THE INFLUENCE OF OPENNESS TO WORLD TRADE AND POLICIES FOR TECHNOLOGY DIFFUSION IN CHINESE STATE-OWNED ENTERPRISES

A Thesis in

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ABSTRACT

The previous literature shows the efforts of the Chinese government to decentralize property rights have the potential to influence the diffusion of continuous casting technology in China’s steel industry. However, it is hard to fully explain the variations in the diffusion of continuous casting technology among Chinese steel firms based entirely on this institutional factor of decentralization. Instead, it is necessary to consider more recent policies, such as the China Western Region Development program and China’s accession to the World Trade Organization (WTO), both of which occurred in the first decade of the 21st century. It is assumed that these factors are capable of motivating steel firms to overcome institutional and technical barriers to installing continuous casting equipment more rapidly than in the period before those two factors came into play. The current study explored the influence of certain market and institutional factors on state-owned enterprises’ (firm level) diffusion speed of continuous casting technology in China during the period 1985–2009. We found that these influential factors matter in different ways based on different periods and regions in terms of continuous casting technology diffusion among Chinese steel firms. In particular, compared to the period before the 2000s, governmental supervision and intervention during the first decade of the 21st century accelerated the rate at which firms adopted new technology and increased firms’ co-movement with market factors thereafter. The government’s interventions such as the China’s Western Region Development program benefit and motivate steel firms in the Western provinces to diffuse continuous casting technology appropriately; for example, Western firms are more willing than non-western firms to replace outdated ingot casting technology by continuous casting technology; Western firms are more motivated to produce sheets and slabs of steel via continuous casting methods than non-western firms are. Although the main point of the China’s Western Region Development program was to help under-developed western areas to become more efficient and productive by establishing large firms, substantial disparities in terms of the adoption of continuous casting technology between large-scale western and non-western firms still exist. Our findings suggest that the government should focus on supporting the adoption of new technology rather than on encouraging firms to grow in terms of scale. Furthermore, even though China’s Western Region Development policy constituted a great effort to expand the investment budget for Western firms, this growth in the investment budget of western firms did not motivate those firms to diffuse continuous casting technology more rapidly. China’s accession to the WTO is also proving to be a factor capable of motivating steel firms, especially old steel firms and firms that produce sheets and slabs of steel, to meet the challenge of using technically sophisticated continuous casting technology. Overall, despite their close association with central government, former “key” firms became more sensitive to the market after China’s accession to the WTO and consequently adjusted their strategies more rapidly according to market conditions. In summary, China’s accession to the WTO appears to be motivating the country’s steel firms to overcome the institutional and technical barriers to installing continuous casting technology and to take action in this regard more rapidly than during the pre-WTO period. Without using a specific variable to measure the direct effects of WTO accession on the diffusion of continuous casting technology, all the conclusions were drawn based on testing whether other influential factors had different effects depending on whether the pre-WTO period or the post-WTO period is considered.
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Chapter 1

Introduction
1.1 Research question to address

Since the Chinese government initiated market reforms in 1979, the country’s state-owned enterprises have adopted technology in an effort to improve efficiency to different extents and at varying rates. Their efforts to do so are based not only on the government’s attempts to influence firms’ management structure but also on other institutional factors such as regional effects and openness to the world trade. Fisher-Vanden (2003) shows that the decentralizing enterprises' supervision authority from the central government to local governments playing a crucial role in state-owned firms’ adoption of new technology. In addition, compared with centrally controlled steel firms, locally controlled firms now have more autonomy in responding to market forces and thus have the potential to improve their efficiency, and, therefore, they are more apt to adopt technology for this purpose. This is so, even though firms that are centrally controlled continue to have better access to updated technology thanks to their closer relationship to the central government. However, it is still unknown whether China’s accession to the WTO and regional effects, i.e., unbalanced regional development, also influences the adoption of technology at the firm level. The Chinese government sees its market reforms as a way to improve firms’ efficiency; however, China’s comparative inefficiency in comparison with global competition and its unbalanced economic development should be considered. These are important issues for policy makers and researchers to understand and address, as the present study offers evidence to suggest that these two factors influence technology adoption and innovation in Chinese steel firms.

1.1.1 Regional development disparities in China

Since China initiated market reforms in 1979, its soaring economy has shown extraordinary growth at an average rate of over 10% annually, making China the second largest economy in the world in 2011. However, China’s GNI (Gross National Income) per capita in 2010 is US$3,620 (current), which is still far below the world average of US$8,722 (current) (World Bank,
Studies show that the income disparities between the undeveloped western regions of China and the developed coastal regions appear to be large. Drawing on data from 1952 to 2000, Keng (2006) demonstrated that the extent of regional economic disparities in China appears to be substantially larger than in developed countries such as Japan and the US. The residents’ income per capita in coastal areas such as Shanghai has risen to match the income per capita of medium-developed countries. On the other hand, though, some hinterland and western regions such as Gansu have barely met the income per capita of low-income countries, the income disparities between rich and poor regions are only growing larger. In Table 1-1, the difference between urban residents’ per capita disposable income between Shanghai and Gansu is shown. The ratio of the province with the highest, Shanghai, over the province with the lowest, Gansu, per capita disposable income of urban residents is as follows: 1.65 in 1985, 2.15 in 1993, 2.38 in 2000, and 2.42 in 2009. It is evident that the ratio is increasing, which suggests a growing income gap in China.

<table>
<thead>
<tr>
<th>Year Region</th>
<th>1985</th>
<th>1993</th>
<th>2000</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai</td>
<td>1075.00</td>
<td>4297.33</td>
<td>11718.01</td>
<td>28837.80</td>
</tr>
<tr>
<td>Gansu</td>
<td>650.00</td>
<td>2002.50</td>
<td>4916.25</td>
<td>11929.80</td>
</tr>
<tr>
<td>Ratio</td>
<td>1.65</td>
<td>2.15</td>
<td>2.38</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Unit: current RMB Yuan
Source: MacroChina

In addition to the low per capita income of residents in the comparatively undeveloped regions in China, the absorption of new technology in these regions continues to lag behind that in developed coastal areas. Wu et al. (2003) document that the substantially under-developed western provinces such as Chongqing, Guizhou, Ningxia, Guangxi, Shaanxi, Qinghai, Xinjiang, and Tibet are relatively less developed in terms of technological capabilities. After 2000, the regional technology adoption gap remained substantial. In a later study, comparing the eastern, central, and western areas, Wang et al. (2012) showed that in particular the western areas are failing to keep up with the other regions in
adopting the new technologies necessary to improving efficiency. Therefore, western areas have a long way to go in order to implement energy-efficient technology always achieved in the eastern coastal areas. The Chinese government has established a number of policies designed to prevent these regional disparities from continuing to expand, and these are discussed in detail below.

1.1.2 World competition faced by Chinese firms

When China joined the World Trade Organization (WTO) in 2001, its access to world trade brought both benefits and challenges to Chinese firms from the world market. Chinese firms have been able to sell their products in an environment of fewer international trade barriers; for example, high import tariffs and policy restrictions on China’s goods should be eliminated in other WTO member countries. As a result, China’s average annual growth rate of total exportswas 21.3% over the period 2001 to 2010 compared to a rate of 15.0% over the period 1992 to 2000 (World Bank, 2012b). Further, China is currently the second largest importer in the world. With the gradual liberalization of trade especially after China joined the WTO, the average annual growth rate of total imports was 21.0% over the period 2001 to 2010 compared to a rate of 14.3% over the period 1992 to 2000 (World Bank, 2012c). The main component boosting high imports is the increasing domestic demand for high-quality products. We can take look at China’s steel and iron industry as an example. Although China became the largest steel and iron producer in the world, the country remains a big iron and steel importer. In 2009, China’s crude steel output reached 567.8 million tons growing at an annual rate of 13.5%, whereas China imported 17.6 million tons of steel growing at an annual rate of 14.6%. China’s steel production reached 630 million tons in 2010, and yet the country still imported about 16 million tons of high-quality and value-added products (Zhou, 2011). China supplies high amounts of labor and natural resource but manufactures low-quality products. Meanwhile, the increasing demand for high-quality and value-added steel shows that the country is weak in terms of its ability to produce high-quality products in the context of world trade, and therefore is forced to import the products.
China has recognized that in order to compete with the world’s advanced-level producers; it must address its energy inefficiency in the industrial sector. Overall, by reducing its energy intensity, China’s industrial sector will reduce costs and become more competitive in the world market. Although the Chinese government tried numerous policies from around 1990 to the end of the 2000, the country’s energy intensity failed to meet the world’s best practice. Figure 1-1 shows the total energy use (kg of oil equivalent) per $1,000 GDP for China, India, the United States, and Japan as well as the world average. We can see a drop in energy intensity for China in this period, but it is still far behind developed countries such as the US and Japan. India, an important competitor of China in world trade, has achieved the world’s average level energy intensity, which China was not able to achieve. There is plenty of room for China to improve its energy intensity.

**Figure 1-1 Countries’ energy intensity per GDP in 1992 to 2009**

*Unit: Energy use (kg of oil equivalent) per $1,000 GDP (constant 2005 PPP)*

*Source: World Bank, 2012d*
1.2 Background

1.2.1 Review of China’s steel industry

As shown in Figure 1-2, China surpassed Japan to become the largest producer of crude steel in the world from 1996 onwards. Compared to the world’s other big steel producers, the output growth rate of steel production was rapid, especially after 2000. Thus, China’s steel industry is a good example for researching energy intensity. The iron and steel industry consumed over 13.6% of total primary energy in 2006 (Zhang et al., 2010), which is probably the most extreme example of an energy-intensive industrial sector. China’s steel industry is also making marked progress in terms of energy intensity. Comprehensive energy consumption (kilograms of standard coal) per ton of steel dropped from 920 kgce/t in 2000 to 630 kgce/t in 2008. Compared to the world advanced level of 587 kgce/t in 2008 (Wang, 2010), however, China remains relatively inefficient in terms of energy use. To take another example from Table 1-2, compared to the world most energy-efficient countries, the average coke consumption per ton of crude steel is much higher in China. According to China Iron and Steel Association (2008), in 2007, China’s total crude steel production reached a new milestone, namely 489,288 thousand metric tons, which accounted for 36% of the world’s steel production. 

Source: World Steel Association, 2012
However, in the same year, China was responsible for half the carbon dioxide emissions of the steel industry worldwide (Hong et al, 2010).

**Table 1-2 Coke consumption per ton of crude steel output (unit: kg)**

<table>
<thead>
<tr>
<th>Country</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>740</td>
<td>720</td>
<td>710</td>
</tr>
<tr>
<td>Japan</td>
<td>380</td>
<td>380</td>
<td>420</td>
</tr>
<tr>
<td>US</td>
<td>200</td>
<td>170</td>
<td>170</td>
</tr>
</tbody>
</table>


China accounted for 46.69% of the world’s crude steel output in 2009 (World Steel Association, 2012). It will be hard for China to maintain such large-scale production, however, if the country continues to depend on exporting low-quality products. In addition, the domestic demand for high-quality and high value-added steel is increasing, so that given China’s WTO membership, more foreign competitors are entering the domestic steel market. China also has become the largest steel importer (22 million tons of crude steel) in 2009 (World Steel Association, 2012). Hence, it is not a good strategy for the Chinese steel industry to maintain its large international market share by producing an overabundance of low-quality and low-value-added steel. Past studies, which emphasized the importance of adopting technology, have shed light on the ways in which China could produce high-quality steel (Fisher-Vanden et al., 2009). The next section focuses on China’s continuous casting technology, which can both improve product quality and reduce energy intensity (Fisher-Vanden, 2003; Fisher-Vanden et al., 2009).
1.2.2 Diffusion of continuous casting in China’s steel industry

In this section, we consider a specific advanced casting technology: continuous casting in crude steel production. In general, steel casting technology includes either ingot processes or continuous processes. In the continuous casting process, a container of molten steel is lifted up and from a hole in the bottom of the container the fluid steel is poured into the casting machine to solidify. This casting machine shapes and cuts the fluid steel as required according to a continuous process. The continuous casting machine directly shapes the fluid steel into slabs, blooms, or billets using a simple step-by-step process, which is a more advanced alternative to the traditional ingot casting method. In the ingot casting method, molten steel is first poured into the ingot molds to solidify and then the molds are reheated in a soak process. After that, in contrast to the continuous casting process, an additional primary rolling process is needed to roll the ingots in order to produce the slabs, blooms, or billets required. Comparing to traditional ingot casting process, the continuous casting technology can save the energy significantly by skipping the reheating process in soak process and primary rolling process. Studies have found that continuous casting as an alternative to the old ingot casting method can significantly save energy consumption. Price et al., (2001) found that compared to traditional ingot casting, continuous casting reduced energy consumption by approximately 90%. Although China’s steel industry has a long way to go before it joins the ranks of the countries that are producing steel efficiently, we can see that China is taking steps to becoming more energy-efficient, by, for example, installing continuous casting technology equipment (Wang, 2007). By 2002, there were 22 steel plants in the largest steel producer- Shanghai Baoshan Iron and Steel Group had adopted continuous casting technology in China. There were 11 steel plants that had adopted continuous casting technology on average in top 5 largest steel firms (Concast Standard, 2002). In China, continuous casting output as a percentage of total steel output rose from around 10.1% of total steel production in 1985 to 99.1% in 2009 (World Steel Association, various years). As discussed in the
previous section, many studies have emphasized the necessity for firms to adopt advanced technologies, for instance, continuous casting, in order to improve production quality. We conclude that continuous casting not only brings results in terms of energy saving, it is also the key to improving production quality. Figure 1-3 shows the continuous casting ratio in the US, Japan, China, and India over the period 1985 to 2009. China’s continuous casting ratio fell far behind those of the US and Japan in the early 1980s. A steady increase in the absorption of this technology continued until the early 1990s, but the speed accelerated in the mid-1990s. Although the average continuous casting ratio of China’s industry reached 77.4% in 2000, compared to developed countries such as the US (96.4%) and Japan (97.3%), the problem of high energy consumption remained. By the mid-2000s, however, China had almost caught up with developed countries such as Japan and the US by achieving a high continuous casting adoption ratio at 97.7% in 2005. China succeeded in almost catching up because many institutional factors served as motivation for its industry to obtain advanced technology including openness to world competition and government policies.

Figure 1-3 Continuous casting ratio in several countries

Having explored the overall growth pattern of China’s continuous casting technology absorption, we next consider the variations in the diffusion of continuous casting in the aggregate for the key large and medium-size steel firms during 1985 to 1995. At the beginning of the market reform period in 1985, several institutional and market constraints made it difficult for steel firms to access advanced technologies. These constraints may differ among the steel firms depending on the type of ownership. Fisher-Vanden (2003) concluded that centrally controlled firms have advantages in obtaining additional financial support and making a timely technology accession, which is consistent with China’s Eighth and Ninth Five-Year Plan that the central government mainly supports the large-scale key steel firms to install continuous casting equipment (SETC, 1991&1996). After 2000s, most of steel firms invested in continuous casting by their own investment budget, and the government was funding continuous casting technology in more specific type. In the Industrial Restructuring Planning Framework of China's "Tenth Five-Year Plan" (SETC, 2001), it stated that the government should support the development of large-scale metallurgical equipment such as thin sheets and slabs continuous casting equipment. This policy is also consistent with current finding that even with technical sophistication, steel firms gain more motivated to produce sheets and slabs steel with continuous casting technology in 2000s. As a result, some Chinese steel firms are quickly converting over to continous casting, whereas others are not. In this sense, as Figure 1-4 shows, very few steel firms can access the countinous casting technology in 1985. It can be explained by the reason that the extremely high cost of installation of a new merged technology. As shown in Figure 1-5, by the end of 1995, variations in continuous casting ratios have increased significantly. Some firms have achieved close to 100% continuous casting, while, others have not adopted it at all. However, during the same period, less heterogeneity existed among Japanese and U.S. firms in the diffusion of continuous casting. Figures 1-6 and 1-7 show the variation in continous casting is decreasing over time, which follows the pattern of the world’s advanced level in continous casting in Japan and the US. The goal of this paper is to identify the factors that explain the change in the variations among Chinese steel firms for the period of 1985-2009.
Figure 1-4 CC ratio distribution: 1985

Source: China Iron and Steel Association & TNC, 1985

Figure 1-5 CC ratio distribution: 1995

Source: China Iron and Steel Association & TNC, 1995

Figure 1-6 CC ratio distribution: 2000

Source: China Iron and Steel Association & TNC, 2000

Figure 1-7 CC ratio distribution: 2009

Source: China Iron and Steel Association & TNC, 2009
1.3 Objective of the thesis

The figures in section 1.2 show the variances in the rate of diffusion of continuous casting among Chinese steel firms during 1985 to 2009. The goal of this study is to identify the factors that are important to interpreting those variations in the context of different government policies. Previous research shows that a firm’s management structure matters (Fisher-Vanden, 2003). However, based on up-to-date data, the institutional factors including openness to world trade and policies that support substantial undeveloped areas may also have mattered in more recent years. Previous research has shown that continuous casting technology can improve both product quality and reduce energy intensity (Fisher-Vanden, 2003; Fisher-Vanden et al., 2009). China’s accession to the WTO may have affected all Chinese steel firms regardless of their management structure in terms of the global market as a motivator for them to adopt new technology and thus improve their efficiency and product quality in order to compete with other foreign advanced firms. China Western Development program is considered the government’s great effort to eliminate regional disparities and close the energy intensity and product quality gaps between the comparatively undeveloped western regions and the developed coastal regions.

The current research is addressed by following steps: the speed at which the firm’s diffuse continuous casting technology, based on the logistic growth curve, is compared across time. Two categories of factors potentially influence this diffusion speed: one category relates to measuring the firms’ attributes when responding to the demands of the market, and the other relates to considering the relevant policies. Comparisons of regression during several periods offer information about the firms’ performance based on the policies in place at the time. Comparisons of regression for western and non-western steel firms capture the policy effect after China’ Western Development program was proposed. The thesis is organized as follows: Chapter 2 provides a historical perspective on China’s decentralization policy, accession to the WTO, and Western Region Development, with special emphasis on China’s steel industry. Chapter 3 describes the model and presents the estimation results. Chapter 4 and 5 discuss the policy implications of the findings and concludes the study.
Chapter 2

Historical Review of

China’s Steel Industry

Before the Chinese government’s announcement in 1979 that it would establish a market economy, the Chinese economy was a centrally planned system, in which all the goods sold in China had prices set by the government. Chinese enterprises operated within strict limitations of autonomy in terms of responding to market demands, and state-owned enterprises were the major managerial structures of firms. Before the reform period, few privately owned steel enterprises were allowed by the government, which managed the steel industry through the Ministry of Metallurgical Industry (MMI) (Ma et al., 2002). After the reform policy was announced in the late 1970s, the ownership types in China’s industrial sector diversified. The present study focuses on the steel industry, a heavy industry sector. In the late 1970s, the MMI categorized the state-owned steel enterprises in accord with two definitions: “key” and “local.” The firms defined as key were directly controlled by the MMI, which was directly affiliated with the central government, and those defined as local are controlled by the provincial or local government (Wu, 2000). Many policies were implemented during the market reform period in order to make Chinese enterprises more market-driven. Among these, the decentralization of property rights is a crucial factor in market reform, which is an issue that will be taken up later in a section that presents a historical review of the Chinese steel industry.

A good way to determine changes in productivity resulting from decentralization in the early stages of market reform (i.e., the period 1985–1993) is to compare the respective performances of key and local steel enterprises in terms of energy efficient technology diffusion. Making such a comparison is effective because on the one hand key firms are directly controlled by the central government and are limited operationally in terms of their ability to respond to market effects. However, on the other hand, local firms operate based on local market demand and face less supervision from the government than key firms do (Fisher-Vanden, 2003). Thus, this variance of steel-firm ownership type shows the decentralization efforts of the Chinese government policies. Fisher-Vanden (2003) also demonstrates that because local firms in comparison with key firms are
subject to less government supervision, and have more incentive to respond to market demands and thus are more motivated to improve efficiency by adopting new technology more rapidly. Hence, this study showed a positive impact of government decentralization effort on technology diffusion, which is also consistent with the following facts. The Chinese government encouraged decentralized and non-state steel firms to merge. By 1993, 20% of the national total of ferrous metals was being produced by non-state enterprises (China Iron and Steel Association, 1994). Although previous studies showed that improved productivity had resulted from decentralization, recent studies have suggested that more centralized and large-scale firms are doing better in terms of efficiency due to factors such as scale effects and easy access to the financial support, which may foster the adoption of new technology and thus improve efficiency. One of the emphases of the present study is to explore the role of the government’s decentralization policy in improving firms’ productivity in the later period in the context of world competition. Specifically, more recent data will be used to compare the key steel firms and the local steel firms in terms of their respective adoption of continuous casting technology.

2.2 Deeper Market Reform and the Pre-WTO Period (1994–1999)

2.2.1 Management Structure and Administration

Although the Chinese private industrial sectors continued to expand after market reforms had been instituted, the central government was still working to improve the supervision of the key industries. Only a small proportion of total national output, 15% in 1993 according to Che et al. (1998), was produced by the private sector. Before China’s accession to the WTO in early 2000s, government intervention had played a much more important role in the steel firms’ decision-making processes than market forces (LLP, 2012). The Chinese government’s intervention policy related to the steel industry is likely to mean that results based on early market reform period data will differ significantly from results based on the current period given the decentralization’s effects on firms’
performance. However, studies (Kole et al., 1997; Martin et al., 1995) based on the more recent data show that state-owned enterprises were not necessarily less efficient than non-state-owned enterprises. Using data from the period 1994–1997, Sun (2002) examined the role of government in the performance of China’s SOEs during the process of privatization. He found that a balance needs to be struck and maintained between governmental supervision and individual firms’ autonomy in order to benefit firms’ decision-making processes; i.e., too much or too little government participation in a firm’s operations negatively impacts performance. This result is unsurprising, because too much government supervision overly restricts firms’ autonomy to respond to market forces. Yet, too little government supervision makes it difficult for firms to access institutional resources such as financial and technical support. Fisher-Vanden (2003) used data from 1985 to 1995 to show that key steel firms which are subject to a high level of intervention from central government are insensitive to market factors. One focal period of present research is 1994–1999, which was chosen to capture the effects of the government’s market reform policy on firms’ performance while the government also encouraged state-owned firms to adjust their strategies in order to prepare for entry into WTO. In particular, the present study examines whether ownership type (key or local) still matters in terms of firms’ technology diffusion in the new market and policy background.

2.2.2 Market Reform in the Pre-WTO era (Transition Period to the WTO Accession)

When the WTO was established in 1995, China joined the WTO negotiations and formally submitted an application for inclusion. In the same year, the Chinese government’s request led to the establishment of the China’s accession to the WTO Working Group. To prepare for potential WTO entry in the future and, therefore, global competition, Chinese enterprises had to account for the advantages and challenges associated with improving production efficiency. During the period 1994–1999, the Chinese government took a number of steps to liberalize its price and reduce tariffs and in, to prepare for WTO accession negotiations (Adhikari et al., 2002). There is also evidence to show
that the Chinese government made a considerable effort to eliminate nontariff barriers in order to prepare for WTO accession: it is estimated that the number of licenses and quotas imposed by the Chinese government associated with import products dropped by around 80% from 1992 to 1999 (Ianchovichina et al., 2001). This may have boosted international trade (for example, China became the largest steel producer in 1996), and in addition Chinese enterprises made efforts to improve technology diffusion in order to compete with foreign firms. As shown in Figure 1-3, China accelerated its continuous casting diffusion beginning in 1994 and reaching its peak in 1999. However, the extent to which China was open to world trade effects before the WTO period may have been limited. Without the restrictions imposed by WTO membership, the tariff and non-tariff barriers remained in force during this period. By comparing the results on this transition period (1994–1999) with those for the post-WTO accession period, we can examine the effects of China’s accession to the WTO on the steel firms’ ability to adopt new technology.

2.3 Regional Development and the Post-WTO Period (2000–2009)

2.3.1 China’s Policies on Regional Disparities: The Western Development Program

In the introduction, evidence was presented regarding unequal regional economic development in China since market reform. The eastern coastal regions benefited significantly and achieved rapid economic growth because of the advantage due to their location and government’s policies. However, the western region of China is developing much more slowly, such that some areas continue to struggle with poverty. The western regions are facing problems such as a fragile environmental ecology system, barriers to transportation access, barriers to new technology, inefficient use of resources, and conflicts between development and environmental conservation. In order to help the western part of China catch up with the east, in 2000 the central government adopted a policy called China’s Western Development in order to boost the economy in the less developed western areas. According to China’s Western Development Bureau (2001), the policy
covers a total of 11 provinces including autonomous regions of Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, Yunan, Guangxi, Inner Mongolia, Ningxia, Tibet, and Xijian, and one municipality, i.e., Chongqing, which taken together account for 71.4% of mainland China, but for only 17.2% of total national GDP in 2000 (NBS, 2001). The main strategies of this policy include developing public facilities (such as the transportation, telecommunications, and power generation systems), encouraging foreign investment, recruiting skilled labor from developed regions of China, and the promotion of education and technology innovation and environmental conservation (China Western Development Bureau, 2001). Next, we discuss the effects of this policy on technology innovation pertaining to improvements in energy saving and quality in China’s steel industry.

The China Western Region Development program policies have brought a range of opportunities to the western iron and steel industry in terms of efforts to increase production, improve quality, and reorganize industrial structure. The overall demand and supply in the steel industry were almost equal in China’s western provinces except in Tibet and Ningxia before China’s Western Development program went into effect (Dong, 2003), and there are more opportunities for western steel firms to increase their supply based on the apparent high demand created by this policy. The four main projects announced under this policy are west to east electricity transportation, south to north water transportation, west to east gas transportation, and the Qinghai–Tibet Railway (NDRC, 2002). These four wide-reaching projects will potentially boost the demand for both high-quality steel and specific types of steel. Problems confronted by western steel firms included producing steel of low quality and with low-added value, similarity in product types, insufficient output to meet market demand, especially in new infrastructure construction demand, and the new increasing demand for steel types such as pipe steel for oil and gas transportation, pipe steel for oil exploration, silicon steel sheet used in electricity industry and steel used in home appliances and high-tech electronics industries (Dong, 2003).
Based on market demand, China’s Western Development policies promote investment in new technology diffusion and industrial structure optimization as well as upgrades to key western iron and steel firms (NDRC, 2002). Improving energy saving in industrial sectors is important in efforts to achieve environmental conservation goals. In China’s 11th Five-Year Plan, the western iron and steel industry is one of the key industries, which are targets for the circular economic development included by the China Western Development program (NDRC, 2007). There are numerous inefficient small- and medium-scale firms in the western region (Dong, 2003), and, in 2009, of the 66 firms in the nation producing a total of more than 1 million tons crude steel, only 8 were in the western region (China Iron and Steel Association, 2010). The lack of large firms and variations in firm size are two factors that are likely to be contributing to the overall low and divergent energy intensity levels in western areas. Zhang et al. (2008) found that the size of a firm matters in terms of how efficiently it performs; i.e., compared with firms of small and medium size, large firms have greater potential to become highly efficient based on economies of scale. Dong (2003) concluded that consolidating and shutting down small firms in particular in the iron and steel industry will improve energy saving performance. All these findings are consistent with current government policies included in the China Western Development program, which sought to merge and reorganize iron and steel firms, improve industrial concentration, and support the infrastructure of medium and large steel firms including the Jiuquan, Baotou, Chongqing, and Panzhihua iron and steel group firms (NDRC, 2002).

Efforts to optimize industry structure such as merging and reorganizing the iron and steel firms have been made to reduce the energy intensity since China’s Western Development program went into effect in 2000; however, Zhang et al.(2011) found that from 1995 to 2008, the western region still had not achieved a level of energy intensity on a par with those realized by the eastern and central regions. Furthermore, Zhang et al. (2011) observed that unlike the eastern and central regions, the existing variances in energy intensity in the west are growing larger. According to Wang
et al. (2012), based on 2005–2009 data the overall energy intensity of the western regions in China is comparatively higher than that of other regions. Further, Wang et al. (2012) suggested that in order to solve this problem, the government should set Chinese western enterprises the target of improving their technological capabilities rather than expanding scale as the best bet for catching up with the eastern and central regions. To achieve efficiency in western regions, the government put a policy in place that promoted expansion of firm size rather than one that focused on improving firms’ technology. This policy, however, has the potential to result in the waste of enormous amounts of energy (Wang et al., 2012). The following section focuses on determining the effects of China’s Western Development policy on the promotion technology diffusion specifically in continuous casting in steel industry. Zhang et al. (2008) indicated that to achieve sustainable economic growth in conjunction with goals focused on preserving natural resources and protecting the environment, China needs to encourage its industrial sectors to reduce their energy intensity by applying energy-saving technology, e.g., continuous casting technology in steel industry. In the present paper, we use the data from 2000 onwards pertaining to large- and medium-sized western iron and steel firms in order to determine whether the key steel firms are achieving the China Western Development program’s policy goal of improving their energy saving performance.

2.3.2 China’s Steel Industry and Entry to the WTO

In December 2001, China became a formal member of the WTO, which constituted a milestone in the government’s efforts to integrate the Chinese economy into global markets. According to the Xinhua News (2000a), on acceding to the WTO, China was able to enjoy corresponding rights, such as unconditional Most Favored Nation (MFN) treatment by other member countries, tariff reductions, the elimination of non-tariff barriers (quotas and licensing), and the elimination of trade discrimination. In addition, China can use the WTO rules to resolve international
trade disputes, while key industries in the national economy, such as telecommunications, banking, and iron and steel are open to competitors financed by foreign capital at the request of the WTO (Xinhua News, 2000b). It is likely that this induced changes to China’s industrial sector in the face of global competition, and that it has become a factor influencing firms’ sensitivity to market changes. Subsequent discussions detail firms’ responses to trade openness.

Specifically, we take China’s steel industry as an example of the benefits and competition accruing to Chinese heavy industrial sectors after China’s accession to the WTO. On the basis of China’s WTO membership, all the country’s industrial sectors including the steel industry received the great benefits of a low tariff and the elimination of non-tariff barriers such as quotes and import licensing by foreign countries (Xinhua News, 2000a). As shown in Figure 2-1, China managed a significant jump in steel exportation after WTO entry in 2001, and the country’s exportation growth rate increased much faster than that of any of the world’s other top steel producers until 2007. However, China’s steel exports dropped dramatically in the late 2000s, as a result of reduced global demand for steel and increasing costs due to the appreciation of the RMB during this period (MOFCOM, 2009). It can be inferred from the data presented in Figure 2-1 that China’s steel export fluctuated significantly during the 2000s, and that this may have had a great impact on the steel firms because they relied to a great extent on export in order to expand production. In particular, once the steel firms had made an initial investment in expanding, it would have been hard for them to decrease their output quickly.

Compared to China’s unstable exports, Japan, another of the world’s top steel producers, was much less elastic to the change of world demand such that its exports grow at a stable rate throughout the 2000s. A possible reason for Japan’s stability in this regard is the country has achieved a high industrial concentration through its merger and reorganization efforts. Therefore, Japan can adjust its product-type structure based on world demand. In 2007, Japan’s two leading steelmakers, Nippon Steel and JFE, produced 69.7 mmt of crude steel, which accounted for 58% of the total national
crude steel output in that year (Hong et al., 2010). In contrast, the share of China’s top five domestic steelmakers accounted for 27% of China’s steel production in 2007 (China Iron and Steel Association, 2008; World Steel Association, 2012). Further, the difference in scale between Japan and China may have contributed to the difference in regard to the efficiency of the steel industry in these two countries as well. Zhang et al. (2008) found that firm size matters in terms of efficiency: large firms perform better in productivity efficiency than small firms. In addition, Japan is also regarded as a steel producer with high-quality and high-value-added products, whereas China’s steel firms produce an excess of low-quality steel (Fisher-Vanden et al., 2009). China’s low-quality output was mainly used in the construction of infrastructure facilities which is particularly unattractive in circumstances of low world demand especially during the global economic recession of the late 2000s. The present paper examines the relationship between scale effects and energy saving technology diffusion in China’s steel industry in order to determine whether, as compared to small steel companies, the large steel companies performed better in diffusing technology for energy saving and quality improvements. In addition, in this paper, we consider whether and to what extent the steel firms are using new technology to replace old equipment or to expand production. In the WTO background, the present results will examine whether it is consistent with a study by Ma (2002), which shows that productivity can be improved by replacing old and inefficient production technology with advanced technology.
Openness to world trade means that China’s domestic steel market now faces global competition. According to Hu et al. (2000), in the WTO era, China was obliged to lower its tariff for steel imports: in fact, the tariff dropped from 10.58% in 2000 to 8.07% in 2005. Non-tariff barriers such as quotas and registrations for steel imports were eliminated. Furthermore, the government policy stipulating that imported steel should only be distributed by the government’s designated agencies was removed as a requirement of WTO membership. In addition, the subsidy given to steel firms to encourage them to export their products was eliminated. However, because of its high production capacity at low prices, China has become involved in more anti-dumping disputes since acceding to the WTO. For example, the US has imposed anti-dumping duties on China’s steel products since China’s WTO accession (MOFCOM, 2009). Developing and expanding the domestic market is the solution to absorbing China’s own huge production capacity (Hu et al., 2000). Hence, China needs to innovate in terms of technology if it is to improve its efficiency and product quality and adjust its output based in order to compete with foreign firms in the domestic market. Based on
the background of openness to world trade, government policies and foreign competition should provide sufficient motivation for China to promote technology diffusion in a bid to improve energy saving and lower costs.

In addition, openness to world trade can be regarded as an opportunity for China to enhance its diffusion of new technology in energy saving and environmental conservation. A study by Weber (2001) showed that results such as economic growth, easier access to foreign technologies, more foreign competition, and more strict international environmental contracts encourage countries to adopt technologies in order to improve efficiency and can lead to better environmental conservation. However, Williams (2001) drew opposite conclusions: after China joined the WTO, many Chinese firms expanded to a considerable degree, likely imposing a further burden on the environment. To achieve fast growth in GDP from world trade, China could loosen its domestic environmental regulations and thereby more easily compete with foreign firms, though the costs to the environment could be significant. In particular, the present paper evaluates the effects of China’s openness to the world trade on the country’s steel industry’s energy-saving technology diffusion.

The challenges of acceding to the WTO for China’s steel industry have arisen from the scarcity of high-quality and high-value-added steel and from China’s industrial structure whereby the country produces an overabundance of low-quality steel (Hu et al., 2000). Hu et al. (2000) showed that in the 2000s competition in the world steel industry was very strong—especially in regard to high-quality and high-value-added steel. This study (Hu et al., 2000) also suggested that at the beginning of the 2000s, the supply surplus was mainly due to a “structure surplus” in the domestic steel market; that is, though China’s steel firms were supplying the domestic market with an overabundance of low-quality steel, the domestic demand for high-quality steel relied on import. Especially with China’s accession to the WTO, the import of high-quality and high-value-added products such as sheets and slabs of steel (flat products) increased in the first half of the 2000s. From Figure 2-2, we can see that China’s imports of high-quality steel (flat products) accounts for an
extremely large proportion of total steel imports throughout the 2000s. As Figure 2-4 shows, the proportion of China’s total steel export given over to flat steel continued to grow in the 2000s, which may indicate that China is willing to turn out high-quality steel in order to compete in the world market. A comparison of Figure 2-2 and Figure 2-4 shows that the gap between the export and import of flat production as respective proportions of the total export and import is still large, such that China needs to make more effort is to become competitive in regard to flat steel production. In general, the production process for flat steel such as sheets and slabs is more complicated and capital intensive than the production process for long products such as wires and rods (Ma at al., 2002). The current paper is written based on the assumption that world competition in the first decade of this century motivated Chinese steel firms to adopt new technology in order to improve the quality of their products and their production structure. As shown in Figure 2-3, China experienced an increase in its overall steel imports at the beginning of the 2000s when it joined the WTO. However, the imports began to drop after 2003, on the other hand, the domestic steel use (crude steel equivalent) kept increasing the average rate of 15.86% from 2003 to 2009 (China Iron and Steel Association, 2010). This phenomenon may have been because of China’s steel industry’s new technology R&D and the diffusion of technology in steel-quality improvements, and changes in production composition structures. Specifically, the present paper examines whether and the extent to which China’s steel firms adopted new technology in order to improve steel quality, in particular continuous casting technology, after 2000 (Fisher-Vanden et al., 2009).
Figure 2-2 Composition of China’s steel imports

Unit: 1,000 tons
Source: World Steel Association, 2010

Figure 2-3 Imports of semi-finished and finished steel products

Unit: 1,000 tons
Source: World Steel Association

Figure 2-4 Composition of China’s steel Exports

Unit: 1,000 tons
Source: World Steel Association
Chapter 3

Model Specification, Data Description, and Estimation Results
3.1 Empirical model specification

In this study, we assume that steel firms make investment decisions based on an analysis of net present value. That is, they compare the cash flow that they expect to see after adopting continuous casting technology with the cash flow they had with ingot casting. Profit-driven firms will invest in continuous casting if the NPV of the gain they expect to realize from doing so is greater than the one-time investment cost.

To capture individual firms’ decision-making processes and consequent choice between two technologies, this paper adopts the model proposed by Fisher-Vanden (2003), which not only considers the specific firms’ attributes but also other institutional constraints such as the factors that can affect whether the profitability of one technology outweighs the profitability of alternatives. Under this model, investment in continuous casting technology will be made if,

\[
\sum_{t=t+1}^{T} \frac{(1-\delta)^{1-(t+1)}}{(1+r)^{l-t}} R(X^R) - C(X^C) > 0,
\]

(1)

Where, \(X^R, X^C\) include the factors that influence the return spread between marginal investment in continuous casting and ingot casting and the cost spread between marginal investment in continuous casting and ingot casting; \(r\) is the interest rate and \(\delta\) is the depreciation rate. \(R(X^R)\) and \(C(X^C)\) are return and cost spread between the marginal investment in continuous casting and ingot casting.

As noted by Fisher-Vanden (2003), due to the unique investment environment faced by Chinese steel firms, it is necessary to consider the institutional constraints imposed on steel firms such as government policies and relative openness to world trade and the economic factors that affect firms’ investment decisions in a market economy. Specifically, \(X^R, X^C\) include variables, which will be discussed in more detail in the next section.
3.1.1 Factors affecting continuous casting technology diffusion in China

Following Fisher-Vanden (2003), we now discuss the factors that can potentially affect the continuous casting technology diffusion speed in Chinese steel firms:

We assumed a negative correlation between firm age ($AGE$) and speed of continuous casting diffusion. It is difficult to apply continuous casting technology to the conventional open hearth furnaces (OHF) that were widely used by steel firms established before 1950, which is consistent with the finding in the study (Fisher-Vanden, 2003) that older firms diffused continuous casting technology faster than the younger firms. In this paper, we will determine whether the negative relationship that we assume obtains between firm age and technology diffusion holds for each of the three periods.

As firms gain more experience with new technology over time, they should realize an increased per unit profit because laborers and managers should make fewer mistakes at each stage of the production process. This study will use the variable ($ADOPT$) to capture this effect. Fisher-Vanden (2003) shows that early adopters, such as key firms, adopted continuous casting technology more slowly than local firms did. The current study will examine whether early adopters have sufficient incentives to adopt new technology more rapidly in the context of China’s accession to the WTO and China’s Western Development program.

Earlier studies have shown that a large firm size ($SIZE$) can have both positive and negative effects on the speed at which continuous casting technology is diffused. Fisher-Vanden (2003) found economies of scale in large steel firms. In the same study, it also pointed out that a large firm size also hinders firms’ adoption of continuous casting technology because with an increase in scale, the operation process for continuous casting becomes more complicated than for conventional ingot casting. After China’s accession to the WTO, the government put policies in place to develop large-scale firms as a way to achieve world-level efficiency as foreign large-scale steel producers did by
adopting new technology. The China Western Development program also supported efforts to improve efficiency in the target western areas through large-scale firms. These two factors are captured by the up-to-date data presented in the current study.

In the late 1970s, the MMI categorized state-owned steel enterprises according to two definitions: “key” and “local.” The firms defined as key were directly controlled by the MMI, affiliated with the central government, and those defined as local were controlled by the provincial or local government. With the end of the MMI in 2000, steel firms are no longer referred to as either key or local, but the former key firms were still more closely associated with the central government than the former local firms were. Therefore, it remains meaningful to continue exploring the relationship between firms based on these management-structure types and technology diffusion. Using data for the period 1985–1995, Fisher-Vanden (2003) showed that in comparison with local firms, key firms have an advantage in terms of adopting continuous casting technology earlier but have fewer incentives to adopt it rapidly in response to market factors. Based on up-to-date data, this research examines this relationship in the new background that both key and local firms faced global competition on even terms due to China’s openness to the world trade, even though some institutional constraints have continued to exist.

In recent years, increasing market demand for flat products (sheets and slabs) has increased, and some steel firms have adopted continuous casting technology in order to produce more flat products based on market demand. Although the initial investment in producing sheets and slabs is high, firms may still find making such an investment to be profitable given increasing market demand. In the present study, we consider such changes in the new market based on more recent data.

Many studies have investigated the expansion–replacement dilemma related to new technologies. Ma (2002) showed that efforts to improve productivity are supported by replacing old and inefficient production technology rather than by adopting advanced technology for the purpose
of expansion. However, Oster (1982) suggested that an expansion strategy is the most appropriate for continuous casting. The present study explores this relationship by the variable of output growth ($Q$) based on recent data in the context of Chinese firms’ motivations for WTO access to adopt technology in order to improve efficiency.

According to the results of previous research (Fisher-Vanden, 2003), a firm’s location also affects diffusion speed. The results suggest that during the period 1985–1995, there is a positive correlation between the diffusion speed and economic growth in the region in which the firm is located. The current research uses the basic idea of the regional disaggregation method (Keidel, 1995) to determine whether other regions fell behind before regaining production capacity. Underdeveloped regional economies represent areas that may have benefited from recent government policies, for example China’s Western Region Development program, which covers a total of 11 provinces including autonomous regions such as Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, Yunan, Guangxi, Inner Mongolia, Ningxia, Tibet and Xijian, and one municipality, Chongqing. One dummy variable includes the regions that China’s Western Region Development program focuses on in order to analyze the regional effects arisen from this policy.

The age of the capital stock ($KSTOCK$) will affect technology diffusion in two ways: First, we assume a downward-sloping production function. Therefore, firms with older capital stock will yield higher marginal returns than those with newer capital stock that have already invested in inputs factors. Second, firms with older capital stock are more likely to use furnace technology, which is less profitable with continuous casting. In this regard, older capital stock will have a negative impact on the diffusion of new technology.

The variable of investment constraints ($INVEST$) captures the likelihood that the firm will access investment capital. In this study, we adopt the assumption made in Fisher-Vanden (2003), whereby firms with better access to investment capital are more likely to have a greater growth rate.
in capital stock. Investment budgets especially in the private sector constrain a firm’s ability to acquire new technology in developing China. According to Fisher-Vanden (2003), a key firm is less likely than a local firm to be constrained by its own budget, because key firms can easily gain financial support from the central government. The current study makes a comparison between the sensitivities of western and non-western region firms to investment capital after 2000. It can be concluded that if the western steel firms do become more efficient through adopting new technology adoption, they will do so as a benefit of the China Western Development program. The present research investigates whether the investment constraints apply to the adoption of new energy efficient technology. Table 3-1 shows description for each variable for three separate periods: 1985-1993, 1994-1999 and 2000-2009.
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Firm Age</strong> (<strong>AGE</strong>)</td>
<td>The number of years since the firm was established in 1993</td>
<td>The number of years since the firm was established in 1999</td>
<td>The number of years since the firm was established in 2009</td>
</tr>
<tr>
<td><strong>Years since first adopting CC</strong> (<strong>ADOPT</strong>)</td>
<td>The number of years since a firm first adopted continuous casting technology in 1993</td>
<td>The number of years since a firm first adopted continuous casting technology in 1999</td>
<td>The number of years since a firm first adopted continuous casting technology in 2009</td>
</tr>
<tr>
<td><strong>Firm size</strong> (<strong>SIZE</strong>)</td>
<td>Total crude output (in 10,000 tons) in 1993</td>
<td>Total crude output (in 10,000 tons) in 1999</td>
<td>Total crude output (in 10,000 tons) in 2009</td>
</tr>
<tr>
<td><strong>Management structure</strong> (<strong>KEY</strong>)</td>
<td>This is a dummy variable, which indicates whether a firm is a key firm (=1) or non-key firm (=0).</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type of product produced</strong> (<strong>SHEETS</strong>)</td>
<td>The firm’s share of production of flat sheet or slabs in 1985</td>
<td>The firm’s output (in 10,000 tons) of wires and rods in 1994</td>
<td>The firm’s output (in 10,000 tons) of wires and rods in 2000</td>
</tr>
<tr>
<td><strong>Regional effects</strong> (<strong>R1–R7</strong>)</td>
<td>Region 1 represents the West (Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, Yunan, Guangxi, Inner Mongolia, Ningxia, Tibet, Xijiang, and Chongqing)—eleven firms or 16% of the sample; Region 2 represents the North Hinterland (Heilongjiang, Jilin, Shanxi)—3 firms or 5% of the sample; Region 4 represents the Central Core (Henan, Anhui, Jiangxi, Hubei, Hunan)—14 firms or 21% of the sample; Region 5 represents the North Coast (Liaoning, Greater Hebei, Shandong)—20 firms or 29% of the sample; Region 6 represents the East Coast (Jiangsu, Shanghai, Zhejiang)—7 firms or 10% of sample, and Region 7 represents the South Coast (Fujian, Guangdong, Hainan)—3 firms or 5% of the sample.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age of capital stock</strong> (<strong>KSTOCK</strong>)</td>
<td>The ratio of a firm’s net fixed assets over the original fixed assets value in 1985</td>
<td>The ratio of a firm’s net fixed assets over the original fixed assets value in 1993</td>
<td>The ratio of a firm’s net fixed assets over the original fixed assets value in 2000</td>
</tr>
<tr>
<td><strong>Investment constraints</strong> (<strong>INVEST</strong>)</td>
<td>The firm’s average annual growth rate of the capital stock for 1985-1993</td>
<td>The firm’s average annual growth rate of the capital stock for 1994-1999</td>
<td>The firm’s average annual growth rate of the capital stock for 2000-2009</td>
</tr>
</tbody>
</table>
3.1.2 Dependent variable (SPEED)

Following Fisher-Vanden (2003), in estimating diffusion speed $\beta_i$, we use the logistic growth curve of Griliches (1957),

$$CC_{i,t} = \frac{1}{1+e^{-(\alpha_i+\beta_i t)}}, \quad (2)$$

where $\beta_i$ is firm $i$’s diffusion speed, which captures how much the continuous casting ratio $CC_{i,t}$ changes (the continuous casting ratio is a calculation according to the share of continuous casting output over total crude output during 1985–1993, 1994–1999, and 2000–2009 correspondingly) in responses to one year change from time $t$ to $t+1$. $\alpha_i$ is the firm $i$’s constant intercept.

3.1.3 Regression on diffusion speed

In order to examine the impact of the factors considered above on the continuous casting diffusion speed of a particular firm, we estimate the following Tobit model, proposed by Fisher-Vanden (2003), :

$$SPEED_i = \alpha + \beta_1 Q_i + \beta_2 SIZE_i + \beta_3 SHEETS_i + \beta_4 ADOPT_i + \beta_7 AGE_i + \beta_8 KSTOCK_i + \beta_9 INVEST_i + \beta_{10} KEY_i + \beta_{11} (R1_i - R7_i), \quad (3)$$

where $SPEED_i$ is the diffusion speed of firm $i$’s, which is the estimated result of equation (2), across the corresponding years of interest.
3.2 Data description

The analysis uses data from 65 Chinese steel firms over the course of 25 years (1986–2010). The data is a compilation of information from 25 China Tienuo, a steel consulting firm (2000–2009); from China’s National Bureau of Statistics (NBS, 2000–2009), and from issues of *China Iron and Steel Yearbook*, published annually by the Ministry of Metallurgical Industry in China (1986–2000) and the China Iron and Steel Association (2001–2010). Details of the data sources are presented in Table 3-2, and a statistical summary of the firms is presented in Table 3-3.

<table>
<thead>
<tr>
<th>Main Sources of Energy Data</th>
<th>Contents (Key &amp; medium–large steel enterprises’ firm-level data)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crude output (1985–2009)</td>
</tr>
<tr>
<td></td>
<td>Firm type (key or local) (1985–2009)</td>
</tr>
<tr>
<td></td>
<td>Profit, firm age, and net, original, and fixed assets (1985–2000)</td>
</tr>
<tr>
<td>China’s National Bureau of Statistics</td>
<td>Profit, firm age, and net, original, and fixed assets (2000–2009)</td>
</tr>
<tr>
<td>China Tienuo Steel Consulting Corporation (TNC)</td>
<td>Continuous casting output (2001–2009), data for 2002 is missing</td>
</tr>
<tr>
<td><a href="http://www.tncsteel.com">http://www.tncsteel.com</a></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All firms</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Sample size</td>
<td>65</td>
</tr>
<tr>
<td>% of total industry output (%)</td>
<td>62.8</td>
</tr>
<tr>
<td>Output of crude steel (10,000 tons)</td>
<td>35687.2</td>
</tr>
<tr>
<td>Average</td>
<td>557.6</td>
</tr>
<tr>
<td>Minimum</td>
<td>12.0</td>
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<tr>
<td>Maximum</td>
<td>2012.7</td>
</tr>
<tr>
<td>Age of firm (yr)</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>62</td>
</tr>
<tr>
<td>Minimum</td>
<td>21</td>
</tr>
<tr>
<td>Maximum</td>
<td>109</td>
</tr>
<tr>
<td>No. of employees (thousands)</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>17198</td>
</tr>
<tr>
<td>Minimum</td>
<td>1507</td>
</tr>
<tr>
<td>Maximum</td>
<td>113610</td>
</tr>
<tr>
<td>Continuous casting ratio</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.92</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.00</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.00</td>
</tr>
<tr>
<td>Diffusion speed of Continuous casting</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.31</td>
</tr>
<tr>
<td>Minimum</td>
<td>4.96</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.00</td>
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</tbody>
</table>

*Source: China Iron and Steel Association (2010)*
Chapter 4

Estimation Results and

Policy Implications
### 4.1 Regressions based on different periods

Table 4-1 Regression of diffusion of continuous casting technology (Tobit model)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>ADOPT</td>
<td>-0.641**</td>
<td>(0.281)</td>
<td>-2.852**</td>
<td>(0.609)</td>
<td>-0.237**</td>
<td>(0.005)</td>
</tr>
<tr>
<td>SIZE</td>
<td>1.236</td>
<td>(1.327)</td>
<td>-3.812</td>
<td>(0.666)</td>
<td>0.442**</td>
<td>(0.068)</td>
</tr>
<tr>
<td>SHEETS</td>
<td>1.657**</td>
<td>(0.606)</td>
<td>1.242</td>
<td>(1.648)</td>
<td>-0.104**</td>
<td>(0.035)</td>
</tr>
<tr>
<td>Q</td>
<td>0.921</td>
<td>(0.664)</td>
<td>-0.117</td>
<td>(0.005)</td>
<td>-1.577**</td>
<td>(0.313)</td>
</tr>
<tr>
<td>AGE</td>
<td>-0.783**</td>
<td>(0.148)</td>
<td>2.461**</td>
<td>(0.319)</td>
<td>0.105**</td>
<td>(0.016)</td>
</tr>
<tr>
<td>KSTOCK</td>
<td>-1.208</td>
<td>(2.078)</td>
<td>-2.020*</td>
<td>(1.156)</td>
<td>0.118</td>
<td>(0.086)</td>
</tr>
<tr>
<td>R1 WEST</td>
<td>-3.864**</td>
<td>(0.590)</td>
<td>-2.343</td>
<td>(1.428)</td>
<td>-0.085</td>
<td>(0.073)</td>
</tr>
<tr>
<td>R2 NORTHHINTER</td>
<td>-3.928**</td>
<td>(0.689)</td>
<td>-4.963**</td>
<td>(2.143)</td>
<td>-0.566**</td>
<td>(0.125)</td>
</tr>
<tr>
<td>R4 CENTRAL</td>
<td>-3.897**</td>
<td>(0.590)</td>
<td>-3.199**</td>
<td>(1.375)</td>
<td>-0.103</td>
<td>(0.075)</td>
</tr>
<tr>
<td>R6 EASTCOAST</td>
<td>-4.263**</td>
<td>(0.708)</td>
<td>5.203**</td>
<td>(1.696)</td>
<td>-0.283**</td>
<td>(0.087)</td>
</tr>
<tr>
<td>R7 SOUTHCOAST</td>
<td>-4.492**</td>
<td>(0.821)</td>
<td>-1.642</td>
<td>(2.153)</td>
<td>-0.398**</td>
<td>(0.147)</td>
</tr>
<tr>
<td>R5 NORTHCOAST</td>
<td>(omitted)</td>
<td>(omitted)</td>
<td>(omitted)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KEY</td>
<td>-1.206**</td>
<td>(0.484)</td>
<td>-1.031</td>
<td>(1.342)</td>
<td>0.061</td>
<td>(0.072)</td>
</tr>
<tr>
<td>INVEST</td>
<td>-7.524**</td>
<td>(1.812)</td>
<td>0.048</td>
<td>(0.578)</td>
<td>0.016**</td>
<td>(0.005)</td>
</tr>
<tr>
<td>CONSTANT</td>
<td>8.785**</td>
<td>(1.726)</td>
<td>-2.295</td>
<td>(2.201)</td>
<td>0.347**</td>
<td>(0.150)</td>
</tr>
<tr>
<td>No. of Observations</td>
<td>675</td>
<td>331</td>
<td>610</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo R²</td>
<td>0.0247</td>
<td>0.045</td>
<td>0.147</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prob &gt; χ²</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant at the 0.10 level.
**Significant at the 0.05 level.
Standard errors shown in parentheses.

In Table 4-1, the regression results based on the three focal time periods are presented. Column 1 presents the full sample of 75 steel firms for 1985–1993, Columns 2 and 3 present results for the firms for 1994–1999 and from 2000–2009, respectively. The regressions are separated in corresponding periods based on the continuous casting technology diffusion trend in Figure 1-3 and the institutional factors underlying this trend. In Figure 1-3, it is evident that the first acceleration of continuous casting technology occurred around 1990. In
addition, it is shown in the figure that the growth rate of the continuous casting ratio in 1990 and 1991 are 36.81% and 18.83%, respectively, and before and after that adoption is slower, which may have been caused by several factors such as the government’s decentralization and market reform policies. The second jump in this technology adoption occurred in 1994 and 1995, when the growth rate of continuous casting ratios are 16.86% and 17.72%, respectively, and adoption kept growing at a stable speed until the late 1990s. In this period from 1994 to 1999, Chinese firms were preparing for the foreign competition expected to arise should China be admitted to the WTO and this expectation may have motivated firms to adopt technology to improve efficiency and product quality. In particular, this study examines whether and to what extent Chinese steel firms became more motivated to overcome the institutional and technical barriers to adopting continuous casting technology during the period of 1994 to 1999 as compared to the period of 1985 to 1993. At beginning of the 2000s, the rate at which China adopted continuous casting continued to lag behind the adoption rate of more advanced countries such as Japan and the US. In 2000, continuous casting ratios in China and Japan were 77.40% and 97.30%, respectively. China’s continuous casting technology adoption caught up Japan and the US in the mid-2000s, which may be positively correlated with institutional factors such as the government’s policies and WTO accession, which are investigated in the following part.

The coefficients associated with the number of years since a firm first adopted continuous casting technology (ADOPT) in Columns 1, 2, and 3 are significantly negative, which is inconsistent with the “learning-by-doing” story wherein an early adopter with more experience installs the new technology more rapidly. One reason for this unexpected result over the period 1985 to 1993 is that firms, e.g., key firms, with earlier access to new technology because of their strong association with the central government are less motivated to make a rapid change over to continuous casting than those firms without such a
relationship. According to Fisher-Vanden (2003), the key steel firms with early access are likely to be less motivated to improve their efficiency through adopting new technology than local firms are. However, a firm’s management structure (key or local) does not matter in terms of continuous casting diffusion after 1993 based on the regressions shown in columns 2 and 3. A comparison of the magnitude of the coefficients associated with the variable ADOPT show that this factor in column 2 (1994–1999) is significantly larger than that in either column 1 (1985–1994) or column 3 (2000–2009), which indicates that the later adopters diffused continuous casting technology more rapidly during the period of 1994 to 1999 than during either of the other two periods. This result is consistent with the finding (Ni et al., 2000) that China’s steel industry began to access continuous casting technology in the 1980s and that continuous casting technology became easier to adopt due to the government’s promotion and development of this technology in the late 1990s. The present study also showed that some of the steel firms that had not used continuous casting technology previously had become full continuous casting producers in the late 1990s. Such firms can be seen as extreme examples of “late adopters,” and as they embraced continuous casting technology the diffusion rate of this technology increased rapidly in the late 1990s.

A review of the Chinese steel industry (Hong et al., 2010) shows that China lacked sufficient large-scale steel firms to compete with the world’s advanced steel firms after accession to the WTO. This study also indicated that to solve this problem, the Chinese government focused on achieving international competitiveness through encouraging large firms to adopt technology. The regression covered the post WTO period will examine this effect. In the 2000s, the positive relationship between firm size and technology diffusion was significantly strong. This result suggests that large-scale steel firms are more likely to gain the government’s support and diffuse technology quickly than small-scale firms are. This study did not show the factor of firm size mattered before 2000. In conclusion, the way in
which or the extent to which firm size matters depends on the policy and market background. Large-scale firms diffused technology more quickly than previously in order to compete with large firms worldwide after China’s accession to the WTO.

It is assumed that the positive relationship between the production of wires and rods and the adoption of continuous casting is due to less sophisticated continuous casting procedures for producing wires and rods than for producing sheets and slabs. In column 3, the variable SHEET measures each steel firm’s production of wires and rods, which is negatively correlated with diffusion speed during the 2000–2009 period. In other words, the results show that the more wires and rods the steel firms produced, the less motivated they were to adopt continuous casting technology in order to produce those types of steel. The results for this period conflict with the original assumption whereby firms were expected to be more likely to produce wires and rods with the continuous casting technology because of the less technical sophistication. These results are not surprising. We found a large proportion of flat steel such as the sheets and slabs imports in total steel imports in the 2000s, as shown in Figure 2-2, and it can be inferred that the competition from the international market for sheets and slabs is high. Therefore, Chinese firms, which produced sheets and slabs, tended to adopt continuous casting technology more rapidly than that produced wires and rods. It can be expected that this competition will motivate China’s steel firms to improve efficiency and quality in flat steel production through the use of continuous casting technology.

A comparison of the significance of the coefficient associated with output growth (Q) shows that firms were most likely to replace the existing ingot casting capacity during the post-WTO period (2000–2009). Many studies have shown that different firms make different decisions regarding whether to use continuous casting technology to expand their production or replace the existing old style equipment. An earlier research (Oster, 1982) showed that expanding production with continuous casting equipment is more profitable than replacing
the ingot casting equipment in use. However, in a more recent research study, Ma (2002) showed more advantages of replacing the old and inefficient equipment by new technology over expanding the production, which is consistent with our finding that it was in the post-WTO period that firms were most likely to replace existing ingot casting capacity. Firm age (AGE) is a significant factor in all three periods, although the signs vary. In the 1985 – 1993 period, compared to older firms, younger firms adopted continuous casting more rapidly because of their advantages in terms of innovation or their compatibility with continuous casting. After 1993, this effect in both regressions becomes significantly positive, which may imply that older firms are catching up with the technology diffusion due to the institutional factor change and market effects. In specific, the old firms may totally phase out the outdated open-hearth furnace, which was widely used before the 1950s and incompatible with the continuous casting technology.

The coefficient associated with the age of a firm’s capital stock is negative in the 1994 – 1999 period, which implies that during this period, firms with younger capital stock (newer equipment) were diffusing more quickly than other firms were. Compared to the previous period over 1994 to 1999, in the 2000s (2000-2009), firms with older capital stock were likely to diffuse more rapidly than were firms with newer capital stock, suggesting that the firms tended to replace obsolete ingot casting with continuous casting technology. This finding is consistent with the analysis in coefficient associated with output growth (Q). According to Fisher-Vanden (2003), firm management structure (KEY) is a significant factor in diffusion speed during the 1985–1995 period, which is consistent with the results in Column 1 showing that key firms incorporate continuous casting technology at a slower rate than do local firms. This situation does not appear to have changed during the late 1990s (1994–1999), but this effect is not statistically significant. With the end of the Ministry of Metallurgical Industry (MMI) in 2000, the categories of key and local for steel firms ceased
to exist. However, it is still meaningful to continue exploring the management structure effects of the WTO context after 2000 according to these designations. Previous research (Fisher-Vanden, 2003) shows that key firms were directly supervised by the central government, that they supplied key government industries such as the military, and that they were less sensitive to market factors than local firms were. In the 2000s, the former key firms are likely to have retained strong connections with the central government. For example, the Anshan Iron & Steel Group and the Shanghai Baoshan Iron & Steel Group are still directly supervised by the central government. The coefficient associated with management structure in Column 3 is positive but insignificant, which suggests that key firms may catch up in terms of technology diffusion speed due to changes in institutional factors such as China’s accession to the WTO and the government policies of the 2000s. The effect of investment growth (INVEST) is significant and positive after 2000, which suggests the existence of a strong positive relationship between investment growth and diffusion speed. Before 2000, the results show that firms were more insensitive to investment constraints and that they were more likely to obtain a technology diffusion investment from outside resources such as from governmental support. Overall, China’s openness to world trade encouraged both former local and key firms to incorporate continuous casting technology into their process in a bid to efficiency and product quality. In particular, the former key firms tend to maintain a strong connection with the government and are less likely to be slow to adopt continuous casting technology in the post-WTO period than in the pre-WTO period. The market reforms and WTO also motivated the firms—especially for old steel firms and the firms which are producing sheets and slabs steel—to overcome the difficulties of incorporating continuous casting equipment into their manufacturing processes. Openness to world competition also accelerated efforts to replace old and outdated technology. By exploring the firm size effect, we found that, in the post-WTO period (2000–2009) large-scale firms gained an advantage in
incorporating new technology, which appears consistent with the government’s policy on improving the steel industry’s ability to compete globally through improving the technology capabilities of large firms (Hu et al., 2000).

The changes in coefficients associated with the regional dummy variables (R1–R7) across the three periods reflect the regional variance of technology diffusion based on the different institutional factors (different periods). During the 1985–1993 period, the technology diffused more rapidly to the steel firms located in the western and central areas than to those in other areas with the exception of the north coast, which is surprising given their relatively limited economic development. The government may have played a more important role in these relatively undeveloped areas in terms of helping the firms there to become more efficient by adopting continuous casting technology. With a closer consideration of market reform policy, the government may have begun to intervene in these undeveloped areas to a lesser extent than it had previously. During the 1994–1999 period, the relatively undeveloped western, north hinterland and central areas may have received less support from the government and so they diffused technology more slowly than did firms in the coastal areas (north coast, east coast, and south coast). But the regional economic disparities remained, and to address this problem, the Chinese central government instituted a number of policies including the China Western Development program in 2000. Based on our analysis of the data, it is evident that the western regions caught up again in technology diffusion in the 2000s. To further examine the differences between the western and non-western regions in the context of China’s Western Development program in the 2000s, we ran two separate regressions for western and non-western firms for the period of 2000–2009.
### 4.2 Regressions based on the regional effect (2000–2009)

#### Table 4-2 Regression of diffusion of continuous casting technology (Tobit model)

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>All firms (2000–2009)</th>
<th>West only</th>
<th>Non-West only</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>ADOPT</td>
<td>-0.237** (0.046)</td>
<td>-0.074** (0.042)</td>
<td>-0.264** (0.054)</td>
</tr>
<tr>
<td>SIZE</td>
<td>0.442** (0.068)</td>
<td>0.232** (0.082)</td>
<td>0.656** (0.070)</td>
</tr>
<tr>
<td>SHEETS</td>
<td>-0.104** (0.035)</td>
<td>-0.733** (0.063)</td>
<td>-0.049 (0.037)</td>
</tr>
<tr>
<td>Q</td>
<td>-1.577** (0.313)</td>
<td>-4.602** (0.407)</td>
<td>-0.836** (0.324)</td>
</tr>
<tr>
<td>AGE</td>
<td>0.105** (0.016)</td>
<td>0.170** (0.024)</td>
<td>0.124** (0.018)</td>
</tr>
<tr>
<td>KSTOCK</td>
<td>0.118 (0.086)</td>
<td>0.545 (0.461)</td>
<td>-0.041 (0.074)</td>
</tr>
<tr>
<td>WEST</td>
<td>-0.085 (0.073)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORTHHINTER</td>
<td>-0.566** (0.125)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CENTRAL</td>
<td>-0.103 (0.075)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EASTCOAST</td>
<td>-0.283** (0.087)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOUTHCOAST</td>
<td>-0.398** (0.147)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EASTCOAST KEY</td>
<td>0.061 (0.072)</td>
<td>0.012 (0.057)</td>
<td>-0.127 (0.082)</td>
</tr>
<tr>
<td>INVEST</td>
<td>0.016** (0.005)</td>
<td>-1.928** (0.177)</td>
<td>0.015** (0.005)</td>
</tr>
<tr>
<td>CONSTANT</td>
<td>0.347** (0.150)</td>
<td>0.642** (0.168)</td>
<td>-0.090 (0.156)</td>
</tr>
<tr>
<td>No. of observations</td>
<td>610</td>
<td>150</td>
<td>490</td>
</tr>
<tr>
<td>Pseudo $R^2$</td>
<td>0.147</td>
<td>0.130</td>
<td>0.138</td>
</tr>
<tr>
<td>Prob $&gt; \chi^2$</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Significant at the 0.10 level.
**Significant at the 0.05 level.

Standard errors shown in parentheses.

As discussed earlier, the regional disparities in economic development and efficiencies existed throughout all three focal periods, and the government instituted a number of policies to eliminate China’s unbalanced regional development. Among these policies, China’s Western Development program designed to boost the development of the country’s western regions, was the most significant of the 2000s. On this basis, this research explored the extent to which government or market factors influenced the western or non-western regions differently in the context of China’s Western Region Development program. Two separate regressions for western and non-western steel firms were run. Both the early
adopters (ADOPT) in western regions and non-western regions diffused continuous casting technology more slowly than later adopters did, which is inconsistent with the “learning-by-doing” story wherein an early adopter with more experience installs the new technology more rapidly. It may suggest that the “later adopters” gain more motivations to overcome the technical barriers to diffuse this technology more rapidly than “early adopters”.

Comparing the firm size (SIZE) in Columns 2 and 3, larger firms are diffusing more rapidly in non-western regions than that in western regions during the China Western Development period in the 2000s. In other words, the larger firms in west are performing worse than that in non-west. Although, many policies included in China’s Western Program are meant to benefit large-scale firms in the west by enabling them to improve their efficiency, we can still see disparities among large western firms and large non-western firms in terms of the diffusion of energy-efficient technology during the period covered by this program. One reason why this program was not entirely successful is that the government only supported the expansion of firm scale rather than the adoption of new technologies (Wang et al., 2012). Because of the availability of the data, the variable SHEETS is calculated by wire and rod steel production. Because of the negative sign of the variable SHEETS in the regressions in both Column 2 and Column 3, we find that both western and non-western firms tended to use continuous casting technology to produce sheets and slabs of steel rather than wires and rods. In addition, western firms are more likely to be motivated to adopt this technology, which is not in line with our original assumption. However, this result is not surprising, given the high market demand for steel sheets and slabs, and the western firms’ interest in using efficient technology based on market demand. A comparison of the respective magnitudes of the coefficient associated with output growth (Q) shows that this variable tended to influence western firms more than non-western ones. In other words, the western firms’ showed a stronger interest in replacing outdated ingot technology than in
expanding their capacity. The extent to which firms in the western region lacked behind firms in other regions in terms of adopting new technology may not have remained stable during the focal periods. The coefficients associated with investment growth (INVEST) are significant in both the western and the non-western region but their signs are different. The positive sign of the coefficient for the non-western firms suggests that those firms were more restricted by their own investment constraints. The negative sign of the coefficient for the western firms indicates that the more investment growth the western firms had, the more slowly those firms diffused continuous casting technology. Based on the findings above, my results suggest that even though government policies such as the China’s Western Region Development focused on supporting western firms in an effort to expand their investment budget, high investment growth does not appear to be associated with a high speed of continuous casting diffusion. Government policies, therefore, should concentrate on investing in advanced production technology such as continuous casting technology in order to achieve the production efficiency.

In conclusion, the China’s Western Region Development program does appear to have a positive impact on western steel firms, in as much as the rate at which they have adopted technology has accelerated. The potential for increased demand for high-quality steel such as sheets and slabs steel resulting from China’s Western Region Development program may be motivating western firms to adopt advanced technology. Western steel firms are more likely to achieve production efficiency in an appropriate way than non-western firms are; for example, western firms are more motivated to replace old equipment with continuous casting technology to achieve efficiency, which is consistent with a finding reported in Ma (2000). Though the main focus of China’s Western Region Development program is to achieve efficiency and productivity through large-scale firms, the disparities in the rates at which large-scale western and large-scale non-western firms are adopting energy-efficient
technology still exist. To compete with world most advanced steel producers, however, large firms in the western region still require more effort and policies to support efforts to improve efficiency.
Chapter 5

Conclusion
Important questions pertain to the factors that matter most to technology diffusion. These factors appear to have a different level of influence during different periods depending on the relevant prevailing governmental policies. Due to insufficient up-to-date firm-level data, previous research, unlike the present study, have generally been unable to capture the influence of these factors in the last decade, characterized by China’s Western Development and the country’s accession to the WTO, and how the influence of these factors during this period differs from their influence in other times. In particular, the present research focused on the diffusion of continuous casting technology in China’s iron and steel industry by drawing on firm-level data from 1985 to 2009, which allowed the researcher to investigate the factors affecting the diffusion of continuous casting technology. The findings of the present paper differ from findings in previous research: according to previous research for the period 1985–1995, steel firms with a high level of government supervision and intervention diffused new technology more slowly and were less motivated by market factors than were firms with a low level of government supervision and intervention (Fisher-Vanden, 2003). Based on up-to-date data, the findings of the present study show that government interventions, such as China’s Western Region Development program, benefit and motivate western steel firms to diffuse continuous casting technology in appropriate ways and thereby accelerate the diffusion of continuous casting technology. The main purpose of China’s Western Region Development program was to help the undeveloped western areas to become efficient and productive through the creation of large-scale firms. However, despite this effort, disparities in the extent to which western large-scale firms and non-western large-scale firms have adopted energy-efficient technology exist. The government, therefore, should concentrate on supporting the adoption of new technology rather than on extending firm size. The current study also suggests that the government should make a greater investment in continuous casting technology diffusion for western steel firms. China’s accession to the
WTO is also motivating steel firms—especially for old steel firms and the firms which are producing sheets and slabs steel—to overcome the initial difficulties associated with incorporation continuous casting equipment into their production processes. The former key firms, which were relatively insensitive to market factors in the pre-WTO period because of their close relationship with the central government have become more motivated to improve their processes and to become more commercially viable in the face of China’s new openness to world trade.

There are still some problems, which cannot be solved in current stud. Previous studies (Fisher-Vanden, 2003; Fisher-Vanden et al., 2009) described continuous casting technology as capable of significantly improving steel quality and reducing the energy intensity of individual steel firms. However, due to a lack of up-to-date data on firm-level steel quality and energy intensity, the extent to which continuous casting technology improves firms’ performance in terms of steel quality and energy intensity may change from period to period. For example, in the 2000s, emerging technology in production processes other than the casting process also improved firms’ productivity, and continuous casting technology became more accessible due to lower installation costs. Thus firms’ increased productivity performance to a greater extent than during other periods due to a technological revolution. Firms’ motivation to improve their performance in production quality and energy intensity through continuous casting technology is also subject to change over time. As this result, the question as to whether and how improvements in steel firms’ productivity performance inspired by China’s Western Region Development and accession to WTO are directly associated with the continuous casting diffusion is unclear. To answer this question, data relating to firm-level steel quality and energy intensity should be collected for further research studies, and then the relationship between the diffusion of continuous casting and firms’ productivity performance in energy and quality will be known.
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