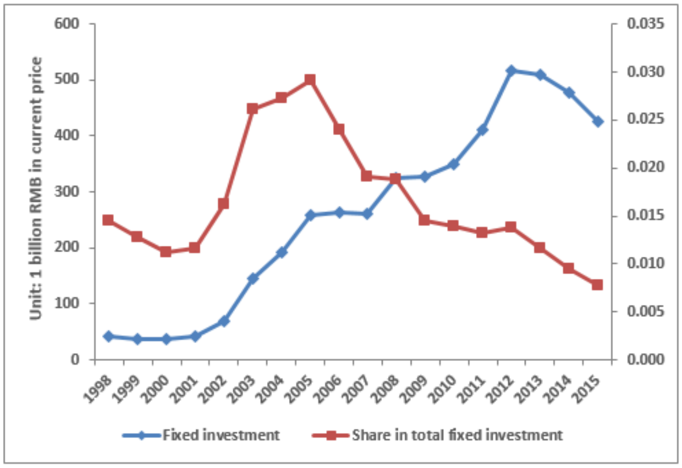

Figure 8: Fixed Investment in the Steel Industry

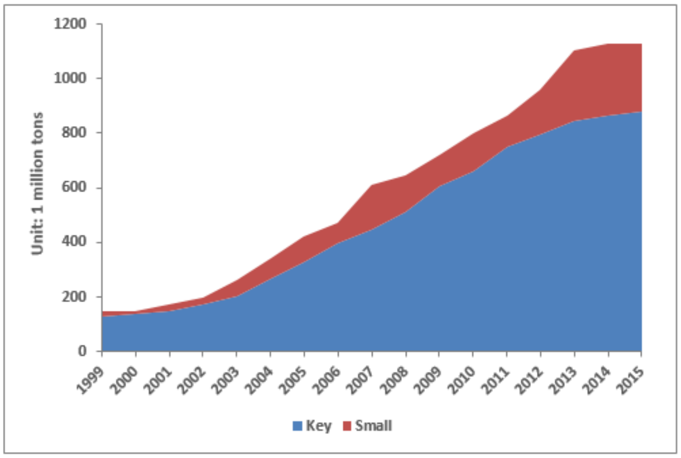

Figure 9: Production Capacity of Steel

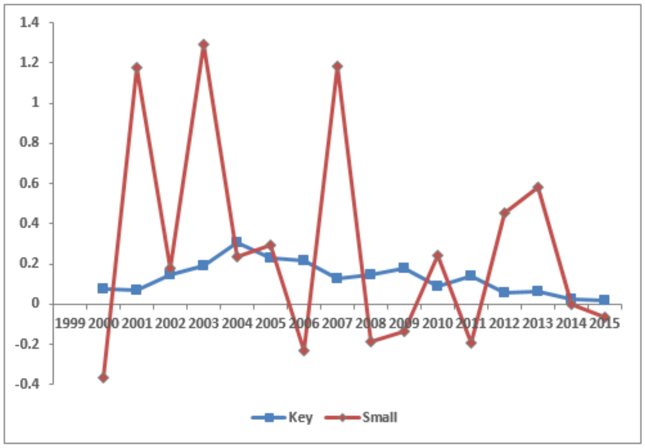

Figure 10: Growth Rate of Steel Capacity

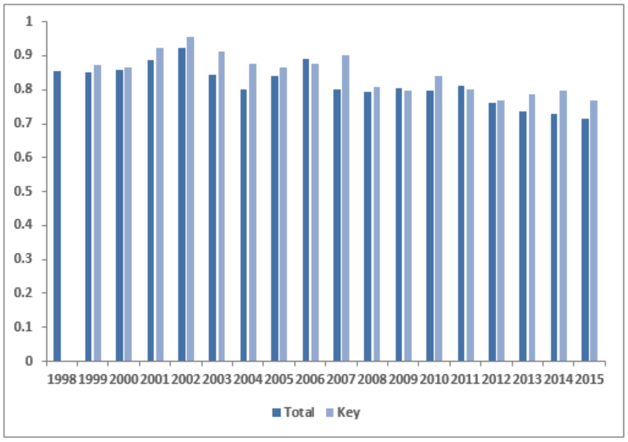

Figure 11: Utilization Rate of Steel Capacity

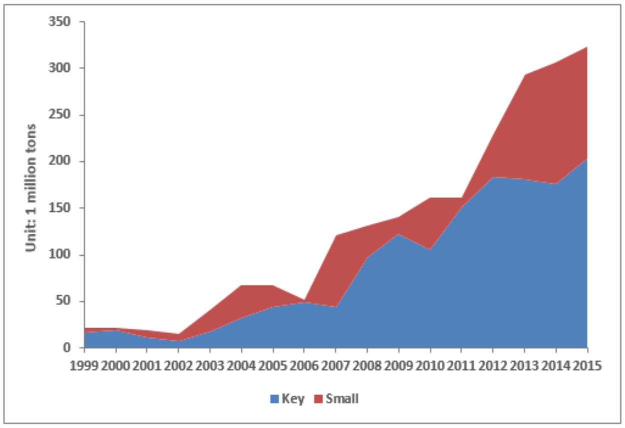

Figure 12: Excess Capacity of Crude Steel

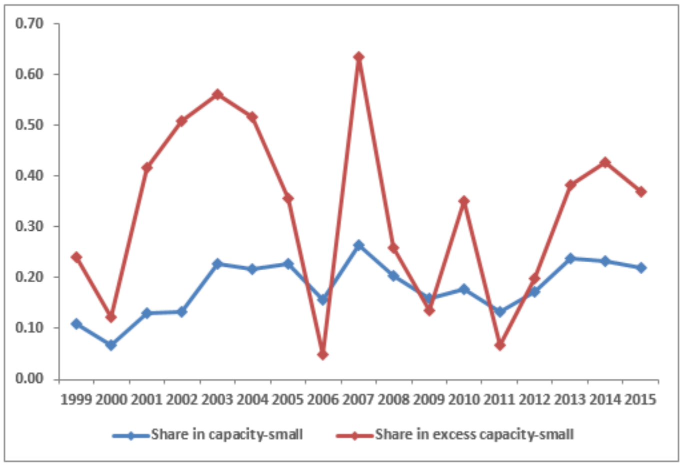

Figure 13: Shares of Key Firms in Total Capacity and Total Excess Capacity

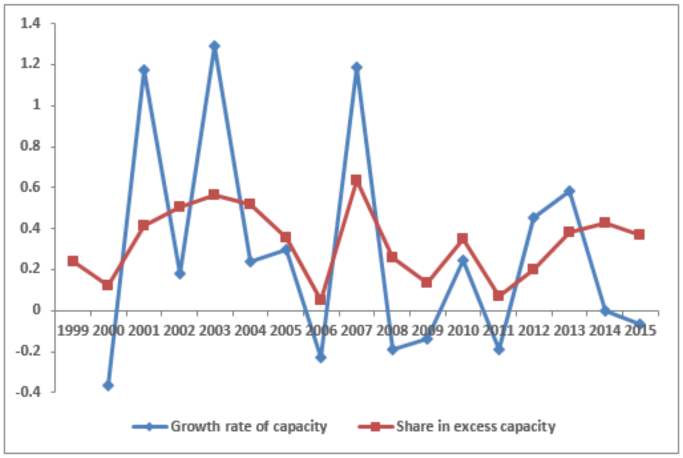

Figure 14: Capacity Growth Rate of Small Firms and Shares of Small Firms in Total Excess Capacity

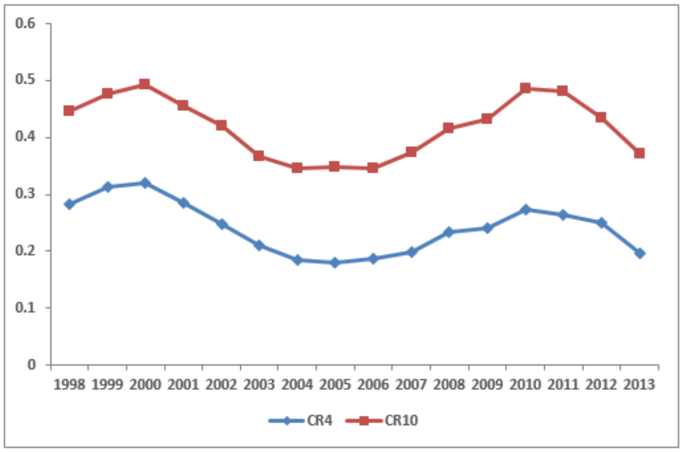

Figure 15: Concentration Ratio

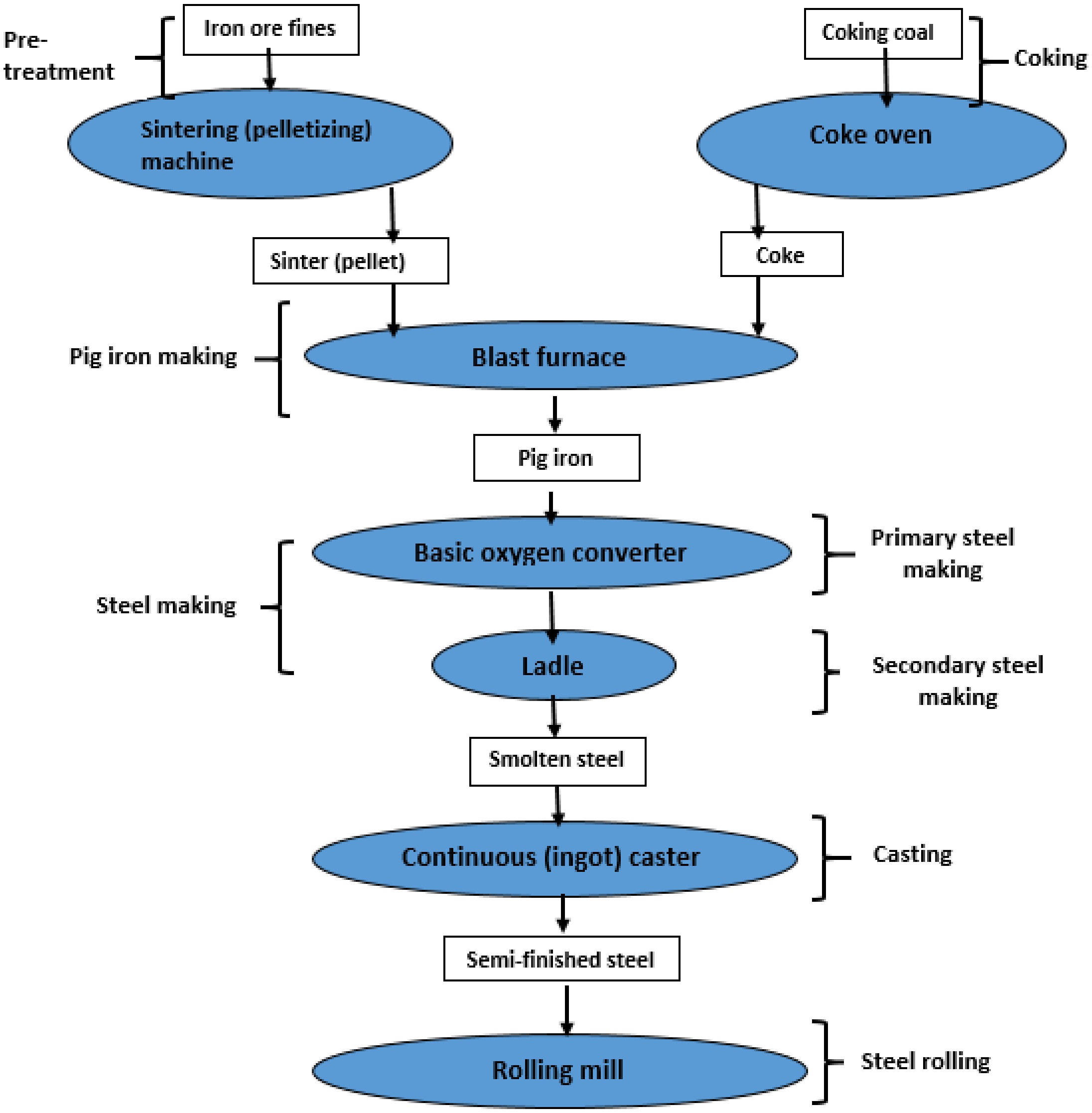

Figure 16: Steel Technology of Integrated Facilities

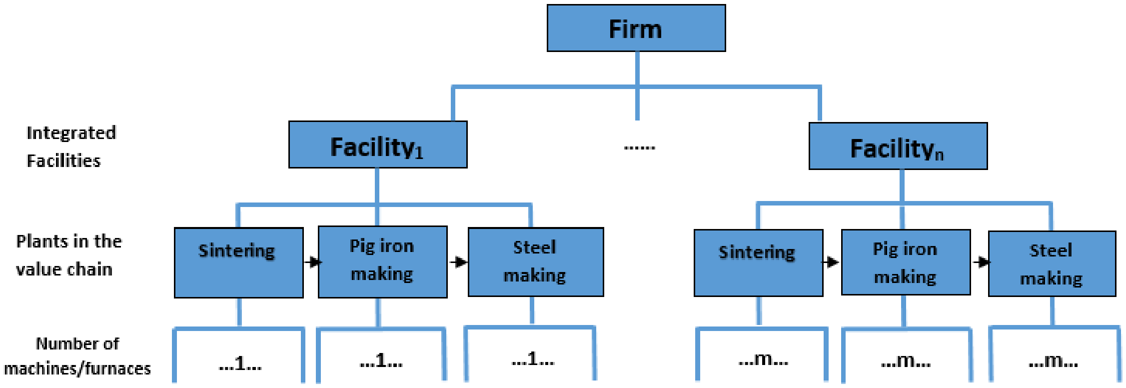

Figure 17: Structure of Integrated Facilities

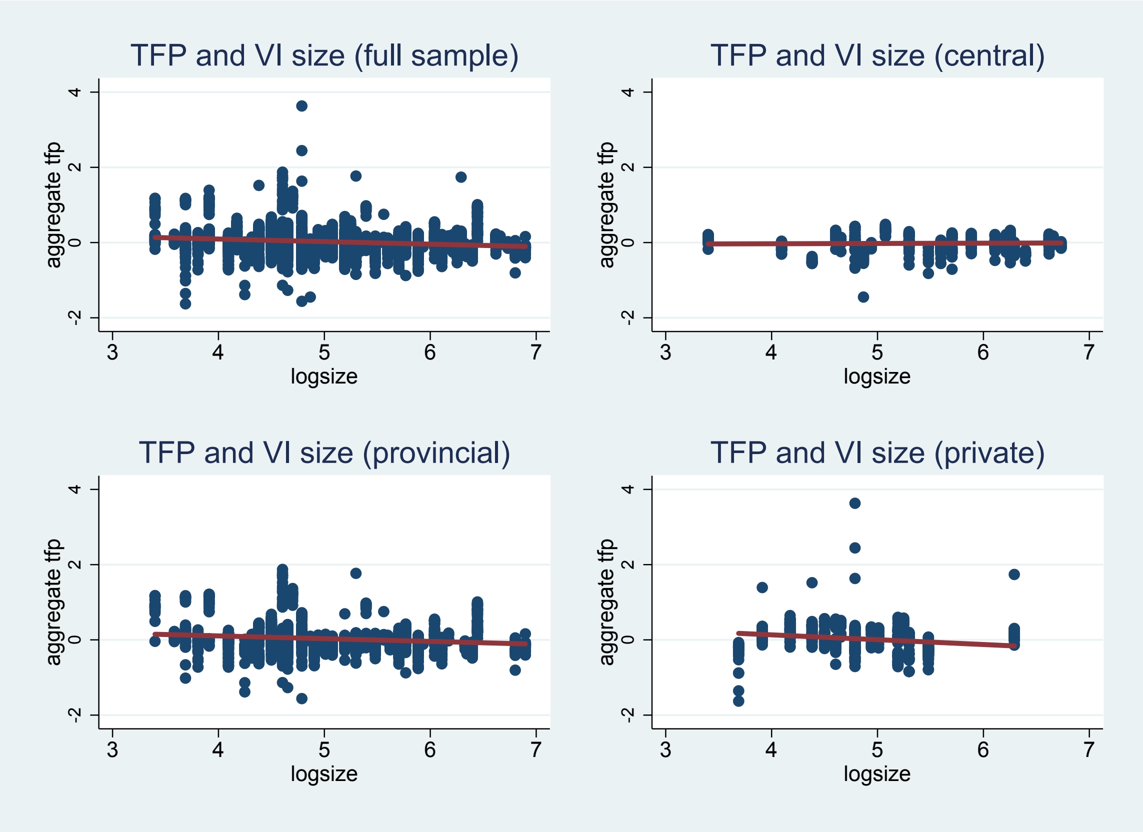

Figure 18: Facility-level TFP and Size of Integrated Facilities

Notes: VI represents integrated facilities. Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility; each plot represents a facility-month observation.

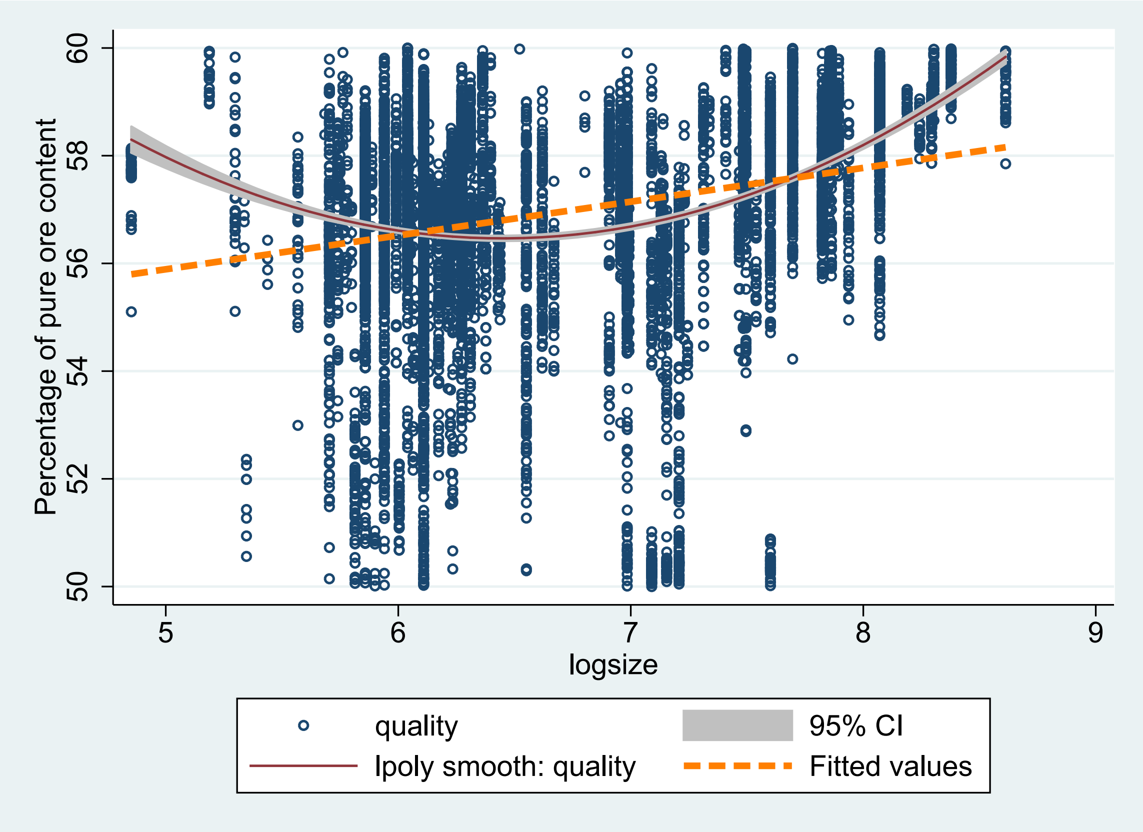

Figure 19: Grade of Iron Ore and Size of Iron-Making Plants (Blast Furnace)

Notes: Blast furnace size is measured by the effective volume of the furnace in cubic meters (m^3).

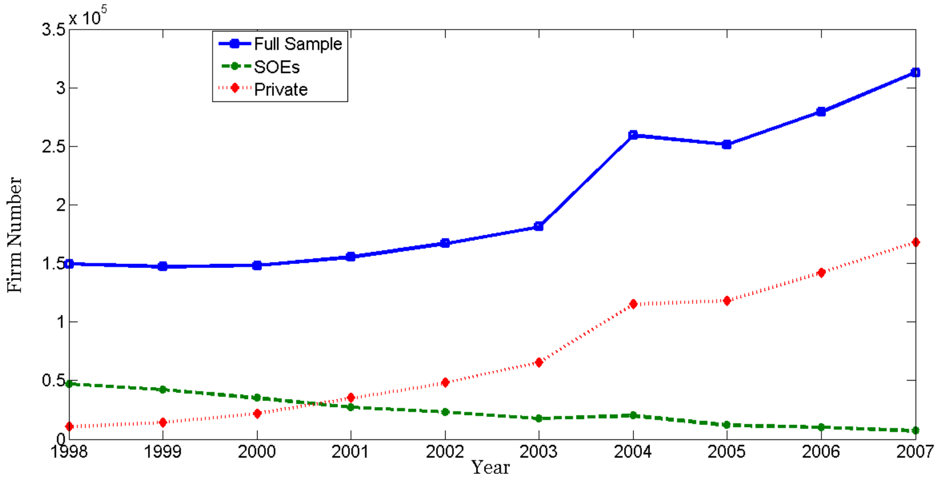

Figure 20: Firm Number Evolution in the Chinese Manufacturing Sector

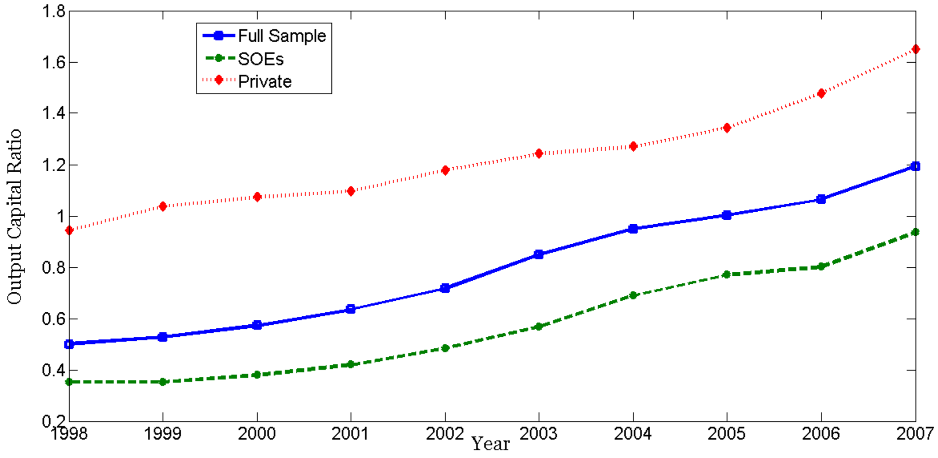

Figure 21: Output Capital Ratio of Chinese Manufacturing Sector

Table 1: China Steel Overview

Year	Number of firms	Value of industrial output (1 billion RMB)	Share of steel in the total value of Industrial Output (%)	Employment (1 million)	Output per man-year (tons)
1998	3,260	388.32	5.7	28.5	40.2
1999	3,042	409.74	5.6	27.7	44.8
2000	2,997	473.29	5.5	26.2	49.1
2001	3,176	570.73	6.0	24.9	60.8
2002	3,333	649.24	5.9	23.9	76.2
2003	4,119	1,000.74	7.0	25.6	86.9
2004	4,992	1,566.45	8.4	26.1	104.4
2005	6,686	2,124.78	8.4	28.7	123.8
2006	6,999	2,540.38	8.0	29.6	142.2
2007	7,161	3,370.30	8.3	30.4	160.9
2008	8,012	4,472.80	8.8	31.4	163.4
2009	7,773	4,263.62	7.8	32.3	178.6
2010	7,881	5,183.36	7.4	34.6	184.8
2011	6,742	6,406.70	7.6	34.0	206.5

Sources:

[a] Number of firms in 1998 is from Industrial Survey Data; 1999-2008 are from China Steel Yearbook, various issues; 2009-2011 are from China Statistical Yearbook, various issues.

[b] Value of industrial output is in current values; 1998 is from Industrial Survey Data; the rest are from China Statistical Yearbook, various issues.

[c] Employment in 1998 is from Industrial Survey Data; 1999-2003 are from China Data Online; 2004-2011 are from China Statistical Yearbook, various issues.

[d] Shares of steel in the total value of the industrial output are based upon the author's calculation.

[e] Output per man-year = Crude steel/employment, based upon the author's calculation.

Table 2: Total Number of Firms, Integrated Facilities, Equipment and Production Share by Ownership

Panel A: Sintering (Machine)

	(1) Full Sample	(2) Central	(3) Provincial	(4) Private
Number of Machines	343	56	203	84
Product Share	100%	19.8%	61.3%	18.9%

Panel B: Iron Making (Blast Furnace)

	(1) Full Sample	(2) Central	(3) Provincial	(4) Private
Number of Furnaces	490	92	249	149
Product Share	100%	19.3%	59.4%	21.3%

Panel C: Steel Making (Basic Oxygen Furnace)

	(1) Full Sample	(2) Central	(3) Provincial	(4) Private
Number of Furnaces	342	68	209	65
Product Share	100%	18.4%	63.4%	18.3%

Panel D: Integrated Facilities

	(1) Full Sample	(2) Central	(3) Provincial	(4) Private
Number of Facilities	136	26	77	33

Panel E: Firm

	(1) Full Sample	(2) Central	(3) Provincial	(4) Private
Number of Firms	59	9	35	15

Table 3: Summary Statistics of Equipment Size by Ownership

Panel A: Sintering (Machine)					
	(1) Number	(2) Mean	(3) Std. Dev	(4) Min	(5) Max
Total	343	156	127	24	853
Central	56	204	161	24	853
Provincial	203	158	127	24	550
Private	84	122	84	24	360

Panel B: Pig Iron Making (Blast Furnace)					
	(1) Number	(2) Mean	(3) Std. Dev	(4) Min	(5) Max
Total	490	1016	926	128	5500
Central	92	1230	1046	200	4038
Provincial	249	1127	1036	128	5500
Private	149	698	460	179	2680

Panel C: Steel Making (Basic Oxygen Furnace)					
	(1) Number	(2) Mean	(3) Std. Dev	(4) Min	(5) Max
Total	342	95	62	12	300
Central	68	123	66	30	260
Provincial	209	93	63	12	300
Private	65	72	39	30	180

Notes: The size of a sintering machine is measured by its effective areas in m^2; the size of a blast furnace is measured by its effective volumes in m^3; the size of a basic oxygen furnace is measured by its tonnage.

Table 4: Summary Statistics of Integrated Facility Size by Ownership

	(1) Number	(2) Mean Size	(3) Std. Dev	(4) Min	(5) Max
Total	136	218	185	30	990
Central	26	301	212	30	840
Provincial	77	227	190	30	990
Private	33	131	96	40	540

Notes: Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility.

Table 5: Number and Production Share of Integrated Facilities by Size

Panel A: Size Distribution of Integrated Facilities

	(1) 1st quartile size<90 Number	(2) 2nd quartile [90,160) Number	(3) 3rd quartile [160,300) Number	(4) 4th quartile size≥300 Number	(5) Total Number
Central	3	6	5	12	26
Provincial	16	21	18	22	77
Private	13	11	8	1	33
Total	32	38	31	35	136

Panel B: Output Share by Integrated Facilities Size

	(1) 1st quartile size<90 Output Share	(2) 2nd quartile [90,160) Output Share	(3) 3rd quartile [160,300) Output Share	(4) 4th quartile size≥300 Output Share	(5) Total Output Share
Central	0.8%	1.5%	2.9%	13.3%	18.5%
Provincial	6.0%	11.6%	14.3%	31.7%	63.5%
Private	4.3%	4.6%	6.7%	2.4%	18.0%
Total	11.1%	17.7%	23.9%	47.4%	100.0%

Notes: Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility; the size quartiles are calculated over the observations in the whole sample; output is measured by steel.

Table 6: Internal Configuration of Integrated Facilities

Sintering (Machine)						
		(1)	(2)	(3)	(4)	(5)
			1st quartile	2nd quartile	3rd quartile	4th quartile
Ownership	Variables	Total	size<90	[90,160)	[160,300)	size≥300
Central	Number of Machines	2.06	2.34	2.38	2.50	1.66
	Average Size	267	102	95	222	393
Provincial	Number of Machines	2.38	1.71	2.22	2.41	2.87
	Average Size	189	116	141	225	248
Private	Number of Machines	2.12	1.71	2.31	2.09	5.00
	Average Size	129	74	147	151	360
Iron Making (Blast Furnace)						
		(1)	(2)	(3)	(4)	(5)
			1st quartile	2nd quartile	3rd quartile	4th quartile
Ownership	Variables	Total	size<90	[90,160)	[160,300)	size≥300
Central	Number of Furnaces	2.27	2.71	2.28	2.13	2.25
	Average Size	2031	475	985	1902	2840
Provincial	Number of Furnaces	2.67	1.99	2.84	2.59	2.94
	Average Size	1406	613	809	1770	2125
Private	Number of Furnaces	2.82	1.85	3.29	3.56	3.00
	Average Size	707	482	614	826	2680
Steel Making (Basic Oxygen Furnace)						
		(1)	(2)	(3)	(4)	(5)
			1st quartile	2nd quartile	3rd quartile	4th quartile
Ownership	Variables	Total	size<90	[90,160)	[160,300)	size≥300
Central	Number of Furnaces	2.42	1.30	1.83	2.26	2.97
	Average Size	131	45	87	94	183
Provincial	Number of Furnaces	2.57	1.49	2.21	3.09	3.13
	Average Size	94	47	67	81	151
Private	Number of Furnaces	1.90	1.09	2.00	2.69	3.00
	Average Size	75	54	79	84	180

Notes: Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility; the size of a sintering machine is measured by its effective areas in m^2; the size of a blast furnace is measured by its effective volumes in m^3; the size of a basic oxygen furnace is measured by its tonnage.

Table 7: Production Functions

	(1)	(2)	(3)	(4)	(5)	(6)
	Sintering		Iron Making		Steel Making	
Variables	OLS	GMM	OLS	GMM	OLS	GMM
l	0.212***	0.215***	0.119***	0.101***	0.0602***	0.0583***
	(0.0077)	(0.0034)	(0.0047)	(0.0013)	(0.0044)	(0.0021)
k	0.812***	0.901***	0.298***	0.378***	0.155***	0.137***
	(0.0065)	(0.00027)	(0.0048)	(0.0011)	(0.0037)	(0.0029)
m			0.594***	0.555***	0.746***	0.862***
			(0.0050)	(0.0049)	(0.0048)	(0.0019)
age	0.000885***	0.0006501	0.000267*	-0.000436*	-0.000305***	-0.000522***
	(0.00028)	(0.00090)	(0.00014)	(0.00024)	(0.00010)	(0.00017)
Observations	7,630	7,630	10,087	10,087	8,514	8,514
R-squared	0.808		0.921		0.927	
Ownership FE	YES	YES	YES	YES	YES	YES
Province FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES

Note: Standard errors of GMM are computed via bootstrap of 1000 replications.

Table 8: Dispersion of TFP

	(1)	(2)
Variables	Std Dev	90:10 ratio
Sintering	0.58	2.31
Iron Making	0.21	1.30
Steel Making	0.11	1.25
Integrated Facilities	0.79	1.91

Notes: 90:10 ratios for sintering, iron making and steel making are based on the average productivity of machines/furnaces over time. The ratio for integrated facilities is based on the average productivity of integrated facilities over time.

Table 9: Ownership Premium in Productivity

	(1)	(2)	(3)
Variables	Sintering logtfp	Iron Making logtfp	Steel Making logtfp
Private	-0.0855***	0.0515***	0.0576***
	(0.0153)	(0.00606)	(0.00379)
Provincial	-0.102***	0.0110**	0.00819***
	(0.0133)	(0.00558)	(0.00315)
Constant	0.0395	-0.0640***	-0.0384***
	(0.0293)	(0.0122)	(0.00721)
Observations	8,728	11,837	8,510
R-squared	0.015	0.020	0.047
Time FE	YES	YES	YES

Notes: Machines/furnaces of central state-owned facilities are the omitted group. Private and provincial indicate ownership dummies.

Table 10: Equipment TFP and Equipment Size by Production Stage

	(1)	(2)	(3)
Variables	Sintering logtfp	Iron Making logtfp	Steel Making logtfp
logsize	-0.160***	-0.0443***	-0.0251***
	(0.0127)	(0.00541)	(0.00440)
Private x logsize	-0.0104	-0.0460***	-0.0637***
	(0.0184)	(0.00901)	(0.00656)
Provincial x logsize	0.0609***	0.0146**	-0.0277***
	(0.0145)	(0.00623)	(0.00481)
Private	-0.0981	0.319***	0.307***
	(0.0887)	(0.0595)	(0.0292)
Provincial	-0.426***	-0.0964**	0.117***
	(0.0721)	(0.0431)	(0.0227)
Constant	0.814***	0.238***	0.0772***
	(0.0687)	(0.0391)	(0.0219)
Observations	8,728	11,837	8,510
R-squared	0.070	0.045	0.157
Time FE	YES	YES	YES

Notes: The size of a sintering machine is measured by its effective areas in m^2; the size of a blast furnace is measured by its effective volumes in m^3; the size of a basic oxygen furnace is measured by its tonnage. Machines/furnaces of central state-owned facilities are the omitted group. Private and provincial indicate ownership dummies.

Table 11: Difference in the Share of Rich Ore (%) in 2012

	(1)
Variables	Share of rich ore
Private	-14.29*
	(8.429)
Provincial SOE	-2.231
	(7.997)
Constant	56.10***
	(6.972)
Observations	76
R-squared	0.061

Notes: Central SOEs are the omitted group. Private and provincial indicate ownership dummies.

Table 12: Weights for TFP Aggregation

	(1)	(2)	(3)
	Weight 1 Elasticity	Weight 2 Value Share	
Sintering	$\hat{\gamma}_2 * \hat{\gamma}_3$	Mean	Std Dev
	0.48	0.52	0.16
Iron making	$\hat{\gamma}_3$	Mean	Std Dev
	0.86	0.82	0.05
Steel making	1	1	

Notes: $\hat{\gamma}_2$ is the estimated elasticity of material input (iron ore) in iron-making production function. $\hat{\gamma}_3$ is the estimated elasticity of material input (iron) in steel-making production function.

Table 13: Ownership Premium of Integrated Facility TFP

	(1)	(2)
Variables	Facility logtfp	Facility logtfp
logsize		0.00715
		(0.0164)
Private x logsize		-0.136***
		(0.0237)
Provincial x logsize		-0.0809***
		(0.0187)
Private	0.0622***	0.707***
	(0.0178)	(0.122)
Provincial	0.0393**	0.460***
	(0.0156)	(0.103)
Constant	-0.0911***	-0.140
	(0.0341)	(0.0960)
Observations	3,440	3,440
R-squared	0.018	0.053
Time FE	YES	YES

Notes: Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility. Private and provincial are ownership dummies.

Table 14: Ownership Premium of Integrated Facility TFP by Facility Size

	(1)	(2)	(3)	(4)
	1st quartile	2nd quartile	3rd quartile	4th quartile
	size<90	[90,160)	[160,300)	size≥300
Variables	logtfp	logtfp	logtfp	logtfp
Private	0.327***	0.135***	-0.198***	0.195***
	(0.0528)	(0.0464)	(0.0277)	(0.0451)
Provincial	0.248***	0.119***	-0.0515**	-0.0223
	(0.0527)	(0.0421)	(0.0257)	(0.0175)
Constant	-0.222***	-0.141*	-0.0408	-0.101**
	(0.0822)	(0.0811)	(0.0616)	(0.0472)
Observations	748	918	802	972
R-squared	0.082	0.037	0.107	0.056
Time FE	YES	YES	YES	YES

Notes: Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility. The size quartiles are calculated over the facility-month observations in the pooled sample. Private and provincial are ownership dummies.

Table 15: Number of Equipment and Facility Size by Production Stage

	(1)	(2)	(3)
Variables	Poisson Sintering Number	Poisson Iron Making Number	Poisson Steel Making Number
logsize	-0.246***	-0.0652*	0.370***
	(0.0342)	(0.0337)	(0.0362)
Private x logsize	0.603***	0.436***	0.133**
	(0.0495)	(0.0458)	(0.0522)
Provincial x logsize	0.508***	0.192***	-0.0426
	(0.0388)	(0.0378)	(0.0403)
Observations	3,440	3,440	3,440
R-squared			
Owner FE	YES	YES	YES
Time FE	YES	YES	YES

Notes: Number is simplified for number of machines/furnaces. Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility. Private and provincial are ownership dummies.

Table 16: Average Equipment Size and Facility Size by Production Stage

	(1)	(2)	(3)
Variables	Sintering logsize	Iron Making logsize	Steel Making logsize
logsize	0.715***	0.750***	0.617***
	(0.0323)	(0.0281)	(0.0204)
Private x logsize	-0.133***	-0.274***	-0.170***
	(0.0466)	(0.0406)	(0.0294)
Provincial x logsize	-0.323***	-0.0850***	-0.00481
	(0.0368)	(0.0321)	(0.0232)
Observations	3,440	3,440	3,440
R-squared	0.337	0.538	0.594
Owner FE	YES	YES	YES
Time FE	YES	YES	YES

Notes: Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility. The size of a sintering machine is measured by its effective areas in m^2; the size of a blast furnace is measured by its effective volumes in m^3; the size of a basic oxygen furnace is measured by its tonnage. Private and provincial are ownership dummies.

Table 17: TFP Correlation by Ownership and by Facility Size

Panel A: TFP correlation between sintering and iron making

		(1) 1st quartile size<90	(3) 2nd quartile [90,160)	(5) 3rd quartile [160,300)	(7) 4th quartile size≥300
Central	Mean	0.005	0.188	0.411	0.396
	Std. Dev	(0.0569)	(0.437)	(0.364)	(0.313)
Provincial	Mean	0.337	0.327	0.422	0.487
	Std. Dev	(0.311)	(0.398)	(0.306)	(0.339)
Private	Mean	0.573	0.535	0.257	0.240
	Std. Dev	(0.163)	(0.294)	(0.400)	

Panel B: TFP correlation between iron making and steel making

		(1) 1st quartile size<90	(3) 2nd quartile [90,160)	(5) 3rd quartile [160,300)	(7) 4th quartile size≥300
Central	Mean	0.058	0.123	0.354	0.308
	Std. Dev	(0.0723)	(0.447)	(0.301)	(0.341)
Provincial	Mean	0.225	0.275	0.164	0.358
	Std. Dev	(0.437	(0.383)	(0.491)	(0.314)
Private	Mean	0.475	0.357	0.178	0.123
	Std. Dev	(0.229)	(0.373)	(0.480)	

Notes: The correlation is calculated over the monthly TFP by integrated facilities. Facility size is measured by the total size of basic oxygen furnaces (steel making) within the facility. The size quartiles are calculated over the facility-month observations in the pooled sample.

Table 18: Total Cost Per Unit of Capacity

Panel A: Iron Making (Blast Furnace)	
Size (m^3)	Unit cost(unit:1,000RMB))
450-1000	360
1000-2500	390
2500-4000	415
>4000	475
Panel B: (Steel Making) Basic Oxygen Furnace	
Size (tonnage)	Unit cost(unit:1,000RMB))
≤50t	2650
60-80	3350
100-120	4150
150-180	4650
200-250	5150
≤300	5750

Notes: Data Source: Chinese Iron and Steel Association. 1 US Dollar = 6.78 RMB.

Table 19: Production Function: Robustness Check

	(1)	(2)
	Steel Making	
	Price-Adjusted GMM	Non-Adjusted GMM
Variables		
l	0.0598***	0.0583***
	(0.0022)	(0.0021)
k	0.117***	0.137***
	(0.0027)	(0.0029)
m	0.870***	0.862***
	(0.0015)	(0.0019)
age	-0.000629***	-0.000522***
	(0.00020)	(0.00017)
Observations	8,514	8,514
Ownership FE	YES	YES
Province FE	YES	YES
Time FE	YES	YES

Note: Standard errors of GMM estimation are computed via bootstrap of 1000 replications.

Table 20: Ownership Premium of Productivity in Steel Making: Robustness Check

	(1)	(2)
Variables	Price-Adjusted logtfp	Non-Adjusted logtfp
Private	0.0746***	0.0576***
	(0.00402)	(0.00379)
Provincial	0.0179***	0.00819***
	(0.00334)	(0.00315)
Constant	-0.0459***	-0.0384***
	(0.00765)	(0.00721)
Observations	8,510	8,510
R-squared	0.056	0.047
Time FE	YES	YES

Notes: Furnaces of central state-owned facilities are the omitted group. Provincial and private are ownership dummies.

Table 21: Output Quality Differences by Ownership

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Sintering Qualification	Sintering Grade Stability	Iron Making Qualification	Iron Making Premium Grade	Steel Making Qualification	Steel Making Secondary
Private	-5.259***	-10.35***	-0.131**	-2.674***	-0.101*	-38.13***
	(0.392)	(0.814)	(0.0586)	(0.769)	(0.0569)	(1.432)
Provincial	-3.233***	-2.195***	0.0819	-10.72***	-0.118**	-24.45***
	(0.340)	(0.707)	(0.0539)	(0.708)	(0.0473)	(1.190)
Constant	95.52***	90.60***	99.86***	70.06***	99.87***	55.36***
	(0.750)	(1.559)	(0.118)	(1.544)	(0.108)	(2.729)
Observations	8,728	8,728	11,837	11,837	8,510	8,510
R-squared	0.024	0.026	0.006	0.031	0.007	0.081
Time FE	YES	YES	YES	YES	YES	YES

Notes: All quality measures are in percentage points. Secondary denotes the share of steel that goes through secondary steel refining and provides an important piece of evidence on the quality of steel.

Table 22: Quality-Adjusted Ownership Premium of Facility-level Productivity

	(1)	(2)
Variables	logtfp	logtfp
Private	0.0622***	0.0571***
	(0.0178)	(0.0185)
Provincial	0.0393**	0.0490***
	(0.0156)	(0.0158)
Constant	-0.0911***	0.120
	(0.0341)	(0.416)
Observations	3,440	3,440
R-squared	0.018	0.050
sinter quality	NO	YES
iron quality	NO	YES
steel quality	NO	YES
Time FE	YES	YES

Notes: Central state-owned facilities are the omitted group. Provincial and private are ownership dummies.

Table 23: Size Classification Criteria

	Annual sales	Employment
Large	≥400 million	≥1,000
Medium	[20 million, 400 million)	[300, 1000)
Small	≤20 million	≤300

Currency unit: RMB

Table 24: Size and Ownership Distribution of Chinese Manufacturing Firms

	(1) State-owned	(2) Collective	(3) Private	(4) HMT	(5) Foreign	(6) Others
1998						
Large	553(48.72)	137(12.07)	5(0.44)	114(10.08)	145(12.78)	181(15.95)
Medium	4,262(55.32)	1,261(16.37)	90(1.17)	565(7.33)	436(5.66)	1,090(14.15)
Small	42,297(30.03)	52,986(37.62)	10,281(7.30)	14,828(10.53)	10,005(7.10)	10,454(7.42)
2007						
Large	607(11.52)	129(2.45)	714(13.55)	797(15.13)	1,312(24.90)	1,710(32.45)
Medium	600(5.61)	475(4.44)	2,327(21.77)	2,046(19.14)	2,644(24.74)	2,597(24.30)
Small	5,755(1.94)	15,475(5.21)	164,675(55.43)	28,654(9.64)	31,037(10.45)	51,494(17.33)

Besides firm number of each category, corresponding percentage points are reported in the parentheses(%).

Table 25: Profitability and Export Performance of Chinese Manufacturing Firms

		1998			2007	
	(1) Large	(2) Medium	(3) Small	(4) Large	(5) Medium	(6) Small
Profitability						
Full Sample	.029	-.062	-.021	.062	.046	.025
SOE	.012	-.113	-.102	.054	.003	-.032
Private	.082	.016	.027	.070	.057	.040
Export						
Full Sample	.178(.257)	.182(.369)	.150(.648)	.261(.321)	.283(.428)	.196(.519)
SOE	.085(.130)	.100(.229)	.036(.379)	.112(.136)	.079(.124)	.039(.190)
Private	.012(.030)	.207(.495)	.129(.718)	.228(.211)	.180(.306)	.128(.418)

Export intensities of firms with positive export values are reported in the parentheses.
profitability = profit/sales
export performance = export/sales

Table 26: Summary Statistics

	(1)	(2)	(3)	(4)	(5)	(6)
	SOEs&Private		SOEs		Private	
Variables	Full sample	Trimmed sample	Full sample	Trimmed sample	Full sample	Trimmed sample
I/K						
Mean	-0.56	0.062	-0.61	-0.032	-0.55	0.092
Median	0.04	0.045	0	0.0002	0.084	0.083
SD	75.96	0.57	111.83	0.50	60.52	0.59
Y/K						
Mean	25.53	9.53	15.11	3.22	28.68	11.36
Median	4.22	4.23	0.97	1.04	5.72	5.63
SD	1724.91	16.29	2595.26	9.36	1355.85	17.36
CF/K						
Mean	1.62	0.51	1.16	0.11	1.76	0.63
Median	0.18	0.18	0.012	0.014	0.25	0.25
SD	125.23	1.19	191.25	0.75	96.87	1.27
DAR						
Mean	0.63	0.60	0.79	0.71	0.58	0.57
Median	0.63	0.62	0.75	0.71	0.59	0.60
SD	4.96	0.28	0.65	0.31	5.66	0.26
COV						
Mean	3.55e+09	0.12	1.54e+10	0.10	10,937.79	0.12
Median	0.02	0.04	0	0.002	0.03	0.04
SD	2.02e+13	0.32	4.21e+13	0.49	7.76e+06	0.25

Trimmed represent samples that are truncated at 1 percentile level at both tails. To keep consistency with previous notations, Y denotes sales, CF cash flow, COV interest coverage ratio and DAR total debt to total asset ratio. I exclude observations with negative capital stocks.

Table 27: Test for Financing Constraints by Ownership

Dependent variable:	(1)	(2)	(3)
$(I/K)_{it}$	SOEs&Private	SOEs	Private
$(I/K)_{i,t-1}$	0.00838	0.168	-0.0344
	(0.0518)	(0.108)	(0.0532)
$(I/K)^2_{i,t-1}$	0.0493	0.0426	0.0354
	(0.0346)	(0.0520)	(0.0361)
$(CF/K)_{i,t-1}$	0.0219***	0.0101**	0.0233***
	(0.00189)	(0.00445)	(0.00209)
$(Y/K)_{i,t-1}$	0.00962***	0.0118***	0.00936***
	(0.000590)	(0.00184)	(0.000594)
$COV_{i,t-1}$	0.0198***	0.00572	0.0304***
	(0.00315)	(0.00435)	(0.00499)
$DAR_{i,t-1}$	0.0731***	0.0343***	0.0830***
	(0.00483)	(0.00982)	(0.00575)
Time dummies	Y	Y	Y
2-digit industry dummies	Y	Y	Y
Ownership dummies	Y	N	N
Observations	368,652	80,851	287,801
Number of firm	144,464	28,268	117,510
F test(p-value)	0	0	0
AR(1) test(p-value)	0	0.000109	0
AR(2) test(p-value)	0.698	0.458	0.637
Hansen Test(p-value)	0.00147	0.00897	0.156

Dataset is trimmed at 1 percentile level at both tails for all the regressors reported in the table. The estimation is by two-step system GMM; 2-digit industry dummies and year dummies are included;ownership dummies are introduced in the full sample regression in column (1). Levels of I/K and $(I/K)^2$ dated at t-3 are used as GMM type instruments for the first-difference equation;first differences of I/K and $(I/K)^2$ dated at t-2 are used as GMM type instruments for the level equation;CF/K, Y/K, COV, DAR dated at t-1 plus time and industry dummies are used as standard instruments(for column (1), ownership dummies are also included). WC-robust standard errors are reported in parentheses for heteroscedasticity adjustment.*** p<0.01, ** p<0.05, * p<0.1

Table 28: Test for Financing Constraints by Ownership and Firm Size

Dependent variable:	(1)	(2)	(3)	(4)
$(I/K)_{it}$	SOEs		Private	
	Large	Medium&Small	Large	Medium&Small
$(I/K)_{i,t-1}$	-0.196	0.117	-0.332	-0.140**
	(0.166)	(0.130)	(0.218)	(0.0612)
$(I/K)^2_{i,t-1}$	0.247	-0.00431	0.400*	-0.0534
	(0.245)	(0.0649)	(0.227)	(0.0486)
$(CF/K)_{i,t-1}$	-0.113	0.00911	-0.0141	0.0318***
	(0.214)	(0.00642)	(0.0515)	(0.00274)
$(Y/K)_{i,t-1}$	0.00494	0.0421***	0.0162**	0.0259***
	(0.0525)	(0.00711)	(0.00739)	(0.00141)
$COV_{i,t-1}$	0.0151	-0.00246	-0.0222	0.0199***
	(0.0298)	(0.00629)	(0.199)	(0.00663)
$DAR_{i,t-1}$	-0.0127	0.0941***	0.0836	0.0900***
	(0.104)	(0.0245)	(0.364)	(0.0102)
Time dummies	Y	Y	Y	Y
2-digit industry dummies	Y	Y	Y	Y
Observations	3,679	77,172	1,553	286,248
Number of firm	1,104	27,620	779	117,164
F test(p-value)	0	0	0	0
AR(1) test(p-value)	0.498	0.000695	0.0138	1.92e-10
AR(2) test(p-value)	0.519	0.433	0.994	0.793
Hansen Test(p-value)	0.300	0.00297	0.119	0.0624

Dataset is trimmed at 1 percentile level at both tails for all the regressors reported in the table. The estimation is by two-step system GMM; 2-digit industry dummies and year dummies are included; size dummies are introduced in the all-size regressions in column (1) and (4). Levels of I/K and $(I/K)^2$ dated at t-3 are used as GMM type instruments for the first-difference equation;first differences of I/K and $(I/K)^2$ dated at t-2 are used as GMM type instruments for the level equation;CF/K, Y/K, COV, DAR dated at t-1 plus time and industry dummies are used as standard instruments(for column (1) and (4), size dummies are also included). WC-robust standard errors are reported in parentheses for heteroscedasticity adjustment.*** p<0.01, ** p<0.05, * p<0.1

Table 29: Test for Financing Constraints by Region

Dependent	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
variable:		East&Coast			Northeast			Middle			West	
$(I/K)_{it}$	SOEs&Private	SOEs	Private	SOEs&Private	SOEs	Private	SOEs&Private	SOEs	Private	SOEs&Private	SOEs	Private
$(I/K)_{i,t-1}$	-0.0270	-0.0251	-0.0435	-0.497***	-0.320	-0.399**	0.164	0.283	0.130	0.0659	0.0148	-0.0709
	(0.0541)	(0.132)	(0.0545)	(0.156)	(0.286)	(0.176)	(0.139)	(0.187)	(0.155)	(0.128)	(0.208)	(0.210)
$(I/K)^2_{i,t-1}$	0.0417	0.0680	0.0378	-0.123**	-0.0769	-0.0440	0.0383	0.0680	0.0558	0.0130	-0.0486	0.0131
	(0.0392)	(0.0763)	(0.0384)	(0.0598)	(0.105)	(0.0740)	(0.0672)	(0.0624)	(0.0814)	(0.0769)	(0.112)	(0.113)
$(CF/K)_{i,t-1}$	0.0212***	0.0161***	0.0215***	0.0161**	0.00346	0.0154*	0.0319***	0.0124	0.0342***	0.0199***	-0.00622	0.0223***
	(0.00226)	(0.00390)	(0.00233)	(0.00689)	(0.0153)	(0.00853)	(0.00518)	(0.00956)	(0.00599)	(0.00568)	(0.0131)	(0.00485)
$(Y/K)_{i,t-1}$	0.00886***	0.00731***	0.00878***	0.00888***	0.0104***	0.00798***	0.0152***	0.0153***	0.0142***	0.0102***	0.0187***	0.00814***
	(0.000677)	(0.00227)	(0.000664)	(0.00149)	(0.00215)	(0.00153)	(0.00176)	(0.00332)	(0.00178)	(0.00150)	(0.00463)	(0.000957)
$COV_{i,t-1}$	0.0226***	0.00557	0.0316***	0.00191	0.00609	0.00538	0.0167**	0.0106	0.0311**	0.0191***	0.0118	0.0269**
	(0.00475)	(0.00702)	(0.00621)	(0.0112)	(0.0162)	(0.0144)	(0.00742)	(0.00816)	(0.0143)	(0.00617)	(0.00726)	(0.0121)
$DAR_{i,t-1}$	0.0788***	0.0223*	0.0862***	0.0740***	0.0434*	0.0960***	0.0681***	0.0476**	0.0743***	0.0471***	0.0134	0.0579***
	(0.00585)	(0.0122)	(0.00658)	(0.0197)	(0.0255)	(0.0248)	(0.0167)	(0.0207)	(0.0196)	(0.0131)	(0.0169)	(0.0172)
Time dummies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2-digit industry dummies	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ownership dummies	Y	N	N	Y	N	N	Y	N	N	Y	N	N
Observations	246,615	34,337	212,278	20,816	7,368	13,448	58,313	20,046	38,267	42,908	19,100	23,808
Number of firm	96,323	11,721	85,163	8,854	2,891	6,104	23,246	7,226	16,405	16,044	6,431	9,839
F test(p-value)	0	0	0	0	0	0	0	0	0	0	0	0
AR(1) test(p-value)	0	0.0772	0	0.00438	0.134	0.0160	3.27e-06	0.000249	5.42e-05	0.000346	0.00209	8.30e-05
AR(2) test(p-value)	0.653	0.600	0.599	0.424	0.327	0.291	0.450	0.462	0.823	0.406	0.393	0.966
Hansen Test(p-value)	0.00573	0.157	0.0803	0.541	0.124	0.198	0.278	0.496	0.275	0.769	0.271	0.790

Dataset is trimmed at 1 percentile level at both tails for all the regressors reported in the table. The estimation is by two-step system GMM; 2-digit industry dummies and year dummies are included;ownership dummies are introduced in the full sample regressions in each region. Levels of I/K and $(I/K)^2$ dated at t-3 are used as GMM type instruments for the first-difference equation;first differences of I/K and $(I/K)^2$ dated at t-2 are used as GMM type instruments for the level equation;CF/K, Y/K, COV, DAR dated at t-1 plus time and industry dummies are used as standard instruments. WC-robust standard errors are reported in parentheses for heteroscedasticity adjustment.*** p<0.01, ** p<0.05, * p<0.1

Table 30: Test for Financing Constraints by High-Tech and Non High-Tech Industry

Dependent variable:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$(I/K)_{it}$	Pooled-sample	High-tech industries			Non high-tech industries		
		SOEs&Private	SOEs	Private	SOEs&Private	SOEs	Private
$(I/K)_{i,t-1}$	0.00861	-0.00825	-0.0732	-0.120	0.0105	0.166	-0.0306
	(0.0517)	(0.165)	(0.0974)	(0.110)	(0.0538)	(0.121)	(0.0555)
$(I/K)^2_{i,t-1}$	0.0500	-0.0218	0.0202	0.0124	0.0491	0.0377	0.0329
	(0.0346)	(0.197)	(0.0960)	(0.104)	(0.0349)	(0.0471)	(0.0367)
$(CF/K)_{i,t-1}$	0.0220***	0.0254**	0.0248*	0.0309**	0.0219***	0.00971**	0.0236***
	(0.00190)	(0.0117)	(0.0135)	(0.0155)	(0.00191)	(0.00467)	(0.00211)
$(Y/K)_{i,t-1}$	0.00947***	0.00851*	0.00605	0.00648**	0.00953***	0.0118***	0.00933***
	(0.000580)	(0.00498)	(0.00401)	(0.00257)	(0.000576)	(0.00176)	(0.000581)
$COV_{i,t-1}$	0.0192***	0.0107	0.0160	-0.0313	0.0197***	0.00530	0.0305***
	(0.00315)	(0.0177)	(0.0170)	(0.0318)	(0.00325)	(0.00459)	(0.00512)
$DAR_{i,t-1}$	0.0748***	0.0102	-0.0527	0.0638	0.0769***	0.0348***	0.0884***
	(0.00478)	(0.0308)	(0.0352)	(0.0394)	(0.00490)	(0.0105)	(0.00580)
Time dummies	Y	Y	Y	Y	Y	Y	Y
High-tech industry dummy	Y	N	N	N	N	N	N
Ownership dummies	Y	Y	N	N	Y	N	N
Observations	368,652	11,918	5,681	6,237	356,734	75,170	281,564
Number of firm	144,464	4,971	2,226	2,829	140,486	26,566	115,142
F test(p-value)	0	0	0.00252	0	0	0	0
AR(1) test(p-value)	0	0.335	0.129	0.192	0	7.52e-05	0
AR(2) test(p-value)	0.686	0.796	0.855	0.877	0.732	0.428	0.753
Hansen Test(p-value)	0.000963	0.720	0.310	0.417	0.00327	0.00978	0.165

Dataset is trimmed at 1 percentile level at both tails for all the regressors reported in the table. The estimation is by two-step system GMM; year dummies are added; high-tech industry dummy is included for the full sample regression in column (1); ownership dummies are included in the regressions in column (1), (2) and (5). Levels of I/K and $(I/K)^2$ dated at t-3 are used as GMM type instruments for the first-difference equation;first differences of I/K and $(I/K)^2$ dated at t-2 are used as GMM type instruments for the level equation;CF/K, Y/K, COV, DAR dated at t-1 plus dummy variables in each regressions are used as standard instruments. WC-robust standard errors are reported in parentheses for heteroscedasticity adjustment.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 31: Test for Financing Constraints in the High-Tech Industries

Dependent variable:	(1)	(2)	(3)	(4)
	SOEs		Private	
$(I/K)_{it}$	Large	Medium&Small	Large	Medium&Small
$(I/K)_{i,t-1}$	0.0146	-0.0834	-0.0675	-0.218**
	(0.0852)	(0.129)	(0.216)	(0.109)
$(I/K)^2_{i,t-1}$	0.137**	0.0799	-0.163	-0.0112
	(0.0535)	(0.0967)	(0.164)	(0.104)
$(CF/K)_{i,t-1}$	-0.0180	0.0193	0.630	0.0217
	(0.202)	(0.0126)	(1.093)	(0.0160)
$(Y/K)_{i,t-1}$	0.0518	0.0215*	0.0254	0.0181***
	(0.0374)	(0.0125)	(0.0211)	(0.00684)
$COV_{i,t-1}$	-0.0882	-0.00224	1.060	-0.0391
	(0.0857)	(0.0228)	(0.929)	(0.0424)
$DAR_{i,t-1}$	0.0318	-0.125**	-1.178	0.0404
	(0.153)	(0.0615)	(1.463)	(0.0642)
Time dummies	Y	Y	Y	Y
Observations	282	5,399	29	6,208
Number of firm	111	2,157	18	2,820
F test(p-value)	1.62e-06	0.0220	0.494	7.17e-09
AR(1) test(p-value)	0.104	0.257	0.769	0.253
AR(2) test(p-value)	0.763	0.431	0.272	0.614
Hansen Test(p-value)	0.204	0.551	0.398	0.155

Dataset is trimmed at 1 percentile level at both tails for all the regressors reported in the table. The estimation is by two-step system GMM;size dummies are introduced in the all-size regressions in column (1) and (4). Levels of I/K and $(I/K)^2$ dated at t-3 are used as GMM type instruments for the first-difference equation;first differences of I/K and $(I/K)^2$ dated at t-2 are used as GMM type instruments for the level equation;CF/K, Y/K, COV, DAR dated at t-1 plus time and industry dummies are used as standard instruments(for column (1) and (4), size dummies are also included). WC-robust standard errors are reported in parentheses for heteroscedasticity adjustment.*** p<0.01, ** p<0.05, * p<0.1

Table 32: Test for Financing Constraints in the Non High-Tech Industries

Dependent variable:	(1)	(2)	(3)	(4)
	SOEs		Private	
$(I/K)_{it}$	Large	Medium&Small	Large	Medium&Small
$(I/K)_{i,t-1}$	-0.0182	-0.222*	-0.188**	-0.274***
	(0.144)	(0.125)	(0.0958)	(0.0653)
$(I/K)^2_{it}$	0.250	0.0442	0.290*	-0.0524
	(0.196)	(0.0713)	(0.164)	(0.0473)
$(CF/K)_{i,t-1}$	-0.0818	0.00735	0.0303	0.0273***
	(0.161)	(0.00512)	(0.0435)	(0.00235)
$(Y/K)_{i,t-1}$	0.00931	0.0250***	0.0193***	0.0216***
	(0.0162)	(0.00460)	(0.00446)	(0.00101)
$COV_{i,t-1}$	0.0132	-0.00189	0.00135	0.0154**
	(0.0260)	(0.00516)	(0.0671)	(0.00626)
$DAR_{i,t-1}$	-0.0398	0.0560***	0.115	0.0714***
	(0.0580)	(0.0176)	(0.0769)	(0.00918)
Time dummies	Y	Y	Y	Y
Observations	3,397	71,773	1,524	280,040
Number of firm	1,013	25,962	761	114,805
F test(p-value)	0.128	0	0	0
AR(1) test(p-value)	0.280	0.0270	0.00496	2.58e-10
AR(2) test(p-value)	0.502	0.0217	0.755	0.0142
Hansen Test(p-value)	0.287	9.58e-07	0.294	2.81e-07

Dataset is trimmed at 1 percentile level at both tails for all the regressors reported in the table. The estimation is by two-step system GMM;size dummies are introduced in the all-size regressions in column (1) and (4). Levels of I/K and $(I/K)^2$ dated at t-3 are used as GMM type instruments for the first-difference equation;first differences of I/K and $(I/K)^2$ dated at t-2 are used as GMM type instruments for the level equation;CF/K, Y/K, COV, DAR dated at t-1 plus time and industry dummies are used as standard instruments(for column (1) and (4), size dummies are also included). WC-robust standard errors are reported in parentheses for heteroscedasticity adjustment.*** p<0.01, ** p<0.05, * p<0.1

APPENDIX

A.1 APPENDIX FOR CHAPTER 1

I describe the $M\&A$ policies in Table A1 and Table A2. And Table A3 and Table A4 illustrate major merger and acquisitions transactions in the Chinese steel industry between 1997 and 2012.

Table A1: M&A Policy

Policy document	Launching agency	Main content
2001 Metallurgy 10th Five Year Plan	The State Economic and Trade Commission	It briefly brought up the efforts in M&A that steel makers should put in. The Plan directs big firms to establish big-scale integrated group, and small firms to aim at production specialization and fulfill local need. However, this policy document doesn't lay out any specific plans about consolidation.
2005 Notice No.35 Steel Industry Development Policy	National Development and Reform Center (NDRC)	It sets specific goals for consolidation: CR10 should be raised to at least 50 percent by 2010 and 70 percent in 2020; it also directs that the steel industry aim to build two giant firms with capacity over 30 million tons and several ones with capacity over 10 million tons. The NDRC particularly promotes M&A and encourages restructuring through shareholding across different ownership. However, no specific guidance for M&A is laid out.
2006 Notice No.1084 Harness total production, eliminate the outdated capacity, accelerate the structural adjustment in the steel industry	NDRC	The NDRC put forward its initiatives of M&A during the 11th Five Years. It encouraged large and competitive steel firms to conduct M&A based on market orientation, assets and resources across ownership and both within and across regions. It instructed that the bureau of finance, social security and treasury should carry out measures to support M&A. The NDRC particularly emphasized the merger initiative of Anshan and Benxi steel, brought up the issue of Shougang （首钢）restructuring and relocation, and launched the plan of merger across the steel firms within Hebei province. Baosteel（宝钢）was also set as a successful example of M&A.
2009 Steel Industry Adjustment and Revitalization Plan for 2009-2011	State Council	The plan laid out M&A goals for several steel enterprises: Set Baosteel（宝钢）, An-Ben（鞍本）and Wugang （武钢）M&A cases as the role models; For the firms already realized M&A, i.e. An-ben （鞍本）, Guangdong （广东钢铁集团）, Guangxi （广西）Hebei（河北）and Shandong（山东）steel groups, promote substantive M&A by achieving uniform management within the groups for both production-supply-sale and human resource-asset; Encourage both within region and cross region merger, including Anben（鞍本）with Pangang（攀钢）and Northeast Special Steel（东北特钢), Baosteel（宝钢）with Baotou（包钢）and Ningbo steel（宁波）Tianjin tube with Tianjin iron, Tianjin steel and Tianjin Metallurgy Taigang （太原） Aim to establish three to five steel giants with steel capacity over 50 million tons and several large firms between 30 million to 50 million tons. The plan emphasized that better institutions for M&A should be built.
2010 Directive No.34 A few comments on accelerating the structural adjustment in the steel industry	State Council	The document required the provincial-level government set up M&A plans and report to the Ministry of Industry and Technology Information for approval. It pointed out that SASSC should adjust annual evaluation goals for SOEs that suffer a periodical worsening performance and a rise in liability ratio due to M&A. Support M&A through project approval, land supply, credit, capital market finance and budget of state-owned asset. Aim to raise CR10 to 60 percent in 2015 from 48.8 percent in 2009. Establish 3-5 internationally competitive steel firms; 6-7 competitive firms.
2010 Notice No. 381 (implement the directives of document no. 34 of the State Council)	Ministry of Industry and Information Technology	It launched guidelines for local governments to report M&A projects.

Table A2: M&A Policy (Continued)

Policy document	Launching agency	Main content
2011 Steel Industry 12th Five Year Plan	Ministry of Industry and Information Technology	The central government particularly encourages the large competitive steel firms to engage in M&A across region and ownership. Push forward the M&A courses for: Angang with Pangang, Bengang and Fujian Sangang, etc; Baosteel with Guangdong, Wugang with Yunnan and Guangxi, Shougang with Jilin, Guizhou and Shanxi, etc. Reinforce the outcomes of M&A in Hebei and Shandong provinces, promote M&A plans for Tangshan Bohai steel （唐山渤海） Taiyuan steel（太原）. Guide Hebei, Jiangsu, Shandong, Shanxi, Henan, Yunnan provinces to engage in M&A.

Table A3: M&A in the Steel Industry

Time (official announcement date)	Description of M&A	Type	Location
The end of 1997	Hunan government merged Hunan Xiangtan steel, Lianyuan steel and Hengyang steel tube	Within region; big SOEs	Hunan
9/8/1997	Handan steel acquired Wuyang steel	Back then, Wuyang was central SOE Handan was big local SOE	Hebei
1997	Handan acquired Hengshui steel tube	Within region SOEs	Hebei
10/1998	Taiyuan steel acquired Lin steel (临钢)	Within region SOEs	Shanxi
11/17/1998	Baoshan steel acquired Shanghai metallurgy share holding company(zero price acquisition) and Shanghai Meishan steel and renamed the new company Shanghai Baosteel	Within region; between central and local SOE	Shanghai
02/2000	Jiangsu merged Huai steel with Nanjing steel (Huai transfered state assets to Nanjing steel); the two were split up in 2005	Within region, big SOEs	Jiangsu
03/2000	Pan steel acquired Chengdu seamless tube	Within region, between big local SOE and other local firms	Sichuan
5/24/2002	Pan steel acquired Chengdu steel (Pangang merged its seamless company with Chengdu steel and established a new Chengdu steel Co., Ltd.)	Within region; between local SOE and non state	Sichuan
6/30/2004	Pan steel acquired Sichuang great wall special steel Co., Ltd.	Within region; between local SOE and non state	Sichuan
2004	Zhongxin Taifu (中信泰富) acquired Hubei Daye special steel	Cross region; Hong Kong and SOE	Hubei
4/30/2005	Wuhan steel acquired Echeng steel	Within region; central and big local SOE	Hubei
8/16/2005	Anshan steel merged with Benxi steel; established Anben steel (but in fact they operated independently even after the merger)	Within region; central and provincial SOE	Liaoning
11/2005	Jianlong acquired New Fushun steel (60%)	Cross region; big private and local SOE	Beijing&Liaoning
01/2006	New Wuan was established by merging 14 private steel firms	Within region; private	Hebei
2/28/2006	Hebei government merged Tangshan steel, Xuanhua steel and Chengde steel; established the new Tang steel group	Within region; big local SOEs	Hebei
5/12/2006	Ma' anshan steel acquired Hefei steel (71%)	Within region; big local SOEs	Hefei
06/2006	Zhongxin Taifu (中信泰富) acquired 80% of the shares of Shijiazhuang steel	Cross region; Hong Kong and SOE; Shijiazhuang steel changed ownership to joint-venture	Hebei
12/2006	Sha steel acquired Huai steel (64.4%)	Within region; big private and SOE	Jiangsu
4/28/2007	Baosteel acquired Xinjiang Bayi Steel	Cross region; central firm and big local SOE	Shanghai Xinjiang
1/8/2007	Wuhan steel acquired Kunmin steel	Cross region; central and big local SOE	Hubei&Yunnan
8/9/2007	Hunan Hualing acquired Jiangsu Xi steel (55% of its share); jointly owned with the central firm Huarun (45%)	Cross region; big SOE and (private)	Hunan and Jiangsu
12/2007	Sha steel acquired Jiangsu Yonglian steel	Within region; big private	Jiangsu
01/2008	Sha steel acquired Changzhou Xinrui special steel (51%)	Within region; big private	Jiangsu
1/8/2008	Pan steel acquired Xichang New Steel Co,.Ltd (acquired 66 percent of its shares)	Within region; big SOEs	Shandong
03/2008	Shandong steel acquired Zhangdian steel as its wholly-owned subsidiary at its establishment	Within region; big SOEs	Shandong

Table A4: M&A in the Steel Industry: Continued

Time (official announcement date)	Description of M&A	Type	Location
6/28/2008	Baosteel acquired Guangdong steel	Cross region; central and provincial SOE (acquired 80% of its shares via cash)	Shanghai&Shandong
6/30/2008	Hebei government merged Tang steel and Handan steel;	Within region; big SOEs established the new Hebei steel group	Hebei
9/3/2008	Wuhan steel acquired Liuzhou steel; established a new firm Guangxi steel co., Ltd (Wugang acquired 80% of its share via cash)	Cross region; central and provincial SOE	Hubei&Guangxi
12/12/2008	Shougang acquired Shuicheng steel to 51.65%) (increased its shareholding from 34.56% (4/29/2005)	Cross region; SOEs	Beijing (Hebei)&Guizhou
3/1/2009	Baosteel acquired Ningbo Steel (holding 56.12% of its shares; Hangzhou steel is holding 34% of the shares)	Cross region; central firm and local firm	Shanghai&Zhejiang
05/2009	Shanghai Fuxing high-tech acquired Nanjing steel	Cross region; private and SOE	Shanghai&Jiangsu
8/8/2009	Shougang acquired Shanxi Changye steel (90% of its share)	Cross region; SOEs	Beijing (Hebei)&Guizhou
8/12/2009	Shougang acquired Gui steel (Guiyang special steel & Guiyang steel)	Cross region; SOEs	Beijing (Hebei)&Guizhou
8/18/2009	Shougang acquired Yili Xinyuan （伊犁兴源实业）; established the new Shougang Yili steel	Cross region; SOE and private	Beijing(Hebei)&Xinjiang
08/2009	Shaanxi government merged Shaanxi Longmen and Shaanxi Hanzhong; established the new Shaanxin steel group	Within region; SOEs	Shaanxi
1/24/2010	Sha steel acquired Jiangsu Xixing special steel	Within region; private	Jiangsu
03/2010	Hebei steel re-acquired Shijiazhuang steel	Shijiazhuang steel changed its ownership from joint-venture back to SOE.	Hebei
4/27/2010	Ma'anshan steel acquired Changjiang steel (55%)	Within region; SOE and private	Anhui
05/2010	Anshan steel acquired Pan steel; established a new group named An steel group corporation.	Cross region; central and provincial SOE	Liaoning&Sichuan
6/8/2010	Benxi steel merged with Beitai steel; established a new Ben steel group corporation	Within region; SOEs	Liaoning
07/2010	Tianjin government merged Tianjin Steel Tube, Tianjin steel group, Tianjin Tianye, Metallurgy group and Tianjin Metallurgy Group; established the new Bohai Steel Group	Within region; SOEs	Tianjin
12/9/2010	Baosteel acquired Fujian Desheng Nickle	Cross region; central and local ; vertical merger	Shanghai&Fujian
2011	Henan Anyang steel (河南安阳) acquired Henan Fengbao special steel, Anyang Yaxin Steel,Anyang Xinpu Steel	Within region; SOE and private new mode of acquisition between SOE and private through gradual buy-in	Henan
3/1/2012	Shougang acquired Tonghua steel	Cross region; SOEs	Beijing(Hebei);Jilin
4/18/2012	Baosteel acquired Guangdong Shaogang	Cross region; central and provincial SOE	Shanghai&Guangdong

A.2 APPENDIX FOR CHAPTER 2

A.2.1 Linkage of Integrated Facilities

Our data set reports information for each individual stage of integrated facilities but does not directly link machines/furnaces across stages within firms. The majority of firms in our sample operate multiple equipment in each production stage, therefore a firm could run several integrated facilities. In practice, within firms, integrated facilities are independent of each other. A subset of equipment in the upstream supplies intermediate materials only to certain equipment in the downstream. The supply chain remains fixed as the linkage is determined at the design stage to ensure that production capacity of each individual stage should be in proportion to its immediate downstream. In the process of production, sintering plants deliver sinter directly to blast furnaces that are tied to them through leather belts. The iron making plants, in turn, are in charge of transporting smelted iron to the downstream basic oxygen furnaces right after the iron leaves the blast furnaces. Production of each stage are strictly aligned with one another, and output of each stage is transferred in time to the downstream stages. Based on these features of the vertically-integrated firms, production of two consecutive stages in the same periods should be a good criterion to identify linkage across stages, and we can ignore inventory and also dynamic decisions, etc. As an industry convention, the ratio of iron production to steel production is roughly 1 and that of sinter to iron is 1.25.[1] The scatter plots in figure A1 and A2 provide convincing evidence to justify the linkage that we identified.

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[1] The information on the criterion of internal linkage in the steel value chain comes from a phone interview with an engineer at the Design & Research Institute of Wuhan Iron & Steel Group in July 2016.

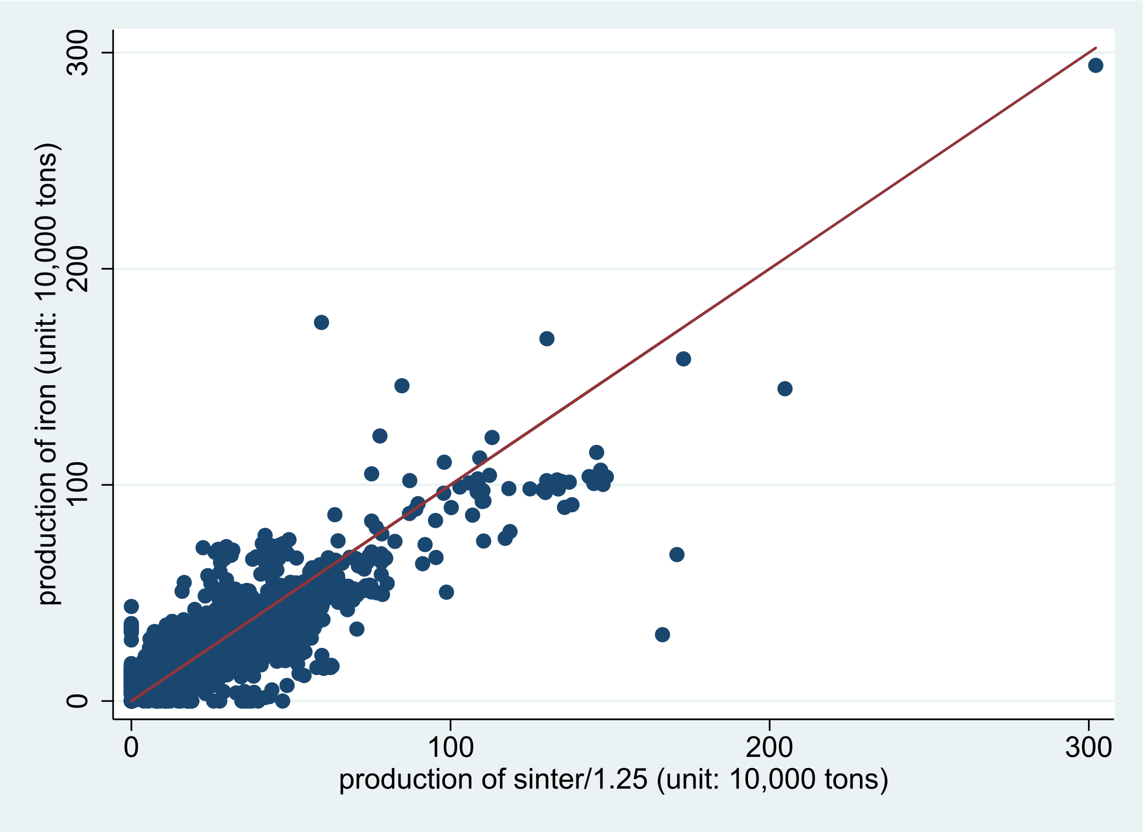

Figure A1: Linkage: Sintering-Iron Making

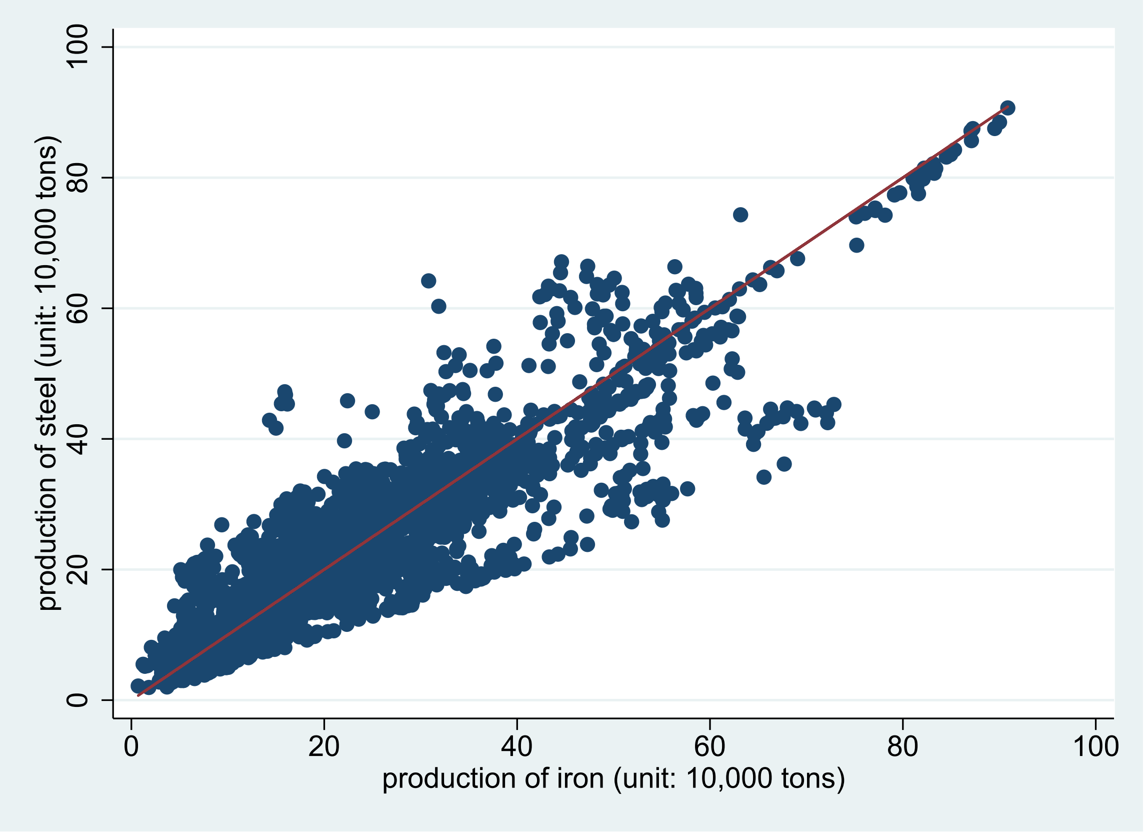

Figure A2: Linkage: Iron Making-Steel Making

A.2.2 Algorithm

As discussed in Ackerberg et al. (2015), the GMM estimation approach that we take to the finite samples is subject to the convergence of local minimums. To address this concern, we follow a flexible algorithm to set initial values for the objective function. We start from the OLS estimates $\theta_{ols} \equiv (\alpha_{ols}, \beta_{ols}, \gamma_{ols})$ (estimated elasticities for labor, capita and material input respectively), and then we draw 100 random vectors $v \equiv (v_l, v_k, v_r)$ from a uniform distribution ranged from 0.8 to 1.2.[2] We give perturbation to the OLS estimates using the random vectors v and make 100 sets of initial values at $\theta_p \equiv \theta_{ols} \cdot v'$, $p = 1, 2, ..., 100$. For each set of initial values, we obtain an optimal $\hat{\theta}_p$, and we value the objective function using $\hat{\theta}_p$. Finally we pick our estimates of $\tilde{\theta}$ from the minimal values of the objective functions using these 100 different sets of initial values.[3]

A.2.3 Nature of Internal Configuration: a Heuristic Model

We abstract here from decisions on total investment in production capacity. That is, we take investment in production capacity as given, and analyze firms' choice with respect to the size of equipment to achieve this goal. A simple example illustrates the firms' problem.

A firm plans to increase its iron making capacity by $1000m^3$.[4] It has two options, i.e. to build a single $1000m^3$ furnace (option 1) or to build two identical $500m^3$ furnaces (option 2). Installation takes one period to realize and production takes place in period 2. Without loss of generality, we restrict our discussion to two periods. The firm faces uncertainty in demand in period 2, i.e., with probability p, it will face a booming market with strong demand, which we denote a high state (H), and with probability $1 - p$ a downturn with sluggish demand, which we denote a low state (L).

- Payoff

  The payoff of option 1 (2) is $\pi_{1H}(\pi_{2H})$ in H state and $\pi_{1L}(\pi_{2L})$ in L state. As indicated by our empirical analysis, iron making displays increasing returns to scale. Hence, the economies of scale implies that $\pi_{1H} > \pi_{2H}$. In addition, production flexibility of smaller furnaces in the low state implies that $\pi_{2L} > \pi_{1L}$.

- Investment cost

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[2] We relax the range to (0.7,1.3) and (0.9,1.1) too, and obtained robust estimates.

[3] Ideally, one can expand the number of initial-value sets for robustness check. In our case, the convergence is reached among these 100 sets of values.

[4] In practice, firms make capacity decisions in terms of m^3 instead of tonnage. However, the production capacity in terms of tonnage of two $500m^3$ is not necessarily equal to that of a single $1000m^3$.

We discussed in section 5.1 that investment costs per unit of capacity (c) increase with furnace size, i.e. $c_1 > c_2$. Thereby the total investment cost under option 1 is higher than that under option 2, $f_1 = 1000 * c_1 > f_2 = 500 * 2 * c_2$.

- Expected payoffs under two options

$$v_1 = p\pi_{1H} + (1-p)\pi_{1L} - f_1$$
$$v_2 = p\pi_{2H} + (1-p)\pi_{2L} - f_2$$

The firm's optimal internal configuration realizes the highest payoff. The firm chooses to build a $1000m^3$ furnace if and only if the following condition is satisfied:

$$\frac{\pi_{2L} - \pi_{1L} + f_1 - f_2}{\pi_{2L} - \pi_{1L} + \pi_{1H} - \pi_{2H}} < p \tag{A1}$$

Intuitively, if the benefit of economies of scale is large enough to offset the higher cost in building a larger furnace, and the probability of a high state is high, then it is optimal for the firm to build a single plant instead of building two smaller plants.

In practice, firms may face various constraints that affect their decisions.

- Regulatory constraints

  The regulatory constraints that firms face building larger plants could be translated into an additional cost (E) to the regular investment cost, so the total investment cost becomes $\tilde{f}_1 = f_1 + E$. Other things equal, the LHS of equation (A1) increases to $\frac{\pi_{2L}-\pi_{1L}+\tilde{f}_1-f_2}{\pi_{2L}-\pi_{1L}+\pi_{1H}-\pi_{2H}}$, which may induce the firm to install two $500m^3$ furnaces instead.
- Capital constraints

  Credit constraints that firms face create a wedge ($\tau > 1$) between the per unit investment costs of constrained and the unconstrained firms, which leads to an increase in the differences in the total investment costs under two investment options. That is, $\tilde{f}_1 - \tilde{f}_2 = 1000 * \tau * (c_1 - c_2) > f_1 - f_2$, which in turns drives up the LHS of equation (A1). Other things equal, firms are more likely to install two $500m^3$ furnaces.
- Human capital constraints

  The lack of human capital and capable managers likely prevents larger plants from achieving their full production potential, thereby lowering the benefits of economies of scale. So a firm facing human capital constraints has a lower $\pi_{1H} - \pi_{2H}$, which increases the LHS of equation (A1), and thereby increasing the likelihood it builds two $500m^3$ furnaces.

- Raw material constraints

  Smaller furnaces are more flexible in the quality of their inputs they can use. This is a different kind of flexibility than being cheaper to start-up/shutdown in the face of changing demand conditions. Raw material constraints can be reflected in equation (A1) in various ways. For example, in a high state, the market may be short of good quality iron ore. In this case, other things equal, a two $500m^3$ can even do better than a $1000m^3$ furnace. When a firm is constrained in their access to higher quality raw materials, the flexibility of the smaller furnaces in raw materials can (partially) offset the disadvantage of diseconomies of scale, help close the gap between π_{1H} and π_{2H}, and result in an increase in the LHS of equation (A1). In short, a firm facing raw material constraints is more likely to install two $500m^3$ furnaces.

A.3 APPENDIX FOR CHAPTER 3

A.3.1 Definition of SOE

In Chapter 3, I follow Jefferson et al. (2003) and Brandt et al. (2012) to categorize ownership by a firm's registration type. As to SOEs, as indicated by Table A5, firms that are registered as state-owned enterprises, state-owned jointly operated enterprises and wholly state-owned companies are defined as SOEs throughout the analysis. However, this definition has its flaws as it may omit firms that are registered as other limited liability (159) and shareholding limited (160) but are in reality controlled by the state. To examine the importance of the SOEs in the "Other domestic" category disguised by modern corporate governance, I identify firms in type 159 and 160 as "disguised" SOEs if state capital of the firms accounts for majority shares. Table A6 reports the number and the gross value of industrial output (GVIO) shares of SOEs and "disguised" SOEs respectively.

The "disguised" SOEs contributed to 4.1% of GVIO in the manufacturing industries in 1998, whereas the share increased to 4.9% in 2007. On the contrary, the GVIO share of the SOEs by registration type dropped dramatically from 39.2% to 8.5%. The two opposing patterns indicate the increasing role the "disguised" SOEs plays in the state sector. In the smelting and pressing of ferrous metals industry, or broadly defined steel industry, the "disguised" SOEs play a more significant role compared with the average manufacturing industries, as the GVIO share amounted to 10.1% in the industry in 2007. In Chapter 3, the inclusion of the "disguised" SOEs does not affect the main conclusion. In addition, our sample that Chapter 2 draws on already incorporates the "disguised" SOEs.

Table A5: Ownership Classification

Code	Ownership category
State-owned	
110	State-owned enterprises
141	State-owned jointly operated enterprises
151	Wholley state-owned companies
Collective-owned	
120	Collective-owned enterprises
130	Shareholding cooperatives
142	Collective jointly operated enterprises
HMT-owned	
210	Overseas joint ventures
220	Overseas cooperatives
230	Overseas wholly owned enterprises
240	Overseas shareholding limited companies
Foreign-owned	
310	Foreign joint ventures
320	Foreign cooperatives
330	Foreign wholly owned enterprises
340	Foreign shareholding limited companies
Private	
171	Private wholly owned enterprises
172	Private-cooperative enterprises
173	Private limited liability companies
174	Private shareholding companies
Other domestic	
159	Other limited liability companies
160	Shareholding limited companies
143	State-collective jointly operated enterprises
149	Other jointly operated enterprises
190	Other enterprises

Source: Jefferson et al. (2003) Appendix.

Table A6: SOEs and Disguised SOEs

	Total Manufacturing Industries			
	1998		2007	
	(1) Firm number	(2) GVIO share	(3) Firm number	(4) GVIO share
SOEs	47,104	39.20%	6,962	8.50%
Disguised SOEs	2,703	4.10%	2,345	4.90%
	Smelting And Pressing Of Ferrous Metals			
	1998		2007	
	(1) Firm number	(2) GVIO share	(3) Firm number	(4) GVIO share
SOEs	792	64.20%	156	22.60%
Disguised SOEs	50	5.10%	57	10.10%

Table A7: 2-Digit Industry Classification

Code	Industry
13	Agricultural and Sideline Foods Processing
14	Food Production
15	Beverage Production
16	Tobacco Products Processing
17	Textile Industry
18	Clothes, Shoes and Hat Manufacture
19	Leather, Furs, Down and Related Products
20	Timber Processing, Bamboo, Cane, Palm Fiber and Straw Products
21	Furniture Manufacturing
22	Papermaking and Paper Products
23	Priting and Record Medium Reproduction
24	Cultural, Educational and Sports Articles Production
25	Petroleum Processing, Coking and Nuclear Fuel Processing
26	Raw Chemical Material & Chemical Products
27	Medical and Pharmaceutical Products
28	Chemical Fiber
29	Rubber Products
30	Plastic Products
31	Nonmetal Mineral Products
32	Smelting & Pressing of Ferrous Metals
33	Smelting & Pressing of Non-ferrous Metals
34	Metal Products
35	Ordinary Machinery Manufacturing
36	Special Equipment Manufacturing
37	Transport Equipment Manufacturing
39	Electric Machines and Apparatuses Manufacturing
40	Communications Equipment, Computer and Other Electronic Equipment Manufacturing
41	Instruments, Meters, Cultural and Office Machinery Manufacture
42	Craftwork and Other Manufactures
43	Waste Resources and Old Material Recycling and Processing

Source: China Data Online. http://chinadataonline.org/member/hyn/

Table A8: High-tech Industry Classification

Industry	Code
Nuclear Fuel Processing	253
Informational Chemical Products	2665
Medical and Pharmaceutical Products	27
Chemical Medicine Manufacture	271+272
Biological and Biochemical Products	276
Sanitation Materials and Medical Articles	277
Aerospace and Aeronautic Equipment	376
Aeroplane Manufacture and Repair	3761
Aerospace Equipment	3762
Other Flying Equipment	3769
Electronic and Communications Equipment Manufacturing	40-404
Communications Equipment	401
Communications Transmitting Equipment	4011
Communications Exchange Equipment	4012
Communications End-equipment	4013
Mobile Communications and End Equipment	4014
Radar and Set Equipment	402
Broadcasting and TV Equipment	403
Electronic Parts	405
Electric Vacuum Parts	4051
Semiconductor Products	4052
Electronic Parts	4053
Photoelectron Parts and other Electronic Parts	4059
Electronic Components	406
Home Audio-Visual Equipment	407
Other Electronic Equipment	409
Electronic Computer and Office Machinery Manufacture	404+4154+4155
Integrated Computer	4041
Computer Net Equipment	4042
Computer Peripheral	4043
Office Machinery Equipment	4154+4155
Medical Treatment Instruments, Equipment Apparatuses, Instruments and Meters Manufacturing	368+411+412+4141+419
Medical Treatment Instruments and Equipment Apparatuses	368
Instruments and Meters Manufacturing	411+412+4141+419

The classification includes manufacturing firms only.
Source: The Chinese National Bureau of Statistics.
*www.stats.gov.cn/tjbz/t*20061123_402369836.*htm*

Table A9: Region Classification

Region	Provinces, Municipalities or Autonomous Regions
East	Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian Shandong, Guangdong, Hainan
Northeast	Liaoning, Jilin, Heilongjiang
Middle	Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan
West	Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Xizang Shaanxi,Gansu, Qinghai, Ningxia, Xinjiang

Source: The Chinese National Bureau of Statistics.
$www.stats.gov.cn/tjzs/t$20110613_402731597$.htm$

Figure A3: Map of People's Republic of China

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