TECHNOLOGICAL DIFFUSION IN CHINA'S IRON AND STEEL INDUSTRY

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E-98-26 DECEMBER 1998

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November 1998

Draft. Please do not cite

CITATION

This document appears as Discussion paper 98-26 of Belfer Center for Science and International Affairs and as contribution E-98-22 of the Center's Environment and Natural Resources Program. Comments are welcome and may be directed to the author at the Belfer Center.

This paper may be cited as Karen Fisher-Vanden. "Technological Diffusion in China's Iron and Steel Industry." BCSIA Discussion Paper 98-26, ENRP Discussion Paper E-98-22, Kennedy School of Government, Harvard University, December 1998.

EXECUTIVE SUMMARY

Any serious attempt to address the global climate change problem must involve the diffusion of energy-efficient technologies into the industrial sector of countries critical to future global emissions. China is expected to be the largest emitter of greenhouse gas emissions by early next century due to its high economic growth and reliance on coal. Although the diffusion of energy-efficient technologies in China has increased since the start of market reforms in 1978, much improvement is still needed.

In an attempt to understand the impediments to technological diffusion in China, this paper explores the dominant factors influencing the diffusion rate of continuous casting technology—an advanced technology that can achieve energy savings of ~10% per ton of crude steel produced—among Chinese steel firms. Informed by the literature on technological diffusion and interviews with individuals associated with the steel industry in China, this paper develops a theoretical model of the diffusion process and empirically tests potential factors affecting firm-level diffusion of continuous casting technology using panel data of 75 steel firms in China covering the period 1985-1995. The empirical results suggest that although market forces are beginning to have an effect on the diffusion rate, institutional constraints continue to impede the process.

This research makes important contributions to the literature by providing not only one of the few econometric analyses of the determinants of technological diffusion in developing countries, but also one of the few analyses of a country critical to a climate change solution—China.

ACKNOWLEDGMENTS

This work was supported by the Crump Fellowship for research on energy and the environment, a travel grant from Harvard's University Committee on Environment with funds provided by the Exxon Corporation, and the Luce Foundation. The author benefited from insightful discussions with Richard Garbaccio, Mun Ho, Adam Jaffe, Gary Jefferson, Dale Jorgenson, Barry Naughton, Robert Stavins, and Takashi Sugimoto.

This work also benefited from valuable insights obtained from interviews in China with the following individuals: Erhard Wallentin, Shi Chenxing, and Zhou Qun of Concast Standard, Professor Tian Naiyuan of China's University of Science and Technology Beijing, staff at Shougang Iron and Steel (especially Liu Lijun), Shi Yingyi of the Beijing Energy Efficiency Center (BECon), Liu Zhiping of China's Energy Research Institute, Olaf Stalfort of SMS Schloemann-Siemag, staff at the Beijing Central Engineering and Research Incorporation of Iron and Steel Industry (especially Shi She), Zhang Xinchuan, Xue Chuanzhao, and Dong Yizheng of China's Ministry of Metallurgical Industry, Qin Hai of Chongqing Special Steel, staff at Chongqing Iron and Steel (especially Ceng Zuqian), staff at Baoshan Iron and Steel (especially Wang Chengwei, Zhang Qinglang, Wu Dongying, Ren Yan, and Xie Jianping), and Shao Weiqiu and Hou Tielin of Shanghai Metallurgical Holding Co. I am immensely grateful to Karen Eggleston—my travel companion in China. Without her assistance, this field research would not have been possible.

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1. Introduction

To reduce future emissions of greenhouse gases from human activities requires the incorporation of more energy-efficient technologies into the production process. Experience (e.g., with the Montreal Protocol on Substances that Deplete the Ozone Layer) shows that international environmental commitments are much easier to obtain if viable alternatives exist. However, this implies more than providing the necessary incentives for the development and adoption of advanced energy technologies in industrialized countries. Attention must be given to the diffusion of these technologies in countries critical to a global climate change solution—e.g., China and Russia. Large countries like China that are making the transition from a planned economy to a market economy, experiencing high rates of economic and population growth, and predominately coal-based, are critical to any climate change agreement since future emissions in these countries are expected to swamp any efforts by industrialized countries to lower greenhouse gas emissions. China in particular has received much recent attention since it is expected to be the largest emitter of greenhouse gases before the middle of the next century.

Prior to the start of market reforms in 1978, the diffusion of advanced technologies in China was controlled by the central government, with targeted industries specified in the central plan. Politics played a large role in determining which firms received investment capital and had access to advanced equipment from foreign suppliers. With the introduction of market reforms in 1978, the situation has started to improve. The primary source of investment has shifted from central government budget allocations to retained earnings, and firms are gaining better access to advanced technologies. Although these initial results are promising, serious efforts to encourage the diffusion of energy-efficient technologies are still needed in China. For instance, the central government still restricts access to foreign equipment suppliers through a lengthy approval process, allowing only equipment that cannot be built domestically to be imported.

In an attempt to understand the impediments to technological diffusion in China, this paper explores the dominant factors influencing the diffusion rate of continuous casting technology among Chinese steel firms. Continuous casting is an advanced technology that can achieve an energy savings of ~10% per ton of crude steel produced. Informed by the literature on technological diffusion and interviews with individuals associated with the steel industry in China, this paper empirically tests potential factors affecting firm-level diffusion of continuous casting technology using panel data of 75 steel firms in China covering the period 1985-1995. The results suggest that although market forces are beginning to have an effect on the diffusion rate, certain institutional constraints continue to impede the process.

This research contributes to the literature in several ways:

(1) Econometric analyses of the determinants of technological diffusion in developing countries or economies in transition have been lacking in the literature. Due to the difficulties in acquiring reliable firm-level data necessary for econometric analyses, most studies on technological diffusion in developing countries have involved case study analyses. Because the focus of studies of technological diffusion has in general been on industrialized countries where an important underlying assumption is a fully-functional market economy, no one has empirically examined the effects of *market forces* on the diffusion of new technologies. Due to the current dual nature of China's economy—part planned and part market—and the gradual introduction of the market through reforms, it is possible to analyze the effect of market forces on diffusion while avoiding important country differences that can affect the diffusion rate.

(2) A majority of the past work on technological diffusion has focused on the discrete choice of *adoption* (i.e., first use of an innovation by a firm) rather than *conversion* (i.e., the conversion of a firm's entire production process to the new innovation), which is a choice of degree. When assessing energy efficiency improvements within a sector comprised of a large fixed capital stock, conversion of the existing capital stock rather than first adoption should be the focus. Complexities arise, however, when examining the issue of conversion since it involves a dynamic modeling approach requiring cross-sectional time series data that can be difficult to obtain. By concentrating on continuous casting technology in China's steel industry, it is possible to compile a panel data set (75 steel firms, 11 years) appropriate to conduct an analysis of the determinants of conversion to continuous casting technology. Concentrating on one technology also avoids having to account for inherent differences among technologies which can significantly influence the results.

(3) Most of the current work examining the effects of market reforms in China on firm performance has focused on productivity—i.e., the amount of factor inputs required per unit output. This research takes a closer look at the issue by examining one of the primary contributors to productivity improvements: The incorporation of more efficient technology.

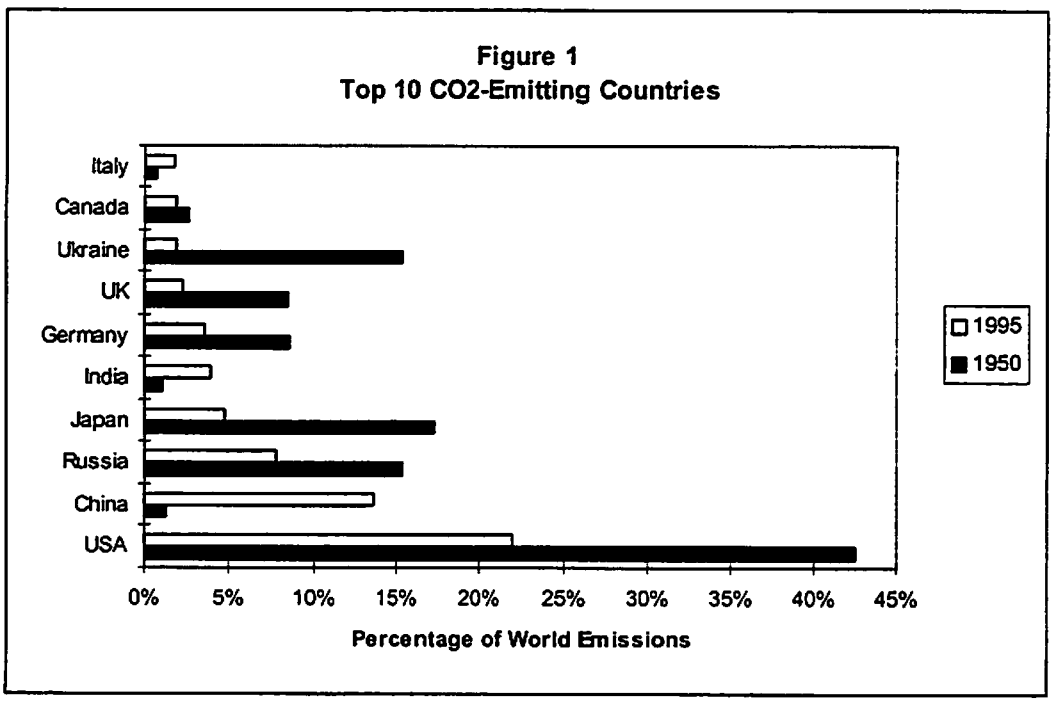
This paper is organized as follows. Section 2 provides an overview of China's energy use and greenhouse gas emissions, China's current participation in an international climate change agreement, and market reforms that are helping to lower China's energy intensity[1]. Section 3 discusses the history of technological improvements in China's iron and steel industry—an industry which is one of the largest users of coal and is currently undergoing significant changes due to market reforms—and presents information from interviews in China with individuals associated with the steel industry. These interviews identify certain institutional constraints as important factors affecting the diffusion rate of new technologies in China.

[1] Energy intensity is defined as energy consumed per unit output

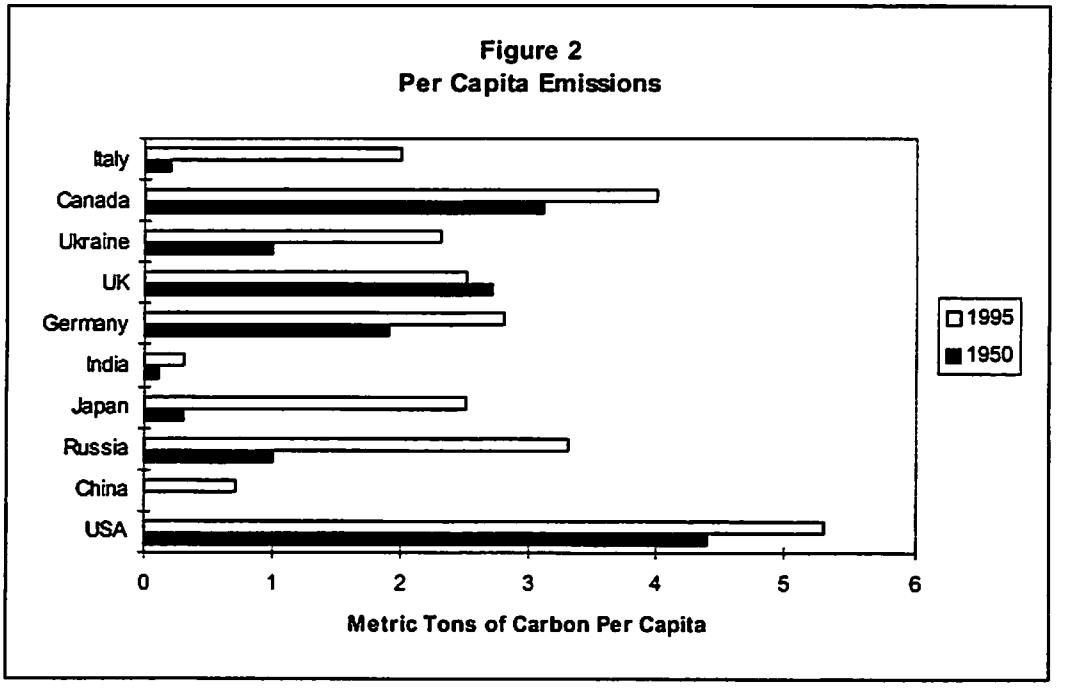
Informed by the literature on technological diffusion and by the interviews conducted in China, Section 4 looks at the issue of the diffusion of continuous casting technology in China both theoretically and empirically. As a point of departure, Section 4.3 develops a theoretical model of continuous casting diffusion under the assumption that firms are profit-seeking and operating under market conditions. To measure the influence of "market" factors on technology choice among Chinese firms, results from the empirical estimations of a random effects model using panel data of 75 Chinese steel firms over 11 years (1985-1995) are presented in Section 4.4. Section 4.5 modifies the "market" model to account for "institutional" constraints that can have a significant influence on the diffusion of continuous casting technology in China. Section 4.6 presents results from the random effects model of Section 4.4 with these "institutional" constraints added. Section 5 offers conclusions.

2. China's Energy Use and Carbon Emissions

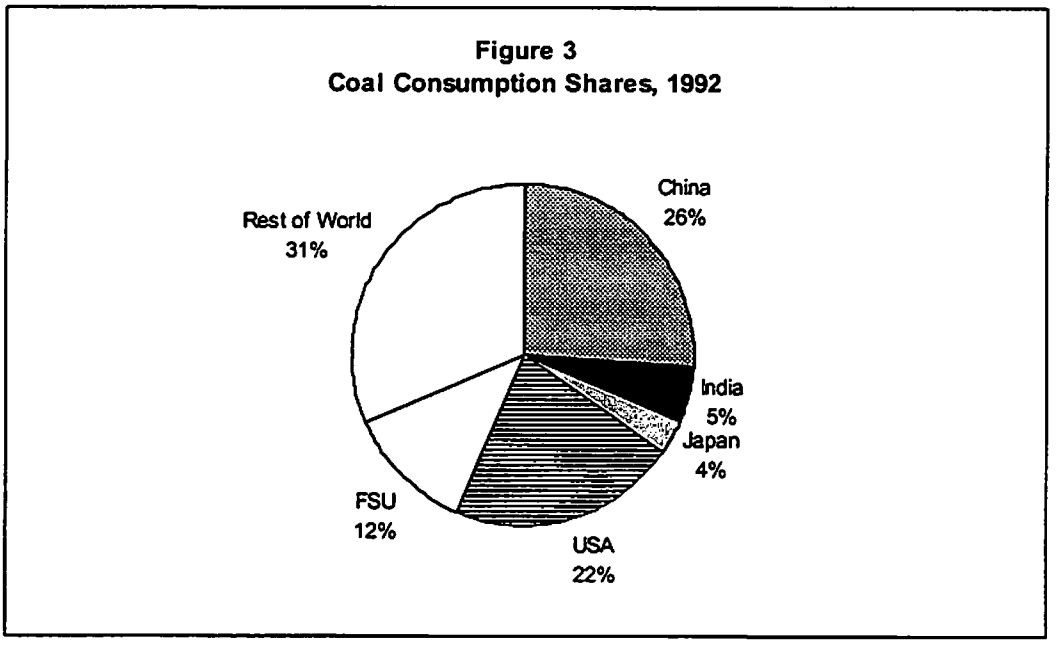
The importance of China with respect to future carbon emissions is evident from Figure 1. China rose from being the tenth largest CO^2-emitting country in 1950 to the second-largest CO^2-emitting country in 1995. In terms of per capita emissions, however, China is one of the smallest due to its large rural population (Figure 2). As shown in Figure 3, in 1992, China was the largest coal consumer in the world, which has serious implications for greenhouse gas emissions since coal has the highest carbon content among the fossil fuels. With continued high economic and urban population growth likely in the future, China is expected to become the largest emitter of CO_2 by early in the next century.



Source: TRENDS, 1997. Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory



Source: TRENDS, 1997. Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory



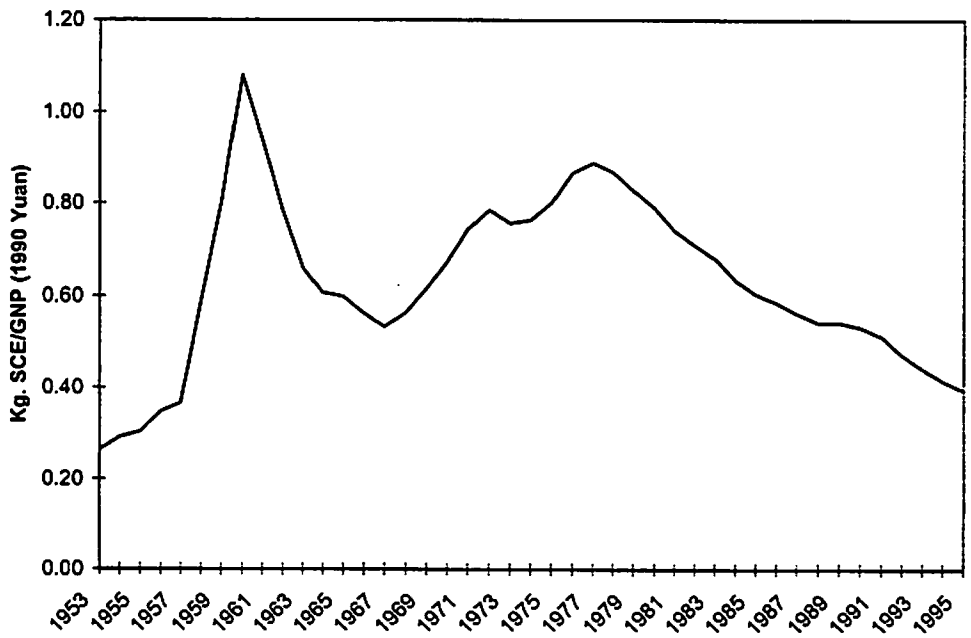
Source: Sinton et al [1996]

Although China is an important country from the standpoint of future emissions, it is exempt from commitments to reduce greenhouse gas emissions outlined in the Kyoto Protocol of the Framework Convention on Climate Change (FCCC) adopted in December 1997. This exemption was based on China's developing country status, its low contribution to cumulative emissions thus far, and its low per

capita emissions. However, China's future contribution to global emissions is worrisome since many believe it will swamp efforts by developed countries to lower emissions. This concern prompted a Senate resolution, approved in July 1997, that urges the Clinton administration to oppose a climate change treaty unless it includes emissions caps for developing countries (Greenwire, 7/28/97). Programs such as international tradable permits and joint implementation (referred to as the "Clean Development Mechanism" (CDM)) have been discussed as possible ways to include developing country participation. One way these programs achieve low-cost emissions reductions is by encouraging the adoption of energy-efficient technologies in developing countries.

Although there is great potential for further energy-efficiency improvements in China, China has since the 1970's made significant strides in lowering its energy intensity. As shown in Figure 4, China's energy/output ratio has fallen dramatically since the late 1970's. This fall can be attributed to two factors: (1) Structural change—in particular, the shift from heavy industrial production to light industrial production; and (2) Technological change—i.e., the incorporation of more energy efficient technologies into the production process. Although both are having an effect, recent studies (e.g., Polenske and Lin [1993], Garbaccio, Ho, and Jorgenson [1997]) point to technological change as the major factor behind China's energy efficiency improvements.

Figure 4
Energy-Output Ratios, 1953-1995



Source: Garbaccio, Ho, and Jorgenson [1997]

The late 1970's marks not only the start of China's decline in energy intensity, but also the beginning of market reforms, suggesting that market reforms may have contributed to this energy intensity trend reversal. Prior to the start of market reforms in 1978, diffusion of advanced technologies in China was controlled by the central government, with targeted industries specified in the central plan. Politics played a large role in determining which firms received investment capital and had access to advanced equipment from foreign suppliers. Since the introduction of market reforms, the primary source of investment has shifted from central government budget allocations to retained earnings, and firms have gained better access to advanced technologies. Although these initial results are promising, certain institutional constraints still impede the diffusion of energy-efficient technologies in China. For example, the central government continues to restrict access to foreign equipment through a lengthy approval process allowing only equipment that cannot be built domestically to be imported.

The most successfully implemented market reform thus far in China has been the reform of the pricing system. Prior to reforms, prices for agricultural products, consumer goods, and industrial products were set by the central government. In 1984, the Chinese government passed regulation allowing state-owned enterprises to sell output above a set quota at prices different from state-set prices. This led to marginal decisions of producers based on market prices rather than plan prices. As shown in Table 1, the factor input prices most heavily controlled are the prices of energy inputs. In 1990, crude oil faced a plan price one-sixth of the market price, and of total crude oil production, 80% was sold at plan prices. Price reforms implemented in 1992-1994 have dramatically reduced the amount of energy sold at (lower than market) plan prices. Liberalization of prices will increase the average prices of energy inputs, providing incentives for firms to increase efforts to lower energy consumption. However, even with these recent reforms, certain key industries (e.g., those with substantial political influence) continue to receive significant portions of their energy inputs at below-market ("guidance") prices.

Table 1
Plan vs. Market Prices for Key Production Inputs, 1990

Material	Market Price/Plan Price	Plan Quantity Allocation %
Crude oil	5.92	80%
Coal	2.70	46%
Heavy Oil	2.66	41%
Timber	2.49	22%
Fertilizer	2.30	39%
Copper	2.29	17%
Gasoline	2.07	64%
Diesel Fuel	2.01	55%
Aluminum	1.92	28%
Electric Power	1.77	75%
Steel Products	1.76	30%
Kerosene	1.68	73%
Nitric Acid	1.65	40%
Aluminum Products	1.52	28%
Caustic Soda	1.47	47%
Copper Products	1.46	8%
Pesticide	1.33	62%
Pig Iron	1.33	47%
Iron Ore	1.31	78%
Soda Ash	1.27	40%
Cement	1.24	16%
Crude Salt	1.23	86%
Sulphuric Acid	1.12	40%
Plate Glass	1.11	41%

Source: Garbaccio [1995]

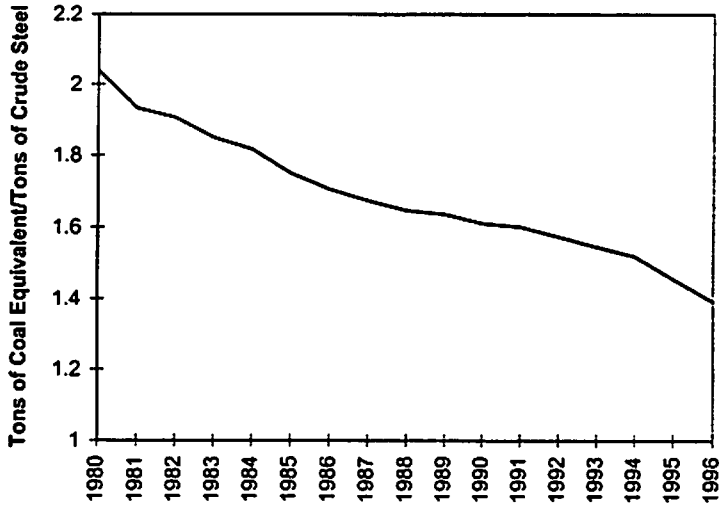
An important industry with respect to China's overall energy consumption is iron and steel. As discussed further in Section 3, this is largely the result of China's emphasis on the development of its steel industry over the last 50 years. China's desire to become the largest steel producer in the world—a goal reached in 1996—has not always been based on economics. Over-ambitious production targets resulted in an overabundance of low quality steel in recent years, causing steel prices to plummet and requiring China to import large quantities of higher quality steel products from countries like Japan.

China's emphasis on steel production also led to preferential treatment given to the steel industry with respect to investment allocations and scarce energy inputs. In 1994, energy consumed by the iron and steel industry amounted to 16% of total energy consumed by China's industrial sector (Sinton et al [1996]). With 70% of total end-use energy consumed by the industrial sector, this implies that the iron and steel industry consumed approximately 11% of China's total end-use energy. Much of the energy consumed by the iron and steel industry is in the form of coke—a product of coal.

Of the world's steel producers, China uses more energy to produce one ton of steel than most other countries (Lin [1994]). Lin [1994] identifies seven reasons for China's high energy per ton ratio, including China's use of obsolete furnaces, low penetration of continuous casting technology, and high

iron to steel ratio. Although China's steel industry has become more energy efficient since the start of reforms (Figure 5), there is still great potential for further improvements in energy efficiency.

Figure 5
Energy-Output Ratio of the Iron and Steel Industry



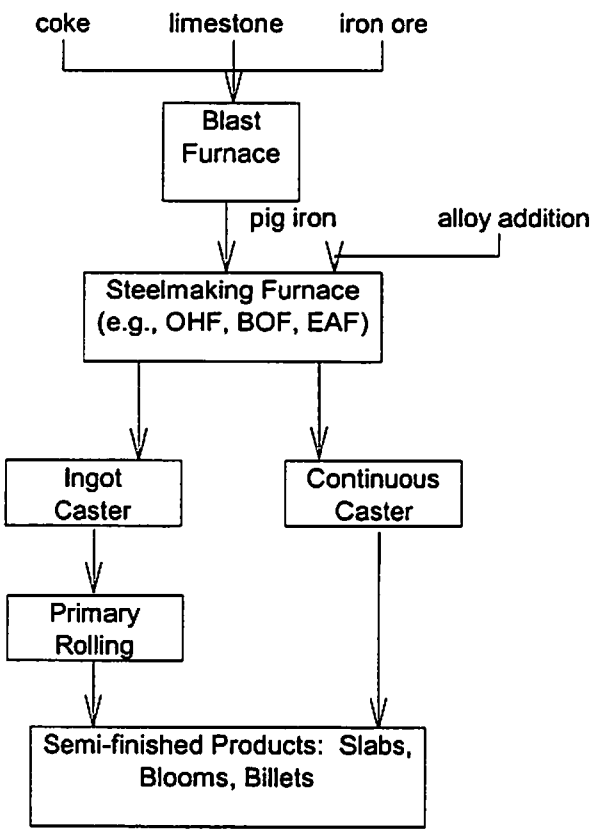
Source: *The Yearbook of Iron and Steel Industry*, Ministry of Metallurgical Industry, annual; Lin[1994]

Two distinct processes of steel production in which energy efficiency can be improved by replacing obsolete technology are the steelmaking process and the casting process. There are three alternative furnace technologies in the steelmaking process: Open hearth furnace (OHF), basic oxygen furnace (BOF), and electric arc furnace (EAF). A basic oxygen furnace can easily replace an open hearth furnace, with an energy savings of approximately 3.0 GJ per ton of steel (Worrell [1995]). EAF is used in the production of secondary steel and requires about half the amount of energy as other process routes since it utilizes scrap and thus avoids the energy-intensive process of pig-iron production. In 1982, 61% of steel production in the US used BOF, 8% used OHF, and 31% used EAF. In China, 50% used BOF, 32% used OHF, and 18% used EAF. In 1993, 62% used BOF, 0% used OHF, and 38% used EAF in the US while 64% used BOF, 14% used OHF, and 22% used EAF in China (World Energy Council (1995)).

Two technologies are part of the casting process: Ingot casting and continuous casting. A representation of the steel production process is shown in Figure 6. Iron ore, limestone, and coke are added to the blast furnace to produce molten pig iron. Molten pig iron is transferred to steelmaking furnaces, where it is converted to molten steel through the addition of alloy elements and the process of carbon oxidation. The molten steel is then physically transferred to the casting process via ladles. With ingot casting, the molten steel is made first into ingots and then reheated and shaped into the semi-

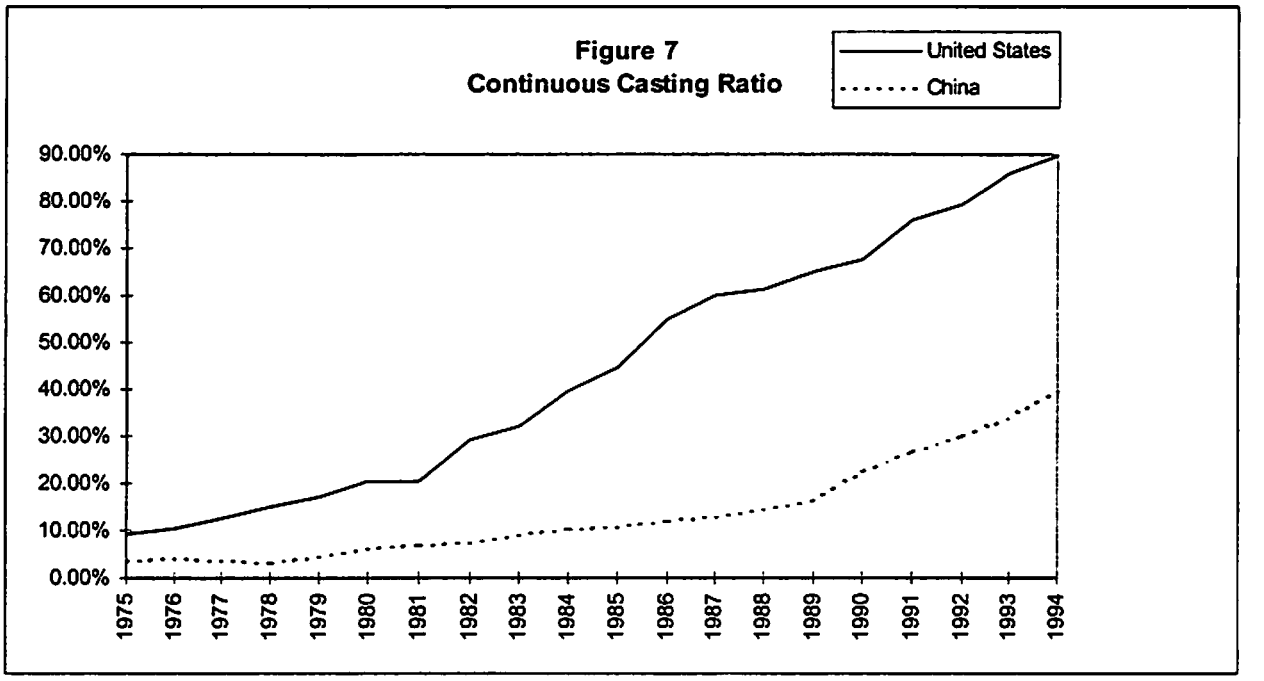
finished product in the primary rolling stage. Continuous casting bypasses this reheating stage by converting the molten steel directly into the semi-finished product.

Figure 6
The Steelmaking Process



Source: Wilshire, Homer, and Cooke [1983]

Switching from ingot casting to continuous casting is estimated to achieve an energy savings of 1.1-1.8 GJ/ton—approximately 10% energy savings per ton of steel produced (Worrell [1995]). In 1975, the percentage of continuously cast steel in the United States was 9.8% while in China this percentage was 3.5% (IISI [1995]). However, since 1975, China's rate of diffusion has lagged behind that of the U.S. and other developed countries—the percentage of CC steel in the U.S. in 1994 was 90%, while in China the percentage was only 40% (Figure 7).



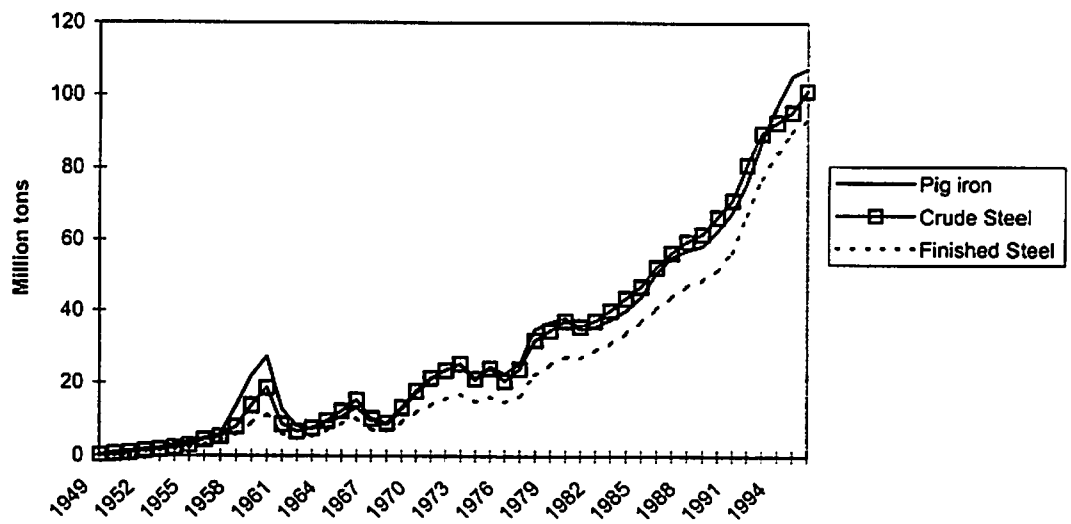
Source: *Steel Statistical Yearbook*, International Iron and Steel Institute (IISI), various issues.

A goal of this research is to identify the dominant factors contributing to China's slow conversion to continuous casting technology. Two approaches are taken. First, Section 3 provides results from a case study of China's iron and steel industry, including information collected from interviews conducted in China with various individuals associated with the steel industry. Second, after a review of the technological diffusion literature, Section 4 develops a theoretical model of diffusion of continuous casting technology and provides results from an econometric analysis using cross-sectional time series data of 75 Chinese steel firms over the period 1985-1995.

3. Technological Innovation in China's Iron and Steel Industry[2]

The iron and steel industry has been the focus of development in China since the establishment of the People's Republic of China in 1949. Following the Soviet example, the Chinese emphasized the development of heavy industry by directing the majority of capital construction investment to heavy industry at the expense of light industry and agriculture. The steel industry was a large recipient of this capital construction investment. The Chinese considered steel to be the key link to development, which led the government to set high output targets supported by large capital investment flows. As a result, growth in steel output has been considerable (Figure 8).

Figure 8
Production of Pig Iron, Crude Steel, and Finished Steel



Source: *The Yearbook of Iron and Steel Industry*, Ministry of Metallurgical Industry, annual; Hinton [1985].

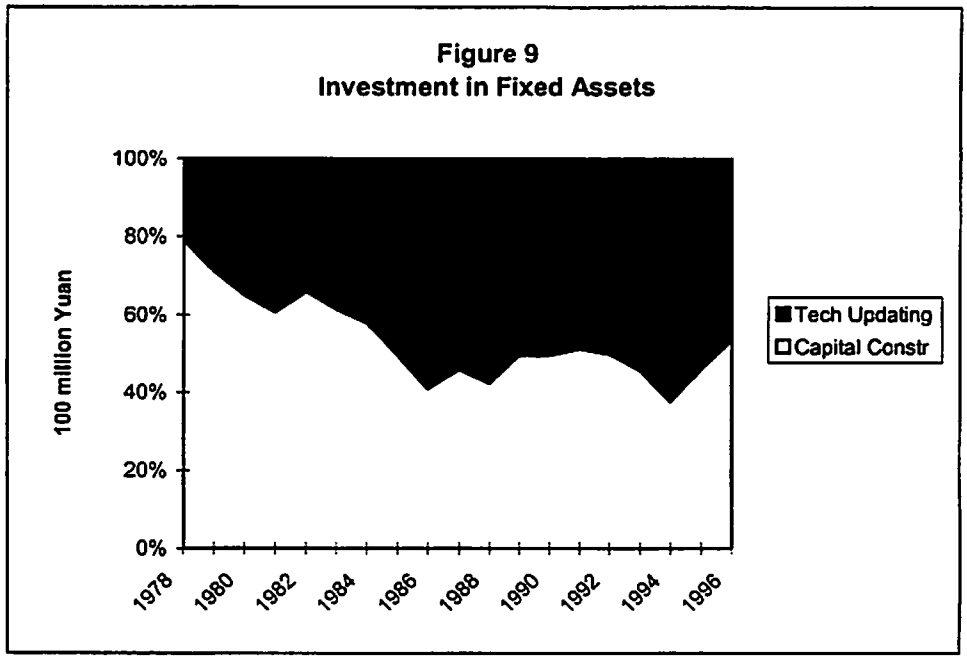
A notable jump in iron and steel production occurred during the "Great Leap Forward" (1958-1962) as a result of a national campaign of "all people making steel." Thousands of small-scale steel facilities and "backyard furnaces" sprang up as part of this national campaign, causing most of the production increase to come from pig iron and crude steel production and not finished products. With the change in leadership as a result of the death of Mao Zedong in 1976, emphasis shifted from heavy industry to light industry and agriculture; however, the steel industry was able to maintain its phenomenal growth due to the large excess demand for steel.

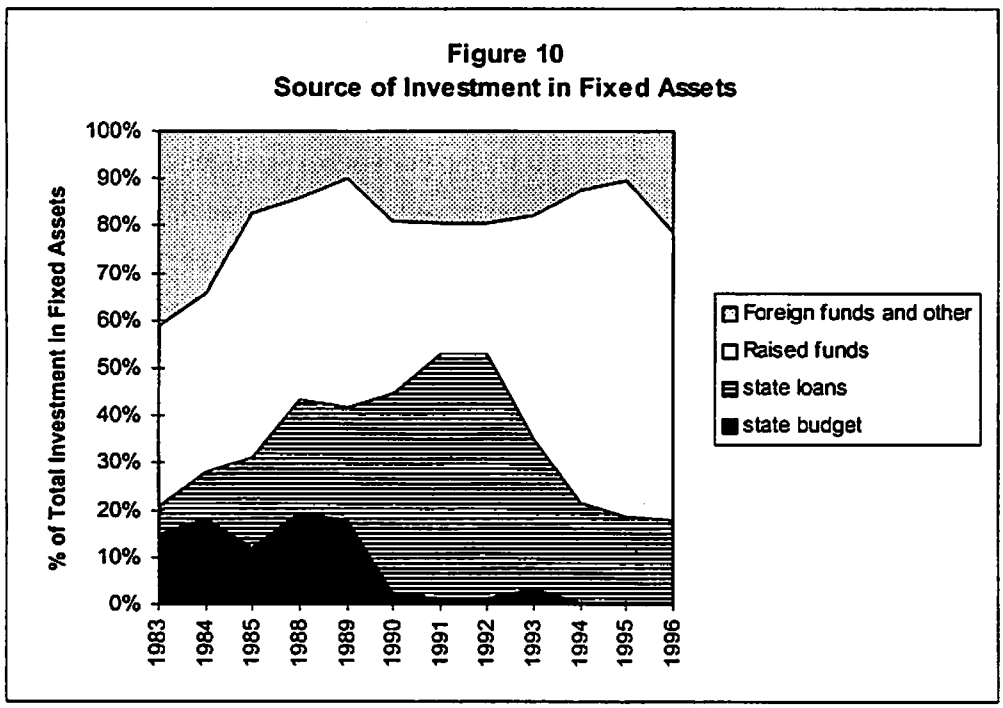
[2] The historical information in this section on the period prior to 1984 draws heavily from Hinton [1985].

Technical innovation in the Chinese steel industry has taken many different forms since 1949. In the early years of the PRC, most technical expertise came from the Soviets, initiated by the 1950 Sino-Soviet Treaty of Friendship. As the Soviets were the developers of the open hearth furnace (OHF), the furnace technology of choice in China was OHF while a more efficient technology, BOF, was being adopted by the rest of the world. The shift to BOF was slow since most Chinese were trained in the USSR and therefore believed that OHF was the superior technology. A change in attitude came as relations with the Soviets began to sour in the early 1960's, and the Chinese began to import technology from the Japanese and Western Europeans—however, since the installed base of OHF was relatively young with many years of productive life left, the conversion to BOF was slow. Even as recently as 1983, the percentage of steel output from OHF in China was 30%.

Technological innovation stalled during the Cultural Revolution of 1966-1976. The emphasis on self-reliance led to the cessation of imports of advanced technologies. With the end of the Cultural Revolution and the death of Mao, imports of steel technology resumed and a large-scale "green field" project, Baoshan Steel, was initiated. This new steel facility was to be a modern Japanese steel facility, built by Nippon Steel and transferred to China. During the late 1970's and early 1980's, the majority of the Ministry of Metallurgy's investment budget was funneled to the construction of Baoshan Steel (Hinton [1984]). This caused much resentment among the Chinese leadership, which led to the temporary suspension of the second phase of construction of Baoshan (resumed two years later), a new policy for importing technology, and a new investment policy which allows firms to use retained earning for renovation and technological updating purposes (Hinton [1984]).

These policies continued under the new leadership of Deng Xiaoping and after the initiation of market reforms in 1978. As shown in Figure 9, emphasis has shifted from investment in capital construction to investment in technical updating and reconstruction. In addition, Figure 10 shows the elimination of the state budget as a significant source of investment and the growth of self-raised funds (retained earnings) as the dominant source of fixed assets investment.





Source: *The Yearbook of Iron and Steel Industry*, Ministry of Metallurgical Industry, annual.

Market reforms have helped increase the diffusion of new technologies in China's producing sector by: (1) Increasing the availability of investment funds for the purchase of new technologies; (2) providing incentives for firms to innovate; (3) expanding access to advanced technologies; and (4) increasing the dissemination of information about new technologies. However, interviews with various

individuals associated with the Chinese steel industry lead to identification of certain institutional constraints in each of these four areas that continue to impede the diffusion of continuous casting technology in China[3].

(1) Credit Constraints

An often-heard explanation from interviews for the slow diffusion of continuous casting (CC) technology is the firms' inability to raise the necessary capital investment funds. As shown in Figure 10, there are currently three primary sources of investment for firms—raised funds (or retained earnings), state loans, and foreign funds. Until the tax reforms of 1994, the level of profit a state-owned firm was required to remit to the state was detailed in contracts which were negotiated with the state on a firm-by-firm basis[4]. Therefore, the terms of the contract depended heavily upon the political strength of the firm's manager. In addition to its profit remittance contract with the state, a firm's retained earnings have been affected by the firm's social responsibilities. In most cases, steel firms are obligated to provide housing, health care, education, and retirement benefits to their employees, retirees, and dependents. Many steel facilities are small cities with housing complexes, schools, and medical facilities located within the steel complex itself. Recent reforms are attempting to free firms from these social responsibilities, but have only scratched the surface.

Given the large capital cost of CC equipment—ranging from $10 million to $250 million—it is rarely the case that a firm is able to fund the purchase of CC equipment out of retained earnings alone. The firm must look to other sources, such as loans. However, it is difficult for firms in China to secure such large sums from domestic banks. Loanable funds in China are limited, causing banks to prioritize projects. Since the Chinese central government controls the banks, there are still preferential lending and "policy loans," which are distributed to support a particular industrial policy promoted by the central government or to bail out failing firms. As part of a national campaign started in the early 1990's to promote the adoption of continuous casting, the state has extended some preferential bank loans for the purchase of CC equipment. However, many firms do not have access to these loans.

In addition, a firm's access to foreign funds (e.g., foreign loans, foreign direct investment) and other sources of investment (e.g., funds raised through equity markets) is limited by the central government. A few firms have been given permission by the central government to offer shares on Chinese (and other) stock exchanges (e.g., the Shanghai and Hong Kong stock exchanges). However, these joint-stock offerings have amounted to a one-time infusion of capital to these firms and not to increased incentives due to private ownership (Steinfeld [1997]). Essentially, these firms have created

[3] See Appendix A for a list of sites visited in China.
[4] The tax reforms of 1994 have created a tax system in which all firms face the same statutory rates.

joint-stock companies out of the most profitable operations of the firm (e.g., the steelmaking facilities) and holding companies out of the less profitable parts (e.g., mining operations), which are saddled with the firm's social responsibilities without the benefit of profits from the steelmaking component of the firm (Steinfeld [1997]). Thus, it is not necessarily the case that the more profitable firms are becoming joint-stock companies. In many cases, these joint-stock firms are some of the least profitable, but are in desperate need of investment capital.

A small number of joint ventures have also been allowed recently by the central government in an attempt to increase the number of specialty products like seamless steel tubes and steel for automobile manufacturing—products which have been heavily imported by China in the past. These joint-ventures are not for the purpose of revitalizing existing plants, but rather to build capability in new product areas.

(2) Incentives to Innovate

In China—as in other countries making the transition from plan to market—the challenge is to increase the efficiency of state-owned enterprises through incentives introduced by market reforms. Recent price reforms in China have been generally successful, since most enterprises now face market prices (especially at the margin) for factor inputs and output. Problems persist, however, due to the fact that state-owned enterprises in China continue to carry a large social burden and managers still face political pressures to expand output.

Since the late 1970's, the Ministry of Metallurgical Industry has separated state-owned iron and steel firms into two categories: "Key" firms and "local" firms. "Key" firms are typically supervised directly by the central government and in the past have been required to supply to "key" government industries such as the military. One way to characterize the difference between "key" and "local" firms is the existence or lack of well-defined property rights. In general, "key" firms must answer not only to central government authorities, but to provincial or municipal authorities as well. Steinfeld [1997], in a case study of three "key" steel firms in China, identifies differences in property rights to be the primary reason for the variation in performance among the firms in his study. For instance, Steinfeld suggests that the poor performance of Anshan Iron and Steel, a "key" firm located in Liaoning province, is likely due to the extraction of the firm's revenues by every level of government, leaving the firm with negative profits in most years and a "triangular debt" situation[5]. In this case, because no level of government is assuming complete ownership of the firm, a "tragedy of the commons" situation emerges.

"Local" firms, on the other hand, have little or no direct supervision from the central government. Since these firms traditionally have supplied to local markets and are in most cases an

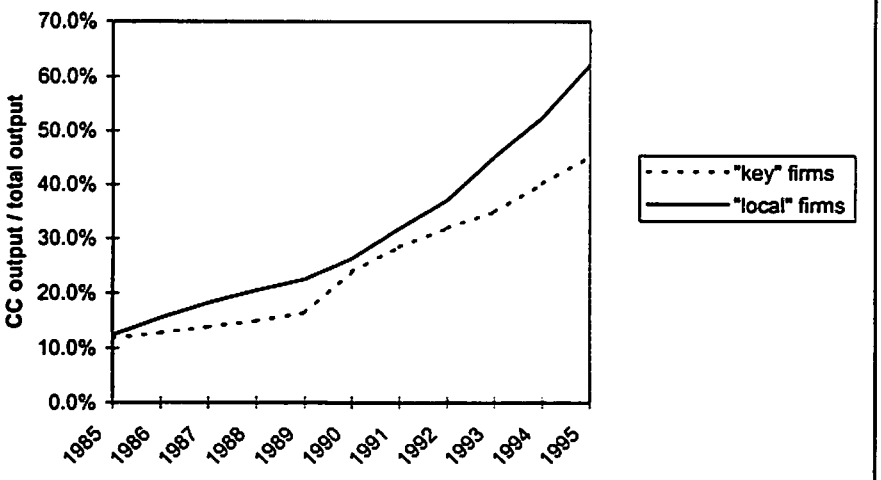
[5] Triangular debt occurs when a firm is unable to pay its suppliers because of nonpayment from its customers.

important source of revenue for the local government, local authorities have an incentive to improve the performance of these firms by reinvesting large portions of the firm's profits back into the firm.

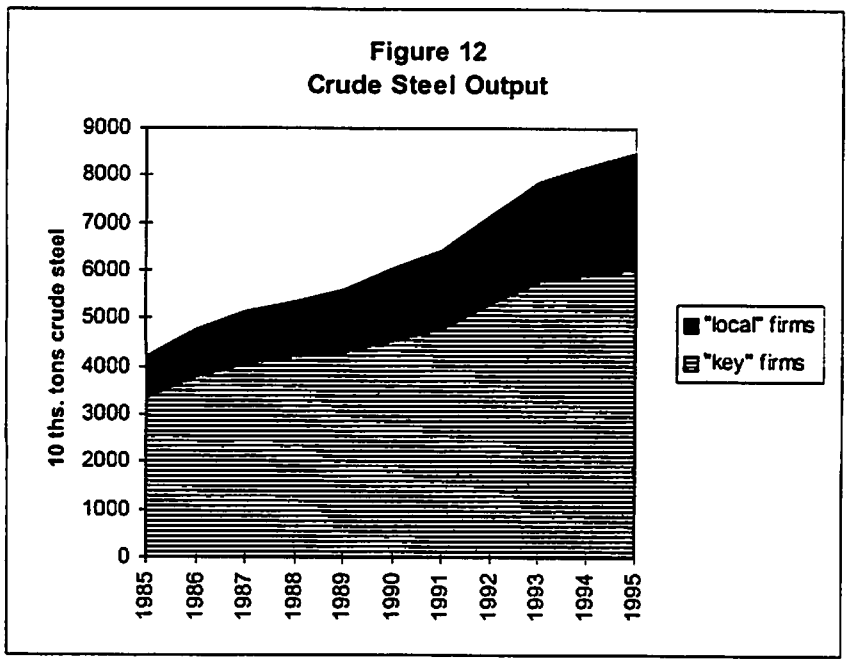
Differences in performance between "key" and "local" steel firms are documented in Jefferson [1990], which finds greater improvements in productivity among local firms than key firms. As discussed in Li [1997], as part of the market reforms introduced in the late 1970's the Chinese central government took serious steps to transfer property rights to the local level. Because of this, Li believes, local authorities possess the incentive to maximize the value of their enterprise. Li finds in his econometric analysis of total factor productivity among Chinese firms a significant improvement of resource allocation, which he attributes primarily to this decentralization of property rights.

On average, local firms are younger in age and smaller in size than key firms, although there is much variation between the two groups—for instance, the largest local firm is larger than 66% of the key firms and the smallest key firm is smaller than every local firm. Figure 11 shows the difference in CC ratios between the two categories over time and shows local firms incorporating CC technology into the production process more rapidly than key firms. In addition, local firms are gaining in terms of their share of total steel output, as shown in Figure 12.

Figure 11
Continuous Casting Ratios

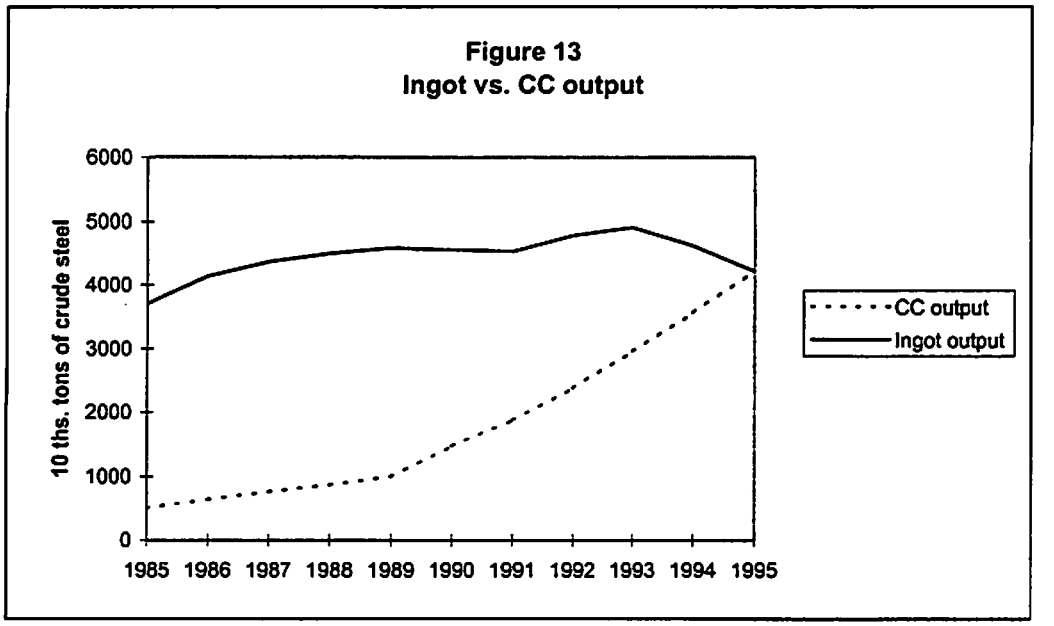


Source: *The Yearbook of Iron and Steel Industry*, Ministry of Metallurgical Industry, annual.



Source: *The Yearbook of Iron and Steel Industry*, Ministry of Metallurgical Industry, annual.

Large state-owned enterprises have incentives to increase annual steel output without regard to costs. A firm's performance has traditionally been measured by its level of output. Therefore, a manager's political power has traditionally been a function of the firm's output growth and managers still feel the pressure to expand output. In addition to the pressure of output growth as a measure of performance, firms feel the pressure to keep their bloated workforce employed. Since there is no social safety net for unemployed workers in China, steel firms, which typically employ a large fraction of the local workforce, are not able to freely fire workers. Because firms seek to maximize output, they may wish to expand production with continuous casting rather than replace ingot casting with continuous casting, which slows the conversion to continuous casting. As shown in Figure 13, prior to 1993, output from both ingot casting and continuous casting increased. This suggests that, until 1993, continuous casting was used to expand production. After 1993, there is some replacement of ingot with continuous casting.



Source: *The Yearbook of Iron and Steel Industry*, Ministry of Metallurgical Industry, annual.

Although increasing production is still an objective for many firms, there have also been efforts to reduce costs within the industry. A cost-target system introduced by Handan Iron and Steel Co., a large "local" steel firm located in Hebei Province, has been extremely successful and is currently being promoted by the central government as a way to reduce costs not only within the steel sector but within other sectors as well. The point of this cost-target system is to set targets for cost per unit output at each level of the production process that must be met by the workers responsible for the particular production unit. Wages and bonuses are determined by the workers' ability to meet their given target. According to Handan, workers also face losing their jobs if they continually miss their given target. This system has resulted in Handan posting positive profits every year since the system was implemented. In addition, Handan reached a 99% continuous casting ratio in 1996, suggesting that this cost-target system also spurred technical innovation within the firm. Because of Handan's success, executives within the company have gained prominence within the Chinese Communist Party. For instance, the manager of the firm is being asked to give speeches on the cost-target system across the country and other Handan executives have been transferred to poor-performing steel firms by the central government in hopes of implementing this system across the industry.

Another way in which the central government is attempting to increase the performance of money-losing firms is by merging these firms with more profitable firms. In many cases, these mergers are forced and not desired by the better-performing firm. An example is the merger of Baoshan Iron and Steel and Shanghai Metallurgy Group, both located in Shanghai. Baoshan is the most modern and one of the most profitable steel firms in China, while Shanghai has been one of the more inefficient steel

facilities in the industry. Baoshan was initially against the merger but has recently relented under pressure from the central government.

(3) Access to Technical Information

The adoption of CC in China has also been slowed by the lack of knowledge about the technology at the firm level. Although market reforms are helping to alleviate this problem, firms have traditionally looked to the central government to provide direction as to which technologies to adopt. Moreover, in the past, firms have had little incentive to innovate and were in many cases reluctant to learn something new. In their opinion, ingot casting worked well and as long as the firm was meeting its output target there was no reason to switch to another technology.

The role of the central government to provide information or to promote certain technologies is still evident today. As discussed above, in the early 1990's, the central government began a national campaign to promote the adoption of CC technology at the firm level. As part of this national campaign, the central government has made low-interest loans available for the purchase of CC equipment and is requiring firms to submit for review plans for converting production to 100% continuous casting.

Technical research institutes—previously under the Ministry of Metallurgical Industry (MMI) and now mostly autonomous—and universities have also helped with the dissemination of information about continuous casting technology. Research institutes provide technical information to steel firms on particular technologies, and also provide services similar to a general contractor such as drawing up technical plans, helping with the approval process, identifying equipment suppliers, and coordinating equipment installation and construction. In addition to being separate from the MMI, these research institutes are now allowed to compete with each other for projects. This competition is likely to improve the dissemination of technical information across China.

(4) Access to Technologies

Another factor which has contributed to the slow diffusion of CC technology is limited access to the technology itself. CC technology has been widely available internationally since the late 1960's/early 1970's, although CC technology for products more difficult to continuously cast (e.g., sheets and slabs) was not available until later. Primary suppliers of CC equipment include Concast Standard (Switzerland), SMS Schloemann-Siemag (Germany), Danieli (Italy), Rokop (US), Mannesmann-Demag (Germany), Davy (Great Britian), Mitsubishi (Japan), Voest-Alpine (Germany), and Paul Wurth (US). Although in industrialized countries CC technology has been largely purchased from this handful of foreign suppliers, this is not the case in China. Instead, the Chinese prefer to build

the technology themselves. The reason seems to be threefold: (i) the high price tag associated with foreign equipment; (ii) limits on foreign exchange; and (iii) the desire for self-sufficiency and promotion of domestic equipment manufacturers.

A number of individuals interviewed emphasized the high price for foreign equipment which, they felt, could be replicated in China for a fraction of the cost. In fact, a strategy of the central government has been to import CC technology that can be reverse engineered so that the equipment can be manufactured domestically in the future. This is supported by the approval process for importing foreign equipment in China. At present, if a firm wishes to purchase foreign equipment it must submit a proposal to the Ministry of Metallurgical Industry for approval.[6] If the equipment costs greater than $30 million, the proposal must also be approved by the State Development Planning Commission (formally the State Planning Commission).[7] To be granted approval, certain criteria must be met. First, the equipment must not be available from domestic suppliers—therefore, imported equipment typically involves the most advanced technology. Second, the firm importing the technology must have the capacity to "digest" the technology and the ability to manufacturer the equipment itself in the future.

Although such an approval process is partly the result of the Chinese government's belief that significant cost savings can be achieved by manufacturing the equipment domestically and of the government's need to keep a tight rein on foreign exchange, it is also the result of China's desire to be self-sufficient. Frequently, firms literally build the CC equipment themselves by gathering components from within the firm and from outside suppliers. Unlike foreign suppliers of CC, there are no separate enterprises within China that solely manufacture CC equipment—rather, the firms build the equipment themselves and assist other firms.[8] Chinese firms are still dependent on foreign suppliers for certain advanced components (such as automation equipment), but over time these components will also likely be available from domestic suppliers. A comment of one interviewee was that unless the Chinese learn to build the equipment themselves, they will be forever dependent on the (foreign) supplier for everything—an undesirable position from their standpoint. This reaction is not surprising given that, throughout history, China has strived for self-sufficiency.

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[6] As of 1998, the Ministry of Metallurgical Industry has been abolished and is now a bureau (with 1/3 of the original staff) under the State Economic and Trade Commission (SETC). Proposals for imported equipment are now submitted directly to the SETC.

[7] The high cost of CC equipment (ranging from $10M to $250M) suggests a lengthy approval process for the purchase of foreign CC equipment.

[8] As discussed previously, there are a number of (now competing) research institutes in China—e.g., the Central Engineering and Research Incorporation of Iron and Steel Industry (CERIS)—associated with the MMI or with a particular steel firm that provide assistance to firms that wish to install new equipment.

4. A Theoretical and Empirical Analysis of Technological Diffusion in China

The previous section identified certain institutional constraints that could explain the slow diffusion rate of continuous casting technology in China. In this section, these institutional factors are compared with market factors that would affect the diffusion of continuous casting in both market and non-market economies. Section 4.1. reviews the diffusion literature and Section 4.2 discusses the S-curve model of diffusion prevalent in the diffusion literature. Section 4.3. presents a theoretical model of technology choice between continuous casting and ingot casting under the assumption that firms are profit-maximizing and operating under market conditions. From this theoretical discussion, a set of "market" factors is identified as possible factors influencing on the diffusion of CC technology if the firm is operating under market conditions. In an attempt to measure the influence of these "market" factors on technology choice among Chinese firms, a random effects model using panel data of 75 Chinese steel firms over 11 years (1985-1995) is empirically estimated. These results are given in Section 4.4. As identified from interviews with various individuals associated with the steel industry in China, there are other "institutional" constraints that can have a profound effect on the diffusion of CC technology among Chinese firms. In Section 4.5., the theoretical model discussed in Section 4.c. is modified to account for these "institutional" constraints. Section 4.6. provides results from an estimation similar to that in Section 4.4., but which includes these "institutional" factors.

4.1. Previous Studies of Technological Diffusion

Previous studies of technological diffusion can be categorized in three different ways: (1) "Interfirm" versus "intrafirm" diffusion; (2) cross-section versus time-series analysis; and (3) diffusion in developed versus developing countries. Most analyses thus far have focused primarily on interfirm diffusion, have involved either cross-sectional or time-series analyses but not both, and have looked only empirically at the issue of diffusion in developing countries via case study.

Table 2 provides a summary of often cited empirical studies of technological diffusion. As evident from this list, the literature has been heavily biased towards the issue of "interfirm" diffusion—i.e., first use of the technology by a firm—with less consideration given to the issue of "intrafirm" diffusion—i.e., a firm's conversion of its entire production process to a new technology. Mansfield (1968), one of the few studies that considers both interfirm and intrafirm diffusion, stresses the importance of accounting for both types of diffusion:

> "To understand how rapidly a new technique displaces an old one, one must consider both the rate of imitation and the intrafirm rate of diffusion—the rate at which a particular firm, once it hs begun to use a new technique, proceeds to substitute it for older methods. Together the rate of

imitation and the intrafirm rates of diffusion determine how rapidly productivity rises in response to the new technique."

What also emerges from Table 2 is the fact that while some analyses use explanatory variables which vary by firm, and others use variables which vary by time, few use variables which vary by both firm and time. Most of the studies in Table 2 use only cross-sectional data and therefore exclude important variables—such as prices—that vary by time and which can have a significant impact on the diffusion rate. The most obvious reason for this bias towards cross-sectional analyses is the lack of adequate cross-sectional time-series data. As shown in this analysis, time-varying effects matter more in the diffusion of continuous casting technology in China than cross-sectional effects.

Many of the studies which include both cross-sectional and time-series data employ hazard rate models in their analyses. Hannan and McDowell [1984], in their study of automated teller machines (ATMs), and Levin et. al. [1987], in their study of optical scanners, both employ hazard rate models to test the effects of firm characteristics that vary over time on the probability that the technology will be adopted[9]. Jaffe and Stavins [1995], on the other hand, use panel data to estimate a structural model of the diffusion of new home insulation in order to test the effects of changes in energy prices, insulation cost, and building codes.

Given the dynamic nature of intrafirm diffusion, it would seem that studies of intrafirm diffusion would incorporate panel data. However, the few studies of intrafirm diffusion (e.g., Griliches [1957], Mansfield [1968], Romeo [1977]) avoid the requirement of panel data by conducting a two-stage analysis. In the first stage, logistic functions (i.e., S-shaped growth curves) are estimated to obtain an estimate of a firm's rate of diffusion (from the coefficient on the time variable). Second, this estimate of a firm's rate of diffusion is regressed on cross-sectional firm-level data.

[9] Rose and Joskow [1990] also use hazard rate models to examine the adoption of new technologies by electric utilities but use data of firm characteristics for specific years thus avoiding the need for panel data.

Table 2
Empirical Studies of Technological Diffusion

Author	Interfirm Diffusion	Intrafirm Diffusion	Cross-Sectional Analysis	Time-Series Analysis
Griliches [1957]—hybird corn		X	X[a]	
Mansfield [1968]—various innovations	X	X	X[a]	
Schenk [1974]—continuous casting	X	X	X	
Romeo [1975]—numeric control machine tools	X	X	X[a]	
Davies [1979]—process innovations	X		X	
Oster [1982]—basic oxygen furnace	X		X	
Hannan and McDowell [1984]—ATMs	X		X	X
Levin et al [1987]—optical scanners	X		X	X
Leary and Thornton [1989]—basic oxygen and electric arc furnaces	X	X		X
Rose and Joskow [1990]—electric utilities	X		X	
Labson and Gooday [1994]—electric arc furnaces		X		X
Jaffe and Stavins [1995]—thermal insulation in new home construction	n/a	n/a	X	X

[a] 2-stage analysis--obtains estimate for cross-sectional rate of diffusion from fitting trend data to logistic functions.

Labson and Gooday [1994], in their time-series analysis of electric arc furnaces for steelmaking, estimate S-shaped growth curves for three industrialized countries that include three economic variables that vary over time, but lack a cross-sectional component. Leary and Thornton [1989] estimate logistic functions for various countries (including economies in transition), but include no cross-sectional variation.

Reviewing the literature, it is difficult to find empirical studies of technological diffusion in developing countries. This is not surprising given the obvious lack of reliable firm-level data in developing countries. Because of this, empirical studies of technological diffusion in developing countries have primarily consisted of case studies with no econometric analyses (e.g., Bhatia [1990],

Hinton [1985], Bernardo and Kilayko [1990], Daxiong et al [1990], Agarwal [1983], Edquist [1990]). Leary and Thornton [1989] estimate logistic functions for a number of former Soviet Union republics in order to compare diffusion rates with those of industrialized countries, but are unable to test possible factors influencing the diffusion rate within these countries due to the lack of firm-level data.

Though few empirical studies on technological diffusion in developing countries exist, there are inadequacies in applying the results from studies of industrialized countries to developing countries. It would seem that firm characteristics affecting the profitability of the innovation such as firm size and ownership structure identified in much of the literature (e.g., Griliches [1957], Mansfield [1968], Davies [1979], Oster [1982], Rose and Joskow [1990]) would also be factors affecting the rate of diffusion in lesser developed countries as well. However, as discussed in section 3, there are additional factors—prevalent in lesser developed countries—that could also have an effect on the diffusion rate—for example:

(1) Credit constraints. Because industrialized countries have been the focus of previous studies of diffusion, the majority of diffusion studies assume that financing of new technologies is available as long as investment in the new technology is expected to deliver a fair rate of return. In developing and transition economies, the excess demand for investment capital is widespread, causing many profitable projects to go unfunded.

(2) Incentives to innovate. As emphasized in the diffusion literature, firm characteristics that affect the profitability of an innovation are key explanatory variables for the rate of diffusion. But this assumes profitability to be the underlying motivation of a firm—an unrealistic assumption in countries like China which are composed predominately of state-owned enterprises that historically have had little autonomy over investment decisions and little incentive to increase efficiency. In addition, firms in developing or transition economies may not be truly facing market prices for key inputs such as energy which will affect a firm's motivation to achieve greater energy efficiency.

(3) Availability of Information. In developing and transition economies, information about new technologies does not disseminate as quickly or efficiently as in market economies.

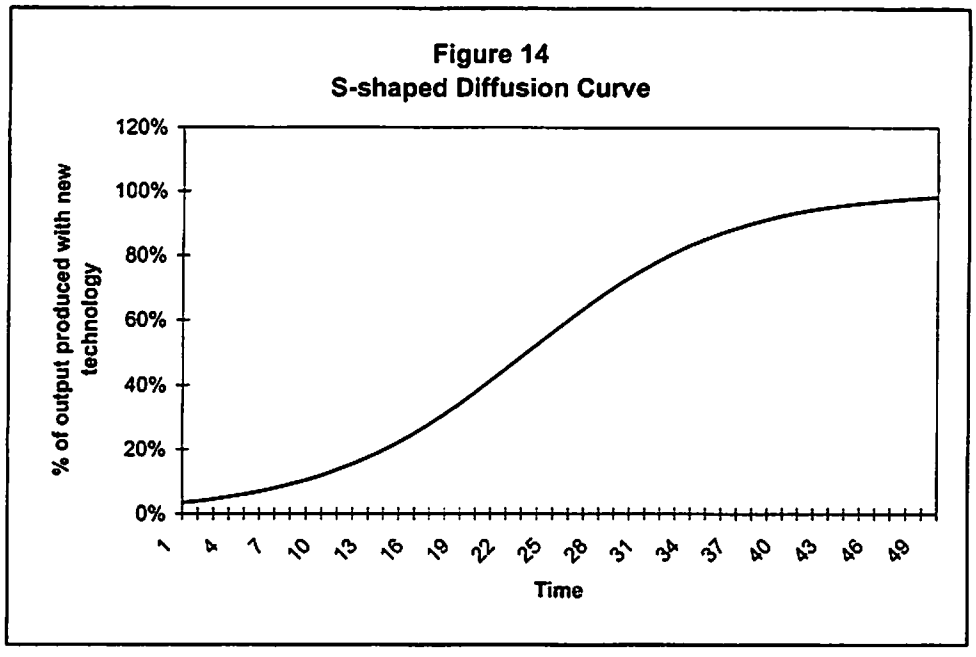
(4) Access to New Technologies. Lastly, not all countries have easy access to new technologies through foreign suppliers, due to either restrictions on foreign exchange or national government policies to promote domestic equipment manufacturers. As will be discussed later in this paper, firms in China must go through an arduous process to gain approval for the purchase of foreign equipment regardless of whether foreign exchange is available to purchase the equipment.

It is important to determine which factors are having a greater effect on the diffusion rate: Factors unique to lesser developed countries or factors also affecting diffusion in industrialized countries. And, more importantly, how does the introduction of market forces—in the case of China—change the situation?

Empirical studies of the effects of market reforms on firm performance in China have focused primarily on productivity (e.g., Li [1997], Jefferson et al [1996]). Jefferson [1990], in particular, is a cross-sectional analysis of productivity variation among Chinese iron and steel firms in 1985. These productivity studies can inform an analysis of technological diffusion in China since the introduction of new technology into the production process is an important contributor (in addition to better management practices and resource allocation) to productivity improvements. Thus, this paper complements these previous productivity studies by separately analyzing this important component of productivity.

4.2. Intra- and Interfirm Diffusion of Continuous Casting Technology

The one characteristic of technological diffusion that has been consistently supported by empirical analyses is that the diffusion of new technologies follows an S-shaped or logistic curve similar to growth curves found in biology and the social sciences. As shown in Figure 14 below, the rate of diffusion of a new technology starts out slow, accelerates in the middle, and slows again near the saturation limit (e.g., 100%). This S-curve model of diffusion can be applied to both intra- and interfirm diffusion. Explanations given for the S-shaped path of diffusion have included the heterogeneity among firms which results in different rates of return for the technology across firms; differences in risk-taking behavior across firms; and variation in the age of capital stock across firms.



The simple S-curve or epidemic model of diffusion is defined as:

$$S_t = \left[1 + e^{-(\alpha+\beta t)}\right]^{-1}$$

where

S_t ≡ proportion of output produced with the new technology;
α ≡ defines the position of the curve on the time scale; and
β ≡ rate of growth coefficient.

A simple test of how well interfirm diffusion of continous casting technology fits the S-shaped diffusion curve is to estimate the following using aggregate industry data:

$$ln\left(\frac{S_t}{1-S_t}\right) = \alpha + \beta t$$

For comparison purposes, the above equation was estimated using aggregate data of the iron and steel industry of both the United States and China. For both countries, the results show that the S-shaped curve fits the data well--the coefficient on time is significant (p-values = 0.00 for both cases) and the R^2's are above .96 in both cases. However, the rate of diffusion, represented as β, is greater in the U.S. (= .23) than in China (= .15), suggesting that the U.S. is diffusing the technology more rapidly.

Although the S-shaped diffusion curve seems to be a reasonable model of the diffusion process of continuous casting technology in China, there are a number of problems with the way the model is defined above. First, it assumes that β is constant across time which, as pointed out in the literature, is problematic since the impact of β is likely to change as the diffusion process progresses (Mahajan and Peterson [1985]). Second, the model is void of any economic variables or firm characteristics to explain

the process of diffusion. Therefore, it is useful to assume that the rate of diffusion, β, is determined by a set of factors. Lastly, the model above is an aggregation of separate diffusion processes of individual firms. Therefore, to understand the diffusion process for the country as a whole, it is necessary to examine the diffusion process at the individual firm level. To address these problems, instead of assuming a constant time parameter β, β is assumed to be a function of variables likely to affect a firm's rate of diffusion of continuous casting technology.

4.3. A Theoretical Model of CC Diffusion Under Market Conditions

The structural model behind a firm's rate of diffusion of continuous casting technology is one that describes a firm's choice between the two technologies—continuous casting and ingot casting. In general, a profit-seeking firm chooses levels of investment, labor, energy, and materials in each period to maximize the sum of discounted profit streams over time:

$$\Pi = \underset{\{I_t, L_t, E_t, M_t\}_{t=1}^{T}}{MAX} \sum_t \frac{1}{(1+r)^t}\left(P_t^Q Q_t\,(K_t, L_t, E_t, M_t) - w_t L_t - P_t^E E_t - P_t^M M_t - P_t^I I_t\ \right)$$

s.t.

$$K_{t+1} = (1-\delta)K_t + I_t \qquad \forall t$$
$$I_t, L_t, E_t, M_t \geq 0 \qquad \forall t$$
$$K_0 \text{ given.}$$

where

Q_t ≡ output at time t;
r_t ≡ market rate of interest;
δ ≡ depreciation rate;
I_t ≡ investment to expand production capacity;
P_t^Q ≡ price of output;
L_t ≡ units of labor;
E_t ≡ units of energy;
M_t ≡ units of material inputs;
P_t^I ≡ price of capital investment;
w_t ≡ wage rate;
P_t^E ≡ price of energy; and
P_t^M ≡ price of materials.

Substituting the capital accumulation equations into the production function, the first-order conditions pertaining to the firm's profit maximization problem (PMP) are:

$$(1)\ \frac{\partial \Pi}{\partial I_t} = 0 \Rightarrow \sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i} = P_t^I;\ I_t \geq 0;\ \frac{\partial \Pi}{\partial I_t} I_t = 0;$$

$$(2)\ \frac{\partial \Pi}{\partial L_t} \leq 0 \Rightarrow P_t^Q \frac{\partial Q_t}{\partial L_t} \leq w_t\ ;\ L_t \geq 0;\ \frac{\partial \Pi}{\partial L_t} L_t = 0;$$

$$(3)\ \frac{\partial \Pi}{\partial E_t} \leq 0 \Rightarrow P_t^Q \frac{\partial Q_t}{\partial E_t} \leq P_t^E\ ;\ E_t \geq 0;\ \frac{\partial \Pi}{\partial E_t} E_t = 0;$$

$$(4)\ \frac{\partial \Pi}{\partial M_t} \leq 0 \Rightarrow P_t^Q \frac{\partial Q_t}{\partial M_t} \leq P_t^M\ ;\ M_t \geq 0;\ \frac{\partial \Pi}{\partial M_t} M_t = 0;$$

The last three first-order conditions are the usual relation that the optimal amount of the factor input the firm should demand is the amount that obtains a return to each factor of production (in this case, the marginal revenue product) equal to the price of the factor input[10]. Due to the recursive nature of the capital accumulation equation, first-order condition (1) is a little more complicated but makes intuitive sense. First-order condition (1) says that the firm should invest to the point where the return to investment—i.e., the sum of discounted and depreciated marginal revenue products over time—equals the price of investment at time t[11].

First-order condition (1) also reflects the net present value (NPV) decision rule which says a firm should choose to invest if the net present value of the investment (after accounting for risk) is positive; i.e.,

$$\sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i} - P_t^I > 0$$

In fact, first-order condition (1) says that the firm should choose the <u>level</u> of investment (or disinvestment) at which the NPV of marginal investment equals zero. However, the discrete choice whether to invest or not is based on the NPV decision rule above. In the case where the firm is choosing among various positive NPV investment opportunities, the firm will choose to invest where the NPV (after accounting for risk) is highest.

As shown in Figure 6 above, the correct model of the steel production process is one of joint production—continuously cast crude steel production and ingot cast crude steel production—rather than separate production processes for CC production and ingot cast production. Since molten steel is

[10] Since non-negativity constraints exist on the variable inputs, we obtain the Kuhn-Tucker conditions as shown in (2)-(4).

[11] Since capital investment is not constrained to be non-negative, it is possible for the firm to choose negative

transferred to the casting process via ladles on rails, adding CC capacity does not necessarily require dismantling old ingot capacity—rather, a new facility with CC equipment can be added to the existing complex. Because of this, it can be assumed that the other factors of production (capital used by both casting process such as furnaces, labor, energy, and materials) are mobile and can easily flow from one casting process to the other. Therefore, the appropriate PMP of the firm is of the form:

$$\Pi = \underset{\{I_t^{cc}, I_t^{ig}, I_t^J, L_t, E_t, M_t\}_{t=1}^{T}}{MAX} \sum_t \frac{1}{(1+r_t)^t} \Big(P_t^Q Q_t\,(K_t^{ig}, K_t^{cc}, K_t^J, L_t, E_t, M_t) - w_t L_t - P_t^E E_t$$
$$- P_t^M M_t - P_t^{ig} I_t^{ig} - P_t^{cc} I_t^{cc} - P_t^J I_t^J \Big)$$

subject to

$K_{t+1}^{ig} = (1-\delta)K_t^{ig} + I_t^{ig}$ $\forall t$

$K_{t+1}^{cc} = (1-\delta)K_t^{cc} + I_t^{cc}$ $\forall t$

$K_{t+1}^{J} = (1-\delta)K_t^{J} + I_t^{J}$ $\forall t$

$L_t, E_t, M_t \geq 0$ $\forall t$

$K_0^{cc}, K_0^{ig}, K_0^J$ given.

where

$I_t^{ig} \equiv$ investment to expand production capacity of ingot cast steel;
$I_t^{cc} \equiv$ investment to expand production capacity of continuous cast steel;
$I_t^J \equiv$ investment to expand total (joint) production capacity;

$P_t^{ig} \equiv$ price of ingot capital investment;
$P_t^{cc} \equiv$ price of continuous casting capital investment;
$P_t^J \equiv$ price of joint capital investment;

$Q_t\,(K_t^{ig}, K_t^{cc}, K_t^J, L_t, E_t, M_t) \equiv$ production function – – two types of capital producing crude steel which, for example, could be represented by the following nested CES production function:

$$= A_0 \left[\left(A_{ig,t}(K_t^{ig})^{\rho_1} + A_{cc,t}(K_t^{cc})^{\rho_1} \right)^{\frac{\rho_2}{\rho_1}} + (K_t^J)^{\rho_2} + L_t^{\rho_2} + E_t^{\rho_2} + M_t^{\rho_2} \right]^{\frac{1}{\rho_2}}$$

where $\rho_1 < 0$ (inelastic) so little substitution occurs between the two types of capital and $0 < \rho_2 < 1$ (elastic) so substitution can occur between the factors of production. The parameters $A_{ig,t}$ and $A_{cc,t}$ reflect productivity differences between the two processes - - continuous casting and ingot casting.

Applying this to a firm's choice between continuous casting and ingot casting equipment, the firm compares

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investment (taking capital out of the production process).

$$\sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i^{cc}} - P_t^{I^{cc}} \equiv \text{NPV of marginal investment in continuous casting}$$

with

$$\sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i^{ig}} - P_t^{I^{ig}} \equiv \text{NPV of marginal investment in ingot casting}$$

and chooses the technology with the higher NPV. In particular the decision rule is:

$$\sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \left(\frac{\partial Q_i}{\partial K_i^{cc}} - \frac{\partial Q_i}{\partial K_i^{ingot}} \right) - \left(P_t^{I^{cc}} - P_t^{I^{ingot}} \right) > 0 \Rightarrow \text{invest in continuous casting}$$

$$\sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \left(\frac{\partial Q_i}{\partial K_i^{cc}} - \frac{\partial Q_i}{\partial K_i^{ingot}} \right) - \left(P_t^{I^{cc}} - P_t^{I^{ingot}} \right) < 0 \Rightarrow \text{invest in ingot casting} \tag{5}$$

This implies that a profit-seeking firm's diffusion of continuous casting technology depends on (1) the marginal revenue product of CC investment relative to ingot; and (2) the price of CC equipment relative to ingot.

To determine the relevant set of factors to include in an empirical analysis of the diffusion process, we first consider the factors that affect the marginal revenue product of CC equipment relative to ingot. Marginal revenue product of capital is equal to the price of output multiplied by the marginal product of capital. The factors affecting the marginal product of capital of CC relative to ingot casting are those factors related to the production function. Since the production function represents joint production with three types of capital stock—i.e., $Q(K^j, K^{cc}, K^{ingot}, L, E, M)$—the difference in the marginal products of capital between CC and ingot is largely captured in the effective units of capital for each casting process: K^{cc} and K^{ingot}.

Factors postulated as affecting the marginal revenue product of CC capital relative to ingot are the following:

- <u>Age of capital stock.</u> This variable captures two effects. First, the older the capital stock, the lower the effective level of capital stock as captured in the capital accumulation with the depreciation term. Therefore, if diminishing returns to each factor of production are assumed—i.e.,
  $$\frac{\partial MP_X}{\partial X} < 0, \; X = K^{ig}, K^{cc}, K^{J}, L, E, M$$
  then the marginal product of capital is higher the older the capital stock. Second, the older the capital stock, the greater chance the firm is using old furnace technology that may be *incompatible*

with CC technology. Open hearth furnaces (OHF)—the older furnace technology—used to convert pig iron to steel. Because of this, it is difficult to synchronize the casting and rolling processes with the steelmaking process if OHF is used. Therefore, continuous casting will be more profitable if it is being used with BOF or EAF rather than OHF.

- Firm age. This variable also captures the possibility of old furnace technology. After the 1950's, few open hearth furnaces were installed. Therefore, the younger the firm, the less the chance for supporting equipment being incompatible with CC technology.

- Years since first CC adoption. This variable captures learning-by-doing effects. The more experience the firm has with CC technology, the higher the capital's effectiveness per unit labor.

- Input prices. Since a signficant amount of energy, labor and materials is saved when ingot casting is replaced with continuous casting, a rise in these input prices relative to the output price increases the attractiveness of CC technology.

- Output growth and regional demand. A number of studies have accounted for regional effects for a variety of reasons. Griliches [1957] finds conversion to hybrid corn to vary across regions due to differences in regional rates of return. Levin et al [1987] include a regional variable in their analysis to account for differences in banking laws across regions. Oster [1982] finds the relative profitability of CC equipment is likely to be higher where the equipment is being used to expand production rather than replace existing ingot casting capacity. Certain regions in China—namely, the coastal regions—have been experiencing phenomenal growth in construction, which has resulted in greater demand for steel.

- Firm size. The effect of firm size on diffusion was highlighted in Mansfield [1968], which sparked numerous studies exploring the effects of firm size on adoption (e.g., Oster [1982], Levin et al [1987], Rose and Joskow [1990]). Firm size can affect the relative profitability of CC equipment and thus the diffusion rate for a number of reasons cited in the literature—e.g., scale economies (positive effect), isolation from market forces (negative effect), or extent of firm's R&D activities (positive effect).

The other variable in the decision rules provided in the set of inequalities (5) above is the relative price of investment. In a market economy, the price of investment in CC equipment relative to ingot is a function of the following factors:

- Firm size. Firm size can also affect the price of CC investment relative to ingot. The technical sophistication of CC equipment rises in increasing proportion to the scale of the operation—much more than for ingot equipment. Therefore, the relative investment cost of CC equipment for large scale operations is likely to be greater than for small scale operations.

- Type of product produced. Continuous casting used in the production of wires and rods requires much less technically sophisticated equipment than CC used in the production of flat sheets and slabs. Because of this, CC equipment for wires and rods has been available much longer and requires much less initial investment than CC equipment for sheets and slabs. Therefore, until *recently* the relative profitability of CC equipment for wires and rods has likely been higher than the relative profitability of CC equipment for sheets and slabs.

- Profit rate. Two primary sources of investment capital for a firm are retained earnings and bank loans—both of which are affected by the firm's profit rate. A firm's level of profits determines its level of retained earnings and its ability to borrow.

4.4. Estimation of the Effects of "Market" Factors on Intrafirm CC Diffusion in China

Under the assumption of a profit-maximizing firm operating in a market economy, the above factors would comprise a list of variables to explain the diffusion of CC technology. Obviously, Chinese steel firms have not necessarily been profit-maximizing or operating under market conditions in the past. However, as a first test, it is useful to see how well these "market" variables explain the diffusion of CC among Chinese firms. Without knowing the exact functional form of the production function, it is difficult to determine the precise relationship between a firm's rate of CC diffusion and the factors derived from the structural model above. We do know, however, that the diffusion process usually follows an S-shaped curve. Therefore, the estimation equation used in the analysis is a variant on the logistic function discussed above with $\alpha + \beta t$ replaced by a function containing the factors derived from the structural model:

$$\ln\left(\frac{S_{it}}{1-S_{it}}\right) = \alpha + \beta^{I} X^{I} + \beta^{T} X^{T} + \beta^{IT} X^{IT} \qquad (6)$$

where

S_{it} ≡ share of output produced with CC technology in firm i at time t;
X^{I} ≡ vector of factors that vary by firm;
X^{T} ≡ vector of factors that vary by time;
X^{IT} ≡ vector of factors that vary by firm and time;
$\beta^{I}, \beta^{T}, \beta^{IT}$ ≡ vector of coefficients; and
α ≡ constant.

The left-hand side of this estimation equation is a logistic transformation of the share of output produced with CC technology. Since this transformation is monotonically increasing in S_{it}, we can interpret the significance of a β coefficient to mean that the corresponding variable has a significant effect on the share of output produced with CC technology. This estimation equation includes variables that vary across time, those that vary across firm, and those that vary across both firm and time. By including variables that vary by both time and firm, the model is able to capture factors that move a firm along the S-shaped diffusion curve and factors that shift a firm to a different curve altogether. The panel data used in this analysis comprise 75 Chinese steel firms and 11 years (1985-1995). These data were compiled from eleven issues of The Yearbook of Iron and Steel Industry, published annually by the Ministry of Metallurgical Industry in China (MMI, annual). A statistical summary of the firms included

in the sample is provided in Table 3.

Table 3
Summary statistics of firms included in sample (1995)

	All Firms	"Key" Firms[a]	"Local" Firms[b]
Sample size	75	30	45
% of total industry output	89%	63%	26%
Output of crude steel (10 th. Tons)	8446	5996	2450
average	108	200	55
minimum	0.3	0.3	0.4
maximum	822	822	215
Age of firm (years)			
average	41	48	38
minimum	13	13	23
maximum	84	84	74
No. of employees (thousands)	2427	1664	763
average	32.4	55.4	15.9
minimum	2.2	5.6	2.2
maximum	246.4	246.4	49.1
Continuous Casting Ratio[c]			
total	50%	45%	62%
minimum	0	0	0
maximum	100%	78%	100%

Source: *The Yearbook of Iron and Steel Industry, 1995*, Ministry of Metallurgical Industry.
[a] Firms traditionally supervised by the central government and which supply to "key" government industries--e.g., military
[b] Firms traditionally supervised by local/provincial government
[c] Continuous casting ratio ≡ (crude steel output continuously cast) / (crude steel output continuously cast + crude steel output ingot cast)

The explanatory variables included in the analysis representing the factors derived from the structural model above are:

(1) Age of capital stock in 1985. This variable is measured as the ratio of the net value of fixed assets to the original value fixed assets (similar to Jefferson [1990]). Therefore, the closer the ratio is to 1, the younger the capital stock. This variable is not only a proxy for the type of furnace in place, it also

signals new investment since older equipment is likely to be replaced sooner than newer equipment.

(2) Firm age. Firm age is measured as the number of years since start-up of the firm.

(3) Years since first CC adoption. This variable is the number of years since a firm first adopted CC technology (= 0 if the firm has yet to adopt CC technology)[12].

(4) Input prices. Both the relative price of energy and the relative price of materials are included in the analysis. The relative price of energy is the lagged percentage change of the ratio of the price index for energy to the price index for steel. A price index for energy was calculated using economy-wide prices of energy obtained from the Statistical Yearbook of China 1996 and weights for the various energy inputs for the ferrous metals industry from the 1992 input-output table for China[13]. The relative price of materials is the lagged percentage change of the ratio of the price index for materials to the price index for steel. A price index for materials was calculated using economy-wide prices obtained from the Statistical Yearbook of China 1996 and weights for the various material inputs for the ferrous metals industry from the 1992 input-output table for China[14].

(5) Output growth and regional demand. Lagged growth rate[15] of a firm's crude steel output--i.e., $(Q_{t-1} - Q_{t-2}) / Q_{t-2}$ was included to control for equipment used for expansion rather than replacement purposes. Regional dummy variables were also included to account for variation in regional demand. There are seven regional dummies corresponding to the following regions[16]: Region 1: Far West (Xinjiang, Tibet, Qinghai, Gansu, Ningxia)—5 firms (7% of sample); Region 2: North Hinterland (Heilongjiang, Jilin, Inner Mongolia, Shanxi, and Shaanxi)—11 firms (15% of sample); Region 3: South Hinterland (Sichuan, Guizhou, Yunnan, Guangxi)—13 firms (17% of sample); Region 4: Central Core (Henan, Anhui, Jiangxi, Hubei, Hunan)—16 firms (21% of sample); Region 5: North Coast (Lianoning, Greater Hebei, Shandong)—21 firms (28% of sample); Region 6: East Coast (Jiangsu, Shanghai, Zhejiang)—6 firms (8% of sample); Region 7: South Coast (Fujian, Guangdong, Hainan)—3 firms (4% of sample).

(6) Firm size. Firm size is measured as a firm's output of steel (in tons) in 1995. Since there was little change in the size of a firm relative to other firms over the 11 year period and to avoid endogeneity problems, firm size is constant over time.

(7) Type of product produced. This variable is represented as the firm's percentage of output in 1985 comprised of flat sheets or slabs. Since we are analyzing the change in the CC ratio *since* 1985, a firm's decision to convert would be based on the percentage of sheet or slab production at the start of the period—i.e., 1985.

(8) Profitability. A firm's profit rate is measured as the lagged ratio of a firm's before-tax profits to net value of fixed assets. This variable is used as a proxy for a firm's attractiveness to lenders and (at least in a market economy) its cost of capital.

The regression results are found in column (1) of Table 4. Equation (6) was estimated using a random effects model[17]. Given the form of the estimation equation, in which the left-hand side equals negative infinity if S equals zero and positive infinity if S equals 1, the regression leaves out these cases. Therefore, these results omit those firms that never produce some level of output using CC technology. This amounts to 21 firms out of a total of 75 (~28%), 9 out of 30 "key" firms (~30%), and 12 out of 45 "local" firms (~27%)—therefore, the number of omitted firms is evenly distributed between "key" firms and "local" firms. Only one firm reaches 100% CC by the end of the period—a firm which is relatively

[12] These data were acquired from Concast Standard AG [1998].

[13] For the 75 firms included in the sample, energy costs account for ~19% of total input costs (SSB [1995]).

[14] For the 75 firms included in the sample, material costs account for ~52% of total input costs (SSB [1995]).

[15] Growth rates rather than changes in the levels were used in order to be scale invariant.

[16] This regional disaggregation was taken from Keidel [1995].

[17] Conducting the Hausman specification test, the null hypothesis that the regressors are independent of the error

small in size, producing 70 thousand tons of crude steel in 1995. The firms omitted account for approximately 11% of total crude steel output produced by the 75 firms.

In general, the market variables do not seem to affect the diffusion process as greatly as would be expected. However, certain variables found to be significant make intuitive sense. The coefficient on the variable representing the number of years since first adoption of CC technology is positive and significant. This suggests that early adopters have an edge in terms of diffusing CC more quickly. Explanations for this include a "learning-by-doing" effect which causes the firm to increase its adoption of the technology as experience with the technology grows. In addition, especially in a country like China where access to new technology has been restricted by the government in the past, the significance of this variable may also be due to a firm's ability to acquire CC technology.

Another variable found to be significant is the age of the firm. The negative coefficient associated with this variable suggests that the younger firms are diffusing more rapidly than older firms. This is not surprising given that younger firms are more likely to have CC-compatible supporting equipment such as furnaces, making it much less costly to introduce CC equipment into the production process. Since only one firm was created after the introduction of CC technology, we can rule out the possibility that this result is due to new plants being brought online with CC already installed.

Regional differences reflecting differences in market conditions also seem to matter. In particular, the results suggest that firms located in region 2 (North Hinterland—Heilongjiang, Jilin, Inner Mongolia, Shanxi, and Shaanxi) and region 3 (South Hinterland—Sichuan, Guizhou, Yunnan, and Guangxi) are not diffusing as quickly as firms in other regions. This is not surprising given that economic conditions in these regions have been substantially worse than in other regions (especially the East Coast region). Many of the steel firms found in inland regions were originally placed there because of the lack of adequate transportation which would have allowed firms in coastal regions to supply to inland regions, and because of previous fears of foreign invasion[18].

The p-value of the coefficient associated with the variable representing a firm's profit rate is .115 which, from the positive value of the coefficient, suggests that profitability may be having an effect on the diffusion rate. This is encouraging since it suggests that the more profitable firms are able to acquire CC equipment. This could be a reflection of a firm's cost-of-capital, in which more profitable firms have higher retained earnings and are more attractive to lenders. However, Chinese profits data must be used with caution. Upon examination of the profits data, a number of firms known to be in poor financial health reported positive profits. This could be the result of the use of before-tax rather than after-tax profits data in the analysis. A firm may have positive before-tax profits but negative after-tax profits

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term is not rejected. Therefore, the random effects model seems to be an appropriate specification.

[18] For instance, Naughton [1996] discusses the "Third Front" program implemented by the Chinese government during the 1960's and 1970's which moved productive facilities into militarily secure areas (typically inland).

once its payment obligation to the government in terms of its "profit responsibility" has been met. The data do not exist on after-tax profits to accurately measure a firm's availability of capital through retained earnings and its attractiveness to lenders.

These results also show a firm's diffusion rate to be unaffected by prices as reflected in the insignificance of the growth rate of both the relative price of materials and energy. Recent price reforms have caused the price of steel to fall relative to the price of energy and materials. However, these results suggest that firms have yet to implement more efficient technologies--such as CC technology--as a reaction to these increases in relative prices. This is either because the magnitude of these relative prices changes have not been high enough or because certain firms are still protected from significant changes in input prices.

Lastly, the time variable was also found to be positive and significant, implying that the passage of time is also having an effect. The time variable captures many factors such as better access to CC technology (e.g., as the number of domestic suppliers grow) and the increase in dissemination of information about CC technology. The importance of the passage of time is also reflected in the R^2's—the "between" R^2 is much less than the "within" R^2, suggesting that cross-sectional differences seem to matter less than the effect of time.

Table 4
Factors Affecting the Diffusion of Continuous Casting Technology

	(1) "market" variables only	(2) "market" and "institutional" variables
Output growth rate (lagged)	-.003 (.050)	.004 (.050)
Firm size	.002 (.001)	.002** (.001)
Sheet or slabs output %	-1.07 (.759)	-.000 (.719)
Years since first adoption	.087** (.028)	.105** (.024)
Relative price of energy (lagged)	1.85 (1.66)	2.06 (1.68)
Relative price of materials (lagged)	-.276 (2.21)	-.356 (2.24)
Profit rate (lagged)	.670 (.425)	.802* (.437)
Age of firm	-.030* (.017)	-.013 (.015)
Age of capital stock in 1985	-.952 (2.55)	.483 (2.19)
Region 1—Far West	-.205 (.292)	-.183 (.296)
Region 2—N. Hinterland	-.462* (.264)	-.386 (.268)
Region 3—S. Hinterland	-.518** (.252)	-.457* (.257)
Region 4—Central Core	-.031 (.230)	-.027 (.234)
Region 5—N. Coast	-.033 (.250)	-.277 (.256)
Region 6—East Coast	-.034 (.263)	.015 (.269)
Region 7—South Coast[a]	--	--
Growth rate of capital stock (lagged)	--	-.184 (.259)
% of foreign CC technology	--	.609** (.259)
"Key" firm	--	-1.97** (.485)
Time	.214** (.049)	.184** (.049)
Constant	-1.37 (2.11)	-2.77 (1.83)
no. of observations	365	365
R^2 overall	.3643	.4285
R^2 within	.6216	.6310
R^2 between	.0534	.1939

[a] Included in the constant term. 4% of firms in the sample are located in Region 7
*significant at the .10 level
** significant at the .05 level
Standard errors shown in parentheses

4.5. A Theoretical Model of CC Diffusion with "Institutional" Constraints

The above "market" factors make up a near complete list of factors that should be taken into account in a study of the diffusion of continuous casting technology among firms operating under market conditions. However, as was determined through extensive interviews conducted in China with various individuals at steel firms, universities, research institutes, government agencies, and foreign equipment suppliers, there are certain institutional constraints that seem to have had a significant impact on the

diffusion rate of continuous casting technology in China—namely, credit constraints, incentives to innovate, availability of technical information, and access to technology.

The firm's profit maximization problem (PMP) can be modified to account for these institutional constraints. By imposing constraints on the existing PMP, we can obtain certain firm behavior while assuming firms in general are profit-seeking[19]. In China, perhaps the best way to characterize firm behavior is to say that firms are facing more than one objective—e.g., profit, employment, and output objectives—simultaneously. The following provides modifications to the above PMP to account for the above institutional constraints.

Credit constraints

With a constraint on the availability of investment capital, the firm faces the following PMP:

$$\Pi = \underset{\{I_t^{cc}, I_t^{ig}, I_t^{J}, L_t, E_t, M_t\}_{t=1}^{T}}{MAX} \sum_t \frac{1}{(1+r_t)^t}\Big(P_t^Q Q_t\,(K_t^{ig}, K_t^{cc}, K_t^{J}, L_t, E_t, M_t) - w_t L_t - P_t^E E_t$$
$$- P_t^M M_t - P_t^{ig} I_t^{ig} - P_t^{cc} I_t^{cc} - P_t^{J} I_t^{J}\ \Big)$$

s.t.

$$K_{t+1}^{ig} = (1-\delta)K_t^{ig} + I_t^{ig} \qquad \forall t$$
$$K_{t+1}^{cc} = (1-\delta)K_t^{cc} + I_t^{cc} \qquad \forall t$$
$$K_{t+1}^{J} = (1-\delta)K_t^{J} + I_t^{J} \qquad \forall t$$
$$L_t, E_t M_t \geq 0 \qquad \forall t$$
$$P_t^{ig} I_t^{ig} + P_t^{cc} I_t^{cc} + P_t^{J} I_t^{J} \leq \overline{PI_t} \qquad \forall t \quad (:\lambda_{1,t})$$

and the following first-order conditions:

$$(1)\ \frac{\partial \Pi}{\partial I_t^{ig}} = 0 \Rightarrow \sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i^{ig}} = P_t^{ig} + \lambda_{I,t} P_t^{ig}\ ;$$

$$(2)\ \frac{\partial \Pi}{\partial I_t^{cc}} = 0 \Rightarrow \sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i^{cc}} = P_t^{cc} + \lambda_{i,t} P_t^{cc}\ ;$$

$$(3)\ \frac{\partial \Pi}{\partial I_t^{J}} = 0 \Rightarrow \sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i^{J}} = P_t^{J} + \lambda_{i,t} P_t^{J}\ ;$$

$$(3')\ P_t^{ig} I_t^{ig} + P_t^{cc} I_t^{cc} + P_t^{J} I_t^{J} \leq \overline{PI_t}\ ;\ \lambda_{i,t} \geq 0\ ;\ (P_t^{ig} I_t^{ig} + P_t^{cc} I_t^{cc} + P_t^{J} I_t^{J} - \overline{PI_t})\lambda_{i,t} = 0\ ;$$

[19] Jefferson and Xu [1991] in their econometric analysis of behavior among Chinese enterprises find strong evidence to suggest Chinese firms are profit-seeking.

(4) $\frac{\partial \Pi}{\partial L_t} \leq 0 \Rightarrow P_t^Q \frac{\partial Q_t}{\partial L_t} \leq w_t$;

(5) $\frac{\partial \Pi}{\partial E_t} \leq 0 \Rightarrow P_t^Q \frac{\partial Q_t}{\partial E_t} \leq P_t^E$;

(6) $\frac{\partial \Pi}{\partial M_t} \leq 0 \Rightarrow P_t^Q \frac{\partial Q_t}{\partial M_t} \leq P_t^M$;

If $\lambda_{I,t}>0$, then the credit constraint is binding (i.e. $P_t^{ig} I_t^{ig} + P_t^{cc} I_t^{cc} + P_t^J I_t^J = \overline{PI_t}$) and, from FOCs (1)-(3), the marginal revenue product of investment > price of investment. Thus, with a binding constraint on investment, FOCs (1)-(3) of the original PMP (without a constraint on investment) will not hold in equality, although FOCs (4)-(6) of the original PMP likely will.

The extent of the investment constraint (if binding) will determine the <u>level</u> of investment in each type of capital since the smaller $\overline{PI_t}$ is, the greater $\lambda_{I,t}$ will be, and the more likely the left-hand side of FOCs (1)-(3) will be less than the right-hand side. Therefore, the outcome of a binding constraint on investment will be to lower investment in all capital and, depending upon the extent of the constraint, possibly eliminate investment in one or more of the three types of capital.

Calling the right-hand side of FOCs (1)-(3) the implicit price of investment, credit constraints have the effect of raising the implicit price of investment in each of the three types of capital. Since investment capital is scarce, similar to the market case, the firm will choose the technology with the higher implicit NPV. However, if a unit of CC technology requires much higher capital investment (as is the case), then the implicit NPV of CC technology may be negative while the implicit NPV of ingot technology may be positive. With no constraint on investment, the NPV of CC is higher than ingot. For example, if the return to ingot investment is 3 and the price is 1, and the return to CC investment is 10 and the price of CC investment is 7, the NPV of CC investment is higher. However, adding a constraint on investment which, say, has a shadow price ($\lambda_{I,t}$) of 1, the implicit NPV for CC is now negative while the implicit NPV of ingot is positive.

<u>Incentives to innovate</u>

A profit-seeking firm with particular output and/or employment objectives can be represented by the above PMP with constraints, such as the following, added:

$Q_t \geq \overline{Q_t} \qquad \forall t \quad (:\lambda_{Q,t})$
$L_t \geq \overline{L_t} \qquad \forall t \quad (:\lambda_{L,t})$

where the first constraint restricts firms to produce at least $\overline{Q}_t$ and the second restricts firms to employ at least $\overline{L}_t$. The first constraint changes the FOC pertaining to capital investment as follows:

$$\frac{\partial \Pi}{\partial I_t} = 0 \Rightarrow \sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i} + \lambda_{Q,t} \frac{\partial Q_i}{\partial K_i} = P_t^I$$

so that the implicit return to investment is higher or lower (depending upon the sign of $\lambda_{Q,t}$) than without the constraint on output. The only time this is important is when the constraint is binding, implying that optimal output without the constraint is lower than $\overline{Q}_t$. In this case, the sign of $\lambda_{Q,t}$ should be negative, implying that a relaxation of the constraint (i.e., lowering $\overline{Q}_t$) would increase the objective function.

Similar to above, this added constraint can change a firm's technology choice. For example, if the price of output is 1, the return to ingot investment is 3, the price of ingot investment is 1, the return to CC investment is 10, and the price of CC investment is 7, the NPV of CC is higher than ingot. However, if a binding constraint on output which results in a shadow price ($\lambda_{Q,t}$) of -0.5 is added, then the implicit NPV of CC is negative and the implicit NPV of ingot is positive.

Availability of technical information

The lack of information about CC technology can be thought of as leaving the option of CC out of the PMP altogether. Therefore, the firm is only deciding between ingot equipment or no ingot equipment—the former being the choice if the NPV of ingot investment is positive and the latter being the choice if negative.

Access to CC technology

Restricted access to CC equipment—because of governmental control over imported equipment, for example—has the effect of increasing the implicit price of CC investment. The constraint added to the firm's PMP would look like the following:

$$I_t^{cc} \leq \overline{I^{cc}} \qquad \forall t \quad (:\lambda_{cc,t})$$

which implies that investment in CC is restricted to less than $\lambda_{cc,t}$. This results in the following FOC pertaining to investment in CC:

$$\frac{\partial \Pi}{\partial I_t^{cc}} = 0 \Rightarrow \sum_{i=t+1}^{T} \frac{(1-\delta)^{i-(t+1)}}{(1+r)^{i-t}} P_i^Q \frac{\partial Q_i}{\partial K_i^{cc}} = P_t^{cc} + \lambda_{cc,t}$$

Therefore, depending upon how binding the constraint is, the NPV of CC investment may be significantly less than the NPV for ingot, whereas without the constraint the NPV of CC investment is significant more.

4.6. Estimation of the Effects of "Market" and "Institutional" Factors on Intrafirm CC Diffusion in China

The following variables are included in the empirical analysis to represent the four institutional constraints above:

(9) Credit constraints. A good measure of a firm's credit constraint is difficult to obtain. To some extent, the profit rate variable included with the "market" variables reflects a firm's credit constraint since if retained earnings are a firm's only source of investment capital, profit rate would determine a firm's access to investment capital. Additionally, a firm's lagged growth rate of capital stock--i.e., $(K_{t-1} - K_{t-2}) / K_{t-2}$--is included as a proxy for capital investment availability. Since investment equals the difference in capital stocks between two years minus depreciation, the growth rate of capital stock is an approximation for a firm's level of investment scaled by the firm's level of capital stock. It can be assumed that the higher a firm's growth rate of capital stock, the greater the firm's access to investment capital.

(10) Incentives to innovate. To capture differences in property rights (and therefore possible differences in a firm's incentive to innovate), an ownership dummy variable is included in the analysis. The dummy variable = 1 if firm is a "key" firm and = 0 if firm is a "local" firm.

(11) Access to CC technology. A firm's percentage of CC equipment purchased from foreign suppliers[20] is used as a proxy for a firm's access to technology. It is assumed that the higher this percentage, the greater the firm's access to not only foreign technology but also domestic technology as well, since if the firm is able to import it is more likely to be able to acquire technology domestically. Additionally, because a firm's experience with a technology increases its ability to build the equipment itself, the lagged change in a firm's CC ratio and the number of years since a firm first adopted CC technology also capture a firm's access to technology.

(12) Access to information about CC technology. There is no good proxy for a firm's access to technical information. A time index is included which captures (among other things) the overall increased awareness of CC technology over time. The time index =1 in 1985, =2 in 1986, etc.

The regression results from including these "institutional" variables are found in column (2) of Table 4. Most of the "market" variables that were significant in the first regression continue to be significant, and half of the additional "institutional" variables are also found to be significant. In particular, the coefficient associated with the "key" dummy variable is negative and very significant, suggesting that the inherent property rights differences between "key" and "local" make a difference in

[20] These data were acquired from Concast Standard AG [1998].

terms of CC technology diffusion—"local" firms seem to be able to diffuse CC technology more rapidly than "key" firms. Access to foreign technology also seems to matter as evident from the positive and significant coefficient associated with this variable. The lagged growth rate of capital stock does not seem to matter, which may or may not suggest that access to investment capital matters. This is because a firm's profit rate is positive and significant which, as discussed above, can also be capturing a firm's access to investment capital through retained earnings. As before, time is still significant and, as discussed above, can be capturing the dissemination of interfirm knowledge about CC technology. Also, adding these "institutional" variables increases the R^2 of the "between" effects, thus increasing the importance of cross-sectional differences.

Certain "market" variables that were not significant in the first regression are found to be significant when the "institutional" factors are added. In particular, firm size is now significant at the 5% level. On average, the "local" firms tend to be smaller; therefore, it is not surprising that the "key" dummy variable and firm size are interrelated. After controlling for whether the firm is a "key" or "local" firm, the results suggest that larger firms are able to diffuse CC more rapidly—similar to results found in the diffusion literature. Experimenting with adding in different combinations of the institutional constraints, it is also found that lagged profit rate is interrelated with the percentage of foreign CC technology owned by the firm. This causes the lagged profit rate variable to become more significant when the percentage of foreign CC variable is added. In terms of possible problems due to multicollinearity, these results suggest that no problem exists since the standard errors are becoming smaller when these "institutional" variables are added (rather than larger) and interrelated variables are both found to be significant. The only possible problem with multicollinearity exists with the firm age variable. On average, "local" firms are much younger than "key" firms and therefore it is not surprising that the "key" dummy variable and firm age are interrelated. The standard error of the coefficient associated with firm age rises slightly when the "key" dummy variable is added and the value of the coefficient falls, causing firm age to become insignificant.

An interesting empirical fact gleaned from looking at the aggregate data (Figure 13) which is not picked up in the regression results is that CC technology now seems to be used to replace ingot production rather than to expand total production. Throughout the period 1985-1995, CC output continues to grow, but ingot production begins to fall in 1993. This suggests that beginning in 1993, CC is being used to <u>replace</u> ingot production rather than supplement it as is the case prior to 1993. This is not surprising since China's goal was to reach an industry-wide production level of 100 million tons of crude steel by the year 2000 in order to become the largest producer of steel in the world[21]. This national goal encouraged firms to maximize output (rather than minimize cost or maximize profit) regardless of whether such a level of demand for steel existed. Since reaching this goal, China has been saddled with

an oversupply of steel, causing the price of steel to plummet and the Chinese government to switch to a national policy of cost reduction.

[21] This goal was reached in 1996.

5. Conclusions

As emphasized throughout this paper, the unique situation in developing countries and transition economies requires a different approach to analyzing the diffusion of new technologies in these countries. In particular, to explain the variation in the rate of diffusion among firms in countries like China, variables that capture the following must be considered: (1) availability of investment capital; (2) incentives to innovate; (3) availability of technical information; and (4) access to technologies.

This research finds that although market forces are beginning to have an influence on the diffusion of continuous casting technology in China, the diffusion rate seems to be more heavily influenced by "institutional" constraints ((1)-(4) above) than "market" factors. In particular, firms with better-defined property rights seem to be diffusing continuous casting technology more rapidly and replacing ingot casting with continuous casting. The results also suggest that firms with better access to foreign suppliers have higher continuous casting ratios. A firm's profit rate also seems to have an influence on a firm's diffusion rate. Although these results are encouraging in that they suggest that market forces are having an effect, a word of caution is required. China's "profit responsibility system" and unstructured accounting system have in the past caused reported profit rates to be highly suspect.

The results also suggest that input prices have had an insignificant effect on the diffusion rate. Until recently, a large portion of energy inputs were purchased at below-market prices. With the implementation of further price reforms in 1993, firms are beginning to face market prices for energy that should encourage the diffusion of energy-efficient technologies in the future. However, the central government needs to do more to increase access to advanced technologies and provide incentives to firms through better-defined property rights.

We should be reminded that increases in technological diffusion do not necessarily imply lower emissions. An entire literature exists on the energy-capital substitution question, in which some researchers have found energy and capital to be substitutes (Humphrey and Morony [1975], Griffen and Gregory [1976], and Halvorsen [1977]) while others have found them to be complements (Hudson and Jorgenson [1973], Berndt and Wood [1975]). Therefore, to increase the diffusion of energy-efficient technology in China, policies to reduce the impediments to technological diffusion need to be combined with policies to encourage energy saving among Chinese firms.

Appendix A—Interviews with individuals in China: Sites visited.

Iron and Steel Firms

- Shougang Iron and Steel—Beijing
- Handan Iron and Steel General Works—Handan, Hebei Province[22]
- Chongqing Special Steel—Chongqing
- Chongqing Iron and Steel—Chongqing
- Baoshan Iron and Steel—Shanghai
- Shanghai Steel Plants—Shanghai

Universities/Research Institutes/Design Institutes

- University of Science and Technology (formally the Iron and Steel University)—Beijing
- Beijing Energy Efficiency Center (BECon)—Beijing
- Capital Engineering and Research Incorporation of Iron and Steel Industry (CERIS)—Beijing

Government

- Energy Research Institute (ERI), State Planning Commission—Beijing
- State Bureau of Metallurgy (formally the Ministry of Metallurgical Industry)—Beijing

Foreign Continuous Casting Equipment Suppliers (located in the PRC)

- Concast Standard—Hong Kong
- Concast Standard—Beijing
- SMS Schloemann-Siemag—Beijing

[22] A former executive of Handan I & S, now at Chongqing Special Steel, was interviewed.

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