Growth Mechanisms and Sustainability

Economic Analysis of the Steel Industry in East Asia

Edited by
Jun Ma
Masashi Yamamoto

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Preface

This book is a compilation of the research conducted under the project "Evolution of International Specialization and Sustainable Utilization of Resources in Northeast Asia: Challenges and Prospects" in the Center for Far Eastern Studies, University of Toyama, Japan. The research project was launched in 2016 as part of the network-based projects: NIHU Area Studies "Regional Structure and Its Change in Northeast Asia: In Search of the Way to Coexist from the Point of View of Transborderism" in collaboration with the Center for Northeast Asian Studies at National Museum of Ethnology of National Institutes for the Humanities (NIHU) and five other leading research institutes in Japan.

Our project focuses mainly on the following two issues. The first issue concerns resources and how the evolution of the international division of labor and international cooperative relations can contribute to the economic growth and social development of the Northeast Asian region in the future. In the second issue, the international division of labor is investigated to examine the limits of the competitive growth model for gaining international comparative advantage through competition over resources and technological innovation from both the macro- and micro-perspectives and consider how a win-win relationship can be achieved among the countries of Northeast Asia and how to construct an optimal symbiotic growth model for the entire region.

Since 2018, we have investigated the steel industry, which has a significant impact on economic and social activities, and have mainly studied the utilization of iron ore resources, international specialization, trade relations, and environmental issues in the steel industry of this region. We have worked together with researchers from other research institutes in Japan and overseas, including China and Korea, to organize seminars and conduct field research.

To write this book, we have collected various data sets related to the steel industry while conducting field studies on major steel manufacturers and institutes in Japan, the Republic of Korea, and China for the past three years. Based on the results of the surveys and research, we completed this book after holding a conference to discuss various issues related to the growth of the steel industry in East Asia in March 2020.

We would like to express our deepest gratitude to Nippon Steel Corporation, POSCO, China Metallurgical Industry Planning and Research Institute, HBIS Group Hansteel Company, and other related organizations in Japan, the Republic of Korea, and China for their cooperation in the field research. We would particularly like to thank Ken Kosugi (General Manager, Head of Department Environment Relations Dept. Environment Div. Nippon Steel Corporation, Japan), Prof. Hyunchul Kim (Graduate School of International Studies, Seoul National University, Republic of Korea), Dongwook Kim (Senior Vice President, Business Coordination Team, Hyundai Motor Group, Republic of Korea), Taehyuk Yim (Department Manager, Corporation Support Division Management Planning Dep, POSCO Japan), Shuping Ma (Research fellow, Vice-Director of Research Office, Enterprise Research Institute, at the Development Research Center of the State Council, China), and Prof. Erbiao Dai (Research Director, Asian Growth Research Institute (AGI), Japan) for their valuable advice during the research.

We are grateful to the anonymous referees, who offered many valuable comments to make our book more complete, to our publisher, Palgrave Macmillan, and in particular, to our editors Jacob Dreyer and Arun Kumar, for keeping us on track toward the publication of this book.

In addition, we would like to thank the NIHU and the University of Toyama for their support not only in terms of funds but also in many other ways.

Finally, we would like to welcome any comments from researchers and practitioners in the steel industry upon reading this book, and we hope that general readers interested in this field will also read this book.

Toyama, Japan — Jun Ma
Hiratsuka, Japan — Masashi Yamamoto

Contents

Notes on Contributors

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Masashi Yamamoto is a Professor at the Center for Far Eastern Studies (C-FES), University of Toyama, Japan. His main research interest is environmental and resource economics from both theoretical and empirical perspectives. Although most of his early works are in the waste management and recycling field, his recent papers analyze more diverse natural resource management issues, such as fisheries and forest management. His major publications include "Socially Optimal Recycling Rate: Evidence from Japan," *Journal of Environmental Economics and Management*, vol. 60, pp. 55–70, 2014 (with T. Kinnaman and T. Shinkuma; funded by JSPS) and "Don't Rely Too Much on Trees: Evidence from Flood Mitigation in China," *Science of the Total Environment*, vol. 732, 2020 (with K. Tembata and K. Matsumoto; funded by NIHU). He has experience in the role of coediting a book through his work on *Economics of Waste Management in East Asia* (Routledge Studies in the Modern World Economy) published by Routledge in 2016, an outcome of a project funded by the Japanese Ministry of Environment. He is also a member of several national-level committees to revise environmentally related laws in Japan, such as the Construction Waste Recycling Law and the Home Appliance Recycling Law.

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CHAPTER 1

Introduction

Jun Ma

The steel industry is one of the oldest traditional industries. It is also among the industries that have grown most sustainably since the First Industrial Revolution, becoming a pillar of the global economy. After World War II, the steel industries of the East Asian countries expanded remarkably in tandem with these countries' strong overall economic growth, and the center of modern global steel production shifted to East Asia.

In 2019, China's crude steel production (996.34 million tons) accounted for the largest share of global crude steel production (totaling 1,875.2 million tons). Japan ranked second (99.3 million tons), and the Republic of Korea ranked sixth (71.4 million tons). These three East Asian countries together represented 62% of world crude steel production. The apparent consumption of crude steel in these three countries is the world's highest, accounting for half the global total.[1]

[1] Calculated by referring to the World Steel Association (2021).

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This book presents a broad investigation of various issues in East Asia's steel industry since the 1980s based on an economic approach. Topics include the sustainable use of resources, international specialization, trade relations, technological innovations, and environmental mitigation, in addition to a consideration of the rapid growth of the Chinese steel industry.

1 Issues Examined in This Book

As a country's level of economic development increases, there is a general tendency for firms in sectors such as the automobile and electrical appliance industries to relocate to countries with lower levels of economic development. However, a different trend has been observed in the steel industry. Since World War II, the scale of production in the steel industry in the East Asian countries has increased significantly, while steel production in Western countries has not significantly decreased. As a result, world crude steel production increased tenfold in the immediate postwar period. There have also been dramatic changes in international specialization in the steel industry in terms of its relation to other industries. The widespread downstream use of steel products has led to segmentation in the steel industry, with international vertical and horizontal divisions occurring simultaneously. In contrast, upstream exporting and importing countries are clearly distinguished: while countries such as Australia and Brazil have become net exporters of steel resources, East Asian countries have become net importers of steel resources. Competition among countries for resources has become more intense over time.

As a result of technological innovations in the steel industry, the reuse of steel resources, the efficiency of the steel production process, and environmental improvements in the steel industry have increased to hitherto unimaginable levels. However, in certain countries, environmental problems caused by the steel industry remain serious.

The drivers of these changes include technological development in fields such as production, transportation, and information; restructuring in the international division of labor, trade structures and resource supply and demand; adjustment in national trade and industrial policies as well as in corporate behavior patterns in individual countries; and interaction among all these factors.

The steel industry in East Asia has not only expanded its scale of production but also undergone significant structural changes in the postwar period. However, systematic empirical research on the international division of labor, resource use, and environmental issues in the regional steel industry is scarce compared to the literature on the automotive, electronics, electrical appliance, and IT industries.

Focusing on the steel industry and adopting an economic approach, the aim of this book is to analyze multiple aspects of the steel industry in East Asia over the past 40 years while attempting to answer the following questions. How has the industry grown? How have its industrial structure and international specialization changed? What innovations have occurred? How have resource and environmental problems been resolved? Which problems remain unsolved? What solutions to such problems can be considered?

2 This Book in Relation to the Literature on the East Asian Steel Industry

Hudson and Sadler (1989) survey the various factors that have contributed to the decline of the international steel industry, such as changes in production strategies, in demand and world trade, and in regional production trends in the steel industry, through the 1980s. Their study also examines the impact of the decline on steelmaking communities and considers local, national, and international initiatives to assist the affected areas and how these initiatives were devised and implemented.

Drawing on case studies on the steel industry in the US, Japan, South Korea, Brazil, and India, D'Costa (1999) explains how and why the steel industry has shifted from advanced capitalist countries to late-industrializing countries. D'Costa also examines the relationship between industrial change and institutional responses to technological diffusion and finds that governments' and firms' differing responses to innovations result in an uneven diffusion of technology and industrial reorganization. Moreover, when it becomes clear that existing institutional arrangements no longer serve the industry well, new arrangements are created that allow for innovative behavior. This phenomenon has often created opportunities for technological "leapfrogging" and the emergence of new technologies in unexpected locations.

In a study on resource networks in the Asia-Pacific steel industry, Wilson (2013) adopts a political economy perspective to investigate the contributions of states and firms to the governance of global production.

Li (2020) examines the principles of supply-side structural reform and current practices in the Chinese steel industry. Focusing on the general requirements for high-quality development, Li's study reviews the evolution of the global and Chinese steel industries in terms of capacity reduction, innovation, and transformation.

Compared to these studies, this book is unique in the following four ways.

First, it focuses on production and demand, trade relations within and outside the East Asia region, and the environmental impact of the regional steel industry in analyzing the industry's growth process, structural changes, and technological innovation from the 1980s to the present. The research in this book differs in subject and period of focus from Hudson and Sadler's (1989) analysis. Accordingly, the results of our research could provide more useful information for policymakers in the present-day steel industry.

Next, we take into account the technological "leapfrogging" emphasized in D'Costa (1999) while discussing the innovation characteristics and processes of Japanese and Korean steel manufacturers. However, our study demonstrates through statistical analysis that technological innovations not only impact the increase in production scale but also industrial structure change (Chapter 8) and solutions to environmental problems in the region (Chapter 7). We also emphasize the importance of inter-processes/interorganization of company coordination across equipment and processes (Chapter 6). The most significant feature of our research is that it elucidates the mechanisms of growth through econometric analysis based on large data sets and case studies based on a detailed survey of companies.

Wilson (2013) analyzes the trade relations and global production networks between Asia and the Pacific from the perspective of resource interdependence. In contrast, this book mainly analyzes the characteristics of the international division of labor and trade (Chapters 3 and 4), sustainable resource utilization (Chapter 5), and environmental protection (Chapter 7) in the growth of the East Asian steel industry.

Finally, in contrast to Li (2020), this book considers the growth of China's steel industry while focusing on East Asia and investigates the issues connected with the growth of the steel industry in this area. In the book, we are of course aware of the rapid growth of the Chinese steel industry. However, we concentrate on elucidating growth mechanisms and examining the essential aspects of the problems of the Chinese steel industry (Chapters 9 and 10) and their impact on other countries (Chapter 11) based on a political economics approach.

3 Structure of This Book

In each of the three countries of East Asia, the steel industry has been a driver of rapid economic growth. This phenomenon is common in Western countries. However, the economic growth model of East Asian countries is of the catch-up type, with a target of reaching the level of advanced countries in Europe and America within a short time period. Thus, the government intervenes through policies to promote the rapid development of the steel industry. At the same time, the problem of overproduction and surplus inevitably arises. As a result, the steel industry in these East Asian countries not only supports the domestic economic infrastructure but also causes significant changes in the vertical and horizontal division of labor within the industry. This has resulted in a major restructuring of the global steel industry.

Focusing on the noted characteristics, in Part I, we discuss the changing processes of the policies, industrial structure, and the international division of labor in the steel industry of the three East Asian countries. This part includes three chapters.

In Chapter 2, to help the reader better understand the issues this book discusses, we first outline the growth of, challenges to, and government policies regarding the steel industries of Japan, the Republic of Korea, and China. Then, other two studies focus on changes in international specialization, trade relations, and industrial structure in the growth of the steel industry in East Asia. Chapter 3 examines the ideal ways in which the intraregional division of labor can overcome the current difficult business environment and strategic challenges to survive in the future. In Chapter 4, we analyze the intraregional and interregional structures of the international division of labor and the interdependence of intermediate goods and final goods ("metal products") by sector and time series in the East Asia region.

Following the unprecedented quantitative expansion at the macro-level, there has been significant qualitative development in East Asia due to national industrial growth policies and continual innovation at the firm level. Originally basing their development on innovations from Western countries, the Republic of Korea and Japan have both succeeded in creating new steel products with high value added in recent decades, and substantial efforts have been made by the steel industry to promote the sustainable use of resources and energy as well as to mitigate environmental damage.

In Part II, we focus on elucidating the mechanisms of growth of the steel industry in East Asia. As an industry that consumes large amounts of natural resources and energy, its growth requires not only effective use of resources and energy but also solutions to the problems of natural disasters and environmental destruction. The steel industry in East Asia has faced the challenge of environmental protection and the evolution of its industrial structure as well as the expansion of its scale. In this part, we analyze how the three East Asian countries have solved these problems. This part consists of four chapters.

In Chapter 5, we focus on the contemporaneous and dynamic effects of disasters and consider the persistence of disaster shocks using data on iron ore employed in making crude steel. We also investigate whether the occurrence of natural disasters causes price fluctuations in the iron ore market.

Chapter 6 focuses on management issues that occur when adopting "new" technology from the outside and uses a case study on POSCO to reveal that the perception of a new technology can be a critical factor for success in technology transfer when a company adopts such a technology.

In Chapter 7, our study postulates that, after excluding emissions from the iron and steel industry, the composition effect actually increases pollution emissions. Significant reduction in CO_2 emissions is accelerated by innovative improvements to production driven by technology and/or regulations of Japanese and Chinese manufacturing.

Based on theoretical analysis, in Chapter 8, we collate panel data by steel product to demonstrate how various factors, especially the technological progress in crude steel production, imports of steel products from Japan and the Republic of Korea, and demand for final goods, affected the domestic production of steel products and final goods that are closely related to steel products in China.

To properly understand the growth characteristics of the steel industry over the past 40 years in East Asia, it is vital to illuminate the growth mechanisms of China's steel industry, which has had a significant impact on the development of the global steel industry. Because it regards the steel industry as a pillar industry for economic growth, the Chinese government has launched various policies to make the steel industry grow quickly, which has led to remarkable growth. However, this growth has been accompanied by overproduction. This problem has increased China's dependence on foreign markets and had a significant impact on the international structure of trade in steel products. When the relationship between China and major overseas markets is strained, the impact on the domestic steel industry and other countries is significant.

Therefore, in Part III, we focus specifically on the Chinese steel industry, which has grown remarkably over the last 40 years, and further analyze the problems and impacts of growth characteristics of China's steel industry. This part consists of three chapters.

Chapter 9 examines the problem of overcapacity and the role of the government and the market in resolving this issue in China's steel industry as the economy shifts from a growth orientation to a quality orientation.

Using data from large and medium-sized Chinese manufacturing enterprises from 2004 to 2007, Chapter 10 investigates labor productivity and surplus labor in Chinese steel firms based on a fixed effects model, a random effects model, and GMM.

Chapter 11 examines the impacts of increasing Chinese imports from and Chinese exports to Japan (in terms of steel industry-specific increases and increases in all manufacturing sectors) on the outcomes of the four national Lower House (*Shūgiin*) General Elections in Japan between 2009 and 2017.

Finally, based on the preceding analysis, we propose policies to promote sustainable future growth for the steel industry in East Asia.

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PART I

The Process of Growth

CHAPTER 2

How Does State Policy Shape East Asia's Steel Industry? A Selective Review

Jie Yang

1 Introduction

Steel is the most widely used metal and the most recycled material in the world. The steel industry employed more than six million people worldwide in 2017, and the total added value of its production processes reached almost 500 billion dollars (Oxford Economics 2019). U.S. firms dominated steel production in the first half of the twentieth century, but leadership[1] in the steel industry shifted to Japan in the late 1970s and then possibly to the Republic of Korea or China (Lee and Ki 2017; Lee and Malerba 2017). Since the beginning of the 2000s, the major Asian economies—Japan, the Republic of Korea, and China—have

[1] Lee and Malerba (2017) define "leadership" as industrial leadership in terms of the domination of global markets in an industry, with such domination being assessed through a combination of measured market share and industry expert evaluations.

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accounted for more than one-third of the world's crude steel production and apparent consumption of either crude steel or finished steel products (Lee et al. 2005). According to Fig. 1, the apparent use of finished steel products in Asia grew by 52% to approximately 1,169 million tons from 2009 to 2018, mostly driven by China's rapid growth in steel demand (51.4%). China, Japan, and the Republic of Korea are also the major steel exporters, accounting for 30% of 2018 global steel exports measured by quantity (World Steel Association 1967–2019).

The iron and steel industry presents one of the most energy-intensive sectors within East Asian economies, especially in emerging economies such as China. Since the first oil crisis in 1973, Japan's steel industry has intensively invested in technology for better energy conservation in production processing and to collect energy, allowing Japan's steel

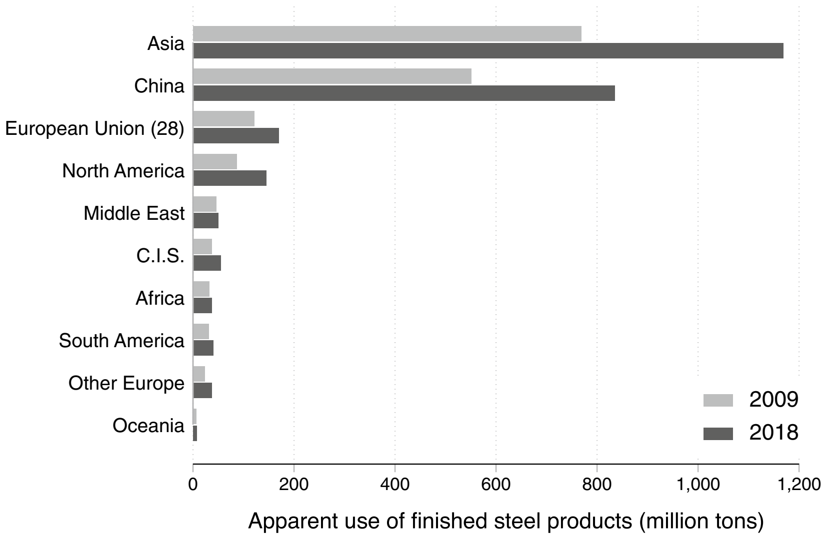

Fig. 1 Apparent use of finished steel products in million tons (*Note* C.I.S. indicates Commonwealth of Independent States. This figure presents the change in the apparent use of finished steel products from 2009 to 2018 for nine of the world's largest steel-consuming economies in Asia, Europe, the CIS region, North America, and South America, which together account for more than 90% of global steel demand. Steel demand in China is presented separately to explain the dramatic growth in Asia. *Source* World Steel Association [1967–2019])

industry to achieve significant energy conservation and energy efficiency (Nippon Steel Corporation 2020). Figure 2 presents international comparisons of energy efficiency in 2015, with Japan assigned the world's highest energy efficiency, followed by the Republic of Korea, Germany, and China. However, the global steel industry is facing increasing pressure to reduce its significant emissions. In 2019, the steel and cement sectors accounted for approximately 17% of total CO_2 emissions from energy and industrial sources, which are difficult to decarbonize because of technical and political economy barriers (United Nations Environment Programme 2019). The Paris Agreement 2-degree scenario requires the iron and steel industry to reduce CO_2 emissions by 50 Gt cumulatively through 2050,

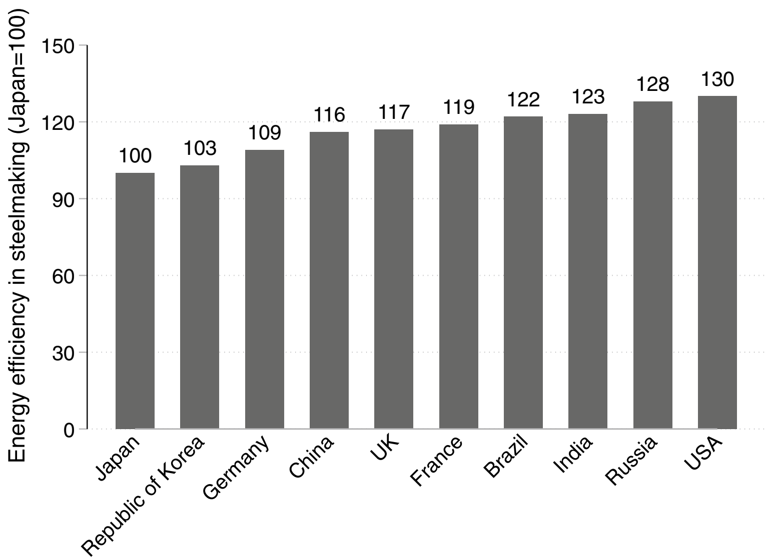

Fig. 2 Energy efficiency in steelmaking by country (2015) (*Note* This figure illustrates international comparisons of energy efficiency [sectors of electricity generation, iron, steel, and cement] and indexes with Japan set at 100. The original Japanese translation data and numerical values were provided by the Japan Iron and Steel Federation. *Source* This dataset is collected from the Nippon Steel Sustainability Report 2020, and the original source is the Research Institute of Innovation Technology for the Earth [RITE])

thereby contributing the largest share (35%) of carbon emission reductions among all industrial sectors (Tian et al. 2018). The production level and the technologies employed are decisive factors for energy use and carbon emissions, while policy settings affect structures and efficiencies within the steel sector.

Issues of productivity growth, structural composition, and the role of technological change in the iron and steel sectors have been discussed from various perspectives in the previous literature. This chapter focuses on key policy changes in East Asia's steel industry. The governments of Japan, the Republic of Korea, and China have always attached great importance to the development of the iron and steel industry. The guidance and intervention of institutional policies in East Asia's iron and steel industry are considered to be highly targeted and efficient. To understand the growth mechanisms and barriers in East Asia's steel industry, the similarities and differences between the institutional policies in Japan, the Republic of Korea, and China and their relationship with current issues are discussed, which may help identify potential future development strategies that lead to a more sustainable development path.

2 Key Policy Drivers of Productivity Growth

2.1 Drivers of Productivity Growth in Japan

The postwar economic achievements of Japan and the Republic of Korea have received considerable attention, and extensive economic research has been conducted on the factors influencing Asian catch-up at the country and industry levels. Lee and Malerba (2017) build on the previous literature and propose a conceptual framework of technology windows (technology and knowledge), demand windows (demand conditions and business cycles), and institutional windows (public policy and institutional settings) that are related to changes in a sectoral system. In terms of the steel industry, Lee and Malerba (2017) note in their study that the steel industry experienced two catch-up cycles. The first was from the United States to Japan in the late 1970s and early 1980s, and the second was from Nippon Steel to POSCO in the Republic of Korea during the late 1990s. The leadership shift from the United States to Japan involved technological and institutional windows. Japanese firms adopted the Austrian innovation of the basic oxygen furnace (BOF) method at an early stage and further improved this method through follow-on innovations (Lee and Ki 2017). The Japanese government was also involved by establishing an approval system for licensing foreign technology, which helped Japanese steelmakers engage in the BOF method at a low cost (Elbaum 2007). Furthermore, the demand for steel was driven first by postwar reconstruction and then by Japan's rapid urbanization and construction and export of steel-intensive products.

Figure 3 shows the growth in crude steel production and GDP since the Second World War. Postwar steel production in Japan can be divided into two phases: a high increasing stage (1965–1973) and a fluctuation and reduction stage (1973–now). Japan's steel industry experienced the expansion of crude steel production and improved ironmaking between 1967 and 1973, which is the high increasing stage, as shown in Fig. 3. During the first phase, crude steel production exhibited annual increases of more than 10%, exceeding GDP growth (Smil 2016). Both Wilson (2013) and Smil (2016) emphasize the influence of the three rationalization plans by the Ministry of International Trade and Industry (MITI)

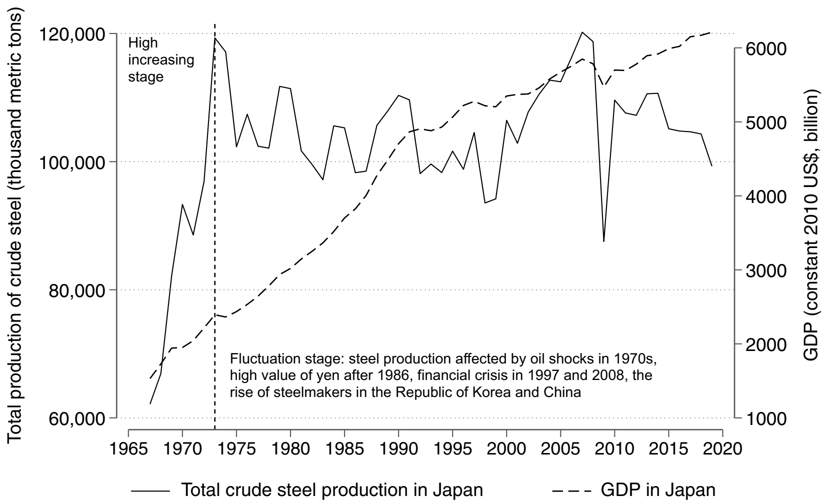

Fig. 3 Trend in total crude steel production in Japan, 1967–2019 (*Note* Data on GDP are in constant 2010 U.S. dollars and converted from domestic currencies using 2010 official exchange rates. *Source* The crude steel production dataset is from World Steel Association [1967–2019], and the GDP dataset is from World Bank [1967–2019])

between 1951 and 1965, which guided the postwar development of the Japanese steel industry. The first two rationalization waves of the 1950s concentrated investments in upgrading rolling mills to new integrated mills, which reduced coke inputs and boosted productivity (Wilson 2013). Furthermore, MITI also shared information with firms on foreign markets, technology, and plans for domestic economic expansion, making it easier for Japanese firms to acquire foreign technology at a low cost and contributed to industry competitiveness (Elbaum 2007). During the third rationalization plan in 1960, MITI started to instruct steel firms to develop investment plans largely on their own, and its role in this process was limited to assisting with firm negotiations (Wilson 2013). Moreover, to sustain interfirm coordination, significant concentration was achieved through the establishment of the Nippon Steel Corporation[2] in 1970 and was immediately recognized as the world's largest steel firm. Nippon Steel also became the industry price leader and established a system of price coordination and promoted the consolidation of the Japanese steel industry. In 1973, crude steel output in Japan reached 100 million tons, and Japan ranked first in the world in 1995 (World Steel Association 1967–2019). The new Nippon Steel Corporation[3] was formed from the merger of the old Nippon Steel and Sumitomo Metal in 2012, further increasing the steel industry's concentration, and the company has been one of the top 5 steel producers in the world for the last two decades. Japan's long record of industrial policy intervention and its industrial coordination pattern of state-firm and firm-firm cooperation were critical factors in the rapid growth of the steel industry and contributed to shaping mineral resource networks abroad (Elbaum 2007; Wilson 2013; Smil 2016).

The Japanese economy took a sudden turn and entered a stagnation period after the first oil shock in 1973, and crude steel showed the same downward trend as the economy. Japan's postwar steel production first peaked in 1973 and then fluctuated mainly between 95 and 110 million tons because of the oil shocks of the 1970s, the high value of the yen after 1986, and the rise of Chinese steelmaking in the 1990s (Smil 2016). During this period, iron and steel development in Japan was highly

[2] The Nippon Steel Corporation was established in 1970 from the merger of Fuji Iron & Steel and Yawata Iron & Steel.

[3] The new Nippon Steel Corporation is called Nippon Steel and Sumitomo Metal Corporation (NSSMC).

focused on technology introduction and innovation for energy savings and production efficiency improvement, which promoted a rapid increase in the competitiveness of Japan's iron and steel industry. Furthermore, tremendous effort was invested in the supply of high-value products in response to the requirements of the automobile industry (Smil 2016). Despite the fluctuation and decline during the second phase, the Japanese steel industry remains the most competitive in the world. In addition to technology improvements and demand for high-quality steel products, a series of highly targeted policies since the 1970s have also played a decisive role in promoting the downsizing of operations and improving profitability through the elimination of excess and inefficient capacity and the accompanying reductions in employment. Section 5 provides an overall review of the reduction policies in Japan, the Republic of Korea, and China.

2.2 Drivers of Productivity Growth in the Republic of Korea

By the 1990s, the Republic of Korea was a major player in the global economy. Together with this economic achievement, the steel industry grew dramatically. Figure 4 shows the trend in total steel production and GDP in the Republic of Korea from 1965 to 2019. The steel industry contributed to shaping the Republic of Korea's rise from a low wage, light industry base to a world leader in advanced industries (Shin and Ciccantell 2009). Figure 4 shows that the catch-up cycle for the steel industry in the Republic of Korea, which is the industry's second postwar catch-up cycle, is divided into four phases. The first is the entry stage (1968–1972), when the steel industry's development was fueled largely by government policies. Pohang Iron and Steel Company (POSCO) was established in 1968 by the government, and it received extensive government support from the beginning. The "Steel Industry Promotion Law"[4] of 1970 granted POSCO numerous benefits, including low-cost and long-term foreign capital, discounts for electricity and rail transport, and limits on steel imports (Shin and Ciccantell 2009).

The second phase is the gradual catch-up stage (1973–1986), in which Pohang Steelworks began producing steel in 1973 and expanded

[4] The Republic of Korea's policy to promote heavy industries in the early 1970s included iron and steel, shipbuilding, nonferrous metals, chemicals, general machinery, electrical equipment, and electronics.

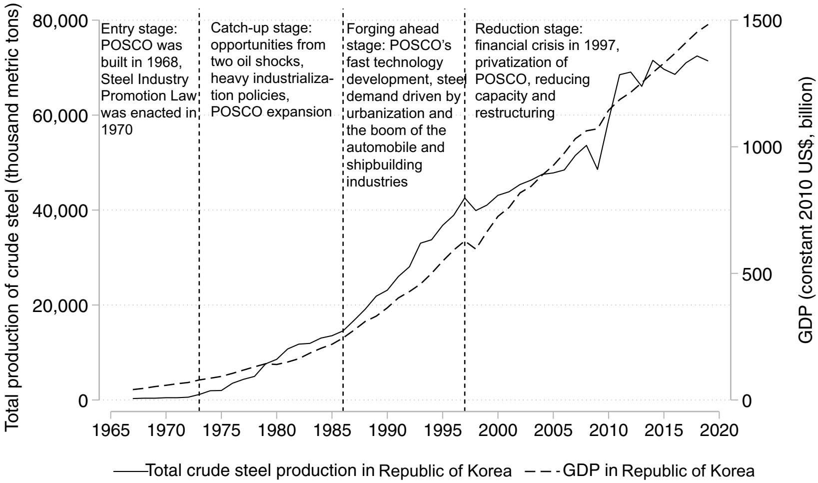

Fig. 4 Trend in total crude steel production in the Republic of Korea, 1967–2019 (*Note* Data on GDP are in constant 2010 U.S. dollars and converted from domestic currencies using official 2010 exchange rates. *Source* The crude steel production dataset is from World Steel Association [1967–2019], and the GDP dataset is from World Bank [1967–2019])

production capacity through 1983 (Chung and Sa 2017). During this phase, which followed two oil shocks, POSCO was able to purchase and import new technologies at a low cost from Japan and consequently obtained comparative competitiveness (Lee and Malerba 2017). Policies were implemented to nurture heavy industries,[5] which significantly drove up steel demand. The government also provided various administrative supports, including domestic loans, foreign borrowing, special depreciation allowances, and very low tax rates (Chung and Sa 2017). As a result, POSCO secured international loans with low interest rates to construct a second steel mill at Kwangyang in 1981. After four expansions, the Kwangyang mill had a capacity of 11.4 million tons of steel, bringing POSCO's total capacity to 20.5 million tons (Shin and Ciccantell 2009).

[5] These policies focused on six sectors, including steel, petrochemicals, machinery, shipbuilding, electronics, and nonferrous metal.

The third phase is the forging ahead stage (1987–1997)—a period of rapid development for POSCO at the technology level, and POSCO secured a greater cost advantage (Chung and Sa 2017). As a large state-owned firm, POSCO required frequent involvement and subsidies from the government, as before, to support massive capital investments and technological innovation. During this phase, POSCO's supply of domestic steel experienced a tremendous rate of increase of 9.8%, which supported the continuous growth of the economy (World Steel Association 1967–2019). POSCO continually expanded its capacity, and the steel industry supported the development of a number of complementary industries, such as automobiles, shipbuilding, containers, railroads, construction, and appliances, spurring a virtuous cycle of economic growth during the last three decades (Shin and Ciccantell 2009). For instance, the automobile industry in the Republic of Korea produced approximately 2.8 million vehicles (more than 1.5 million were exported) by 1999, and POSCO sold approximately 3.5 million tons of steel to the industry (Shin and Ciccantell 2009). Moreover, the appliance industry produced various home appliances during the urbanization period and consumed significant amounts of steel. Projects in the construction industry, including building infrastructures, such as highways and bridges, commercial building construction, and residential construction, also use huge amounts of steel. Furthermore, important to mention is that to secure the expanded use of imported raw materials, the Republic of Korea's steel industry adopted strategies similar to those of the Japanese steel industry by constructing larger steel mills equipped with the newest facilities and technologies to obtain economies of scale. Long-term contracts, multiple raw material sources, and international joint investments were developed as well to secure raw materials use (Shin and Ciccantell 2009; Wilson 2013).

The fourth phase is the reduction stage (1998–now), when steel production began to slow. Lee (2003) considered the Asian financial crisis in 1997 as one of the most important turning points for the steel industry in the Republic of Korea. Although the steel industry was not hit hard by this crisis, the government recognized the limitations of government-led operations in expanding the economy and attempted to shift to a more market-led economy. After this crisis, the government enacted substantial restructuring in the financial, corporate, labor, and public service sectors, although the total production capacity continued to increase immediately after the crisis. One of the big moves in the steel industry was the privatization of POSCO in 1998, a transformation that was completed in 2000. The detailed capacity reduction measures taken by the government and steelmakers are introduced in Sect. 5.

In summary, during the entire growth process of the steel industry in the Republic of Korea, the government's role has been crucial as a guide and director in planning, financing, and evaluating for the industry; these activities included its export-oriented growth policy, the monopolistic position of POSCO in the industry and economy, the support of extensive technological and organizational innovations, and securing raw materials (Shin and Ciccantell 2009).

2.3 Drivers of Productivity Growth in China

China's rise has been the most important change in the global steel industry in the last two decades, and institutional changes have occurred in the Chinese steel industry. In terms of scale, China's iron and steel industry has already quantitatively caught up but remains far from achieving the qualitative leap needed to catch up and lead in competitiveness (Li 2020). Similar to Japan and the Republic of Korea, government policies have had a crucial impact on the steel industry's development course in China. As shown in Fig. 5, the development of China's steel industry also experienced four phases that accompanied rapid economic growth. The first phase is the exploration stage (1965–1979), and the second phase is the stable development stage (1979–1996). This period represented the start-up stage of China's iron and steel industry, which then showed stable development for more than 20 years.

Since the introduction of market-based economic reforms in 1978, the Chinese economy has grown strongly, recording average annual growth of approximately 10% (World Bank 1967–2019). During this second phase, Chinese steel production also expanded rapidly, growing at an average of 7% annually during the 1980s, 10% during the 1990s, and close to 20% in the 2000s (Li 2020). Meanwhile, China's crude steel output broke through 100 million tons in 1996, reaching 10.12 million tons, and China became the largest steel producer in the world (World Steel Association 1967–2019). China's economy developed rapidly, leading to constantly increased demand for iron and steel, and the reform removed some of the previous institutional and systematic obstacles, the planning system gradually shifted to the market system, and productivity

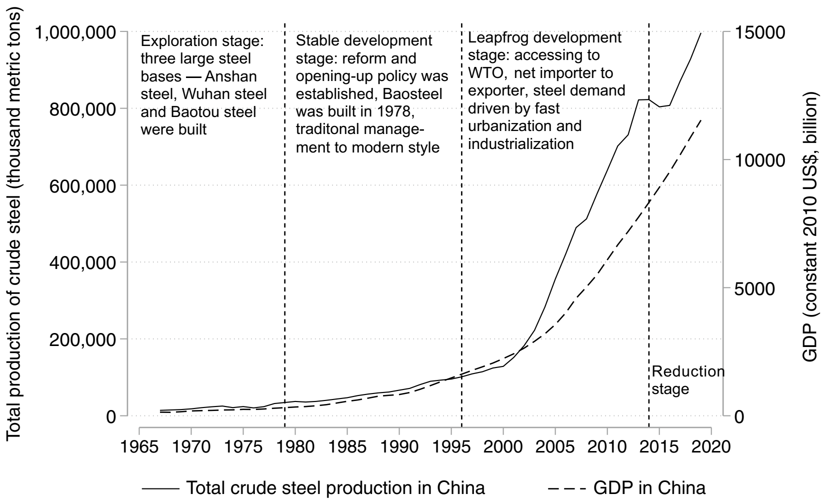

Fig. 5 Trend in total crude steel production in China, 1967–2019 (*Note* Data on GDP are in constant 2010 U.S. dollars and converted from domestic currencies using official 2010 exchange rates. Data on total crude steel production from 1967 to 1971 were estimated by World Steel. *Source* The crude steel production dataset is from World Steel Association [1967–2019], and the GDP dataset is from World Bank [1967–2019])

was released (Li 2020). Furthermore, the industrial policy of "grasping the large and letting go of the small" in 1996 involved a consolidation process under ongoing state ownership for strategic industries, such as the steel industry. The Chinese government has developed the four leading steel enterprises, Baosteel, Shousteel, Ansteel, and Wusteel, into large-scale conglomerates in the form of state sole-funded corporations. Each had an annual output of more than six million tons in 1997 and accounted for 28% of China's total steel output (Nolan and Yeung 2001). Among these four enterprises, Baosteel was built in 1978 to solve the iron shortage problem that plagued the iron and steel industry of Shanghai and, meanwhile, to help the Chinese steel industry realize modernization and further promote economic development. The completion of Baosteel effectively compensated for the shortage of iron and steel varieties and quality in China and satisfied the urgent demand for high-end steel products by downstream industries, such as automobiles, petroleum, and shipbuilding (Li 2020). These two rounds of reforms led to a boom in the steel industry starting in approximately 2000.

The third stage for the development of China's modern iron and steel industry began at the beginning of the twenty-first century and lasted until 2014. This stage represented leapfrog development for the Chinese steel industry according to the analysis of Li (2020), and a new round of economic growth brought a dramatic development of the iron and steel industry after the impact of the Asian financial crisis gradually subsided, along with upgrading the domestic consumption structure and China's accession to the WTO. Despite the impact of the international financial crisis during that period, China's crude steel output generally maintained rapid growth, from 128.5 million tons in 2000 to 822.7 million tons in 2014 (World Steel Association 1967–2019). Product variety and quality improved significantly, allowing China to transform from a net importer into a net exporter during this phase. China's dominance in Asia became even more pronounced, accounting for 77% of regional steel production in 2011 (Wilson 2013). Although the initial reforms in the Chinese steel industry were heavily state-led, reforms during the 1980s and 1990s led in the direction of favoring indirect regulatory functions and granting limited autonomy to steel firms to improve their competitiveness. However, during this stage, the Chinese steel industry had poor firm-level concentration, and the top-tier steel firms that met high global technological standards accounted for only one-third of the national industry (Li 2020). As a result, the Chinese steel industry lacked the ability to produce high-value steel products to meet the increasing need from China's automobile and machinery sectors. To achieve rationalization and technology upgrading, a consolidation process began during this stage. In 2009, Baosteel and Hebei Iron & Steel merged to become the largest steelmaker in the East Asia region and one of the top three steelmakers in the world.

According to the crude steel production data from World Steel Association (1967–2019), in 2014, Chinese steel demand began to shrink for the first time since 2000. In 2015, China's crude steel output was 804 million tons, a decrease of 2.3% compared with the previous year and marking the first decline since 1982. The declines in steel demand and crude steel output indicate that China's iron and steel industry has entered the development stage of reduction. Although the government has been promising to reduce excess capacity, and consolidation has been promoted in the steel industry since 2005, the effects did not begin to appear until 2015. The capacity reduction policies in China are introduced in Sect. 5.

3 Energy-Saving Policies and Environmental Regulations

Furthermore, iron and steel products consume a large amount of energy and discharge a significant quantity of pollutants, making them one of the most important causes of regional air pollution problems. In the face of increasingly stringent environmental laws and regulations, green growth has become an inevitable choice for the iron and steel industry (Li 2020). Energy conservation in steelmaking is crucial to ensure industry competitiveness and to minimize environmental impacts, including water pollution, SO_x emissions, NO_x emissions, and greenhouse gas emissions. In the last two decades, policies related to energy and the environment in East Asia's steel industry have shown similar trends to emphasize the compatibility between environmental protection and economic growth through the utilization of energy-saving technologies. The main policies on emission reduction and energy savings in Japan and the Republic of Korea are presented in Table 1.

Japanese industries, beginning with the steel industry, have implemented energy-saving and CO_2 reduction measures in their manufacturing processes and now possess the world's highest level of energy-saving technologies (Nippon Steel Corporation 2020). During the two oil shocks, the Japanese steel industry invested 3 trillion to support environmental conservation and energy savings by introducing large-scale energy-saving equipment; thereby, 20% energy savings were achieved (Shigeru et al. 2014). As the 5th CO_2 emissions producer in the world, Japan faces increasing political sentiment and demanding CO_2 reductions (Iron and Steel Institute of Japan 2020). Further reduction measures continue to be required in the Japanese iron and steel industry. *The Voluntary Action Programme for the Iron and Steel Industry*, in force since 1997, was enacted to promote the spread of existing energy-efficient technologies, and the *COURSE 50* initiative was announced in 2007 to further reduce CO_2 emissions on a global scale through innovative technology development. Furthermore, the top two steelmakers, Nippon Steel and JFE Steel, adopted a Voluntary Action Program in 1997 and Eco-Processes following the *Commitment to a Low Carbon Society* proposal by the JISF (Japan Iron and Steel Federation) in 2013.

Table 1 Policies on emission reduction and energy savings in Japan and the Republic of Korea

Name	*Release date*
Japan	
Voluntary Action Programme for the Iron and Steel Industry (JISF) **Target**: Reduce total energy consumption by 10% in iron and steel industry by 2010 compared to 1990	1997
COURSE50: CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (NEDO)	2007
Commitment to A Low Carbon Society (JISF) **Four central components**: eco-process, eco-product, eco-solution, development of innovative technologies **Target**: Reduce GHG emissions, targeting fiscal year 2030	2013
The Plan for Global Warming Countermeasures (the Cabinet)	2016
JISF long-term vision for climate change mitigation: A Challenge toward Zero-Carbon Steel (JISF) **Target**: Provide long-term vision for climate change mitigation in Japanese steel industry	2018
Republic of Korea	
Framework Act on Environmental Policy	1990
Sustainable Development Act	2007
First and Second National Energy Master Plan (MTIE) **Industry Target**: Develop technologies for CO_2 free steelmaking and promote ICT-based energy management systems	2008; 2014
Framework Act on Low Carbon Green Growth **Target**: Build a low-carbon society and green industry	2010
2030 Roadmap to Achieve National GHG Reduction Target **Target**: Set sectoral reduction targets	2016
Phase 3 Allocation Plan 2021–2025 **Target**: Achieve the 2030 national GHG reduction target	2019

Note The policy sources are in parentheses. JISF indicates Japan Iron and Steel Federation. NEDO indicates New Energy and Industrial Technology Development Organization. MTIE indicates Ministry of Trade, Industry and Energy (Republic of Korea)

Source Ministry of Trade, Industry and Energy (2014), Iron and Steel Institute of Japan (2020), Lee and Woo (2020), Nippon Steel Corporation (2020), Republic of Korea (2020)

As previously mentioned in Sect. 2 (see Fig. 4), economic development in the Republic of Korea depends heavily on energy-intensive industries, such as steel and manufacturing, and approximately 95% of the primary energy used is imported (Hong et al. 2019). The Republic of Korea embraced the notion of sustainable development as a guiding principle since 1990 (*Framework Act on Environmental Policy*) and the *Sustainable Development Act* was enacted in 2007 to provide institutional support for this new concept (Lee and Woo 2020). To achieve sustainable development and simultaneously consider energy security, economic growth, and environmental impact, the government of the Republic of Korea implemented two rounds of *Energy Master Plans*—in 2008 and 2014 (Ministry of Trade, Industry and Energy 2014). In 2010, the *Green Growth Act* was introduced to further promote new green growth through energy-saving, efficient energy use, and development of green technology (Lee and Woo 2020). Following the state's policy to incorporate environmental considerations in business operations, the Republic of Korea's steelmakers have achieved considerable progress in greening the steel industry. POSCO has focused its business strategy on environmental protection and has taken action in recent years by establishing an environmental management system, minimizing emissions, improving eco-efficiency, piloting low-carbon green growth, and publicizing environmental management results (Li 2020).

Instead of gradually addressing these problems, as Japan and the Republic of Korea have been, the Chinese steel industry must simultaneously deal with overcapacity, energy conservation, environmental pollution, and climate change as a consequence of its tremendous short-term expansion in steel production. Consistent with Chinese steel industry's large production volume, it contributed to approximately 20% of the SO_2 emissions and 27% of the dust and PM emissions for all key manufacturing industries in 2013 (Hasanbeigi et al. 2017). China started to take action to fight environmental pollution in the 1970s and has set down sustainable development as a basic national strategy since 1992 (Zhang and Wen 2008). In 2007, because of the deterioration of ecological environments and growing concerns from the public, the concept of eco-civilization was initially proposed in the 17th National Congress of the Communist Party of China (Li et al. 2020). During the 11th Five-Year Plan (FYP) (2006–2010) and 12th FYP (2011–2015), the government has given prominence to the promotion and application of energy-saving technologies to increase energy efficiency and reduce energy consumption of steel enterprises. Especially, in recent years, many strict policies and regulations were introduced to reduce emissions, and the most stringent environmental standards were enacted in 2013 *Emission Standard of Air Pollutants for Iron Smelt Industry, Steel Smelt Industry, Steel Rolling Industry; Discharge Standard of Water Pollutants for Iron and Steel Industry; Emission Standard of Pollutants for Coking Chemical Industry* to alleviate the environmental impact of the steel industry on air and water pollution. Some of the major policies and standards on emission control and energy savings in Chinese steel industry are summarized in Table 2. According to a report by China Iron and Steel Industry Association (2019), from 2015 to 2018, the SO_2 emissions per ton of steel from major Chinese steelmakers declined from 0.88 to 0.48 kg, and the amount of particulate matter decreased from 0.77 to 0.51 kg per

Table 2 Policies and standards on emission reduction and energy savings in China

Name	*Release date*
National Level Policies	
Comprehensive Work Plan for Energy Saving and Emission Reduction	June 2007
Air Pollution Prevention and Control Action Plan	September 2013
Environmental Protection Law of the People's Republic of China	April 2014
National Climate Change Plan (2014–2020)	September 2014
Ten Measures on Air Pollution Prevention, Ten Measures on Water Pollution Prevention, Ten Measures on Soil Pollution Prevention	January 2015
Overall Plan for the Reform of Ecological Civilization System	September 2015
Comprehensive Work Plan on Energy Conservation and Emission Reduction during 13th Five-Year Plan (2016–2020)	December 2016
Environmental Protection Tax Law	January 2018
Industry Level Policies	
Cleaner Production Standard for Steel Industry	July 2006
Several Opinions of the General Office of the State Council on Further Strengthening Energy Saving and Emission Reduction to Accelerate the Structural Adjustment of the Iron and Steel Industry	July 2010
Emission Standard of Air Pollutants for Sintering and Pelletizing of Iron and Steel Industry	June 2012
Emission Standard of Air Pollutants for Iron Smelt Industry, Steel Smelt Industry, Steel Rolling Industry	June 2012
Discharge Standard of Water Pollutants for Iron and Steel Industry	June 2012
Emission Standard of Pollutants for Coking Chemical Industry	June 2012
Iron and Steel Industrial Pollution Control Technology Policy	May 2013
(a series of new emission standards for the iron and steel industry)	January 2015
Iron and Steel Industry Adjustment and Upgrading Plan (2016–2020)	November 2016
Draft Amendment for Comments on Fugitive Emission Standards for the Iron and Steel Industry and the Special Emission Limits for Sinter and Pellet Plants	June 2017

Source Zhou and Yang (2016), Li (2020), and Li et al. (2020)

ton of steel. By 2018, smoke, dust, and SO_2 emissions (kg/t) from major steelmakers, on average, reached the level of advanced foreign steelmakers.

4 New Norms: Climate Change Policies and Sustainability

The transition of environmental policies in the iron and steel industry in the last two decades mirrors the transformations in the economy of Japan, the Republic of Korea, and China, and these three countries have targeted Carbon Neutrality for global climate response. It is hoped that carbon emission reduction can parallel the structural adjustment and technological upgrading of the industry, which will foster a more competitive iron and steel industry and provide sustaining impetus to economic growth (Yu et al. 2015).

Carbon intensity[6] is an important proxy to measure the environmental-economic balance, and a low carbon intensity indicates low CO_2 emissions relative to the size of the economy (Ritchie 2017). Figure 6 shows that global intensity has been on a gradual downward trend since 1951 and this reduction in carbon intensity has been driven by both high-income and transitioning economies, with some developed countries peaking prior to 1951 (Ritchie 2017). In terms of East Asian economies' carbon intensity, Japan and the Republic of Korea peaked in 1970, and China peaked later in 1977. The steel industry is one of the most polluting industries in these three countries, especially in China. During the 1950s, thousands of small-scale furnaces were set up in China to catch up with the West in steel production, which contributed to the fast growth in carbon intensity (see Fig. 6). Since approximately 1980, China started to promote modernization of the steel industry and adopt more efficient technology, which led to significant improvements in energy efficiency and a continued decline in carbon intensity. Although dealing with the high carbon intensity in the steel industry is typically associated with the uptake of efficient technological solutions, reasonable policy interventions are also essential to achieving the goals of both greater economic growth and a smaller environmental impact (Ritchie 2017).

[6] Carbon intensity measures the quantity of CO_2 emitted per unit of GDP and is measured in kg CO_2/GDP per year.

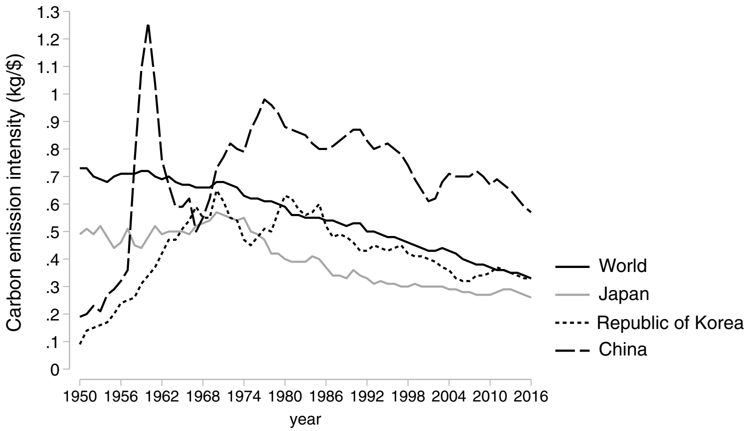

Fig. 6 Trend in carbon emission intensity in Japan, the Republic of Korea, and China (*Note* CO_2 intensity of the three East Asian economies measured in kilograms of CO_2 per dollar [kg/$] of GDP [measured in international dollars in 2011 prices]. *Source* This dataset is sourced from Our World in Data [1950–2016]. Data have been converted by Our World in Data from tons of carbon to tons of carbon dioxide [CO_2] using a conversion factor of 3.664)

As shown in Table 1, the Japanese government started to invest efforts into GHG reduction in the 1990s, and the *Voluntary Action Programme of the Iron and Steel Industry* was first implemented during the First Commitment Period of the Kyoto Protocol to achieve the sectoral emission target by 2020 (Iron and Steel Institute of Japan 2020). The concepts of three eco approaches, together with innovative technology development, were established in 2013 for the second phase of the *Commitment to a Low-Carbon Society* (see Table 1). The main policies in the 2010s aimed at problem-solving through long-term efforts to achieve a midterm target of reducing greenhouse effect gases (GHG) by 26% by 2030 from the baseline of 2013 and a long-term goal to pursue 80% reduction by 2050 (Iron and Steel Institute of Japan 2020). Through the nationally determined contribution (NDC) targets, Japan has provided a long-term vision for climate change mitigation in the iron and steel industry. In response to the *Plan for Global Warming Countermeasures* (2016), JISF proposed a Zero-Carbon Steel concept in 2018 to further improve energy efficiency of the steel industry, which is already the highest in the world (see Fig. 2).

Following the ratification of the Kyoto Protocol and Paris Agreement, a series of energy master policies and reduction targets were implemented in the Republic of Korea starting in the 2000s (see Table 1). Under the *Framework on Low Carbon Green Growth* (2010), a set of reduction strategies were implemented in the 2010s (see Table 1) to reduce GHG emissions by 24.4% below 2017 level by 2030 (Republic of Korea 2020). Meanwhile, in 2010, the largest steelmaker POSCO announced its voluntary GHG target of reducing the CO_2 emissions per ton of crude steel by 9% by 2020 (Kim et al. 2014). The green growth in the Republic of Korea, which is placed as a long-term goal and key policy, is characterized by its strong top-down leadership. The industry sector was estimated to account for 37% of the total GHG emissions in 2017, and the government and the industry sector are working together to build a robust institutional framework, develop technological innovation, e.g., hydrogen reduction steelmaking, and achieve low-carbon transition in energy-intensive industries (Republic of Korea 2020). Recently, POSCO has committed to net zero emissions by 2050 and intends to achieve that target by further reducing coal consumption, improving energy efficiency, and leveraging innovative low-carbon technologies such as hydrogen-based steelmaking (Vercoulen et al. 2018).

Steelmaking in China now accounts for approximately half of global production; therefore, steelmakers face growing carbon risks. Due to large-scale steel production, the steel industry accounted for as high as 10% (even 35%-40% in some major cities) of the total domestic carbon emissions in China during the 2000s (Zeng et al. 2009; Zhou and Yang 2016). The government has decided to transform China's economic development pattern to a sustainable, resource-saving, and low-carbon economy since 2006 (Li et al. 2020). Furthermore, China put forward its NDC in 2015, promising to lower its energy intensity by 40–45% by 2020 compared with 2005 and reach peak emissions by 2030 (Vercoulen et al. 2018). The reduction targets were then assigned to the iron and steel industry, which is similar to the top-down strategy for green growth in the Republic of Korea. As shown in Table 1, China's *National Climate Change Plan* was implemented in 2014, and the *Adjustment and Upgrading Plan of the Steel Industry* was enacted in 2016 to implement green upgrading, promote green consumption, and decrease energy intensity in the steel industry by 2020. Besides energy-saving policies and carbon emission targets, sector structure adjustment through closing outdated facilities (see Sect. 5) and market-related policies through adjusting the tax (*Environmental Protection Tax Law*) were applied as well (Wang et al. 2017). Meanwhile, China's largest steelmaker Baowu Steel Group aims to peak its carbon emissions by 2023 and achieve carbon neutrality by 2050 (China Association of Circular Economy 2021).

East Asia has the world's largest iron and steel production, consumption, and exports and, thus, has a significant influence on the world iron and steel community. East Asia's iron and steel industry will play an important role in achieving the goal of addressing climate change.

5 Excess Capacity in East Asia's Iron and Steel Industry

The global steel industry has been struggling with excess steelmaking capacity and low profitability for a long time. According to steelmaking capacity data from the OECD (2000–2019), the global steelmaking capacity currently stands at 2.36 billion tons, of which China accounted for approximately 50% (1.15 billion tons) by 2019. Because China's total production of crude steel in 2019 was approximately 996.34 million tons, the excess capacity[7] in the steel industry was approximately 150 million tons (World Steel Association 1967–2019; OECD 2000–2019). Figure 7 reveals the trends in global excess capacity and East Asian economies from 2000 to 2019. Global excess capacity increased rapidly following the global financial crisis in 2008 and has been decreasing since 2015, led by the trend in excess capacity in China. In Japan, steel has ceased to be a growth industry and offers low profitability, resulting in effectively no increase in capacity since 2000 (OECD 2000–2019). By contrast, in the Republic of Korea, both the steelmaking capacity and crude production have been increasing at a slow and steady pace, while both countries' excess capacity has remained relatively constant between 2000 and 2019.

[7] The volume of excess capacity by country was calculated by deducting the production volume from existing production capacity. Excess capacity = steelmaking capacity-total production of crude steel, and the datasets are collected from OECD (2000–2019) and World Steel Association (1967–2019).

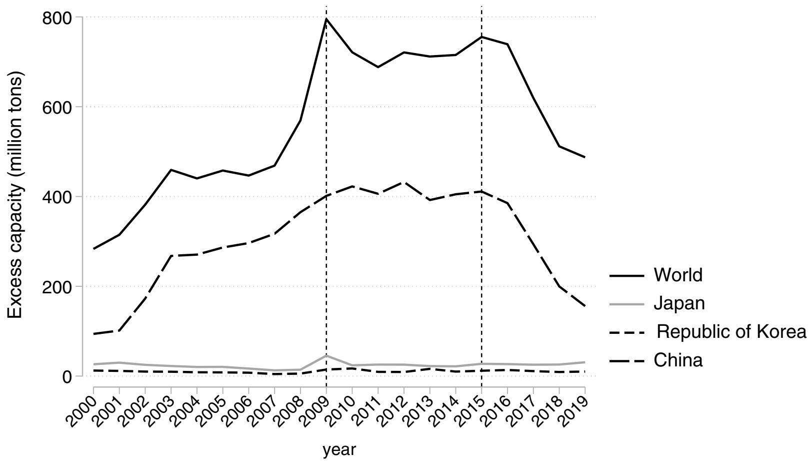

Fig. 7 Excess capacity in East Asia's iron and steel industry (*Note* This figure shows the trend in excess capacity in Japan, the Republic of Korea, and China from 2000 to 2019. Excess capacity in this study is calculated based on the following equation: excess capacity = steelmaking capacity-total production of crude steel. *Source* This dataset is sourced from OECD [2000–2019] and World Steel Association [1967–2019])

Unlike the Republic of Korea and China, the postwar increasing stage of the Japanese steel industry did not last long. The period of high economic growth ended in the 1970s, and the period of stagnation began. Kawabata (2017a) mentions that overcapacity exacerbates the supply–demand relationship and has led to a worldwide decline in the prices of steel products and the profitability of steel companies. In the face of a repeat profitability crisis, the Japanese government started to take action to solve the overcapacity problem in the 1970s, as presented in Table 3. First, the *Law on Provisional Measures for the Stabilization of Specified Depressive Industries* and the *Law on Temporary Measures for the Structural Improvement of Specified Industries* were implemented during 1978 and 1988 to address the overcapacity of electric furnace steelmakers. Under these two laws, the flat electric furnace sector banned the expansion of electric furnaces until 1988, and 2.38 million tons of capacity were processed by the end of 1988 (Kawabata 2017b). However, after the

Table 3 Policies for capacity reduction in Japan

Policy name	*Release date*
Law on Provisional Measures for the Stabilization of Specified Depressive Industries (METI) **Target**: Reduce the inefficient production capacity of electric furnaces steelmakers	1978–1983
Law on Temporary Measures for the Structural Improvement of Specified Industries (METI) **Target**: Reduce the inefficient production capacity of electric furnaces steelmakers	1983–1988
Law on Temporary Measures to Facilitate Industrial Restructuring (METI) **Target**: Reduce the inefficient production capacity of blast furnaces steelmakers	1987–1996
Act on Temporary Measures for the Facilitation of Business Innovation in Specified Business Operators (METI) **Target**: Reduce the inefficient production capacity of blast furnaces steelmakers and accelerate restructuring	1995–2002
Act on Special Measures for Industrial Revitalization (METI) **Target**: Reduce the inefficient production capacity of blast furnaces steelmakers, accelerate restructuring, and promote employment adjustment	1999–2014
Employment Adjustment Subsidy (METI & MHLW) **Target**: Promote employment adjustment by providing subsidies during the period of capacity reduction in the steel industry	1970s–2010s

Note The policy sources are in parentheses. METI stands for Ministry of Economy, Trade and Industry. MHLW stands for Ministry of Health, Labour and Welfare, which was formed from the merger of the former Ministry of Health and Welfare and the Ministry of Labour
Source Kawabata (2017b)

bubble economy collapsed, overcapacity issues returned for the electric furnace steelmakers.

The *Law on Temporary Measures to Facilitate Industrial Restructuring* was implemented in 1987 to deal with the hollowing-out of industries after the yen appreciation, which especially affected those regions with concentrations of export industries. The government enacted different policies for electric furnace steelmakers and blast furnace steelmakers, and this law targeted blast furnace steelmakers, which led to rapid capacity reduction. During the 1990s and 2000s, two more acts—the *Act on Temporary Measures for the Facilitation of Business Innovation in Specified Business Operators* and the *Act on Special Measures for Industrial Revitalization*—were implemented to further solve the overcapacity problem of both blast furnace steelmakers and electric furnace steelmakers. As a result, blast furnace steelmakers completed the reduction in overcapacity during the 2000s, and their profits improved significantly (Kawabata 2017b). Although the reduction policies for electric furnace steelmakers did not work as successfully as did those for blast furnace steelmakers, they also managed to achieve a significant reduction. Japan started its overcapacity reduction in the 1970s and almost completed the process during the 2000s, which resulted in relatively steady steel production than that of the Republic of Korea and China. According to estimates by the World Steel Association, global capacity utilization averaged 69.4% in 2016, and Japan's capacity utilization rates achieved almost 81% in 2015 (Brun 2016).

The Republic of Korea started to address overcapacity issues in the 1990s, although it has been a long-standing problem that was first noted in 1980 (Lee 2003). As mentioned in Sect. 2, the government has played a key role during the whole process of planning and fueling the rapid growth of the steel industry. Lee (2003) analyzes the major trends in the Republic of Korea's steel industry after the 1997 financial crisis and implies that the government's intervention in the steel industry continued until the mid-1990s, which exacerbated the market distortion and excess capacity problem. However, this problem was invisible because of the rapid economic growth in the 1980s, making steelmakers extremely vulnerable when the financial crisis occurred in 1997. Given the long-term overinvestment in the steel industry, the overcapacity problem was revealed by a decline in steel demand after the crisis. First, two mid-sized steelmakers, Hanbo Steel and Sammi Steel, declared bankruptcy in 1997. Then, a number of steel firms, including a few medium-sized steel firms, had to cease operations and suspend or stopped planned investments after the crisis (Lee 2003). Steel firms also began to downsize, reducing employment substantially in 1997–1998. The crisis led to significant policy changes, including the accelerated privatization of the largest steel firm. As a result of the public sector reform process in 2000, POSCO, which was previously state owned, was privatized.

The Asian financial crisis became a turning point for the Republic of Korea's economy as it shifted from a government-driven to a market-driven economy, which gave steelmakers more flexibility to adjust their steel production capacity. Unlike China, the steel sector in the Republic of Korea needs no considerable consolidation or restructuring. Figure 8 presents the trend in the crude steel output CR2 of the steel sector in

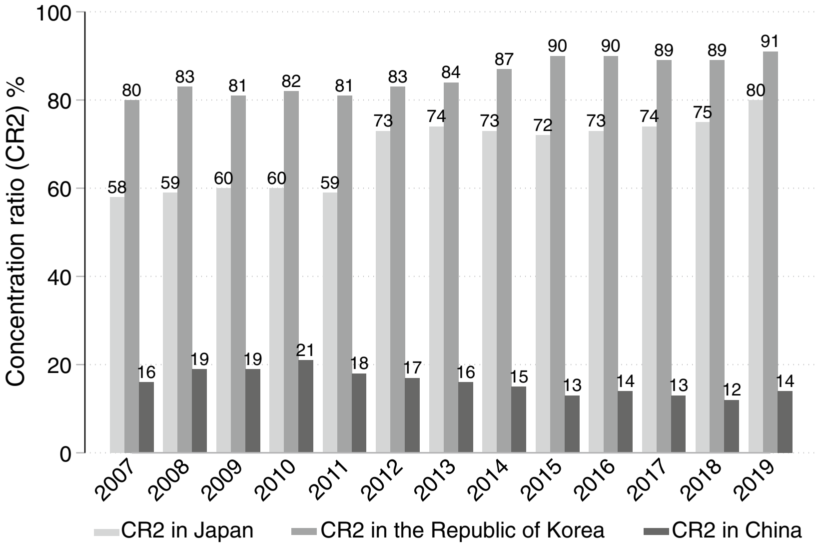

Fig. 8 The concentration ratio (CR2) in East Asia's iron and steel industry (*Note* The top two steelmakers in Japan are Nippon Steel and Sumitomo Metal Corporation [NSSMC] and JFE Steel Corporation. In the Republic of Korea, they are POSCO and Hyundai Steel Company. In China, they are Baowu Steel Group and Hebei Iron and Steel (HBIS) Group. The crude steel production of the NSSMC includes Nippon Steel only before 2012, and the crude steel production of the Baowu Steel Group includes the merged production data of the Baosteel Group and Wuhan Iron and Steel Corporation. *Source* This dataset is sourced from the top steelmaker list developed by Metal Bulletin [2010] and the World Steel Association [1967–2019])

Japan, the Republic of Korea, and China. The CR2 in Japan's steel sector reached 80%, and the Republic of Korea's steel sector reached 91% by the end of 2019. POSCO alone accounted for more than 60% of the market in 2019, and it focused on high-end products for the automotive and shipbuilding industries to adjust to global overcapacity (World Steel Association 1967–2019).

From 2000 to 2015, the persistent increase in global capacity was led by the rapid expansion of China's steel industry. Government intervention has been considered the most influential factor triggering excess capacity through market distortions, especially in China. China's overcapacity was identified as occurring because of its rapid development of the steel sector after 2000. Investments in steelmaking capacity fueled by production incentives, land and energy subsidies, and loose lending policies by both national and provincial governments led to massive increases in China's steel production capacity (Brun 2016). In addition to production promotion policies, structural adjustment policies (mentioned in Sect. 2) promoted by the Chinese government are criticized for leading investments in new facilities and increasing total production capacity.

In 2005, the Chinese government started to highlight the excess capacity issue and is dedicated to reducing steel production during the 13th FYP period (see Table 4) in response to the increasing trend in the steel industry's excess capacity. Therefore, the excess capacity decline after 2015 is a mixed effect of price variations and policy promotions. Table 4 provides key policies for capacity reductions in China during the 12th and 13th FYP periods. During the 12th FYP, legislation-based methods were applied to reduce excess capacity according to the *Laws on Environmental Protection* and on the basis of industrial policies. The year 2016 marked the beginning of strict overcapacity reducing measures, and the *Opinions on Cutting the Overcapacity of the Iron and Steel Industry to Realize a Turnaround* was issued and implemented, which required achieving a target of further reducing crude steel production capacity by 100–150 million tons in 5 years starting from 2016 (Li 2020). Since 2016, through the implementation of the supply-side structural reform of China's iron and steel industry, the effect of "cutting overcapacity" has begun to appear, and positive changes have been revealed by the trend in global excess capacity (see Fig. 7, trend after 2015). The central government recently prioritized the closure of plants producing low-quality steel from scrap. *Opinions on Cutting the Overcapacity of the Iron and Steel Industry to Realize a Turnaround* and *Catalogue for Guiding Industrial Restructuring* were issued in 2017 and 2019 to eliminate substandard steel production. Although China is still the largest contributor to global excess capacity, its steelmaking capacity has declined significantly in recent years. Excess capacity in China declined by approximately 255 million tons from 2015 to 2019, contributing more than 95% of decreasing global overcapacity (OECD 2000–2019).

Meanwhile, a range of interventionist industrial policies was also deployed to promote consolidation in the steel sector, and 19 mergers between large- and medium-sized steel firms were brokered between

Table 4 Policies for capacity reduction in China

Policy name	*Release date*
The 12th Five-Year Plan (2011–2015)	
Catalogue for Guiding Industrial Restructuring (NDRC)	2011
Instructions to Promote Merger and Reorganization of Major Industries and Enterprises (MIIT)	2013
Air Pollution Prevention and Control Action Plan (SCPRC)	2013
Target: Reduce crude steel production capacity by 15 million tons by the end of 2015	
Guiding Opinions of the State Council on Resolving Serious Production Overcapacity Conflicts (SCPRC)	2013
Target: Reduce crude steel production capacity in Shandong, Hebei, Liaoning, Jiangsu, Shanxi, and Jiangxi by 80 million tons	
The 13th Five-Year Plan (2016–2020)	
Opinions on the Development of the Iron and Steel Industry to Solve the Overcapacity Problem (SCPRC)	2016
Opinions on Cutting the Overcapacity of the Iron and Steel Industry to Realize a Turnaround (MIIT)	2016
Target: Reduce crude steel production capacity by 100–150 million tons and increase utilization rates to 80% by 2020	
Target: Reduce crude steel production capacity by 140 million tons from 2016 to 2018	
Opinions on Well Cutting Overcapacity of the Iron and Steel and Coal Industries to Realize a Turnaround (IMJM)	2017
Target: Accelerate the exit of inefficient production capacity	
Catalogue for Guiding Industrial Restructuring (NDRC)	2019
Target: Ban illegal induction furnace (IF) steelmaking and ensure the effective closure of IF capacity by 2020	

Note The policy sources are in parentheses. NDRC stands for National Development and Reform Commission. SCPRC stands for State Council of the People's Republic of China. MIIT stands for Ministry of Industry and Information Technology. IMJM stands for Inter-Ministerial Joint Meeting
Source Ministry of Economy, Trade and Industry (2018) and Li (2020)

2005 and 2010 (Wilson 2013). Furthermore, Baosteel Group Corporation and Wuhan Iron and Steel (Group) Company conducted a joint reorganization in 2016, which resulted in a significant reduction in Baowu Steel subsidiaries and capacity. However, in terms of organizational structure, the crude steel output CR10 in 2014 was almost 37% (Chen et al. 2016), and the CR2[8] in 2019 was a mere 14% (see Fig. 8), which was

[8] The crude steel output of Baowu Steel Group and Hebei Iron and Steel Group.

extremely low compared with Japan and the Republic of Korea. Therefore, the Chinese steel market is still quite fragmented. Because China accounts for the largest share of the world market, its role in future overcapacity reduction remains central. Through mergers and acquisitions, Chinese enterprises are expected to become stronger and have more resources and bargaining power to resolve problems, such as overcapacity, wasted resources, rising energy and raw material costs, and environmental pollution.

6 Conclusion

This chapter examined the major policies that contributed to shaping East Asia's steel industry, given that the state's significant role in the steel sector is common to Japan, the Republic of Korea, and China. Government intervention occurred in the form of both direct and indirect interventions during the steel industry's total development period. Following Japan's model of dramatic economic ascent via steel and other heavy industries, the Republic of Korea and China contributed to the establishment of East Asia as a rapidly growing region after the Second World War. In addition to the fact that the steel industry is highly driven by economic growth, it has also served as an ideal partner to help materialize the potential of other industries, such as automobiles, shipbuilding, and construction, in Japan, the Republic of Korea, and China. The nature of the steel industry is a strategic sector that requires massive capital investments and technological innovation, offers significant contributions to other industries, and requires frequent involvement through subsidies by governments in both developing and developed countries (Shin and Ciccantell 2009). Furthermore, Japan, the Republic of Korea, and China share the same problem of strong dependence on imported raw materials, especially iron ore. Industrial policy interventions are decisive factors helping East Asia's steel industry obtain sources of comparative advantage.

However, government interventions risked overreaching, which contributed to excess capacity difficulties that worsened with economic maturity, particularly in China. In 2015, China accounted for almost half of the nominal global overcapacity in steel, while Japan and the Republic of Korea accounted for less than 5% (Brun 2016). Although recent steelmaking capacity in China has declined significantly, efforts to further promote the adjustment of the steel industry's structure through mergers or closures should continue to improve integrated efficiency, steel technology diffusion, and negotiating power over iron ore pricing. Further consolidation of the market could be one solution for the current overcapacity problem in the steel sector, and the Chinese government plans to increase the share of the ten largest steelmakers to more than 60% by 2025 (National Development and Reform Commission 2005). Unlike Japan and the Republic of Korea, China's steel market is currently quite fragmented, and leading steel firms only have advantages in competing at the low value-added end of the market. In the high value-added and high profit part of the industry, Baowu Steel Group may be the only Chinese steelmaker that is able to directly compete with the established giants of Asia in Japan and the Republic of Korea (Li 2020).

In contrast, because of different economic structures, market environments, and production volumes, policy distinctions are also noted in this chapter. The main difference is that the governments in Japan and the Republic of Korea have tended to limit direct intervention and have instructed steel firms to develop plans and take action independently after the rapidly increasing period. After several rounds of market-oriented reforms, the voluntary efforts of steelmakers in Japan and the Republic of Korea became as essential as the institutional policies for addressing overcapacity problems and controlling pollution emissions. However, in the case of China, similar voluntary firm behaviors are not expected, especially for small and medium-sized enterprises with inferior equipment and less incentive to develop advanced technology. Corporate behavior changes through direct policy interventions may be more effective for coping with energy conservation and the environmental issues associated with the steel industry. Given that the Chinese steel industry accounts for approximately half of global production and consumption, the country's regulatory practices and carbon reduction efforts in the steel sector may significantly contribute to addressing global climate change challenges. Furthermore, environmental regulations to mitigate pollutant emissions and carbon emissions can help reduce inefficient capacity in China, which will also benefit the sustainable development of the global steel industry.

In conclusion, this chapter only focuses on the role of government intervention and policy changes in East Asia's steel industry, while many other important factors are not discussed. Questions such as how trade restructures East Asia's steel industry, how it shapes the domestic market and steelmakers' competitiveness, what responsibility East Asia's steel industry holds for alleviating climate change, how China's rise influences the global steel market, and how to efficiently adjust employment and maintain profitability during capacity reduction periods are also critical issues. The subsequent chapters attempt to provide empirical evidence for these important questions related to the further development and sustainability of the steel industry in East Asia.

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CHAPTER 3

Changes in the Competitive Environment and Division of Labor Structure in Northeast Asia: A Focus on the Iron and Steel Industry

Bong-gil Kim

1 Introduction

Since the global economic crisis in 2008, international trade communities have worried about rising protectionism, as protectionist measures such as import restrictions and tariff increases have been historically prevalent during periods of economic slowdown. Recently, "neoprotectionism," focusing on nontariff measures and trade frictions, has become intense.[1]

The iron and steel industry is one of the industries that have been most strongly affected by such changes in international trade and the competitive environment. In addition, the iron and steel industry has been facing

[1] Protectionism in the process of economic globalization has evolved from trade policy based on the introduction of tariff limitations and, later, from nontariff protection instruments into a complex, comprehensive state mechanism for increasing the competitiveness of the national economy in the process of globalization, which we call neoprotectionism.

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a severe competitive environment of overcapacity, mainly from China, and a slowdown in global demand since the 2010s. The double shock of the expansion of protectionism and the spread of coronavirus disease 2019 (COVID-19) has severely damaged the manufacturing industry and the world economy. In other words, the growth momentum of the global iron and steel industry is weakening, and the competition to survive is becoming even more intense in global markets.

In the iron and steel industry, three countries, i.e., the Republic of Korea (ROK), Japan, and China,[2] show different development patterns and supply–demand structures but have developed while "competing and cooperating" with each other. Moreover, these three countries have become dominant players in the global steel industry by producing more than 60% of the world's crude steel and consuming more than 50% of the steel produced. In particular, since the 2010s, intraregional specialization has intensified, accompanied by the rapid improvement in the technological development capability of the ROK and China. Under the current difficult business environment surrounding the iron and steel industry of KJC, it is expected that the competition to survive will become more intense in global markets.

The purpose of this article is to examine the ideal ways in which the intraregional division of labor can overcome the current difficult business environment and strategic challenges to survive in the future, focusing on the iron and steel industry. In addition, this article explores policy issues related to the future direction of the intraregional specialization structure in the iron and steel industry.

Regarding the structure of this article, Sect. 2 provides an overview of the development trends and supply–demand structure of the iron and steel industry in KJC, and Sect. 3 examines the trade structure and competitiveness of their iron and steel industry. Then, Sect. 4 draws conclusions and discusses prospects for future research.

Unless otherwise stated, data on production, consumption, and trade are obtained from the Worldsteel database (World Steel Association 1980–2020) and the United Nations Comtrade database (United Nations 2000–2019) as an original source with the customs statistics for each economy. Data on production capacity are obtained from the Organization for Economic Cooperation and Development (OECD) database

[2] Hereafter, Republic of Korea (ROK), Japan, and China are denoted as KJC.

(OECD 2000–2020). For detailed trade data, we mainly rely on the official statistics of the national industry associations.

2 Overview of the Iron and Steel Industry in Northeast Asia

The iron and steel industry is one of the most basic material industries supporting industrialization in each country, and it has the following characteristics.

First, it is an industry with large "economies of scale" in the production process.[3] In the iron and steel industry, two major production systems are observed: integrated production with a blast furnace (BF) and semi-integrated production with an electric arc furnace (EAF, as in a mini mill). An integrated steel mill is an enterprise that adopts an integrated production system to integrate ironmaking, steelmaking, and rolling processes vertically in the same enterprise. This system needs economies of scale, especially in the ironmaking and steelmaking processes, and it fits mass production. Second, the supply and demand of the steel industry are inelastic to prices in the short term; thus, prices fluctuate greatly in response to economic fluctuations. Third, regarding the trade of steel products, short-distance or intraregional trade accounts for a high proportion because the transportation costs are high due to the size and weight of steel products. The high proportion of intraregional trade is another reason for the price inelasticity of steel supply and demand.

Table 1 shows the trends in the supply and demand volume of crude steel in KJC.

Regarding the ROK, crude steel production and consumption[4] have gradually been increasing for 10 years since the 2000s. Crude steel production has been rising at an average annual growth rate of 2.6%, from 43.1 million tons in 2000 to 58.1 million tons in 2010. However,

[3] According to the empirical rule, the minimum optimal scale of newly constructed integrated steelworks is 3 million tons of annual production in crude steel (Kawabata 2017, interview with the Korea Iron and Steel Association by the author, November 2019).

[4] Apparent consumption is calculated by production plus imports minus exports. It is the most important indicator of consumption. Fluctuation in inventory and indirect trade is neglected. Apparent consumption is calculated after converting exports and imports, recorded as weights for various steel products, into crude steel by using a certain coefficient.

Table 1 Trend of crude steel production and consumption in KJC (unit: billion tons)

	Production			*CAGR*	*Apparent consumption*			*CAGR*
	2000	*2010*	*2018*		*2000*	*2010*	*2018*	
Korea	43.1 (5.1%)	59.0 (4.1%)	72.5 (4.0%)	2.9%	40.1 (4.7%)	54.3 (3.8%)	56.0 (3.1%)	1.9
Japan	106.4 (12.5%)	109.6 (7.6%)	104.3 (5.7%)	−0.1	79.6 (9.4%)	67.4 (4.8%)	71.3 (3.9%)	−0.6
China	128.5 (15.1%)	638.7 (44.6%)	928.3 (50.7%)	11.6	138.6 16.4%	612.1 (43.2%)	869.8 (47.9%)	10.7
World	848.9	1,433.4	1,818.6	4.4	846.9	1,416.4	1,830.8	4.3

Note CAGR is the compound annual growth rate, which is the average annual growth rate from 2010 to 2018; the numbers in parentheses are the global share
Source Compiled by the author based on data from World Steel Association (1980–2020)

it increased at an average annual growth rate of only 0.3% from 2011 to 2018, reaching 72.5 million tons in 2018. Moreover, crude steel consumption increased by 3.2% on an annual average basis up to 2010, but thereafter, through 2018, consumption decreased by 0.7% on an annual average basis due to sluggish domestic demand.

Domestic consumption rapidly increased from 40.1 million tons in 2000 to 54.3 million tons in 2010, but thereafter, the growth rate decreased, reaching 56.0 million tons in 2018.

Regarding the Japanese iron and steel industry, the growth rate of production and consumption has followed a slightly downward trend since the 2000s. The crude steel production volume in Japan increased at an average annual growth rate of 0.3% from 2000 to 2010 and decreased at an average annual growth rate of 0.4% from 2011 to 2018. Crude steel consumption decreased by 2.0% on an annual average basis from 2000 to 2010 and increased by 0.3% on an annual average basis from 2011 to 2018. In response to the deterioration in profitability due to such a decrease in demand, Japanese steel enterprises have continued to restructure and integrate since the 1990s to improve their profit structure, and currently, there are three BF manufacturers.[5]

[5] The three companies are Nippon Steel, JFE, and Kobe Steel (Japan Iron and Steel Federation [JISF]. www.jisf.or.jp/).

Regarding China, unlike Japan and the ROK, crude steel production and consumption have increased rapidly since the 2000s. Crude steel production in China increased approximately 5 times (at an average annual growth rate of 17.3%) in the 10 years since 2000, and crude steel consumption also increased approximately 6 times (at an average annual growth rate of 19.5%). Then, it recorded increases at average annual growth rates of 4.1 and 3.8 from 2011 to 2018.

In 2018, regarding the share of global crude steel production and consumption, China ranked first in the world, accounting for 50.7 and 45.9, respectively; Japan accounted for 5.7% and 3.9%, respectively; and the ROK accounted for 4.0 and 3.1, respectively. In other words, these three countries produce more than 60% of the world's crude steel and consume more than half of the crude steel produced (Table 1).

Regarding the ranking of world steel enterprises in 2018, two Japanese companies (Nippon Steel and JFE Steel), one Korean company (POSCO), and six Chinese companies (Baowu Group, HBIS Group, Shagang Group, etc.) are among the global top ten in crude steel production (World Steel Association 1980–2020). In other words, except for ArcelorMittal, which is the world's No. 1 producer, all nine companies are located in Japan, China, and the ROK, and the three countries have become dominant players in the global steel industry. In particular, since the 2000s, compared to their Japanese counterparts, the growth of steel companies in the ROK and China has been remarkable.

Regarding the export dependence (exports/production) of the three countries in 2018, the export dependence of the ROK is 41.5%, that of Japan is 34.4%, and that of China is only 7.4%. These figures show that the ROK and Japan have a considerably higher export dependence than China. In other words, compared to China, Japan and the ROK have an export-oriented production structure. In the three countries, the ROK is a smaller net exporter than China and Japan in terms of the export scale. However, regarding export dependency, the ROK has maintained a high degree of more than 40% since the 2010s due to the stagnation of domestic demand industries, such as the automotive, shipbuilding, and construction industries, and excessive domestic supply due to a new entry.[6]

[6] In 2020, Hyundai Steel became the ROK's second largest BF manufacturer after POSCO (Kim 2020, p. 5).

As of 2018, regarding import dependency (imports/domestic demand), the import dependency of the ROK was 26.6%, which was considerably higher than that of Japan, 8.4%, and that of China, 1.7%. However, regarding the import volume, the ROK is larger than Japan and China, where domestic demand is larger than in the ROK. In 2018, the import volume of the ROK was 14.93 million t, that of China was 14.4 million t, and that of Japan was 6 million t. That is, the ROK is characterized by a structure with a high degree of dependence on imports, despite its high degree of dependence on exports.

3 The Intraregional Division of Labor Structure of the Iron and Steel Industry of KJC

This subsection analyzes the trade structure and structure of international specialization in the iron and steel industry of KJC. Then, we analyze export competitiveness by comparing the trade specialization coefficient in the iron and steel industry of KJC.

3.1 International Trade Structure

The export of steel products[7] from the ROK increased by an annual average growth rate of 5.9% in the 2000s to 24.5 million tons in 2010. Thereafter, the export volume increased by an annual average growth rate of 2.5% to 30.1 million tons in 2018. The ROK accounts for 6.6% of the world's total exports. Specifically, the export volume began to decline after peaking at 31.9 million tons in 2014. As of 2018, its export volume made the ROK the world's fourth largest exporter, followed by China (68.8 million tons), Japan (35.8 million tons), and Russia (33.3 million tons).

Regarding the ROK's exports by destination, the proportion of exports to Asian economies was approximately 50%. In 2018, the largest export destination was China (13.3%), followed by Japan (12.4%), India (10.3%), the United States (8.2%), and Mexico (7.0%) in 2018. In particular, since the 2010s, exports to Association of Southeast Asian Nations (ASEAN) economies such as Thailand, Malaysia, Indonesia, and Vietnam have

[7] Steel products based on the four-digit HS code classification include semifinished products and final steel products. The range of steel products is HS 7201–7229 and HS 7301–7307.

increased rapidly, while exports to China have decreased. One feature of the ROK that is not observed in Japan or China is the high share of exports to North American countries, such as the United States and Mexico.

Regarding the ROK's share of exports by product, in 2017, flat products accounted for the largest share, 68.7%, followed by pipes and tubes at 14.8%, long products at 10.9%, and primary materials and semifinished products at 5.6% (Table 2). Looking closely at higher value-added products such as cold-rolled steel sheets and galvanized steel sheets for automobiles, we find that such products have become the main export products since the mid-2000s. In particular, exports of cold-rolled steel sheets and galvanized steel sheets increased by an annual average growth rate of 10.0% from 2005 to 2015, reaching 14.93 million tons in 2017.

Regarding imports, the import volume of the ROK increased by an annual average of 8.0% in the 2000s to a record high of 24.8 million tons in 2010 due to the rapid expansion of domestic demand. Thereafter, the ROK's imports began to decline in line with the increase in domestic production. The import volume declined by an annual average rate of 2.5% in the 2010s to 14.93 million tons in 2017.

Table 2 Global trade balance of the ROK, Japan, and China (2017) (unit: million dollars)

Product group	*JAPAN*			*CHINA*			*ROK*		
	Export	*Import*	*Balance*	*Export*	*Import*	*Balance*	*Export*	*Import*	*Balance*
Primary materials	3,531	3,113	418	1,503	8,052	−6,549	1,039	4,161	−3,122
Semifinished products	1,764	153	1,611	9	604	−594	437	1,092	−655
Flat products	18,263	3,174	15,089	29,398	10,348	19,050	18,111	7,925	10,186
Long products	4,947	946	4,001	12,649	2,639	10,011	2,870	3,408	−538
Pipe and tube products	3,736	1,027	2,709	12,454	2,184	10,270	3,898	1,374	2,524
Total	32,241	8,413	23,827	56,014	23,826	32,188	26,355	17,960	8,394

Note The range of steel products is HS 7201–7229 and HS 7301–7307

Source Compiled by the author based on the database from the United Nations (2000–2019), Korea Iron and Steel Association (2000–2019)

By import destinations, in 2018, China was the largest import destination (48.6%), followed by Japan (36.3%), Taiwan (3.2%), and Vietnam (2.2%). In particular, the ROK's imports are concentrated in China and Japan, which account for more than 80% of its total imports. The share of imports by product was 44.1% for flat products, 23.2% for primary materials, 19.0% for long products, 7.7% for pipes and tubes, and 6.1% for semifinished products. Additionally, nonalloyed steel products such as hot-rolled steel sheets account for more than 60% of the imports of flat products (Table 2).

Japan was the largest exporter in the world until 2010, but its exports began to decline in 2011, and it is now the second largest exporter in the world. Steel product exports from Japan increased by an annual average growth rate of 4.1% in the 2000s to 42.7 million tons in 2010. Thereafter, the export volume continued to show a downward trend, decreasing by an annual average rate of 2.2% in the 2010s to 35.8 million tons in 2018. Regarding exports by destination, in 2018, Asian economies were the main export trading partners with China (15.2%), South Korea (14.9%), Taiwan (7.8%), and Vietnam (6.2%). In 2017, the share of exports from Japan by product was 56.7% for flat products, 15.4% for long products, 11.6% for pipes and tubes, 11.0% for primary materials, and 5.5% for semifinished products.

Regarding imports, the import volume of Japan decreased by an annual average of 1.5% in the 2000s to a record high of 4.4 million tons in 2010. Thereafter, the import volume increased by an annual average growth rate of 4.0% in the 2010s to 6.6 million tons in 2018. In terms of imports by destination, in 2018, the ROK was the largest import trading partner (62.3%), followed by China (15.9%), Taiwan (17.4%), and Vietnam (1.8%). Japan's imports are concentrated in the ROK and China, which account for more than 80% of its total imports. By product, in 2017, the share of import items was 37.7% for flat products, 12.2% for pipes and tubes, 11.2% for long products, 11.0% for primary materials, and 1.8% for semifinished products (Table 2).

However, there are unusual observations in the share of export items of Japan and the ROK.

Regarding flat products, the ratio of hot-rolled sheets and strips with relatively low value added is very high in the middle classification in the ROK and Japan. This unique export structure is based on exporting high-grade host materials to downstream subsidiaries and affiliated companies in various economies.

China is the top export country worldwide, leading the global steel trading market. China was the world's largest importer until 2005; thereafter, exports increased sharply due to a surge in production accompanying the expansion of capital investment, and since 2011, China has become the world's largest exporter. Steel exports from China increased by an annual average growth rate of 14.1% in the 2000s to 41.6 million tons in 2010. Thereafter, the export volume increased by an annual average growth rate of 6.5% in the 2010s to 68.8 million tons in 2018.

Regarding export destinations, China is more diversified than Japan and the ROK, and the ROK (10.6%) and Vietnam (10.3%) are countries to which China's share of exports exceeds 10%. By product, in 2017, flat products accounted for 56.7%, long products accounted for 15.4%, pipes and tubes accounted for 11.6%, primary materials accounted for 11.0%, and semifinished products accounted for almost zero. The high export ratio of long products is one of the important features. Most of these products are commodity-grade construction steel, such as bars and wire rods, which can be manufactured without technological difficulty. In addition, some of the bars are actually billets, which have a lower value added than bars. Some alloy steel sheets are functionally equivalent to nonalloy hot-rolled sheets. Because a value-added tax (VAT) refund can be received if an export item is an alloy steel, export companies in China have declared to customs billets as alloyed bars and declared hot-rolled sheets as alloy steel sheets by adding a small amount of boron.[8] Manipulating the VAT refund rate for export items is one of China's important export policies.

Regarding imports, China's import volume decreased by an annual average rate of 1.9% in the 2000s to a record high of 17.2 million tons in 2010. Thereafter, the import volume continued to show a downward trend, decreasing by an annual average rate of 2.2% in the 2010s to 14.4 million tons in 2018.

In terms of imports by destination, in 2018, Japan was the largest import trading partner (39.8%), followed by the ROK (27.1%), Taiwan (10.0%), and Indonesia (8.0%). In particular, China's imports are concentrated in Japan and the ROK, which account for more than 60% of its total imports. By product, in 2017, China's share of import items was 43.4%

[8] Kawabata (2017, pp. 22–23) and JETRO (2018).

for flat products, 33.8% for primary materials, 11.1% for long products, 9.2% for pipes and tubes, and 2.5% for semifinished products.

3.2 The Intraregional Trade Structure in the ROK, Japan, and China

The analysis thus far confirms that intraregional trade accounts for a large proportion of the global steel trade. Such characteristics can be confirmed between Japan, China, and the ROK.

Based on World Steel Association (1980–2020), which supplies data on the global steel industry, we see that intraregional trade in both Europe and Asia accounts for a large proportion of the global steel trade. The former has reached 118.5 million tons; the latter has reached 117.2 million tons. Combined, their share in the global trade accounted for 52.5% in 2018.

Table 3 shows the proportion of intraregional trade in the total steel trade value (exports + imports) between the three countries. The proportion of intraregional trade of Japan was 47.6% in 2010 but declined

Table 3 Intraregional steel trade in KJC (2017) (unit: million dollars, %)

		ROK	*Japan*	*China*	*Total*	*World*
ROK	Exports		2,989 (11.3)	3,664 (13.9)	6,653 (25.2)	26,355
	Imports		5,430 (30.2)	7,811 (43.5)	13,241 (73.7)	17,960
	Total		8,419 (19.0)	11,475 (28.7)	19,894 (44.9)	44,315
Japan	Exports	5,202 (16.1)		6,008 (18.6)	11,210 (34.8)	32,241
	Imports	3,016 (35.8)		1,469 (17.5)	4,485 (53.3)	8,414
	Total	8,218 (25.9)		7,477 (18.4)	15,695 (38.6)	40,654
China	Exports	7,202 (12.9)	1,340 (2.4)		8,542 (15.3)	56,014
	Imports	3,899 (16.4)	6,631 (27.8)		10,530 (44.2)	23,826
	Total	11,101 (13.9)	7,971 (10.0)		19,296 (30.2)	79,840

Note The range of steel products is HS 7201–7229 and HS 7301–7307
Source Compiled by the author based on the database from the United Nations (2000–2019)

to 38.6% in 2017. In the same period, the proportion of intraregional trade of the ROK declined from 45.7 to 44.9%, and China's proportion decreased from 34.6 to 30.2%. In other words, since the beginning of the 2010s, the proportion of intraregional trade of the three countries has gradually decreased, mainly in line with the decrease in intraregional exports. However, they are still highly dependent on intraregional trade compared to extra-regional trade.

Examining the breakdown of intraregional trade, we see that the dependence on intraregional imports is much higher than the dependence on exports in all three countries, and the ROK and Japan have a higher share of intraregional trade than China. In terms of their dependence on intraregional exports, Japan has the highest share at 34.8%, followed by the ROK at 25.2% and China at 15.3%. Regarding their dependence on intraregional imports, the ROK has the highest share at 73.7%, followed by Japan at 53.3% and China at 44.2%. In particular, the ROK and Japan have a much higher proportion of intraregional imports than China. This finding means that both the ROK and Japan have much higher intraregional procurement rates than China.

In the following, we examine the trade between the three countries to confirm the intraregional division of labor structure in Northeast Asia in detail.

First, the ROK's dependence on trade with Japan has been declining in recent years. The ROK's dependence on exports declined from 16.4% in 2005 to 12.5% in 2010 and 11.3% in 2017. In contrast, the ROK's dependence on imports to Japan rose from 38.4% in 2005 to 40.0% in 2010. Thereafter, it began to decline, falling to 30.2% in 2017.

Regarding the ROK's dependence on trade with China, the export dependency declined from 15.6% in 2010 to 13.9% in 2017, but the import dependency increased sharply from 23.9% in 2010 to 43.5% in 2017. In particular, for the ROK, China was the largest export partner in the first half of the 2000s, but it became the largest import partner after 2007. However, the ROK's dependence on trade with China also rose sharply from 19.7% in 2010 to 28.7% in 2017, and China has become an important trading partner of the ROK.

In short, since the 2010s, the ROK's dependence on exports to Japan has declined, while its dependence on exports to China has risen sharply.

Second, regarding Japan's dependence on trade with China, its export dependence declined from 21.1% in 2010 to 18.6% in 2017, and its import dependence fell from 18.7% in 2010 to 17.5% in 2017. Moreover, regarding the dependence on trade with the ROK, Japan's export dependence declined from 22.4% in 2010 to 16.1% in 2017, while its import dependence rose from 32.9% to 35.8% in 2017. One of the main reasons Japan's dependence on imports to the ROK increased was the increase in imports of high-grade steel products, such as steel sheets for automobiles, accompanied by the improvement in the ROK's technological development capability.[9]

Third, regarding China's dependence on trade with Japan, its export dependence fell from 4.6% in 2010 to 2.4% in 2017, while its import dependence declined from 34.6% in 2010 to 27.8% in 2017. Regarding China's dependence on trade with the ROK, China's export dependence decreased from 15.6% in 2010 to 12.9% in 2017, while its import dependence increased from 14.4% in 2010 to 16.4% in 2017.

Concerning the trade balance among the three countries, the ROK has run a trade deficit with Japan and China since the 2010s. In particular, the ROK's trade deficit with Japan has been decreasing, but its trade deficit with China has been increasing rapidly. On the other hand, since the 2010s, China has had a trade surplus with the ROK and a trade deficit with Japan, and Japan continues to have a trade surplus with the ROK and China.

In the intraregional trade structure between Japan, China, and the ROK, the dependence on intraregional exports has been decreasing, while the dependence on intraregional imports has been increasing in all three countries. By country, since the 2010s, the proportion of Japan in intraregional trade among the three countries has decreased, and the proportions of China and the ROK have increased. In particular, Japan's and the ROK's dependence on trade with China has been increasing rapidly, accompanied by the rapid growth of the Chinese steel industry. This finding means that the "competition and cooperation" relationship in the intraregional division of labor has deepened, accompanied by the production expansion and technological progress of the Korean and Chinese iron and steel industries.

Table 4 shows the degree of intraregional trade dependency by product between the ROK, Japan, and China.

Regarding the ROK's intraregional trade by product, its dependence on exports is the highest at 30.3% for semifinished products, followed

[9] For the technological progress of POSCO, see POSCO (2018).

Table 4 Intraregional trade dependence in KJC (unit: %)

	Exports						*Imports*					
	ROK		*Japan*		*China*		*ROK*		*Japan*		*China*	
	2010	*2017*	*2010*	*2017*	*2010*	*2017*	*2010*	*2017*	*2010*	*2017*	*2010*	*2017*
Primary raw materials	45.8	25.4	85.0	70.4	62.0	39.4	35.0	40.8	25.3	18.0	28.3	15.8
Semifinished products	10.1	30.3	52.1	33.5	6.7	12.2	43.4	63.8	79.2	85.9	26.7	15.4
Plate products	30.2	28.2	43.3	30.8	21.6	16.2	87.6	87.6	75.9	77.0	71.1	67.3
Long products	27.5	24.6	37.9	36.9	18.5	18.9	69.9	85.4	80.6	78.3	26.8	54.7
Tubes and pipes	9.8	10.9	15.9	18.4	7.9	8.1	55.9	72.1	61.5	59.3	37.6	34.6
Total	27.4	25.2	43.5	34.8	20.1	15.3	63.8	73.7	51.6	53.3	48.9	44.2

Note The range of steel products is HS 7201–7229 and HS 7301–7307
Source Compiled by the author based on the database from the United Nations (2000–2019)

by 28.1% for long products and 25.7% for plate products. By country, the ROK's semifinished products are highly dependent on Japan, and the ROK's plate products are highly dependent on China. Moreover, the ROK's dependence on imports is the highest at 68.1% for plate products, followed by 64.3% for semifinished products and 2.2% for long products. The intraregional trade structure of the ROK by product shows similarities to its global trade structure.

Regarding Japan's dependence on intraregional exports by product, primary materials account for the highest percentage at 70.4%, long products account for 36.9%, semifinished products account for 33.5%, and plate products account for 30.8%. By country, exports to the ROK represent a high proportion of semifinished products and nonalloyed long products, while exports to China represent a high proportion of stainless plate products. Regarding Japan's dependence on intraregional imports, semifinished products are the highest at 85.9%, followed by bar steel products at 78.3% and plate products at 77.0%. Most of them are imported from the ROK. By product, nonalloyed semifinished products account for approximately 95%, stainless plate products account for approximately 70%, and nonalloyed long products account for 61%. Japan imports approximately 95% of nonalloyed semifinished products, approximately 70% of stainless plate products and 61% of nonalloyed long products from the ROK.

Finally, concerning China's dependence on intraregional exports by product, primary raw materials account for the highest percentage at 39.4%, followed by long products (18.9%), plate products (16.2%), and semifinished products (12.2%). More specifically, primary raw materials and semifinished products are mostly exported to Japan, and plate products and bar steel are mostly exported to the ROK.

Moreover, in terms of China's dependence on intraregional imports, plate products account for the highest at 67.3%, followed by long products at 54.7%, primary raw materials at 15.8%, and semifinished products at 15.8%. More specifically, bar steel and steel pipe products are mostly imported from Japan, and approximately 30% of plates are imported from Japan and the ROK.

Regarding the intraregional trade structure by product in KJC, intraindustry trade is developing. As described above, the ROK and Japan mainly depend on intraregional markets for semifinished products and plate products, and China depends on such markets for plate products and long products. In particular, in the case of Japan and the ROK, imports from China have been increasing sharply, but most of these imports have mainly been nonalloy hot-rolled sheets used for ships and trucks, commodity-grade construction steel such as bars and wire rods that can be manufactured without technological difficulty, and long products such as rails, which do not have a high value added.

As described above, the intraindustry trade structure through product differentiation can also be confirmed by comparing the export unit prices among the three countries. The intraindustry trade structure is analyzed in detail in the following section. Regarding total steel products, Japan has the highest export unit price, followed by the ROK and China. In most product categories, Japan or the ROK shows a higher export unit price than China. This finding indicates that China is exporting low valued-added, commodity-grade products on the basis of price.

In short, the three KJC countries have grown while cooperating and competing with each other, and they have emerged as the leading countries for the growth of the global steel industry.

3.3 The International Competitiveness of the Iron and Steel Industry of KJC

Below, we examine the trends in international competitiveness by comparing the trade specialization coefficient[10] of main products based on the four-digit HS classification codes. The trade specialization coefficient is calculated as the ratio of the trade surplus (exports − imports) to total trade (exports + imports and taking a value between −1 and +1). When the index is greater than zero and approaches one, it indicates that the product has a comparative advantage in the international market. A value of "+1" means full specialization in exports, while a value of "−1" means full specialization in imports. If exports and imports are in equilibrium, the coefficient is zero, which is complete intraindustry trade.

First, the value added and international competitiveness of iron and steel products are closely related to the production process. The production of iron and steel involves multistage processes. In the iron and steel

[10]TSC is measured based on the degree of specialization in exports. However, the index has some limitations due to the government's export promotion measures and import restrictions.

Table 5 Global trade specialization coefficient of KJC

	Japan		*ROK*		*China*	
	2010	*2017*	*2010*	*2017*	*2010*	*2017*
Primary materials	−0.02	0.06	−0.70	−0.60	−0.44	−0.69
Semifinished products	0.89	0.84	−0.69	−0.43	−0.75	−0.97
Flat products	0.80	0.70	0.20	0.39	0.13	0.48
Long products	0.73	0.68	−0.02	−0.09	0.27	0.65
Pipe and tube products	0.75	0.57	0.34	0.48	0.61	0.70
Total	0.66	0.59	−0.03	0.19	0.16	0.40

Source Compiled by the author based on the database from the United Nations (2000–2019)

industry, two major production systems are observed (Sect. 2).[11] Apart from integrated and mini mills, there is some variety in the enterprises in downstream processes, such as hot rolling companies and surface treating companies. In KJC, integrated enterprises are major producers. The share of integrated production with a BF was 71.9% worldwide, 68.6% in the ROK, 75.5% in Japan, and 89.6% in China.[12]

Table 5 shows the trade specialization coefficient of the iron and steel industries of KJC.

Japan's trade specialization coefficient has been consistently positive and is the highest of the three countries. This finding indicates that Japan's trade balance remains in surplus and that Japan continues to maintain a stable competitive advantage. Since the 2010s, Japan's exports have gradually declined due to increased production and sluggish demand in China and the ROK, which are major export destinations. Therefore, Japan's relative superiority in terms of export competitiveness has been declining. Japan's trade specialization coefficient dropped from 0.66 in 2010 to 0.59 in 2017. However, Japan's trade specialization coefficient remains at a high level of more than 0.5.

Regarding the trade specialization coefficient by product, only semifinished stainless products record a negative figure (−0.67). The other items

[11] The ironmaking process converts iron ore into pig iron with a BF or other types of reducing furnaces. The steelmaking process refines pig iron and/or scrap into crude steel with a basic oxygen furnace (BOF) or an EAF, and it continuously casts the melted crude steel into semifinished products (Kawabata 2017, pp. 7–9).

[12] World Steel Association (2020, p. 11).

remain more than 0.5. In Japan, there is an unusual observation. As described above, although Japan is considered to specialize in the production of high value-added steel products, the export competitiveness of low value-added products such as semifinished products and hot-rolled steel sheets (HS 7207 and 7208) is relatively high. This phenomenon is based on exporting to overseas downstream subsidiaries. Moreover, Japanese steel companies have continued to strengthen their overseas production and sales networks, and they have made domestic structural adjustments to improve their profit structure.

In other words, the high international competitiveness of the Japanese steel industry results from the securing of economies of scale, the technological development capability of high value-added products, and the optimization of the global value chain.

China's trade specialization coefficient also increased from −0.4 in 2000 to 0.16 in 2010 and to 0.40 in 2017. The reason is that exports from China began to increase sharply from the mid-2000s, and, thereafter, the trade balance became a surplus. Regarding China's trade specialization coefficient by product, primary materials and semifinished products show negative figures, but other products continue to show positive figures due to the increase in exports since the mid-2000s. In particular, the trade specialization coefficient for hot-rolled steel sheets, thick plates, and bars and wire rods, which are long products, increased rapidly; notably, most of these products have low value added. Underlying this increase was the rapid increase in production and exports accompanying the expansion of capital investment since the late 2000s. In addition, China mostly depends on imports for semifinished products (−0.97) such as billets, slabs, and blooms as well as primary raw materials (−0.70).

Regarding the structure of the Chinese steel industry thus far, it has developed around medium-sized BF companies rather than large-scale BF for economies of scale, and there is an extremely large number of medium-sized companies. China's iron and steel industry is not superior in either resources or technological ability, and it does not adopt a production method utilizing an abundant labor force for economies of scale. This phenomenon means that China imports semifinished products and primary materials to produce low value-added products and export them.

In other words, the source of Chinese companies' international competitiveness is that many small and medium-sized steel manufacturers have enhanced the productivity of low-priced products by specializing in specific production processes and specific products. In addition, since the 2010s, the Chinese government has been promoting the structural adjustment of the steel industry to secure economies of scale and to strengthen its international competitiveness through the consolidation of small and medium-sized manufacturers. The steelmaking capacity of China has declined significantly in recent years. OECD data show that China's capacity fell by 87.0 mmt between 2016 and 2018.[13]

Regarding the ROK, the global trade balance ran a deficit until the 2000s, and the trade specialization coefficient also recorded a negative figure. However, the trade balance of the ROK has returned to a surplus due to the increase in domestic production and exports from 2011, and since then, the trade specialization coefficient has become positive and continued to increase.

Regarding the trade specialization coefficient by product, primary materials and semifinished products show negative figures, but other products continue to show positive figures. In particular, the trade specialization coefficients of primary raw materials, nonalloyed steels, semifinished alloy steels, nonalloyed steel rods, and other alloyed steel rods continue to be negative. However, plate products increased from 0.15 in 2005 to 0.39 in 2017, and pipe and tube products increased from 0.34 to 0.48 during the same period. In other words, the trade specialization coefficients for high value-added products such as surface-treated steel sheets and stainless sheets for automobiles have become positive and have continued to increase due to the rapid increase in exports since the mid-2000s.

The international competitiveness of the ROK's steel companies results from the securing of economies of scale, the development of high value-added products, and the optimization of the global value chain.[14]

Now, we turn to the ROK's export competitiveness in relation to Japan and China.

As mentioned above, the global trade specialization coefficient of the ROK by products is positive, but in relation to China and Japan, the coefficient has remained negative for most products since the 2000s.

Table 6 shows the ROK's trade specialization coefficient in relation to

[13] OECD (2020).

[14] Kim (2020, pp. 5–7).

Table 6 The ROK's trade specialization coefficient in relation to Japan and China

	Japan			*China*		
	2005	*2010*	*2017*	*2005*	*2010*	*2017*
Primary materials	−0.84	−0.68	−0.82	−0.73	−0.45	−0.45
Semifinished products	−0.95	−0.94	−0.63	−0.90	0.42	−0.93
Nonalloy steel	−0.95	−0.94	−0.60	−0.96	0.50	−0.89
Stainless steel	0.63	0.85	0.56	0.81	−0.14	0.56
Alloy steel	−0.99	−0.99	−0.99	−0.98	−0.48	−0.93
Flat products	−0.38	−0.47	−0.05	0.27	−0.11	−0.21
Nonalloy steel	−0.42	−0.51	−0.08	−0.07	−0.12	−0.12
Stainless steel	0.04	−0.15	0.21	0.93	−0.27	−0.44
Alloy steel	−0.89	−0.83	−0.20	0.83	0.55	−0.26
Long products	−0.32	−0.45	−0.38	−0.54	−0.64	−0.74
Nonalloy steel	−0.44	−0.52	−0.43	−0.62	−0.67	−0.82
Stainless steel	0.08	−0.12	−0.22	−0.02	−0.37	−0.12
Alloy steel	−0.21	−0.42	−0.39	−0.45	−0.75	−0.74
Pipe and tube products	−0.32	−0.48	−0.16	−0.32	−0.48	−0.16
Total	−0.13	−0.56	−0.29	−0.05	−0.26	−0.36

Note Primary materials (HS 7201–7205); Semifinished products: nonalloy steel (HS 7206–7207), stainless steel (HS 7218), alloy steel (HS 7224); Flat products: nonalloy steel (HS 7208–7212), stainless steel (HS 7219–7220), alloy steel (HS 7225–7226); Long products: nonalloy steel (HS 7213–7217), stainless steel (HS 7221–7223), alloy steel (HS 7227–7229); Pipe and tube products (HS 7303–7307)
Source Compiled by the author from data in the United Nations Comtrade database

Japan and China.

Regarding trade with Japan, the ROK's trade specialization coefficient was −0.56 in 2010 but rose to −0.29 in 2017, which means that the overall competitiveness of most products has gradually increased. While the trade specialization coefficient of most products is negative, products with positive figures in relation to Japan include iron and nonalloy steel in ingot form (HS 7206), cold-rolled steel sheets (HS 7209–7210), stainless steel semifinished products (HS 7218–7219), stainless steel wire (HS 7223), wire of other alloy steel (HS 7229), other tubes and pipes (HS 7305), and tube or pipe fittings (HS 7307). However, some products, such as ferrous scrap and electrode rods, are highly dependent on imports from Japan, accounting for approximately 63% of total imports.

Regarding trade with China, which is the largest trading partner, the trade specialization coefficient ranged from −0.13 in 2005 to −0.26 in

2010 and −0.27 in 2017. It can be confirmed that in relation to Japan and China, the export competitiveness of most of the ROK's products has declined since the 2000s.

Regarding the trade specialization coefficient in relation to China, the main products that show a positive figure are high value-added products, which maintain a competitive advantage over China. Concerning the trade specialization coefficient for major products, the figure for ferrous waste and scrap (HS 7204) is 0.52; that for stainless steel flat-rolled products (HS 7220) is 0.76; that for stainless steel semifinished products (HS 7218) is 0.99; that for cold-rolled steel sheets (HS 7209 and HS 7211) is 0.76; that for plate-rolled products of silicon-electrician steel (HS 7226) is 0.28; that for wire of other alloy steel, specifically silicon-manganese steel (HS 7229) is 0.25; and that for other tubes and pipes (HS 7305) is 0.92.

The ROK's trade specialization coefficient in relation to the world and China is lower than that of China.

The main reasons for this finding are the Chinese government's export promotion policy, such as the VAT refund; China's export structure, which is centered on low-priced products; and China's lower import dependence (1.7%) compared to the ROK (26.6%). As mentioned above, in relation to Japan and China, while the ROK has continued to run a trade deficit for most products since the 2010s, the international competitiveness of some high value-added products, such as stainless steel and alloy steel, is increasing.

The analysis above confirms that the international division of labor structure in terms of technology and products has been established and developed between the ROK, Japan, and China. In other words, Japan specializes in high value-added products developed to meet the needs of end users. The ROK has a composition similar to that of Japan, but it mainly specializes in medium value-added products. China mainly specializes in low value-added products.

Such a division of labor structure is made clear by comparing the unit prices of exports by product in the three countries. In 2017, Japan's export unit price was the highest at $1,130, followed by the ROK at $1,050 and China at $999.[15] However, since the early 2010s, the technological development capability of the ROK and China has progressed

[15] Compiled by the author based on the data from the Unites Nations (2000–2019).

rapidly; as a result, intraregional competition is intensifying as the number of competing products in the three countries is increasing.

4 Changes in the Trade Environment Surrounding the Iron and Steel Industry

4.1 Strengthening New Protectionism

Since the global economic crisis in 2008, all countries worldwide have worried about rising protectionism in international trade, as protectionist measures such as import restrictions and tariff increases have been historically prevalent during periods of economic slowdown. Since the mid-1990s, tariffs have been gradually reduced or abolished mainly in developed countries due to the spread of free trade agreements (FTAs) and customs unions.

On the other hand, the "neoprotectionism" movement, which uses nontariff measures as an alternative means of protecting domestic industry, has expanded all over the world since the late 2000s. Such alternative means include not only technical measures such as trade remedy measures, sanitary and phytosanitary (SPS) measures, and technical barriers to trade (TBTs) but also diversified types such as trade-related investment measures, government procurement, and rules of origin. In addition, the scope of protection measures has recently been expanding.

Nontariff measures related to the steel trade mainly consist of trade remedy measures. Trade remedy measures are trade policy tools that allow governments to take remedial action against imports that are causing material injury to a domestic industry. These trade remedies include antidumping duties (ADs), countervailing duties (CVDs), and safeguards (SGs).

The most commonly used are antidumping measures to counteract unfairly low prices. The World Trade Agreement (WTO) on Antidumping states that goods are "dumped" when companies export them at prices lower than those at which they sell in their home market. Dumping is not illegal per se, but it becomes illegal as soon as it results in injury to local businesses in the importing country. Countervailing tariffs are measures to counteract subsidies by national authorities that unfairly enable their companies to export at a lower price. A safeguard action is an "emergency action." An emergency "safeguard" action may be taken where a surge of imports causes or threatens to cause serious material injury to a domestic industry. These trade remedy measures are based on the principles of the WTO Agreement. That is, the WTO identifies three main types of import restraints as trade remedies. These measures do not counteract an unfair practice but allow countries to suspend import surges temporarily to grant local industries time to adjust to increased foreign competition on national markets. In addition to trade remedy measures, there are complicated certification systems such as Indonesia's Indonesian National Standard (SNI) and India's Bureau of India Standards (BIS). Moreover, TBTs, such as complicated processes to arrange trade and amendments to an industrial standard, are used as barriers to exports.[16]

These trade remedy measures are widely known to be consistent with the WTO rules on curbing unfair trade practices. However, if each country determines that "Standards and Conformity Assessment Systems," such as the technical regulations of another country, will hinder its own exports, each country petitions the TBT committee to rectify the matter as a "specific trade concern" (STC). In particular, the number of STC cases has increased significantly, mainly in emerging countries, due to the mandatory implementation of TBT agreements in developing countries since 2005.[17]

By country, not only developed countries such as the United States and those in the EU but also emerging countries such as India, Indonesia, and Thailand have been strengthening their trade remedy measures to protect their domestic industries. ASEAN economies, which are the largest export destinations of KJC, have strengthened their import restriction measures to protect their domestic industries since the 2010s. Furthermore, from the political economy perspective, the iron and steel industry is easily subject to trade frictions because it is a material industry that supports a country's industry. Additionally, in many countries, this industry has an oligopolistic structure.

WTO statistics indicate that antidumping measures have been widely used to protect domestic industries in recent years. Starting in the 2010s, many countries began to use trade remedies as a means to protect their steel industry, and since then, trade remedy measures have been rapidly

[16] POSRI (2019b, pp. 8–9).

[17] The number of STC cases increased from 17 in 2000 to 77 in 2018. Since the TBT committee usually meets three times per year, it is possible to regularly check the correction status of measures in partner countries.

Table 7 Trade remedy measures by industries (1995–2018)

	Base metal (%)	*Plastic products (%)*	*Chemical products (%)*	*Others (%)*
ADs	31	13	20	36
CVDs	44	11	10	34

Source Compiled by the author from Korea International Trade Association (KITA) and WTO data

increasing all over the world. The number of trade remedy measures initiated from 1995 to 2018 *amounted to* 6,613, of which 2,094 measures were related to steel and metal (base metal), accounting for 60% of the total (Table 7).

Examining the number of trade remedy measures initiated, we see that as of 2018, ADs were the most common, accounting for 87% of all trade relief measures (345) at 300 cases, followed by CVDs at 34 cases and SGs at 11 cases. By country, China was the largest at 23.7%, followed by the ROK at 7.3% and India at 5.1%.

In particular, the implementation of the United States' aggressive enforcement of U.S. trade laws was the origin of import restrictions and trade frictions related to the steel industry; notably, the United States is the largest importer of steel products worldwide. The following measures were cited: a restriction on imports of steel and aluminum for national security reasons based on Section 232 of the Trade Expansion Act of 1962; the implementation of SG measures against imports based on Section 201 of the Trade Act; and trade remedy measures. Since then, the EU and Canada have also introduced measures similar to those of the United States as a means of retaliating against unilateral measures imposed by the United States.[18]

Regarding the ROK's iron and steel industry, which has the highest export dependency among the three KJC countries, the details are as follows.[19] As of 2019, the number of trade remedy measures targeting the ROK amounted to 207 cases (up 13 cases compared with previous years), and the number of measures initiated was 36 cases, while 171 cases were in force. Regarding measures, the proportion of antidumping measures

[18] For example, the EU conducted *14 market investigations* into import restrictions over the course of one year, including an implementation of SG measures for steel products in January 2019.

[19] KITA (antidumping.kita.net), retrieved on October 15, 2019.

was the highest at approximately 75% (152), followed by SGs at approximately 22% (46) (up 12 units compared with previous years) and CVDs at 5% (9). By product, steel and metals sectors accounted for the highest proportion of 50.2% (86) out of 171 cases under regulation, followed by chemicals at 19.3% (33), plastics and rubber at 11.7% (20), and textiles at 6.4% (11). In addition, there are 36 products under investigation. By item, there are 10 cases for steel and metals, 7 cases for chemicals, 6 cases for plastics and rubber, 2 cases for textiles and clothing, and 11 cases for other items.

Regarding countries, in 2019, the ROK was a target of trade remedy measures by 27 trading partners. The United States accounted for the largest number of measures at 40 cases (59.8%), followed by India at 32, China at 17 cases, Canada at 13 cases, and Indonesia at 11 cases. Moreover, the number of trade remedy measures targeting the ROK by emerging countries such as India, Indonesia, and Thailand, where imports from the ROK have consistently increased, is gradually increasing.

Regarding antidumping measures targeting the steel sector, which has the highest number of trade remedy measures, the three KJC countries have rarely used antidumping measures to target each other. Between 1995 and 2017, the number of antidumping measures initiated by the three KJC countries to target each other and in force amounted to only 300 cases, accounting for 8% of the total number (3,604 cases) of ADs worldwide.

Moreover, the number of antidumping measures initiated to target the steel and metals sector and in force amounted to only 31 cases, and the chemicals sector has been the most frequent target. Since the 2010s, the number of antidumping measures by China and Japan associated with the steel industry and targeting the ROK amounted to only one case for the steel industry.

Moreover, in the iron and steel industry of KJC, as expected, protectionism by major export partners, such as ASEAN, the United States, and the EU, is increasingly strengthened, the competition for survival will become even more intense, and dependency on the intraregional market will rise.

4.2 *Overcapacity and Steel Exports*

The first step is the definition of overcapacity. This paper considers overcapacity to be the difference between production capacity and demand

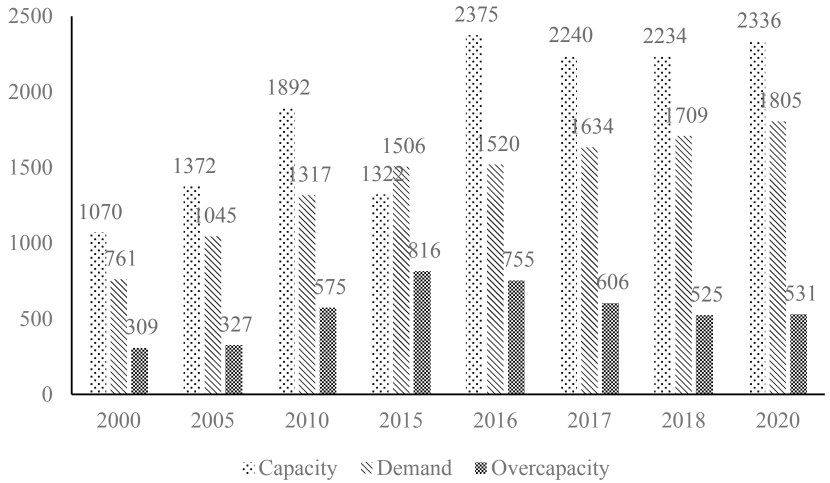

Fig. 1 Trend of global steel overcapacity (unit: million tons) (*Source* Compiled by the author based on the database from OECD [2000–2020] and World Steel Association [1980–2020])

(OECD 2000–2020). This paper calculates the volume of overcapacity in the world and in each country by subtracting the demand volume from the existing production capacity.[20] The OECD committee treats only the worldwide situation of overcapacity. In the worldwide base, neglecting inventory fluctuation, demand equals production. Therefore, the OECD definition is in line with our definition of overcapacity as the difference between capacity and production. The second issue is the promotional factor of overcapacity. In general, overcapacity can be generated as a result of an increase in capacity induced by capital investment or along with shrinking demand. The former is better suited to the current situation in the global iron and steel industry because production capacity has increased enormously since the 2000s (Fig. 1). Brun (2016) indicated that there are two kinds of overcapacity. The first is "cyclical overcapacity," which is caused by the variability of demand, including cyclical demand in one economy or uneven changes among economies. The

[20] Brun considers unutilized production capacity as a simple indicator of overcapacity (Brun 2016).

second is “structural overcapacity,” which is caused by overinvestment due to nonprice factors. According to Brun, nonprice factors are over-investment induced by governmental behavior, exit barriers, investment barriers, etc. However, we should pay attention to not only the process by which overinvestment leads to overcapacity but also the process by which production capacity falls into overcapacity as a result of the competition for survival. The market distortion caused by governmental intervention is the main cause of overcapacity in many countries. Specifically, governmental intervention in many countries includes state ownership involvement in corporate decision making, direct support through low-interest loans and grants, indirect support through the low-priced sale of energy, administrative bailouts to stop the shutdowns of low-performing factories, and debt refinancing (Brun 2016; Kawabata 2017).

According to the OECD (2019), the occurrence of overcapacity is the result of a capacity that exceeds demand. The increment in global capacity from 2000 to 2013 was 1.23 billion tons. Although harmonized statistics are not available, the increment in crude steel production capacity in China in the same period was 957 million tons. In fact, when the Chinese government implemented an economic stimulus package to support the economy during the global financial crisis in 2008, Chinese steelmakers rapidly increased their capital investment due to the expectation of increased domestic demand. A total of 70–80% of the increment in capacity was attributable to China, even considering any possible errors. If China had been the only investor in production capacity, excess capacity of 200 million tons or more would have occurred in 2013. Based on this calculation, the rapid expansion of production capacity in China was a major cause of the increase in overcapacity worldwide. Figure 1 shows the trend of global crude steelmaking capacity and crude steel production. The global production capacity of steel is surveyed by the OECD on a continuous basis. According to this survey (as of 2019), the total crude steel production capacity reached 2.234 billion tons in 2018, compared to 1.070 billion tons in 2000. In the same period, crude steel production increased to 1.89 billion tons from 849 million tons, according to a survey by World Steel Association. That is, the growth in production capacity was larger than that in production records. As a result, the capacity utilization rate showed a downward trend in the 60–80% range. The total overcapacity was 309 million tons in 2000, after which it contracted temporarily but increased again after the world financial crisis, peaking at 820 million tons in 2015 and declining yet again and reaching 525 million tons in 2018.

By country, China, which is the largest producer, accounted for 35.8% (188 MT) of the world's overcapacity (525 MT). Japan, which is the second largest producer, accounted for 12.0% (63 MT), and the ROK, which is the fifth largest producer, accounted for 6.5% (34 MT). In other words, the world's top 5 producers accounted for more than 60% of the world's overcapacity. Based on this calculation, the rapid increase in production capacity in China was a major cause of the growth in global overcapacity. However, this does not mean that all existing overcapacity is in China. That is, it is also necessary to consider whether the expansion of equipment in China was based on competitive advantage (Table 8).

The next point is the relation between overcapacity and steel exports. Under the severe trade environment such as the intensifying trade frictions and the strengthening protectionism, it is necessary to investigate whether overcapacity simply stops operations or deliberately operates to export low value-added products. Brun (2016) indicated that a firm with

Table 8 Crude steel production capacity and operating conditions by country (2018) (unit: million tons)

	Crude steel production capacity (1)	*Crude steel production (2)*	*Apparent consumption (3)*	*Overcapacity (1)–(3)*	*Capacity utilization rate (%)*
World	2,234	1,809	1,709	525	81.0
China	1,023	928	835	188	90.7
India	128	107	97	31	83.6
Japan	128	104	65	63	81.3
United States	113	87	100	13	77.0
ROK	88	73	54	34	83.0
Russia	85	72	41	44	84.7
Turkey	49	37	31	18	75.5
Brazil	51	35	21	30	68.6

Source Compiled by the author based on the database from OECD (2000–2020) and World Steel Association (1980–2020) overcapacity has an incentive to export products with low prices to maintain a steady rate of capacity utilization and to recover fixed costs.[21] This means that massive overcapacity promotes the export of low value-added steel products. However, there is not a sufficient theoretical basis for the claim that overcapacity directly leads to an export drive. For example, it is possible that overcapacity leads to a decrease in capacity utilization. Moreover, it should be noted that exports from countries with overcapacity do not necessarily mean a dumping export drive to maintain capacity utilization.

Regarding Northeast Asia, this region is the center of production, consumption, and overcapacity in the global iron and steel industry, with China situated at the center.[22] As of 2018, China accounted for approximately 50% of crude steel consumption and more than 50% of crude steel production worldwide. The Chinese iron and steel industry is not extremely export oriented, with a net export share of only 7.4%, but in physical terms, China's net exports of crude steel are huge, and they are overwhelmingly the largest worldwide.

The capacity utilization rate of the Chinese iron and steel industry is not particularly low compared to that of other countries. The scale of China's overcapacity and exports is overwhelmingly the largest in the world. Moreover, China's export items are biased toward low value-added products, and the unit price of many Chinese export products is lower than that of products from Japan and the ROK (Sect. 3.3). This finding means that there may be a link between overcapacity and large-scale exports in the Chinese iron and steel industry. As described above, it is possible that overcapacity leads to a decrease in capacity utilization. Moreover, massive overcapacity promotes the lowering of steel prices and leads to a decline in steel company profits. In short, the excess production capacity in the global steel industry is a major cause of deterioration in the profitability of steel manufacturers, and it worsens the supply–demand relationship due to excessive exports. However, even in Japan and the ROK, overcapacity exists to a significant extent compared with the production capacity of each economy. It is necessary for the regions and

[21] Brun quotes the example of past trade frictions as a basis (Brun 2016, pp. 21–23).

[22] According to the OECD (2019), many steel companies in China are installing new EAF facilities, and through the end of 2018, a total of 5.2 mmt of EAF's capacity in China had started operations.

products in which overcapacity promotes low-priced exports to be specified. For this purpose, it is necessary to utilize the results of qualitative case analysis on the nature of production facilities and trade.

5 Concluding Remarks and Future Agenda

Based on the analysis of this article, the following conclusion is drawn. In addition, we search for the future direction of the intraregional division of labor to overcome the current difficult business environment and future challenges.

Analysis has shown that the iron and steel industries of the Republic of Korea (ROK), Japan, and China (KJC) have developed through "competition and cooperation" with each other, but various development patterns and supply–demand structures have been created among these countries. Therefore, intraindustry trade and the intraregional division of labor have been formed and developed in Northeast Asia. In particular, since the 2010s, intraregional specialization has intensified, accompanied by the rapid development of the technological development capability of the ROK and China. Currently, the three countries have become dominant players, and they lead the development of the global iron and steel industry.

The Japanese and Korean iron and steel industries have an export-oriented production structure, and the scales of overcapacity and exports of Japan and the ROK are smaller than those of China. The high international competitiveness of both countries is caused by economies of scale due to large-scale capital investment, a high technological development capability, and the optimization of the global value chain. Meanwhile, as the main factor in the international competitiveness of China, many small and medium-sized steel manufacturers have enhanced the productivity of low-priced products by specializing in specific production processes and specific products.

However, the steel industry of KJC has been facing a severe trade and competition issues, such as increasing protectionism and trade frictions, a slowdown in global demand and overcapacity. The neoprotectionism related to the steel trade has spread not only to developed countries but also to developing countries. Furthermore, the double shock of protectionism and COVID-19 has severely damaged the manufacturing industry and the world economy.

Under the current difficult business environment surrounding the iron and steel industry of KJC, it is expected that the growth momentum of the iron and steel industry will be weakened and that the competition for survival will become more intense in both domestic and overseas markets.

In the following, we explore the challenges for the further growth and survival of the iron and steel industry of KJC.

First, it is important to strengthen the technological development capability for the construction of a new business model that will become the pillar of future growth. As the iron and steel industry is a mature industry, it is necessary to develop new materials and environmentally friendly production processes to survive as a global dominant player in the future. For this purpose, it is necessary to rebuild a strategic cooperation system and the intraregional division of labor structure beyond the boundaries of the steel industry, including BF manufacturers and electric furnace manufacturers in Northeast Asia.

The second challenge is how to address the growing neoprotectionism and trade frictions. As mentioned above, the three KJC countries are large exporters, and China is one of the main countries targeted by major trade remedy measures. Neoprotectionism and U.S.-China trade frictions have a great influence on the division of labor in Northeast Asia because the United States and China are the cornerstones of the industry's global supply chain. Moreover, while the double shock of protectionism and COVID-19 has begun to affect the global value chain, including the collapse of the industry's global supply chains, the movement of the reshoring and nearshoring of overseas production bases has begun.

The three KJC countries should make efforts to maintain trade liberalization based on the rules of capitalism and to strengthen their strategic alliance to prevent the spread of protectionism. For this purpose, it is necessary to enforce mega FTAs early, such as the Regional Comprehensive Economic Partnership (RCEP), while actively utilizing the FTA already signed in the East Asia region.[23] In short, international cooperation is needed during and after the crisis.

Third, how should we address overcapacity due to the slowdown in global demand and new capital investment? Most of the overcapacity in the Northeast Asian steel industry centers on China. However, even in

[23] The RCEP is a proposed FTA in the Asia–Pacific region between the ten ASEAN member states and five of ASEAN's FTA partners: Australia, China, Japan, New Zealand, and the ROK.

the ROK and Japan, overcapacity exists to a significant extent compared with the production capacity of each economy. Overcapacity is unlikely to easily diminish. In addition, the recession in the manufacturing industry due to COVID-19 is expected to continue. However, it is difficult for most steelmakers to drastically cut output because BFs are designed to run constantly, and reducing production to zero is usually a last resort. The three countries should strengthen the intraindustry trade and specialization system: there should be vertical and horizontal intraindustry trade, depending on the degree of the unit price and product differentiation of the traded goods.

Finally, to make the analysis in this paper more convincing, the competitiveness of the iron and steel industry in each economy and the relationship between overcapacity and exports must be clarified more concretely. In particular, the relationship between overcapacity and international trade frictions is an urgent topic. Regarding this topic, the main issue is the impact of government assistance and subsidies, which are a major cause of trade frictions. It is important to consider whether overcapacity is caused by government assistance and market competition, such as intense entry and high withdrawal barriers, or both. These issues represent the future agenda.

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CHAPTER 4

Changes in the Trade Structure of the Metal Products Industry in East Asia from the Perspective of the International Division of Labor

Dan Jin

1 Introduction

Global warming, resulting from the emission of large amounts of carbon dioxide and other greenhouse gases into the atmosphere due to increased production activities and changes in lifestyles, is causing "climate change," which will significantly alter not only the temperature but also the climate of the entire planet. Since the Industrial Revolution, the global average temperature has already risen by 1.1 °C. From 2015 to 2019, the global average temperature was 0.2 °C higher than it was from 2011 to 2015, making this period the hottest five years since records were first kept. This situation is expected to continue at the current trajectory. If climate change continues at the current rate, huge economic losses are expected due to abnormal weather conditions and adverse effects on fisheries and

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agriculture caused by rising sea levels. Reducing the emission of carbon dioxide, the greenhouse gas with the greatest impact on global warming, has become one of the most urgent issues in the fight against climate change, and efforts are being made to reduce emissions through production activities. The industrial sector is the largest contributor to carbon dioxide emissions from production activities, with the steel industry accounting for a large proportion of these emissions. However, the iron and steel industry is a key industry at the national level, and the production scale, technological level, and policy formulation strategy vary from country to country; therefore, the carbon dioxide reduction targets of the iron and steel industry will not be easy to achieve.

The signing ceremony for the Regional Comprehensive Economic Partnership (RCEP) agreement was held on November 15, 2020, after 15 countries, mainly from East Asia, including Japan, China, and the ROK, agreed to a summit. The conclusion of the agreement resulted in the formation of the world's largest FTZs, and the Asian region, which accounts for 28.9% of the global economy, will be the focus of FT and investment. The implementation of the RCEP is expected to strengthen production linkages among the member countries and create a new international division of labor. In the RCEP with 15 participating countries, three countries, Japan, China, and the ROK, account for more than 80% of the economic scale. This is the first economic partnership agreement between Japan and China, its largest trading partner, and Japan and the ROK, its third-largest trading partner. The change in the cooperative relationship among the three countries will have a tremendous impact on economic integration in the East Asia region. In addition, tariffs will be eliminated on 91.5% of industrial products exported from Japan, including steel products, which are a key export item. To promote the sustainable development of the East Asia region and understand the impact of the RCEP agreement on the region, it is necessary to dynamically reexamine the international division of labor in the East Asia region and the trade structure of the steel industry in Japan, China, and the ROK. Therefore, this paper clarifies the trade structure of the steel industry through a time series analysis of the international division of labor for intermediate goods in the East Asia region since 1997 and the "metal products" industry in Japan, China, and the ROK using data from the Asia International Industry Database (YNU-GIO)[1] (annual database) (Jin and Chen 2008).

2 Changes in the Trade Structure in the East Asia Region

In the development of the international division of labor in the East Asia region, we will look at the changes in the procurement rate of intermediate goods from within and outside the region for East Asian countries (regions) between 1997 and 2012 (METI 2012). Table 1 shows the changes in the ranking of the top 10 trading partners for intermediate goods in East Asian countries (regions) (Jin and Mori 2016).

In 1997, the USA was the top country that exported intermediate goods to Japan, followed by China and the ROK, which ranked second and third, respectively, and then Australia and Germany. In 2012, however, China overtook the USA, and China's became the largest exporter to Japan; there was also a noticeable increase in the import rate of intermediate goods from Asian countries, with Japan's imports from Asian countries exceeding those from other countries (regions) in 2012 compared to those in 1997.

In 1997, China's largest import of intermediate goods was from Japan, followed by the USA. Most of the countries (regions) in the top 10 were East Asian countries (regions), but their shares were not very large; in 2012, the USA reversed its position to become No. 1, but the increase in the import rate was not large. In addition to those from the USA, imports from Australia and the emerging economies of India and Brazil are also increasing. However, the total import rate from Asian countries (regions) is by far the largest.

Looking at the partner countries for the ROK's imports of intermediate goods, we see that other than China, the USA, and European countries were dominant in 1997. By 2012, imports from China had increased dramatically, while imports from the USA and European countries had declined. Imports from Australia and East Asian countries are also on the rise.

[1] The Asia International Industry Database (YNU-GIO Table) is a database published by the Research Center for Economic and Social Studies in Asia (ReCESSA), which is affiliated with the Faculty of Economics, Yokohama National University.

Table 1 Change in intermediate goods imported from within and outside East Asian countries (regions) (unit: %)

Rank		*1997*		*2012*
Japan				
1	USA	2.61	China	3.97
2	China	1.17	USA	2.54
3	ROK	0.52	Australia	1.68
4	ROW	0.40	ROK	0.87
5	Australia	0.39	ROW	0.61
6	Germany	0.39	Indonesia	0.58
7	Thailand	0.34	Malaysia	0.58
8	Indonesia	0.31	Thailand	0.53
9	Taiwan	0.28	Germany	0.52
10	Canada	0.26	ROE	0.44
China				
1	Japan	2.16	USA	1.55
2	USA	1.22	Japan	1.52
3	Taiwan	1.11	ROK	1.48
4	ROK	1.10	Australia	1.07
5	Germany	0.56	Germany	0.98
6	ROW	0.55	ROW	0.82
7	Singapore	0.49	Taiwan	0.61
8	Thailand	0.32	Brazil	0.60
9	Malaysia	0.29	India	0.60
10	Hong Kong	0.26	Malaysia	0.54
ROK				
1	USA	6.42	China	11.53
2	Japan	5.71	Japan	5.38
3	China	4.08	USA	5.09
4	ROW	1.41	Australia	2.68
5	Germany	1.39	Germany	1.74
6	Australia	1.09	ROW	1.58
7	UK	0.91	Indonesia	1.14
8	Italy	0.72	Malaysia	1.06
9	Indonesia	0.63	ROE	0.98
10	Singapore	0.56	OPEC	0.93
Malaysia				
1	Japan	8.90	China	6.83
2	USA	6.84	Singapore	5.79
3	Singapore	6.80	USA	4.22

(continued)

Table 1 (continued)

Rank		*1997*		*2012*
4	China	4.42	Japan	3.17
5	Thailand	3.69	India	2.66
6	ROW	2.42	Indonesia	2.48
7	Germany	2.24	Thailand	2.42
8	Taiwan	2.22	ROW	1.80
9	ROK	2.16	Taiwan	1.74
10	Indonesia	1.89	Germany	1.50
Indonesia				
1	Japan	3.48	China	4.77
2	USA	2.41	Singapore	2.07
3	China	2.22	Japan	1.78
4	Singapore	1.37	USA	1.69
5	ROK	1.09	Malaysia	1.33
6	Australia	0.89	Thailand	1.23
7	Germany	0.89	OPEC	1.13
8	ROW	0.85	ROK	1.07
9	Malaysia	0.83	India	1.03
10	Thailand	0.82	Australia	0.99
Philippines				
1	USA	8.21	China	4.76
2	Japan	6.81	USA	3.52
3	China	3.01	Singapore	2.56
4	Singapore	2.89	Japan	1.88
5	ROK	2.17	Taiwan	1.63
6	Taiwan	2.02	Malaysia	1.36
7	Thailand	1.21	ROK	1.06
8	ROW	1.19	Thailand	0.83
9	Germany	1.04	Australia	0.78
10	Australia	1.03	Indonesia	0.75
India				
1	ROW	1.12	China	5.45
2	USA	0.87	ROW	2.50
3	China	0.86	USA	1.82
4	UK	0.77	Malaysia	1.21
5	Japan	0.73	OPEC	1.19
6	Germany	0.68	Indonesia	1.15
7	Malaysia	0.54	Germany	1.14

(continued)

Table 1 (continued)

Rank		*1997*		*2012*
8	Belgium	0.52	ROK	1.05
9	Italy	0.37	Australia	1.04
10	Indonesia	0.31	Japan	0.92
Australia				
1	USA	3.91	China	2.67
2	ROW	1.93	ROW	2.26
3	Japan	1.71	USA	2.13
4	UK	1.03	Malaysia	1.12
5	Indonesia	0.84	Indonesia	0.80
6	China	0.83	Japan	0.70
7	Germany	0.81	Singapore	0.58
8	Italy	0.57	Germany	0.57
9	Singapore	0.48	Thailand	0.54
10	ROK	0.46	UK	0.51
USA				
1	Canada	1.68	Canada	2.60
2	Japan	1.48	China	2.04
3	Mexico	0.99	Mexico	1.38
4	ROW	0.64	Japan	0.85
5	Germany	0.64	ROW	0.83
6	UK	0.63	Germany	0.75
7	China	0.57	UK	0.57
8	France	0.40	India	0.50
9	Italy	0.40	ROK	0.41
10	Taiwan	0.30	Brazil	0.41
Canada				
1	USA	19.96	USA	15.96
2	ROW	1.46	China	2.09
3	UK	1.42	ROW	1.48
4	Japan	1.10	Mexico	1.02
5	Mexico	0.71	UK	0.70
6	Germany	0.62	Japan	0.65
7	China	0.59	Germany	0.60
8	Italy	0.54	OPEC	0.57
9	OPEC	0.51	ROA	0.54
10	France	0.42	Brazil	0.42
Germany				

(continued)

Table 1 (continued)

Rank		*1997*		*2012*
1	ROW	2.61	ROE	5.27
2	France	2.22	ROW	3.70
3	Italy	2.18	Netherlands	3.48
4	ROE	1.92	China	2.84
5	UK	1.89	USA	2.68
6	USA	1.88	UK	2.25
7	Netherlands	1.83	France	2.14
8	Belgium	1.15	Italy	2.13
9	Austria	0.94	Austria	1.81
10	Japan	0.81	Belgium	1.71
Italy				
1	Germany	2.96	Germany	3.44
2	France	2.48	ROE	2.29
3	ROW	1.80	China	1.92
4	UK	1.29	ROW	1.80
5	USA	1.21	France	1.73
6	Belgium	0.89	Netherlands	1.26
7	Netherlands	0.89	USA	1.25
8	Spain	0.88	Spain	1.20
9	ROE	0.87	ROA	0.95
10	Austria	0.56	Belgium	0.94

Note ROW (Rest of the World), ROE (Rest of Europe), ROA (Rest of Asia)
Source ReCESSA, prepared by the author

Looking at the partner countries for Malaysia's imports of intermediate goods in 1997, we see that Japan, the USA, and Singapore ranked first, second, and third, respectively. Asian countries (regions), the USA and Germany, accounted for the top 10 exporting countries. However, in 2012, China ranked first, and the percentages of imports from India and Indonesia increased significantly; additionally, the import rates of many of the top 10 countries (regions) in 1997 decreased.

Looking at the partner countries for Indonesia's imports of intermediate goods, we see that Japan ranked first in 1997, and the USA and China ranked second and third, respectively, but the differences were not large. Imports from Singapore and the ROK were also notable. By 2012, imports from China and Singapore had increased, and the percentage of imports from Singapore exceeded that from Japan. Imports from Europe declined, but imports from OPEC countries and India increased.

Among the partner countries from which the Philippines imported intermediate goods, the USA was the largest exporter in 1997, followed by Asian countries (regions). By 2012, China had overtaken the USA as the largest exporter, and imports from Asian countries (regions) increased as well.

Among countries from which India imported intermediate goods, European countries dominated in 1997. However, by 2012, imports from Europe had decreased, and imports from China had increased substantially. Imports from Japan were low, while imports from Malaysia, OPEC countries, and Indonesia increased substantially.

As described above, the trade structure of intermediate goods in the East Asia region is characterized by the following trends. (1) In 2012, China, known as the "world's factory," became the leading exporter to Asian countries in both name and reality. In recent years, while China has increased its share of imports from East Asian countries (regions), it has also increased its imports from global countries, including the USA, European countries, Australia, South America, and the emerging nation of India. (2) Europe, which accounted for a large share of East Asian countries' (regions') imports in 1997, saw its share of intermediate good exports decreased significantly in 2012. (3) Japan, China, and the ROK have all experienced significant increases in trade with Australia. (4) Malaysia, Indonesia, and the Philippines are deepening their trade ties with Singapore. (5) India, as an emerging country, is strengthening its ties with Asian countries and expanding trade with OPEC countries. Thus, intraregional trade relations have generally strengthened in East Asia.

Now, we focus on the countries from which Australia imports intermediate goods. Imports from the USA and Europe decreased in 2012 compared to those in 1997, but imports from East Asia increased nearly 1.5 times. Among the countries from which the USA imports intermediate goods, in 1997, with the exception of Japan, which ranked second, the USA mainly traded with countries that had signed the North American Free Trade Agreement (NAFTA), and other than that, trade with Europe accounted for most of the USA imports. In 2012, China overtook Japan to rank second, and imports to the USA from India and the ROK increased. The top nations in terms of imports have remained almost unchanged. As of 1997, Canada's imports of intermediate goods were mostly from Japan and China, but by 2012, imports from other

Asian countries had increased. Germany and Italy mainly imported intermediate goods from European countries, except for the USA, in 1997. By 2012, imports from China had increased.

From the above information, the East Asia region's trade relations with the rest of the world can be summarized as follows. (1) European countries procure intermediate goods from within the EU. (2) Australia is actively procuring intermediate goods from East Asian countries (regions), and the USA imports little from East Asian countries (regions) other than China, India, and the ROK.

In general, the interrelationship between intraregional and extraregional trade in East Asia suggests that East Asian countries (regions) have an active intraregional division of production for intermediate goods.

3 Changes in the Trade Structure in Japan, China, and the ROK (by Sector)

Japan, China, and the ROK are influential countries in East Asia with close interrelationships for economic and environmental issues; additionally, economic promotion and international cooperation among the three countries will be very important in promoting the RCEP in the future. To clarify the interdependence of trade among the three countries, this paper analyzes data from 29 endogenous countries (including 11 Asian countries), 59 exogenous countries, and 35 industry sectors[2] from the YNU-GIO Table (Table 2) (Jin and Mori 2016). From 1997 to 2012, a study showed that the procurement of intermediate goods among Japan, China, and the ROK peaked in 2007 and declined in many sectors due to the impact of the Lehman Shock. However, some sectors exhibited a recovery in procurement among the three countries after the Lehman Shock.

The present study analyzed the "chemical products," "metal products," "machinery and equipment," "electronics and electrical equipment," "transport machinery," and "construction" sectors, which are the large input–output sectors in the three countries. From the sectoral data in Fig. 1, Japan's imports from China's "metal products" sector displayed a noticeable rise from 1997 to 2007 but a downward trend after peaking in 2007. The trends for the "machinery and equipment"

[2] In this paper, the 35 sectors were combined into 18 sectors (Table 2) for analysis.

Table 2 Sectoral integration in the Asian international input–output table

Code	*Sectors*	*Code*	*Sectors*
1	Agriculture	10	Machinery and equipment
2	Mining	11	Electronic and electrical equipment
3	Food products, beverages, and tobacco	12	Transport equipment
4	Textiles and clothes	13	Other manufacturing
5	Wood and paper products	14	Construction
6	Coke and petroleum products	15	Electricity, gas and water supply
7	Chemical products	16	Transport
8	Nonmetallic mineral products	17	Computer and related activities
9	Metal products	18	Services

Source ReCESSA, prepared by the author

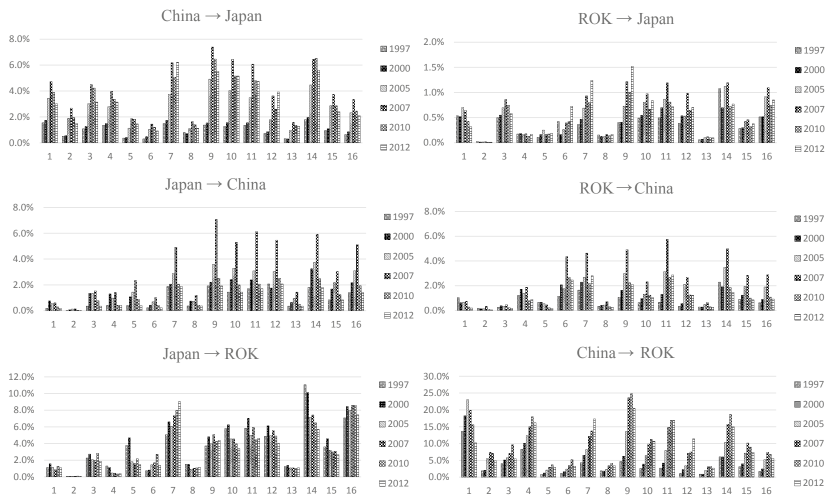

Fig. 1 Supply and demand by sector in Japan, China, and the ROK (unit: %) (*Source* ReCESSA, prepared by the author)

and "electronics and electrical equipment" sectors have remained flat since 2007. Imports from the "chemical products" sector temporarily declined after the collapse of Lehman Brothers but later returned to 2007 levels. In the "construction" sector, procurement rose until 2010 and then declined. Japan's imports from the ROK's "metal products" and "chemical products" sectors peaked in 2007 and then declined before eventually increasing in 2012, with the corresponding level far exceeding the 2007 level. Imports from the "electronics and electrical equipment" sector peaked in 2007 and then declined, falling to the level observed in the early 2000s. The "construction" and "transportation" sectors peaked in 2007 and then declined, with notable recovery in 2012.

In the "metal products," "chemical products," "electronics and electrical equipment," "transport machinery," and "construction" sectors, for which China's imports of intermediate goods from Japan are large, all procurements peaked in 2007 and then declined to below the level observed in 2000 (with the exception of the "transportation machinery" sector). China's imports from the ROK's "metal products" and "construction" sectors peaked in 2007 and have since declined. In contrast, procurement from the "chemical products" and "electronics and electrical equipment" sectors has shown a recovery since 2007.

The ROK's imports from Japan's "chemical products" sector have continued to rise regardless of the impact of the Lehman Shock. Imports from the "electronics and electrical equipment" and "transport machinery" sectors peaked in 2000 and have been on a downward trend ever since. Procurement from the "construction" sector, which had the largest weight in terms of the ROK's imports from Japan, has continued to decline. The ROK's imports from China have increased for the "chemical products" sector and now far exceed those from Japan. In the "textiles and clothing," "metal products," and "construction" sectors, procurement rose from 1997 to 2010 and slowed in 2012.

Next, the interdependence among Japan, China, and the ROK was assessed. Japan's dependence on the "machinery and equipment" sectors in China and the ROK has increased. Additionally, both China and Japan have increased their dependence on the ROK's "chemical products" sector, and both China and the ROK have decreased their dependence on Japan's "electronics and electrical equipment," "transport machinery," and "construction" sectors. In addition, both Japan and the ROK have seen a decline in their dependence on China's "metal products" and "construction" sectors, while Japan's dependence on the ROK's "metal products" sector has increased since the Lehman Shock. The decline in dependence on the "metal products" sector is partly due to the decline in demand following the financial crisis, but it is necessary to look further into the supply and demand structure of metal products among the three countries.

4 Interdependence in the "Metal Products" Industry Among China, Japan, and the ROK

Figure 2 shows the supply from the "metal products" sector to other sectors[3] within Japan, China, and the ROK.

In Japan, compared to that in 1997, the supplies from the "metal products" sector to the "electronic and electrical equipment" (3.92–3.18%) and "transportation machinery" (3.48–3.05%) sectors within the country continuously decreased, while the supplies to the "machinery and equipment" (4.77–5.10%) and "construction" (7.88–9.11%) sectors increased. The largest demand can be observed for the "construction" sector.

In China, the supplies from the "metal products" sector to the "machinery and equipment" (9.51–11.05%), "electronics and electrical equipment" (6.61–7.35%), "transportation machinery" (7.13–9.21%), and "construction" (8.74–10.08%) sectors displayed an increasing trend compared to the levels in 1997. The largest demand can be observed for the "machinery and equipment" sector.

In the ROK, the supplies from the "metal products" sector to the "machinery and equipment" (5.40–6.31%), "electronics and electrical equipment" (1.86–2.40%), "transportation machinery" (2.99–4.01%), and "construction" (6.54–7.83%) sectors have increased compared to the levels in 1997. Demand is highest for the "construction" sector.

Figure 3 shows the supply from the "metal products" sector in Japan, China, and the ROK to other sectors in other countries. To meet the demand from various sectors in Japan, supply from China's "metal products" sector to Japan peaked in 2007 and has been declining since the Lehman Shock in 2008, while supplies to the "machinery and equipment" (0.13–0.56%), "electronics and electrical equipment" (0.10–0.38%), and "construction" sectors (0.12–0.54%) have risen significantly since 2005 compared to the levels in 1997. The "transportation machinery" sector (0.11–0.58%) has displayed a recovery trend since 2010. The supply from the ROK's "metal products" sector to Japan was temporarily

[3] Other sectors refer to sectors other than the "metal products" sector.

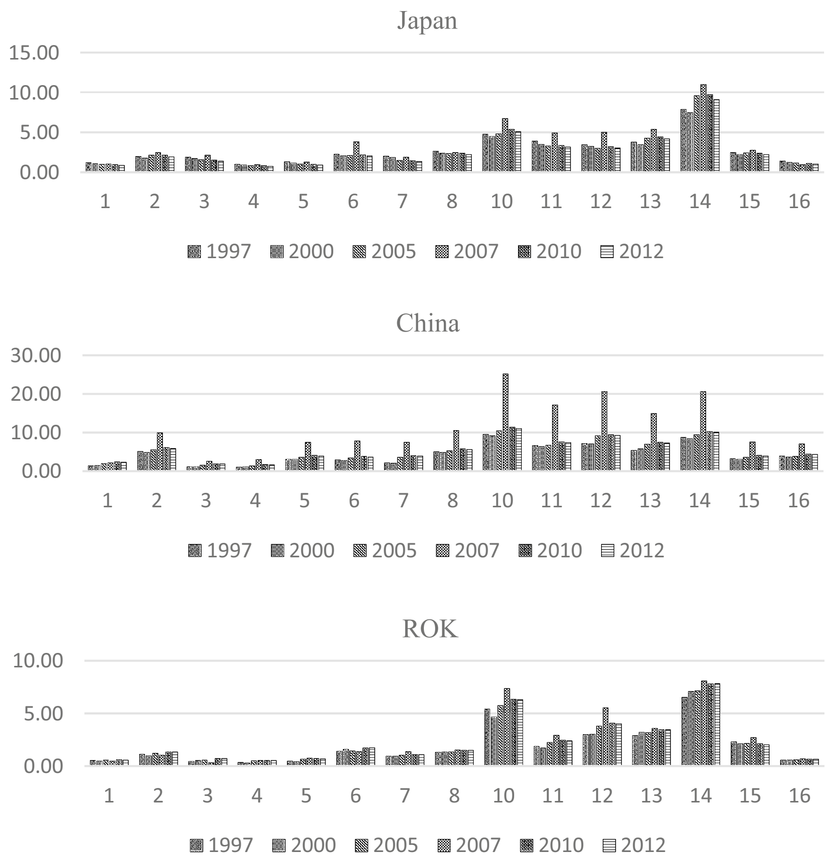

Fig. 2 Supply from the "metal products" sector to other sectors in the same country (unit: %) (*Source* ReCESSA, prepared by the author)

affected by the Lehman Shock, but since 2010, the supplies to the "machinery and equipment" (0.03–0.14%), "electronics and electrical equipment" (0.02–0.08%), "transportation machinery" (0.03–0.10%), and "construction" (0.05–0.18%) sectors have increased significantly.

The supply from Japan's "metal products" sector to meet the demands from the following sectors in China was large: "machinery and equipment" (0.29–0.18%), "electronics and electrical equipment" (0.21–0.14%), "transportation machinery" (0.23–0.17%), and "construction"

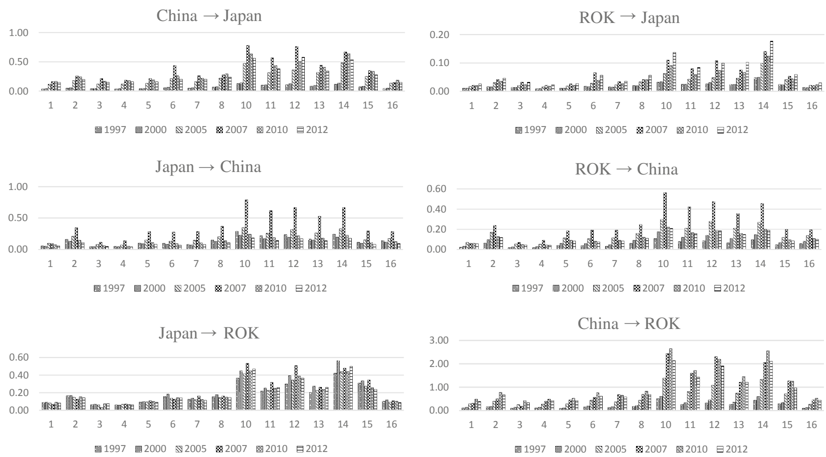

Fig. 3 Supply from the "metal products" sector in a country to other sectors in other countries (unit: %) (*Source* ReCESSA, prepared by the author)

(0.24–0.18%). However, all four sectors experienced decreases in their shares compared to those in 1997. The supplies from the ROK's "metal products" sector to China's "machinery and equipment" (0.11–0.21%), "electronics and electrical equipment" (0.08–0.16%), "transportation machinery" (0.09–0.18%), and "construction" (0.10–0.19%) sectors were large.

The supply from Japan's "metal products" sector to meet the demands from various sectors in the ROK, namely, the "machinery and equipment" (0.37–0.47%) and "electronics and electrical equipment" (0.22–0.26%) sectors, declined after peaking in 2007 but exhibited a recovery trend in 2012. In the "transportation machinery" sector (0.30–0.37%), the supply share peaked in 2007 and has since declined. In addition, the "construction" sector (0.42–0.50%) displayed an increase in its supply share, although this share did not reach the level observed in 2000. The supplies from China's "metal products" sector to the "machinery and equipment" (0.51–2.13%), "electronics and electrical equipment" (0.25–1.43%), "transportation machinery" (0.32–1.91%), and "construction" (0.43–2.10%) sectors have increased, with shares significantly exceeding those in 1997.

Figure 4 shows the demands from the "metal products" sectors in

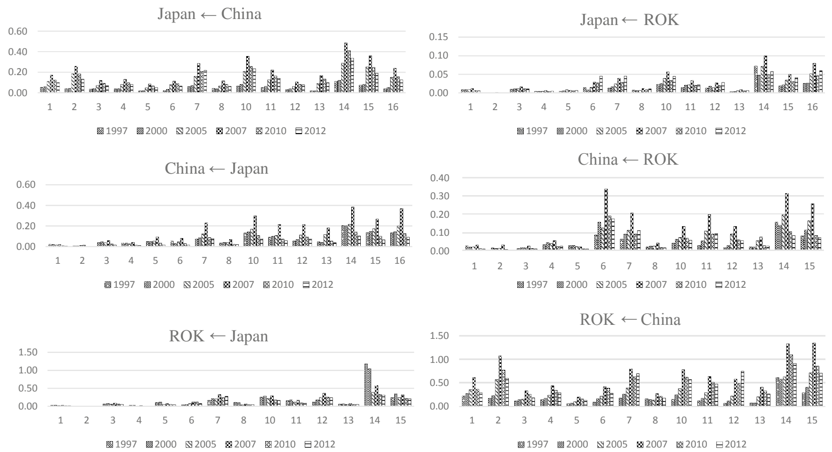

Fig. 4 Demand of the "metal products" sector in a country for other sectors in other countries (unit: %) (*Source* ReCESSA, prepared by the author)

Japan, China, and the ROK for intermediate goods from other sectors in other countries. Japan's "metal products" sector has large demands associated with the "mining" (0.04–0.13%), "chemical products" (0.06–0.22%), "machinery and equipment" (0.06–0.23%), and "construction" sectors (0.11–0.34%) in China, all of which have seen their share decreases since peaking in 2007. Demand from Japan's "metal products" sector to the ROK has continued to increase for the "coal and petroleum products" (0.01–0.04%) and "chemical products" (0.01–0.04%) sectors. In the "construction" sector (0.07–0.06%), the demand is lower than that in 1997.

Demand from China's "metal products" sector for Japan's "machinery and equipment" (0.13–0.07%), "electronics and electrical equipment" (0.09–0.06%), and "construction" sectors (0.20–0.10%) has continued to decline, with the corresponding shares decreasing below the levels in 1997. In contrast, the demands for the "chemical products" (0.07–0.08%) and the "transport machinery" (0.05–0.07%) sectors have increased from the levels in 1997. The demand from China's "metal products" sector for the ROK's "coal and petroleum products" (0.08–0.17%), "chemical products" (0.06–0.11%), and "electronics and electrical equipment" (0.03–0.09%) sectors is higher than that in 1997, and the corresponding shares have increased. Demand for the ROK's "machinery and equipment" (0.04–0.06%) sector peaked in 2007 and has been on a downward trend, while the demand for the "construction" sector (0.15–0.08%) has declined significantly, falling below the level in 1997.

There has been a continuous increase in the demand of the ROK's "metal products" sector for Japan's "chemical products" (0.16–0.28%) sector. In contrast, the demands for Japan's "machinery and equipment" (0.26–0.16%), "electronics and electrical equipment" (0.16–0.09%), and "construction" sectors (1.18–0.31%) have continuously declined. Demand for the "transportation machinery" sector (0.12–0.24%) peaked in 2007 and has been on a downward trend. The demand of the ROK's "metal products" sector for China's "mining" sector (0.17–0.60%) peaked in 2007 and has generally declined but remains significantly above the level in 1997. Demand for China's "machinery and equipment" (0.15–0.58%) and "electronics and electrical equipment" (0.12–0.48%) sectors peaked in 2007 and has been on a downward trend. The demands for China's "chemical products" (0.18–0.70%) and "transportation machinery" (0.07–0.75%) sectors have continued to increase.

The supply and demand structure of the "metal products" sectors in Japan, China, and the ROK can be summarized as follows: from 1997 to 2012, the subsectors with the highest demands for metal products in Japan, China, and the ROK were all concentrated in the "machinery and equipment," "electronics and electrical equipment," "transport machinery," and "construction" sectors. Affected by the 2008 Lehman Shock, the demand peaked in 2007 and has been declining ever since.

The supply structure of the "metal products" sector can be summarized as follows. China's steel sector accounts for the major share of the demand in Japan's "transportation machinery" sector. The ROK continues to increase its supply to meet Japan's demand in the "construction" sector. In 1997, Japan's supply share from the "metal products" sector was high to meet the demands of China's "machinery and equipment," "electronics and electrical equipment," "transportation machinery," and "construction" sectors, but this situation reversed in 2012, with the ROK's share surpassing that of Japan. Compared to that in 1997, the supply from China's "metal products" sector increased significantly in response to the demand from the ROK's "machinery and equipment," "transportation machinery," and "construction" sectors.

The increases in supply from the "metal products" sectors in China and the ROK to the "transportation machinery" and "construction" sectors reflect the increased production capacities of Chinese and the ROK's companies.

Based on the demand structure of the "metal products" sector, the "metal products" sectors in Japan and China both displayed an increase in demand for the "coal and petroleum products" sector in the ROK. In all three countries, the demand of the "metal products" sector for the "chemical products" sector increased, and the demand for the "construction" sector decreased.

5 Conclusions

This paper analyzed the international division of labor structure for intermediate goods in the East Asia region from the perspectives of the international division of labor, interdependence among East Asian countries, and dependence on other countries outside the region. The analysis revealed the following results. (1) China is increasing the number of global partners associated with the trade of intermediate goods, including the emerging market in India and steadily strengthening ties with East Asian countries. (2) In addition to China and Japan, the USA is increasing its imports from India and the ROK, but its ties with the rest of East Asia are weak. (3) Japan's share of intra-East Asian trade in intermediate goods is declining, and Japan's cooperation with India, an emerging country, is particularly lagging. (4) European countries are procuring intermediate goods within the EU. These results indicate that East Asian countries (regions) are experiencing an active division of production within the region. In addition, with the intensification of trade friction between the USA and China and the growing inclination toward protectionism, the conclusion of the RCEP agreement will strengthen cooperation among countries in the East Asia region.

This paper also analyzed the international division of labor structure and interdependence among Japan, China, and the ROK, as changes in economic promotion and cooperation among the three countries will have a significant impact on economic integration in the East Asia region under the RCEP, in which 15 countries are involved. Through the analysis, the following results were obtained. (1) The three countries are becoming increasingly interdependent in terms of the "chemical products" sector, indicating that competition among the three countries is occurring or may occur in the future. (2) The interdependence of the "electronics industry" among the three countries is decreasing, which can be attributed to the transfer of production to Southeast Asia, as well as the economic development of Southeast Asian countries, which is increasing their competitiveness. (3) While both Japan and the ROK have seen a decline in their dependence on China's "metal products" and "construction" sectors, Japan's dependence on the ROK's "metal products" sector has increased since the Lehman Shock.

The decline in dependence on the "metal products" sector was partly due to the decline in demand after the financial crisis, but this paper further analyzed the supply and demand structure of the "metal products" sectors in Japan, China, and the ROK. From the demand structure, we see that in all three countries, the demand of the "chemical products" sector for the "metal products" sector increased. In terms of the supply structure, the following results were found. (1) Japan's supply from the "metal products" sector to China's major industrial sectors ("machinery and equipment," "electronics and electrical equipment," "transportation machinery," and "construction" sectors) was high, but the situation reversed in 2012, with the ROK's share surpassing that of Japan. (2) The supply from China's "metal products" sector to the ROK's major industrial sectors ("machinery and equipment," "transportation machinery," and "construction" sectors) has increased significantly. The increases in Chinese and the ROK's supplies from the "metal products" sector reflect the increased production capacities of Chinese and the ROK's companies.

In this paper, the "steel" sector was integrated into the "metal products" sector for the sake of classification. Since the "steel" sector occupies 80–90% of the "metal products" sector, it can be said that trends in the "metal products" sector reflect trends in the "steel" sector. According to a report by Japan's Ministry of Economy, Trade, and Industry (METI), while profit margins in the "transportation machinery" and "construction" sectors, the main industries with large demands in Japan were higher in 2013 than they were before the Lehman Shock, the demand in the "steel" sector is less than one-third of its pre-Lehman Shock level. The background to this situation is as follows. As shown in the analysis, Chinese and the ROK's companies are increasing their production capacities, which is causing a deterioration in the global steel market. In addition, in a move to reorganize the global steel industry, the Chinese government launched the "Automobile and Steel Industry Adjustment Plan" in 2009 with the aim of upgrading the industrial structure (Koga

2011). For steel, this plan is aimed at improving quality and building international competitiveness. In the ROK, it is reported that R&D expenses are being increased to strengthen international competitiveness. Chinese and the ROK's manufacturers are accelerating their pursuit of technology, and in the near future, a competitive system will be formed among Japan, China, and the ROK for high-value-added, high-grade steel products. Moreover, the shift in global steel demand to emerging countries is expected to progress further as developed countries continue to experience sluggish growth in the medium to long term. The demand for steel is expected to increase due to the growing demands for infrastructure and logistical networks as supply chains are restructured in the Southeast Asia region. For steel products other than those involving high-grade steel, the production and supply in Southeast Asia are expected to increase significantly. In addition, the ongoing transfer of overseas production bases to Southeast Asia has led to concerns about the environmental impact if there is insufficient support for measures to reduce CO_2 emissions associated with the growth of the steel industry in emerging economies.

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PART II

The Mechanism of Growth

CHAPTER 5

Natural Disaster Shocks and Raw Material Prices in the Steel Industry

Kaori Tembata

1 Introduction

Global steel production and consumption have been expanding considerably since the 2000s because of increasing demand and economic development in emerging countries. Notably, the unprecedented growth of the Chinese steel industry has been prominent, making the country a leading player as both a supplier and a consumer in the steel and related industries. As a result of the rapid expansion of the steel industry in recent decades, the global markets for steelmaking raw materials have become increasingly competitive and complex. To maintain sustainable production, it is critical for steel manufacturers to secure raw materials such as iron ore and coal. However, recently, extreme weather events have emerged as an additional concern in the steel industry, exacerbating the imbalance between supply and demand for steelmaking raw materials.

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Given the increasing climate risks in the steel industry, this chapter examines the effect of natural disasters on the prices of steelmaking raw material. By focusing on iron ore, which is used in the production of crude steel, we investigate whether the prices of iron ore are affected by natural disasters in iron ore-producing countries. Iron ore is a key input for crude steel production and is traded globally. It is mined in approximately 50 countries, including Australia, Brazil, China, India, the United States, and Russia. The majority of iron ore is then exported to steel-producing countries, making iron ore the second most traded commodity worldwide (World Steel Association 2019a). Therefore, severe natural disasters in one country may have a widespread impact on the steel and raw material industries through global supply chains. Although anecdotal evidence shows that natural catastrophes have adversely affected the supply of raw materials by damaging mines and infrastructure, we are unaware of any studies that demonstrate the link between disaster shocks and the steel industry. In this context, it is necessary to focus on this important raw material to explore the climatic impact on steel production.

A number of studies have examined whether and to what extent extreme weather events affect the economy by analyzing data on weather conditions such as temperature and precipitation and natural disasters such as storms, floods, and droughts (see Dell et al. 2014; Heal and Park 2016). One strand of the literature has examined the impact of extreme weather and natural hazards on the economy at macro levels. Dell et al. (2009) use cross-sectional data on 134 countries to investigate the relationship between temperature and income. They show that an increase in temperature negatively affects GDP per capita. Their analysis using more detailed subnational data also finds a negative effect of temperature within countries. Noy (2009) analyzes the impact of natural disasters on the macroeconomy by focusing on a series of country characteristics. The author finds that natural disasters cause larger output losses in developing countries and smaller economies. In a study on temperature and aggregate outputs, Dell et al. (2012) demonstrate the causal effect of higher temperature on economic growth in poor countries. They estimate that a 1°C rise in temperature leads to a decline in economic growth by approximately 1.3 percentage points.

Researchers have further focused on the multidimensional impact of extreme weather and natural disasters. A growing body of literature explores the complex mechanisms of climate impacts by analyzing channels through which climate affects the macroeconomy. Evidence of climate shocks is observed in diverse spheres, for instance, in agriculture, productivity, energy production, health and mortality, migration, and violent conflicts (Anttila-Hughes and Hsiang 2013; Chen et al. 2016a; Leiter et al. 2009; Marchiori et al. 2012; Maystadt and Ecker 2014; McDermott and Nilsen 2014). While the link between negative climate impacts and agricultural outcomes may be obvious and straightforward given the importance of weather conditions to agriculture, the findings of the existing literature suggest broad and heterogeneous effects of climate associated with various aspects of the economy. The study by Dell et al. (2012) mentioned above also investigates temperature shocks in both agricultural and industrial sectors, providing evidence of channels through which temperature conditions affect the aggregate economy. Hsiang (2010) estimates the impact of temperature and tropical cyclones in the Caribbean and Central America and reveals that climate shocks resulted in greater economic losses in nonagricultural production than in agricultural production. Using micro-level data, Leiter et al. (2009) find a negative impact of floods on productivity in European firms. Previous studies on climate and the economy suggest that the impact of natural disasters is rather diverse, observed not only in the agricultural sector but also in nonagricultural sectors.

In regard to the steel and iron ore industries, the negative impact of natural disasters may spread beyond the country of origin because a large volume of iron ore is traded in the international market. One strand of literature examines the climate-economy relationship with a particular focus on international trade. Jones and Olken (2010) examine the effects of temperature shocks on international trade. They estimate that a 1°C rise in temperature is associated with a 2.0–5.7 percentage point decline in annual export growth in poor countries. Dallmann (2019) uses a series of bilateral trade data to investigate the effects of weather variations in exporting and importing countries. Analyses using the breakdown of export data show both positive and negative impacts of temperature and precipitation on exports at the sector and product levels.

In the context of the iron ore industry, researchers have analyzed factors that drive up iron ore prices and affect the global market in the wake of a shift in the pricing regime and China's rise over the last two decades. In a qualitative analysis, Wilson (2012) reviews the iron ore market in the Asia–Pacific region and argues that the rapid growth of the Chinese steel industry led to the restructuring of the iron ore market. China's domestic iron ore reserves are low grade and not suitable for steel production. Thus, procurement of iron ore depended on imports in response to the rapid development of steel production, which increased market prices. Sukagawa (2010) also emphasizes the Chinese economic boom and the increased demand for iron ore as main factors that drove an unprecedented price increase in the early 2000s. A quantitative study by Chen et al. (2016b) uses a quantile regression model to examine the factors that affect China's import prices of iron ore. They find that production of crude steel in the previous period has a positive effect on current prices of imported iron ore, while the volume of iron ore imports in the previous period and domestic iron ore production have a negative effect. Wårell (2014) explores the impact of the pricing regime change in the iron ore market in China. Although they do not find clear evidence of the impact of the pricing regime, the results of their empirical analysis suggest that transportation costs and GDP growth are the driving forces that increase the import prices of iron ore.

This study contributes to the literature on the steel and related raw material markets. Research on the iron ore market has investigated aspects such as import volume (Tcha and Wright 1999), price volatility (Astier 2015; Chen et al. 2016b), market structure (Wårell 2014), and international market power (Zhu et al. 2019). While the rise of the Chinese steel industry is the main focus of many previous studies, this study analyzes the steel industry from a different perspective by examining the impact of natural hazards. To the best of our knowledge, this study is the first to empirically demonstrate the impact of natural disaster shocks in the iron ore market. The adverse economic consequences of severe natural disasters may become more pronounced; moreover, they are likely to accelerate further under climate change. This study aims to provide suggestive evidence of the risks associated with natural catastrophic events in the steel industry.

The remainder of this chapter proceeds as follows. Section 2 presents an overview of the global iron ore industry. We also discuss trends in iron ore prices and extreme weather events that may cause price fluctuations. Section 3 describes the estimation model and data used in the empirical analysis. Section 4 presents and discusses the results. Section 5 concludes.

2 Global Iron Ore Industry and Price Volatility

Iron ore, along with coking coal and recycled steel, is an important raw material used in steelmaking. Today, it is estimated that approximately 2 billion tonnes of iron ore are consumed annually to produce

1.7 billion tonnes of crude steel worldwide (World Steel Association 2019a). Figure 1 depicts trends in global iron ore production from 1998 to 2017. The industry has been steadily growing over the last two decades, with production doubling to 2.2 billion tonnes in 2017 from 906 million tonnes in 1998. The leading iron ore-producing countries include Australia, Brazil, China, India, the United States, and Russia, among which Australia and Brazil are the dominant exporters for steel producers worldwide. These two countries alone account for approximately 78% of total iron ore exports today (World Steel Association 2020).

In terms of imports, countries such as Japan, the Republic of Korea, Germany, the Netherlands, and China are the major iron ore importers, accounting for 86% of global total in 2017 (U.S. Geological Survey 2017). Notably, China has emerged as the largest importing country since the 2000s. The country depends on imports for procurement of iron ore while itself being one of the largest producers. The production of iron ore in China is estimated to be 360 million tonnes, following only Australia (883 million tonnes) and Brazil (425 million tonnes) in 2017 (U.S. Geological Survey 2017). Figure 2 shows China's imports of iron

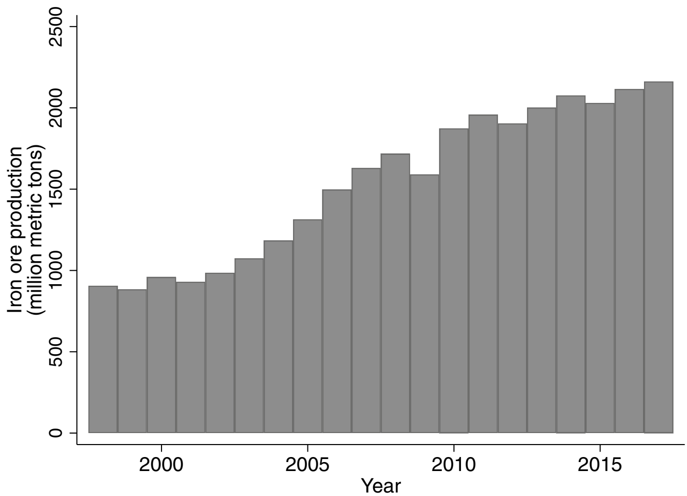


Fig. 1 Trends in global production of iron ore (*Source* World Steel Association [2008, 2018])

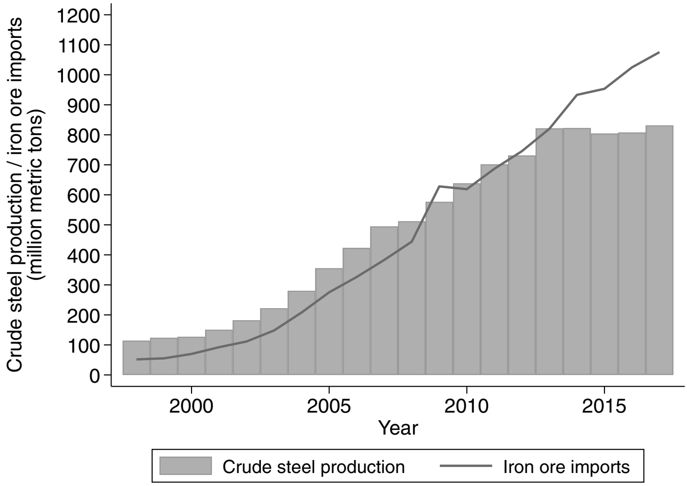


Fig. 2 Trends in China's iron ore imports and crude steel production (*Source* World Steel Association [2008, 2018])

ore by weight, together with the amount of crude steel production. As shown in Fig. 2, imports of iron ore have grown dramatically, in line with increasing trends in the country's steel production during the same period. Iron ore imports into China increased from 70 million tonnes in 2000 to 1,075 million tonnes in 2017. China's share of global iron ore imports also grew from 14 to 68% during this period (World Steel Association 2002, 2019b). Today, China is the largest consumer of the major iron ore exporters; for instance, the country accounted for 84% of Australia's iron ore exports in 2017.

As described above, major steel-producing countries depend on imports of raw materials from foreign countries. Tanaka (2012) categorizes the mass-procurement systems for iron ore in the steel industry into three types: captive mines, long-term contracts, and spot trading. The captive mine approach dates back to the beginning of the twentieth century. It was first established and has been mainly practiced in the United States, where steel firms own captive mines domestically and internationally (mostly in Canada and South America). Long-term contracts between steel firms and iron ore suppliers have been adopted by Japanese steel firms since the 1950s. Other countries also began following this system, including the Republic of Korea and European nations, and now, procurement of iron ore by long-term contracts is most commonly used by large steel firms. Notably, from the 1980s, prices were set by the so-called benchmark system, where dominant steel firms and iron ore suppliers negotiated annual prices in the Asian and European markets. The yearly benchmark system was dissolved in 2010; instead, prices began to be negotiated quarterly based on spot market prices. The third system using spot markets was introduced as the pricing regime shifted during this period. Although the traditional practice based on long-term contracts is still predominant in the steel industry, the use of spot trading has been rapidly expanding in response to the increasing demand for steel products in China and other emerging countries.

Figure 3 shows trends in the monthly spot price of iron ore imported into China. The spot price of iron ore has been volatile throughout the period. Monthly prices rose steadily in the first half of 2008, with the highest price being USD 197.12 per dry metric ton unit (dmtu) in March. The market then witnessed a steep decline in the second half of 2008, and the iron ore price has continued to fluctuate in recent decades. After 2008, spot prices again increased to USD 187.18 per dmtu in February

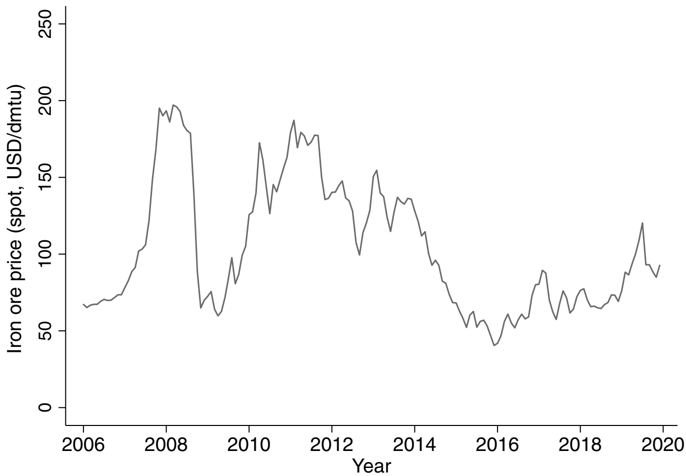


Fig. 3 Trends in iron ore prices (*Note* The values are in nominal US dollars. *Source* World Bank [2020])

2011, then the lowest price of USD 40.50 per dmtu was marked in December 2015. More recently, the average monthly spot price was USD 93.85 per dmtu in 2019. Within that year, the monthly spot price rose from USD 76.16 per dmtu in January to USD 120.24 per dmtu in July.

In addition to the unprecedented growth in China's steel production, natural disaster risks have posed a great concern that may trigger price volatility in steelmaking raw materials. For instance, Australia, one of the largest suppliers of steelmaking raw materials, has experienced extreme weather events in recent years. In November 2010, Australia received record-breaking precipitation in Queensland, the northeastern part of the country. The substantial rainfall and extensive floods in the following months caused widespread damage to the local economy, including coal production in this region (Nihon Keizai Shimbun 2011a). In the affected area, coal mines were inundated, and infrastructure was disrupted (Nihon Keizai Shimbun 2011b). As a result, coal production and shipping were forced into temporary reductions, leading to an increase in the global coal price. Along with the coal price, the price of iron ore reportedly rose during the 2010–2011 flood. Furthermore, iron ore suppliers and steel-producing firms face other climate risks because Australia is also prone to seasonal cyclones. In March 2019, the supply of iron ore was affected by a cyclone that struck in the western part of Australia. The temporary shutdown of a damaged port reportedly contributed to an increase in the iron ore price in spring 2019 (Nihon Keizai Shimbun 2019). More recently, a cyclone hit again in February 2020 and affected shipping of iron ore by destroying ports and railroads in western Australia (Nihon Keizai Shimbun 2020). Because iron ore is an internationally traded commodity, the steelmaking industry can be affected by natural disasters throughout the production process, including the shipping and trading of production inputs.

3 Empirical Analysis

3.1 Estimation Framework

Our empirical analysis aims to investigate the impact of natural disasters on steel production. To examine whether natural disasters affect the production of steel, this study analyzes data on iron ore, which is a key component of raw materials used in the steelmaking process. We use spot prices in China to represent global iron ore prices, with a monthly time series dataset from 2006 to 2019. As we estimate the causal effects of natural disasters on iron ore prices with time series data, this study applies the distributed lag model and incorporates lags for the disaster variables. We begin with the following specification to run the regression model:

$$lnPrice_t = \beta_0 + \sum_{j=0}^{L} \beta_{1,j} Disaster_{t-j} + \beta_2 lnSteel_t + \beta_3 lnTransport_t + \beta_4 lnRate_t + \delta_t + \varepsilon_t, \quad (1)$$

where *Price* is the monthly price of iron ore imported to China, *Disaster* is the number of natural disasters that occurred in iron ore-exporting countries, *Steel* is the crude steel production in China, *Transport* is the shipping cost, and *Rate* is the exchange rate between the US dollar (USD) and Chinese yuan (CNY). In addition, δ denotes a set of time dummies to capture any external events and other seasonal components that may lead to omitted variable bias. Finally, ε is an error term.

The disaster variable in Eq. 1 includes lags indexed by j. With the distributed lag model, this study attempts to capture dynamic causal effects by using contemporaneous values of natural disasters and lagged values over previous months. When a disaster—for instance, a flood—hits, it is possible that its effects persist for more than one month. Natural disasters could directly cause damage to iron ore mines; moreover, iron ore production and exports may be affected by supply chain disruptions, severe damage to infrastructure, temporary loss of labor productivity, etc. The use of lags enables us to explore such underlying assumptions. For example, the estimated coefficient of the one-month lagged disaster variable indicates whether natural disasters in the previous month affect iron ore prices in the current month. Similarly, the coefficient of the six-month lagged variable estimates the impact of a natural disaster occurring six months ago, the coefficient of the 12-month lagged variable estimates the impact of a natural disaster occurring a year ago, and so forth. This study investigates both the immediate and dynamic effects of natural disasters on the prices of iron ore.

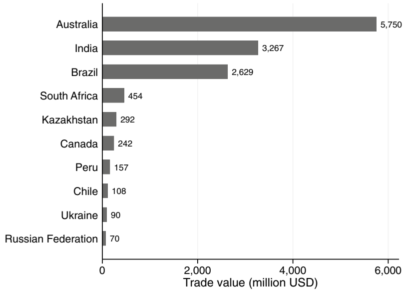
An advantage of using natural disasters in econometric models is that the occurrence of natural disasters itself can most likely be considered exogenous. In this study, we use OLS for the distributed lag regression by assuming that our disaster variable is exogenous. That is, the error term ε in Eq. 1 has a conditional mean of zero, given the present and past values of the disaster variable (Stock and Watson 2015). In other words, ε is uncorrelated with the disaster variables in the present and past periods. Note that it is not assumed that the disaster variables are *strictly* exogenous, where the error term is uncorrelated with the values of the regressor in all time periods, including past, present, and future. Strict exogeneity cannot hold when iron ore and steel producers can predict future disaster events by forecasting, for example, upcoming hurricanes and the possible flooding that follows. In that case, the error term that includes forecasts of natural disasters is correlated with future disaster occurrences, so strict exogeneity no longer holds.

3.2 Data Description

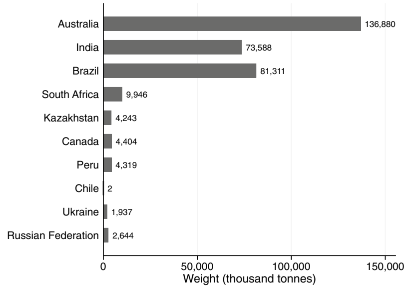
We construct a time series dataset using several different sources. Data on iron ore spot prices are taken from the World Bank. These are the cost and freight for iron ore imported to China (CFR China). To make the prices comparable, the dollar values for iron ore are adjusted to constant 2015 USD using the US GDP deflator. Although the data source provides long-term data on various commodities, monthly data on iron ore are available only after 2006. Overall, our dataset consists of 168 observations for a sample period from 2006 to 2019.

Data on natural disasters are obtained from the Emergency Events Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters at the University of Louvain (CRED and Guha-Sapir 2020). The EM-DAT is the most comprehensive disaster database, including more than 22,000 natural and technological disaster events worldwide. This database uses the following criteria for recording disasters: 10 or more people were reportedly killed; 100 or more people were reportedly affected; a state of emergency was declared; or international assistance was appealed for. Disaster events must satisfy at least one of these criteria to be included in the database. We construct a monthly dataset from the event-based disaster data from the EM-DAT.

As our dependent variable, the iron ore price represents the CFR to China. This study uses disaster events in the top 10 countries that export iron ore to China. These countries are chosen according to data on trade values in 2006. Data are obtained from UN Comtrade using Harmonized System (HS) classification codes. To identify iron ore exports, we use the four-digit code HS2601, labeled *iron ores and concentrates, including roasted iron pyrites*. Figure 4 presents the trade values and weights of



a. Exports in value



b. Exports in weight

Fig. 4 Top 10 iron ore-exporting countries (exports to China, 2006) (*Source* United Nations [2020])

iron ore for the 10 exporters included in the empirical analysis. Australia, India, and Brazil were the leading iron ore trading partners for China at the beginning of the sample period. This trend continues to this day, with a significant increase in value and weight. For instance, Australia's iron ore exports to China exceeded USD 54,000 million or 690 million tonnes, in 2019. With these countries selected, natural disasters in our analysis include extreme temperatures, storms, floods, landslides, droughts, wildfires, earthquakes, and volcanic activity. The variable *Disaster* represents the total number of natural disasters, including all the abovementioned types, that occurred in a given month.

The following control variables are also included in the analysis. While focusing on natural disasters as the variables of interest in this study, we use these control variables to consider possible factors that may affect iron ore prices. These variables are all log-transformed in the regression models. For steel production, we use monthly crude steel production in China provided by the World Steel Association.[1] Data on the crude oil price are obtained from the World Bank. We use the average spot prices from Brent, Dubai, and West Texas Intermediate. The oil price is included to account for the transport costs of iron ore exports. Considering the effect of freight costs for shipping commodities, it is expected that changing oil (fuel) prices have impacts on the prices of iron ore. The values for this variable are converted into constant 2015 USD. Data on

[1] Available at https://www.worldsteel.org/.

Table 1 Descriptive statistics of variables

Variable	*Mean*	*S.D*	*Min*	*Max*
Price of iron ore (USD/dmtu)	109.20	47.71	40.50	221.04
Natural disaster	5.74	2.58	1	16
Flood	2.53	1.92	0	9
Storm	0.74	0.93	0	4
Drought	0.98	1.07	0	3
Extreme temperature	0.65	0.85	0	4
Steel production (thousand tonnes)	59,432.12	14,240.95	30,076.00	89,090.60
Oil price (USD/bbl)	79.25	26.21	29.46	147.62
Exchange rate (USD/CNY)	6.74	0.52	6.10	8.07

the exchange rate are taken from the IMF and represent the USD/CNY rate. We use this variable to account for Chinese economic conditions, which may impact iron ore exports.

Table 1 shows the descriptive statistics of the variables used in this study. The price of iron ore is shown in USD per dmtu. For the natural disaster variable, the number of events varies from one to 16 per month during the sample period in the 10 countries used in this study. On average, natural disasters occurred approximately 5.7 times per month. Table 1 also presents the variables for individual disaster types. In addition to natural disasters as a whole, this study further explores the specific effect of climate-related disasters in a later section. Our sample shows that floods are the most frequent natural disasters, in line with the global trends in the past two decades (Wallemacq and House 2018).

4 Results

4.1 Main Results

In the empirical analysis, we use Eq. 1 to estimate the contemporaneous and dynamic effects of natural disasters on iron ore prices. Our primary results are presented in Table 2. The estimation models with lag structures include up to a 6-month lag of the disaster variables. These lag variables estimate whether the impact of natural disasters persists during the post-disaster period. All specifications are estimated using heteroskedasticity- and autocorrelation-consistent (HAC) standard errors (Newey and West 1987). Following Stock and Watson (2015), we set the value of five as a

Table 2 Dynamic causal effect of natural disasters on the price of iron ore

	Dependent variable: ln(Price of iron ore)							
	No lag (1)	*1 lag (2)*	*3 lags (3)*	*6 lags (4)*	*No lag (5)*	*1 lag (6)*	*3 lags (7)*	*6 lags (8)*
Disaster	0.002	−0.001	0.001	0.009	−0.000	−0.003	−0.002	0.002
	(0.007)	(0.006)	(0.006)	(0.007)	(0.005)	(0.005)	(0.004)	(0.005)
L.Disaster		0.013^{*}	0.011^{*}	0.012^{**}		0.007^{*}	0.007^{*}	0.008^{**}
		(0.007)	(0.006)	(0.006)		(0.004)	(0.004)	(0.004)
L2.Disaster			0.007	0.012^{*}			0.003	0.005
			(0.006)	(0.006)			(0.004)	(0.004)
L3.Disaster			0.016^{*}	0.011^{*}			0.010^{*}	0.008^{*}
			(0.008)	(0.006)			(0.005)	(0.004)
L4.Disaster				0.016^{**}				0.009^{*}
				(0.008)				(0.004)
L5.Disaster				0.013^{**}				0.007^{*}
				(0.006)				(0.004)
L6.Disaster				0.009				0.007
				(0.009)				(0.005)
ln(Steel production)					1.256^{***}	1.210^{***}	1.122^{***}	1.085^{***}
					(0.273)	(0.270)	(0.286)	(0.278)
ln(Oil price)					0.802^{***}	0.804^{***}	0.804^{***}	0.773^{***}
					(0.091)	(0.092)	(0.093)	(0.085)
ln(Exchange rate)					0.280	0.326	0.303	−0.333
					(0.692)	(0.690)	(0.703)	(0.723)
Constant	4.379^{***}	4.341^{***}	4.226^{***}	3.888^{***}	-12.669^{***}	-12.316^{***}	-11.412^{***}	-9.784^{***}
	(0.079)	(0.089)	(0.115)	(0.212)	(2.695)	(2.696)	(2.874)	(2.749)
Observation	168	168	168	168	168	168	168	168
HAC truncation parameter	5	5	5	5	5	5	5	5

(continued)

Table 2 (continued)

	Dependent variable: ln(Price of iron ore)							
	No lag (1)	*1 lag* (2)	*3 lags* (3)	*6 lags* (4)	*No lag* (5)	*1 lag* (6)	*3 lags* (7)	*6 lags* (8)
F-test for joint significance								
Year fixed effects	99.07***	101.24***	86.35***	80.23***	31.99***	33.07***	31.10***	29.09***
Month fixed effects	0.3	0.28	0.47	0.95	3.27***	2.99***	3.07***	3.70***

Notes All specifications include year and month fixed effects. Newey-West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors are in parentheses

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

rule of thumb for the truncation parameter based on the time period of our sample.

In column 1, we first estimate a static model without lags. The coefficient of the disaster variable is positive but insignificant, suggesting no immediate effect of natural disasters on iron ore prices. In columns 2–4, the results for the dynamic causal impact of natural disasters are presented. The estimation models are structured with one, three, or six lags. While the immediate impact remains insignificant, the lagged variables indicate that natural disasters affect iron ore prices in the post-disaster period. The coefficients of the disaster variables with a one-month lag (*L.Disaster*) in columns 2–4 are positive and statistically significant, suggesting that an additional disaster event in the previous month increases the price of iron ore in the present month by 1.1–1.3%. This dynamic effect is also observed when lagged variables are added in the models. In column 4, the lagged disaster variables are positively correlated with iron ore prices. The coefficients of the lagged variables indicate that a past disaster event is estimated to raise current iron ore prices by 1.1–1.6%. The findings show that the impact of natural disasters could persist for five months.

In columns 5–8, the models are estimated with additional control variables. The results are mostly consistent with regard to the disaster variables. Although the magnitude of the coefficients becomes slightly smaller than those in columns 1–4, the results suggest the robustness of the impact of natural disasters on iron ore prices. Steel production is positively related to iron ore prices. The coefficients of steel production are statistically significant, indicating that a 1% increase in China's steel production is associated with a 1.1–1.3% increase in iron ore spot prices. We also find that the oil price is statistically correlated with iron ore prices. The findings imply that transport costs for export affect commodity prices, thus increasing input prices for steel production. On the other hand, we do not find a correlation between the exchange rate and iron ore prices. The results show that the coefficients are insignificant across alternative models. In the bottom rows of Table 2, the F statistics for the joint significance of time fixed effects are presented. The results are similar across alternative models in columns 1–4 and 5–8. The year dummies are jointly significant in all specifications, while the month dummies are jointly significant in the models with control variables.

4.2 Cumulative Effect of Natural Disasters

This section examines the cumulative effect of natural disasters on iron ore prices. The primary analysis in Sect. 4.1 suggests that more frequent natural disasters cause an increase in iron ore prices. By incorporating lags, we find a correlation between iron ore prices and natural disasters occurring a month prior, two months prior, and so forth. To understand the dynamic causal effects in more detail, this section analyzes whether and to what extent natural disaster events cumulatively affect the iron ore price in the present month. To estimate the cumulative dynamic effect, the distributed lag model in Eq. 1 is modified as follows:

$$
\begin{aligned}
lnPrice_t = \theta_0 + \sum_{j=0}^{L} \theta_{1,j} \Delta Disaster_{t-j} + \theta_{1,L+1} Disaster_{t-(L+1)} \\
+ \theta_2 lnSteel_t + \theta_3 lnTransport_t + \theta_4 lnRate_t \\
+ \delta_t + \varepsilon_t, \qquad (2)
\end{aligned}
$$

where the coefficient $\theta_{1,j}$ for the disaster variables is now the j-month cumulative dynamic multiplier (Stock and Watson 2015). The cumulative dynamic multipliers show the cumulative effect of natural disasters on iron ore prices over j months. For example, the one-month cumulative dynamic multiplier is denoted as $\theta_{1,1}$ and is equivalent to the sum of the zero-month dynamic effect $\beta_{1,0}$ and the one-month dynamic effect $\beta_{1,1}$ in Eq. 1. The coefficient $\theta_{1,L+1}$ therefore denotes the total sum of the dynamic multipliers, namely, $\beta_{1,0} + \beta_{1,1} + \beta_{1,2} + \ldots + \beta_{1,L}$.

The results for the cumulative dynamic effects are presented in Table 3. Similar to the main results, we find that the occurrence of natural disasters is associated with the price volatility of iron ore. The estimation model in column 1 includes disaster lags for six months and corresponds to the model in column 4 in Table 2. Here, the coefficient of the one-month lagged variable *L.Disaster* shows the cumulative effects of natural disasters over the past two months (the previous and present months), the coefficient of the two-month lagged variables *L2.Disaster* shows the cumulative effects over the past three months, and so forth. The coefficient of the six-month lagged disaster variable—i.e., the six-month cumulative dynamic multiplier—is positive and statistically significant at the 1% level. The findings suggest that the sum of the effect of natural disasters that occurred over six months induces an 8.2% increase in iron ore prices.

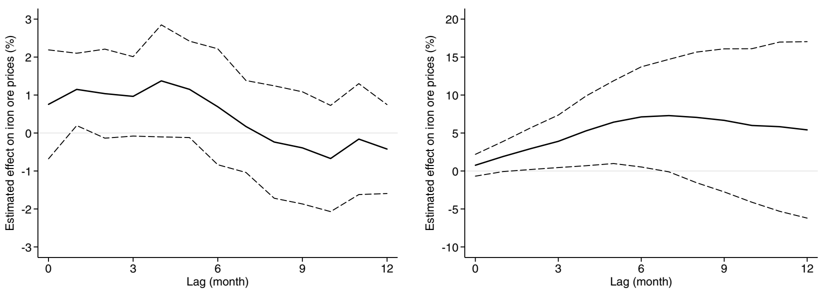
Table 3 Cumulative effect of natural disasters on the price of iron ore

	Dependent variable: ln(Price of iron ore)					
	6 lags (1)	*6 lags (2)*	*12 lags (3)*	*6 lags (4)*	*6 lags (5)*	*12 lags (6)*
Disaster	0.009	0.009	0.008	0.002	0.002	0.001
	(0.007)	(0.006)	(0.009)	(0.005)	(0.004)	(0.005)
L.Disaster	0.021**	0.021**	0.019	0.010	0.010	0.009
	(0.010)	(0.010)	(0.012)	(0.007)	(0.007)	(0.008)
L2.Disaster	0.033**	0.033**	0.029*	0.016*	0.016*	0.013
	(0.014)	(0.014)	(0.017)	(0.009)	(0.009)	(0.010)
L3.Disaster	0.044**	0.044**	0.039*	0.024**	0.024**	0.020*
	(0.017)	(0.019)	(0.021)	(0.011)	(0.012)	(0.011)
L4.Disaster	0.060***	0.060**	0.053*	0.032**	0.032**	0.028**
	(0.022)	(0.024)	(0.028)	(0.013)	(0.014)	(0.013)
L5.Disaster	0.073***	0.073***	0.064*	0.040***	0.040**	0.034**
	(0.026)	(0.028)	(0.033)	(0.015)	(0.016)	(0.015)
L6.Disaster	0.082***	0.082***	0.071*	0.046***	0.046**	0.039**
	(0.030)	(0.031)	(0.040)	(0.017)	(0.018)	(0.018)
ln(Steel production)				1.085***	1.085***	1.113***
				(0.278)	(0.303)	(0.288)
ln(Oil price)				0.773***	0.773***	0.768***
				(0.085)	(0.086)	(0.085)
ln(Exchange rate)				−0.333	−0.333	−0.414
				(0.723)	(0.765)	(0.775)
Constant	3.888***	3.888***	4.063***	−9.784***	−9.784***	−9.748***
	(0.212)	(0.220)	(0.480)	(2.749)	(2.911)	(2.975)
Observation	168	168	168	168	168	168
HAC truncation parameter	5	10	5	5	10	5
F-test for joint significance						
Year fixed effects	80.23***	167.85***	59.76***	29.09***	75.58***	30.12***
Month fixed effects	0.95	0.94	0.98	3.70***	3.56***	3.67***

Notes All specifications include year and month fixed effects. Newey-West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors are in parentheses
**p* < 0.1, ***p* < 0.05, ****p* < 0.01

The following models in Table 3 explore alternative specifications and check the robustness of the estimation results. First, we reestimate the model by changing the value for the HAC truncation parameter to 10. The results are reported in column 2. The coefficients are quite similar to those in column 1, confirming that an alternative HAC truncation parameter does not alter the results. Second, we expand the model by adding the lags of disaster variables to examine whether the disaster impact persists for a longer period. In column 3, the results are similar and exhibit the cumulative dynamic effects of natural disasters on iron ore prices. For example, the coefficient of the three-month lagged variable is positive and statistically significant, indicating that the total effects of natural disasters over three months raise iron ore prices by 3.9%. Similarly, the cumulative effects of natural disasters cause an increase in iron ore prices by 7.1% in six months. We do not find the coefficients of lagged variables to be statistically significant after six months.

Figure 5 illustrates these estimated dynamic effects in more detail. Using the estimated result in column 3 in Table 3, Fig. 5a decomposes the cumulative effects and depicts the individual dynamic effect of natural disasters in each month, while Fig. 5b shows the cumulative dynamic effects for 12 months. In Fig. 5a, the dynamic effects appear to be positive for the first seven month lags and then become negative afterward. Given these positive and negative values, the cumulative dynamic effects increase over seven months, as shown in Fig. 5b. Although it remains positive, the



a. Estimated dynamic effect

b. Estimated cumulative dynamic effect

Fig. 5 Dynamic effect of natural disasters on the iron ore price (*Note* The solid lines represent the estimated effects, and the dashed lines represent the 90% confidence interval. The estimated model includes 12 lags of the disaster variable) estimated cumulative effects gradually decrease after reaching the peak, as the individual dynamic effects become negative during the eighth month.

In addition, we test the robustness of these results by estimating the models with control variables. The models in columns 4–6 show the corresponding results. Again, we find that past disaster events are statistically correlated with price volatility. The positive signs of the coefficients show that the occurrence of natural disasters over the past months cumulatively affects iron ore exports, thereby increasing prices. The findings suggest that the cumulative effects persist for six months after the onset of natural disasters.

Overall, the results in Sects. 4.1 and 4.2 show the dynamic causal effect of natural disasters on the prices of iron ore. By incorporating lagged variables, we find that a price increase is induced several months after natural disasters. The analysis also reveals the total impact of natural disasters in the post-disaster period by estimating the cumulative dynamic multipliers. These results imply that steel producers may suffer from the costs of natural disasters as a negative consequence of higher iron ore prices. This is indeed the case when steel firms cannot increase the prices of their final products to cushion price increases in raw materials (Astier 2015). The findings suggest that natural disasters lead to price fluctuations, causing a negative impact in the steel and iron ore industries.

4.3 Effect of Natural Disasters by Type

We further analyze the impact of natural disasters on iron ore prices by investigating the individual disaster types. Iron ore production and exports may be more sensitive to some natural hazards than others. Moreover, climate shocks such as frequent floods and intense tropical storms have been a great concern for steel producers in recent years. Therefore, this additional analysis explores possible heterogeneity in the effects of extreme weather events, with a focus on climate-related disasters. We run regressions using Eq. 2, which estimates the cumulative dynamic effects. The disaster variables now indicate the number of occurrences for a particular disaster type, that is, floods, storms, droughts, or extreme temperatures.

The estimation results are provided in Table 4. All specifications include six lags of the disaster variable and control variables. In column 1, the results show that floods have an impact on iron ore prices. The coefficients of all lagged variables except the first appear positive and

Table 4 Cumulative effect by disaster type

	Dependent variable: ln(Price of iron ore)			
	Flood (1)	*Storm* (2)	*Drought* (3)	*Extreme temperature* (4)
Disaster	−0.003	−0.022*	0.073**	0.016
	(0.005)	(0.011)	(0.031)	(0.014)
L.Disaster	0.009	−0.035*	0.073**	0.032
	(0.007)	(0.021)	(0.029)	(0.023)
L2.Disaster	0.018*	−0.055**	0.051*	0.032
	(0.009)	(0.027)	(0.030)	(0.029)
L3.Disaster	0.029**	−0.074**	0.036	0.047
	(0.013)	(0.033)	(0.034)	(0.035)
L4.Disaster	0.039**	−0.098**	0.061	0.067*
	(0.017)	(0.040)	(0.037)	(0.038)
L5.Disaster	0.045**	−0.110**	0.078**	0.075*
	(0.019)	(0.045)	(0.036)	(0.045)
L6.Disaster	0.045**	−0.109**	0.058*	0.097*
	(0.021)	(0.053)	(0.033)	(0.054)
ln(Steel production)	0.867***	1.240***	1.230***	1.214***
	(0.272)	(0.270)	(0.249)	(0.281)
ln(Oil price)	0.813***	0.824***	0.824***	0.784***
	(0.080)	(0.089)	(0.093)	(0.093)
ln(Exchange rate)	0.517	0.725	0.620	0.343
	(0.622)	(0.614)	(0.678)	(0.717)
Constant	−9.337***	−13.458***	−13.212***	−12.346***
	(2.729)	(2.800)	(2.606)	(2.686)
Observation	168	168	168	168
HAC truncation parameter	5	5	5	5
F-test for joint significance				
Year fixed effects	25.15***	33.16***	32.58***	30.31***
Month fixed effects	2.67***	2.53**	4.43***	3.65***

Note All specifications include year and month fixed effects. Newey-West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors are in parentheses. The disaster variables include 0–6 lags

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$

statistically significant. As shown in the six-month lagged variable, the cumulative dynamic effects of floods drive up the current price of iron ore by 4.5%. In contrast, the results in column 2 show a negative correlation between storms and iron ore prices. We find dynamic and immediate impacts of storms that lower iron ore prices. The negative sign of the coefficients is not what we expected; nevertheless, the findings show that the market prices of traded commodities may be affected by natural disasters in exporting countries. In column 3, droughts appear to have a positive impact on iron ore prices. The results suggest that droughts tend to increase the prices of iron ore in the early months. In total, the coefficients of the six-month lagged variable indicate that an additional drought event is associated with a 5.8% increase in iron ore prices. Column 4 reports the results for extreme temperatures. We find that extreme temperatures do not immediately affect iron ore prices. The coefficients of the cumulative dynamic multipliers are positive and significant after the four-month lag. The findings suggest that in the long run, extreme temperatures induce a 9.7% increase in iron ore price over six months. The estimation results from individual natural disaster events show evidence of climate-induced price volatility that may affect the iron ore market.

5 Conclusions

This chapter examined the effect of natural disasters on the prices of iron ore, an important raw material used in steel production. The empirical investigation used spot prices of iron ore imported in China to examine whether price volatility is induced by natural disasters occurring in iron ore-exporting countries. Considering the persistent impact of natural disasters that may last after the onset, we estimated the dynamic effect of disasters by incorporating lagged variables in the analysis.

The main results showed that iron ore prices are significantly affected by the occurrence of natural disasters in exporting countries. The estimation results from the models with lag structure demonstrate that significant impacts persist in the post-disaster period, causing an increase in iron ore prices. We found that iron ore prices are estimated to increase by 1.1–1.6% by a disaster event in the previous months. These findings suggest that more frequent disasters may disturb the iron ore market by accelerating price fluctuations. The results were robust when the models included control variables. In addition to natural disasters, we found that steel production in China has a significant impact that drives iron ore prices. Transportation costs, measured by oil prices, also showed a positive association with iron ore prices.

Moreover, an additional analysis estimated the cumulative dynamic effect of natural disasters. The results were similar to the primary results that natural disasters were significantly related to iron ore prices over several months. The findings showed that natural disasters over six months raise iron ore prices by 8.2% in total. When we added more lags in the model, cumulative dynamic effects were also observed over six months, while a significant effect no longer appeared afterward.

This chapter illustrated the relationship between the steel industry and natural disasters, highlighting higher prices of one steelmaking raw material driven by the occurrence of natural disasters. Steel firms worldwide largely depend on imports of raw materials from several different countries. This study suggests that when iron ore exporters are hit by natural disasters, an economic consequence could appear in the prices of imported commodities. In other words, the negative impact may not be limited to a country hit by natural disasters but may further spread to steel producers through the global supply chain. For iron ore-exporting countries, higher export prices could be a disadvantage because they lower the relative costs of domestic iron ore in China and make the iron ore market more competitive (Astier 2015). Moreover, the findings of this study may have important implications for iron ore suppliers and policymakers regarding disaster risk reduction. To reduce the costs of current and future climate change, addressing disaster risks is important in the iron ore-exporting countries. This includes both pre- and post-disaster planning and operations, for example, investment in disaster-resilient facilities and infrastructure through the application of the Building Back Better (BBB) framework (UNISDR 2017). For steel-producing countries, higher raw material costs can also be problematic. In addition to the emerging influence of China's economic growth, natural disasters may trigger price volatility, which causes steel production to be more unstable. Notably, steel firms must bear the higher costs of inputs if they cannot pass along these price increases to their customers in the form of higher steel product prices (Astier 2015). These potential consequences imply that steel firms should pay attention to natural disaster risks associated with procurement of raw materials. Furthermore, an increase in spot market prices may have a broader impact given that the quarterly negotiated prices of iron ore are influenced by spot market prices. In this regard, it is possible to assume that the pricing systems of the iron ore market may continue to transform depending on the economic and political conditions of the leading players in the steel and iron ore industries. Further expansion of spot trading can also be anticipated in raw material markets. Future research must focus on such complex and unique situations to further examine the effect of climate on the iron ore market.

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CHAPTER 6

Technology Transfer Management in the Steel Industry: Transfer Speed, Recognition Lag and Learning Lag

Sungwoo Byun

1 Introduction

The history of the steel industry reflects the history of technology transfer and introduction. The USA introduced technology from Europe; Japan introduced technology from the USA and Europe; and South Korea and China introduced modern steelmaking technology from Japan. Manufacturing equipment and operational technology are essential components of steelmaking technology. Companies that introduce foreign-developed technology can quickly start their operation with imported equipment and operational technology.

For decades, there have been many technology adopters, and there have also been technology providers for adopters. It is not uncommon

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for a technology adopter to become a provider after years of experience in using adopted technologies through trial and error.

The background of technology transfer varies, mostly for economic purposes. Since the steel industry is the backbone of industrial development, especially in underdeveloped countries, economic development has been at the center of technology transfer. A variety of technologies related to steel manufacturing have been promulgated, regardless of language, culture and the history of adopters.

Technology transfers in the steel industry are not limited to modern steel manufacturing technologies such as blast furnaces and converters. Even ancient ironmaking technologies were transferred and moved to other areas, as evidenced from historical records around the world.

Technology transfer has long been widely studied; however, agreement (consensus) on the body of knowledge does not exist in most independent academic fields. Technology transfer is an academically and managerially important area that can be too specific or too general. The characteristics of technology transfer pose a challenge for many researchers, managers and policy makers who use and apply knowledge to solve real-life problems.

This study focuses on general management issues when one adopts 'new' technology from an external provider. Since this 'new' technology is novel to the adopting companies or countries, understanding new technology entails learning time and, in many cases, failures. However, this study tries to explain that the recognition or perception of new technology can be a critical factor of success in technology transfer when a company adopts new technology. Recognition or perception of new technology means that when a company introduces new technologies, the company focuses on what to learn and how to learn, which are challenging tasks, because new technologies are similar to a black box for the adopter. Technologies are initially learned through a learning-by-doing approach, but little confidence is gained regarding the right versus wrong way of doing something. In short, the way a company recognizes a new technology affects what to learn and how to learn.

Essentially, adopting new technologies is a process of learning 'black box' technologies due to the knowledge and experience gaps between providers and adopters. In addition, learning generally requires time and effort to absorb new knowledge. Whereas existing studies have focused on difficulty learning new and complex technologies, this study focuses on how a firm recognizes new technologies, which affects the total learning process and, ultimately, learning time.

This study is organized as follows. In the next section, the traditional view on capital-intensive technology transfer is reviewed, including a discussion of economic backwardness. In Sect. 3, the crude steel production ranking published by the World Steel Association is explained.

Section 4 demonstrates a steel maker's struggle to produce high-grade steel in South Korea, and in Sect. 5, technology recognition and equipment dependence are explained for technology-adopting companies. Next, we discuss how the 'economic backwardness' of latecomers is limited for two reasons in the steel industry. Notably, interprocess adjustment in the steel industry and technical learning and recognition misalignment are explained. Additionally, as an example of interprocess adjustment, tolerance management is explained. Finally, implications for academics, managers and policy makers are given.

2 Technology Transfer in Capital-Intensive Industries

The steel industry is a typical example of a capital-intensive industry in which machinery and manufacturing equipment play central roles in influencing productivity. Compared with automobile manufacturing factories, integrated steel works[1] require, in general, huge investments in management resources from machinery and manufacturing equipment to human capital to manage and operate groups of factories. Thus, most major steel makers in advanced countries, including the USA, Germany and Japan, started manufacturing steel as a national project.

This approach has also been applied in developing counties, such as South Korea and China. In general, steel work investment is not just for the steel industry but also other manufacturing sectors, such as the shipbuilding industry, construction and the automobile industry. Since machinery and manufacturing equipment play central roles in influencing

[1] An integrated steel works is a steel manufacturer that produces steel products through the ironmaking process (with a blast furnace), steel-making process (with a converter) and rolling process. Since a steel works is comprised of multiple factories, it is called a 'steel works' and not a factory.

productivity in the steel industry,[2] technology transfer entails the import of capital assets.

The extant literature has analyzed technology transfer in capital-intensive industries, including the steel industry. The seminal work by Gerschenkron (1962) indicated that in capital-intensive industries such as the steel industry, production technology and know-how are already embodied in capital equipment; therefore, developing countries that import such equipment can produce goods efficiently with economies of scale. These latecomer advantages were known as 'economic backwardness.'

One can easily imagine the merits of embodied technology, for example, automated manufacturing facilities with operating software that are updated versions of legacy software. A new version of manufacturing equipment can give the companies that introduced these facilities advantages over firms with older facilities.

For example, imagine an operator monitoring product quality with physical sight at an old legacy facility. Now, this process can be done with automated programs, AI and machinery, and know-how regarding monitoring product quality is embodied in the equipment. The advantages of updated manufacturing equipment are attractive to engineers, operators and managers.

The economics of backwardness are not limited to the steel industry. In other capital-intensive industries, such as the semiconductor industry, oil refinery industry and chemical industry, latecomers have catch-up advantages. When a firm imports capital goods such as manufacturing equipment, the technology embodied in the capital goods is also transferred (Kim 1997; Lee and Lim 2001). These aspects of technology transfer and the corresponding effects on catch-up speed and capability have been widely researched across various industries and countries.

From Hirschman (1958), transferring capital-intensive machine-paced operations is suitable in underdeveloped countries that lack skilled labor and administration capability. In terms of the technology transfer efficiency, capital-intensive technology has a certain level of efficiency when compared with labor-intensive technology.

[2] However, productivity in the steel industry does not depend solely on manufacturing equipment. Human resources, such as operators, also play critical roles. We will discuss this topic later when we focus on interorganizational coordination.

Although we have obtained various insights from the extant literature, this study argues that such insights are limited in terms of product grade and process integration.

3 Crude Steel Production and Quality Competition in the Steel Industry

Crude steel production is an important indicator used to compare the competitiveness of steel makers. Published annually by the World Steel Association (WSA), this indicator ranks global steel makers in order of crude steel production (Table 1). With Arcelor Mittal at the top, steel makers in Japan, South Korea and China are highly ranked. Although these data are useful for understanding the production volume and trends in the steel industry, such as the expansion of production by Chinese steel makers, some factors require additional attention.

Notably, these ranking data are based on crude steel production only. Crude steel, as the name implies, refers to intermediate products, not finalized products. Intermediate products such as billets, blooms and slabs from the steelmaking process are called crude steel. The manufacturing process of steel products can be roughly divided into an upper process,

Table 1 Top-15 steel makers in 2019 (in million metric tons)

Rank	*Company*	*Tonnage*
1	ArcelorMittal	97.3
2	China Baowu Group	95.5
3	Nippon Steel Corporation	51.7
4	HBIS Group	46.6
5	POSCO	43.1
6	Shagang Group	41.1
7	Ansteel Group	39.2
8	Jianlong Group	31.2
9	Tata Steel Group	30.2
10	Shougang Group	29.3
11	Shandong Steel Group	27.6
12	JFE Steel Corporation	27.4
13	Valin Group	24.3
14	Nucor Corporation	23.1
15	HYUNDAI Steel Company	21.6

Source World Steel Association (2019)

which includes ironmaking and steelmaking, and a lower process, which includes hot rolling and cold rolling. Whereas the upper process centers on the adjustment of the chemical composition of the product, the lower process centers on the adjustment of the mechanical properties of the product. Crude steel is an intermediate product at the boundary between the upper process and the lower process.

The top steel maker data published by the World Steel Association are an indicator of the quantity of intermediate production and are not an indicator of quality competitiveness. The scale of production affects quality stabilization (Byun 2018), but one should refer to other sources in regard to the competitiveness of final product quality. For example, the research analysis reports of World Steel Dynamics, a company that studies the steel industry, the reports of investment companies and academic papers are also helpful sources of information. In addition, supply records and price information for automobile manufacturers, who are major customers of steel products, are also important materials. Moreover, interviews targeting managers, engineers and operators involved in the steel industry are also important sources of information. For example, the automobile industry announces worldwide sales and production volumes every year. Since the number of vehicles sold cannot provide direct evidence of the quality competitiveness among automobile manufacturers, referring to quality evaluations of materials, such as those by JD Power, is useful.

Among Japanese steel makers, according to the World Steel Association's 2019 data, Nippon Steel is ranked 3rd and JFE Steel is ranked 12th; however, in the field of so-called high-grade steel, such as automotive steel sheets, Japanese steel makers are receiving the highest evaluations globally. Steel products are still Japan's most important export item, followed by automobiles.[3]

It is difficult to grade the quality level of steel products because there are high-end products in the product category that have been considered low grade. For example, even in the field of construction steel, which

[3] According to the Ministry of Economy, Trade and Industry (2015), steel products have been a key export item of Japan since the 1990s. In particular, the ratio of exports of steel products is increasing. This rise is due to the expansion of the exports of steel sheets and other products to Japanese automobile assembly bases in overseas market. As of 2015, approximately 40% of steel produced in Japan was for export. Japanese automobile manufacturers that are expanding into overseas markets are taking advantage of the accompanying Japanese steel manufacturers overseas because procuring high-grade steel in the local market is challenging.

does not require strict surface quality requirements, for specially designed architectures such as the Tokyo Sky Tree, high-grade steel that meets customer needs is required. In other words, one cannot judge high grade, middle grade and low grade by the product category alone.

However, from the perspective of automobile makers in Japan, China and South Korea, Japanese steel makers offer high-end products that meet the needs of their customers. Additionally, Japanese steel makers boast a strong reputation in manufacturing steel products with functions suitable for development and manufacturing applications.

4 Struggling to Produce High-Grade Steel in South Korea

To describe the difficulty associated with producing high-end steel products, understanding the technological complexities can be helpful but not provide a full picture. Notably, the organizational learning aspect can also provide important clues.

We use the concept of 'technology recognition' as the reason why companies are overly dependent on manufacturing equipment when introducing new technology. Specifically, in the case of high-grade steel manufacturing in the steel industry, we stress the existence of 'technological recognition' associated with the difficulties of steel makers in emerging countries, including South Korea. In addition, 'interprocess coordination and interorganizational coordination' for high-grade steel production will be described in detail.

South Korea planned to build integrated steelworks beginning at the end of the 1960s and introduced the funds and technology necessary for construction. The main partner was Japan. In the 1960s, South Korea obtained a large amount of funds for the construction of integrated steelworks, in conjunction with Japan, and built integrated steelworks in Pohang in the southeastern part of South Korea as a national project.[4] POSCO (Pohang Iron and Steel Co.) was established as the result of this national project. As shown in Table 1, POSCO has grown to 5th in the world based on crude steel production.

[4] For records of POSCO's early construction, see Hogan (2001).

Table 2 Main equipment suppliers of Pohang Steel Works

Construction period	*Blast furnace*	*Cokes*	*Converter*	*Continuous casting*	*Hot rolling*	*Cold rolling*
Pohang No.1 (1970–1973)	Ishikawajima-harima Heavy Industries	Nihon Otto	Kawasaki Heavy Industries	none	Mitsubishi Heavy Industries	none
Pohang No.2 (1973–1976)	Ishikawajima-harima Heavy Industries	Otto	Kawasaki Heavy Industries	VÖEST	Mitsubishi Heavy Industries	VÖEST
Pohang No.3 (1976–1978)	Ishikawajima-harima Heavy Industries	Otto	Kawasaki Heavy Industries	none	Mitsubishi Electric	none
Pohang No.4 (1979–1983)	Ishikawajima-harima Heavy Industries	Otto	Kawasaki Heavy Industries	VÖEST	Mitsubishi Heavy Industries	VÖEST

Sources POSCO (2003), Mitsubishi Research Institute (1981)

In the history of the Korean steel industry, POSCO became the first integrated steel maker.[5] However, the company is not the first steel maker in South Korea. In the 1950s, immediately after the Korean War, there were already steel makers without blast furnaces in South Korea.

POSCO started the operation of Pohang Steel Works, the first steelworks in the 1970s, and then built a second steelworks in Gwangyang located in the southwestern part of South Korea in the 1980s and started operations. Table 2 shows the breakdown of equipment procurement at Pohang steelworks.

Although peripheral equipment is omitted from Table 2, many pieces of peripheral equipment are imported as well. For example, in addition to a blast furnace, which is the core of a steelworks, the ironmaking

[5] An integrated steel maker is a steel manufacturer that handles manufacturing processes from the upper process of blast furnaces and converters to the lower process of rolling. Some steel makers have electric furnaces instead of blast furnaces and converters. Minimills, which were noted in Christensen (1997)'s research, fall into this category. It should be noted that the term 'integrated' for an integrated steel manufacturer, which will be described later, does not necessarily mean that interprocess and interorganizational coordination exists.

department needs many peripheral tools, such as an unloader for the raw material, a belt conveyor for transporting the raw material from the yard to the blast furnace and blast furnace tuyeres that blow hot air into the blast furnace.

As shown in Table 2, the main equipment at POSCO's No. 1 Steel Works was mostly procured from Japan. In the first phase of construction, the continuous casting process and cold rolling process were not introduced, but in the second phase, equipment was introduced from Europe to produce cold rolling products.

POSCO has been increasing the number of processes and product varieties they provide while receiving operational assistance from the Japan Group, which consists of Japanese steel makers Nippon Steel and NKK. Table 3 below shows the main equipment suppliers of the second steel works in Gwangyang.

While the Pohang steelworks specialize in high-variety low-volume production, Gwangyang steelworks is a low-variety, mass-production facility that concentrates on the production of steel sheets for automobiles. As Table 3 shows, POSCO procured their main equipment from the United Kingdom, Germany and Austria, as well as from Korean heavy industry manufacturers. Following the high dependence on Japan in the initial stage of operation, the second stage focused on technological independence and the production of high-grade steel, which is a high-value-added product.

Although POSCO has become one of the world's top steel manufacturers, the production of automotive steel sheets has not been a smooth process. Table 4 shows the changes in the production capacity of steel sheets for automobiles.

POSCO has focused on the full-scale production of automotive steel sheets, but it has been difficult to mass produce them and secure customers. Furthermore, in the latter half of the 2000s, Hyundai Steel, which purchased the company's intermediate products, launched its own blast furnace and converter and succeeded in tapping the market in 2013 (Byun 2016). POSCO, which predicted that the sales volume of automotive steel sheets would decrease as its ex-customer became a strong rival, began the full-scale development of overseas markets at this time; that is, POSCO started developing overseas coil processing centers.

POSCO has been aiming to expand the sales of automotive steel sheets by constructing Gwangyang works, but it has been difficult to produce high-grade steel for a long time.

Table 3 Main equipment suppliers of Gwangyang Steel Works

Construction period	*Blast furnace*	*Cokes*	*Converter*	*Continuous casting*	*Hot rolling*	*Cold rolling*
Gwangyang No.1 (1985–1987)	Davy McKee, Korea Heavy Industries	Hyundai Heavy Industries	Voestalpine, Hyundai Heavy Industries	Mannesmann Demag, Hyundai Heavy Industries	Mitsubishi Corporation, Hyundai Heavy Industries	Mitsubishi Heavy Industries, Samsung Heavy Industries, Hyundai Heavy Industries, Korea Heavy Industries
Gwangyang No.2 (1986–1988)	Davy McKee, Korea Heavy Industries	Hyundai Heavy Industries	Voestalpine, Hyundai Heavy Industries	Mannesmann Demag, Hyundai Heavy Industries	Mitsubishi Corporation, Hyundai Heavy Industries	Mitsubishi Heavy Industries, Samsung Heavy Industries, Hyundai Heavy Industries, Korea Heavy Industries
Gwangyang No.3 (1988–1990)	Davy McKee, Korea Heavy Industries	Hyundai Heavy Industries	Voestalpine, Hyundai Heavy Industries	Mannesmann Demag, Hyundai Heavy Industries	Mitsubishi Corporation, Hyundai Heavy Industries	Mitsubishi Heavy Industries, Samsung Heavy Industries, Hyundai Heavy Industries, Korea Heavy Industries,

(continued)

In the 1970s, following the transfer of technology from Japan, South Korea's production growth was tremendous. The speed of the production increase after technology transfer was well over 10 times faster than that

Table 3 (continued)

Construction period	*Blast furnace*	*Cokes*	*Converter*	*Continuous casting*	*Hot rolling*	*Cold rolling*
Gwangyang No.4 (1991–1992)	Davy McKee, Korea Heavy Industries	Hyundai Heavy Industries	Voestalpine, Hyundai Heavy Industries	Mannesmann Demag, Hyundai Heavy Industries	Mitsubishi Corporation, Hyundai Heavy Industries	Mitsubishi Heavy Industries, Samsung Heavy Industries, Hyundai Heavy Industries, Korea Heavy Industries

Source POSCO (2003)

Table 4 POSCO's production capacity for automotive steel sheets (unit: thousand tons)

	Domestic demand	*Export*	*Total*
2003	1453	1270	2723
2004	1987	1537	3524
2005	2387	1970	4357
2006	2500	2458	4958
2007	2761	2800	5561
2008	2937	3417	6354
~	~	~	~
2018 (estimated)	2350	5590	7940

Source POSCO (2018)

after Japan succeeded in technology transfer from the steel industry in Europe. However, POSCO is still struggling to produce high-grade steel.

This issue has been investigated and analyzed since the early 1980s. In its industry report in 1980, the Korea Institute for Economics and Technology (KIET) deemed POSCO equal to or superior to Japanese manufacturers in the blast furnace process but inferior to Japan in the steelmaking process and continuous casting. KIET noted that strengthening these processes is a critical issue. Additionally, according to the report of the Mitsubishi Research Institute (1981), the Korean steel industry is rapidly catching up with general-purpose products, and competition with Japanese products is intensifying, but in the field of high-grade steel products, technology transfer and catch up are much slower. In 2015, World Steel Dynamics found that POSCO and Hyundai Steel had lower value-added product mix than Japanese manufacturers. In the same year, POSCO recorded the first deficit in its history due to the mass import of Chinese products into South Korea.[6] Korean engineers and operators in the steel industry are aware of the superiority of Japanese steel makers of high-grade steel.

5 Technology Recognition and Equipment Dependence

In general, companies that introduce new technology lack knowledge of and experience with technology compared to providers. For this reason, a gap in technical knowledge naturally exists between the introduction side and the transfer side. Specifically, when the technology is complicated and introduced from multiple sources, the technical knowledge gap becomes increasingly wider. Therefore, the technology introduction process is also a learning and adaptation process (Leonard-Barton 1988, 1992). The learning process and learning time are related to how the learning company understands what to learn.

In this section, we will introduce how companies that introduce complex technologies understand the technology in the process of introduction, the potential learning biases and the time required for learning and relearning.[7] In this study, from the perspective of the introducing company, determining how to recognize or perceive the technology to be introduced is broadly regarded as 'technology recognition,' and there are two lags related to learning time, namely 'recognition lag' and 'learning lag.'

Recognition lag is the time it takes for a company to determine the correct learning process while learning the characteristics of the introduced technology. For example, a company could think it is possible to produce products by collecting and mixing the newest equipment, but in reality, it takes time to achieve coordination among equipment and

[6] On the other hand, Japanese steel makers were still making profits.

[7] A proverb can make this issue clearer: 'It is like the blind man who touched just part of an elephant and tried from that to describe the whole animal.'

processes. The main cause of recognition lag is the lack of knowledge and experience regarding the introduced technology. Learning lag is the time it takes to 'relearn' in the correct learning process. From the previous example, it is the time required to learn interprocess adjustments.

Recognition lag and learning lag are caused by technical characteristics that are difficult to identify when a technology is introduced, and they are associated with specific assumptions. In addition, perceptual biases hamper the correct understanding of certain factors. After a company experiences recognition misalignment, the company works to correct this misalignment.

As a result, the time required to correct the recognition misalignment is the sum of the time required for noticing the issue, that is, the recognition lag, and the time required for relearning, that is, the learning lag. Below, we explain recognition lag and learning lag due to misalignment and give examples of interprocess coordination in the steel industry.

5.1 Why is Interprocess Coordination Important in the Steel Industry?[8]

Despite being a massive process-driven industry, certain products, such as automotive steel sheets and electrical steel sheets, require delicate control over multiple processes. Steel makers producing high-grade steel were not initially successful but have achieved success after trial and error.

In general, steel makers in emerging countries that introduce technology first construct blast furnaces and build the production process from converters to continuous casting. This approach is sufficient for producing normal-grade products such as slabs. Subsequently, the hot-rolling process can be added to produce hot-rolled coils. To produce cold-rolled coils with high added value, cold rolling and annealing processes can be added to the hot-rolling process (Fig. 1). Steel makers increase the types of steel products they produce by adding processes in a specific order.

In the initial stage of operation, a process from blast furnace to hot-rolling operations is performed, thus primarily resulting in hot-rolled coils. It is relatively easy to establish the introduced equipment for

[8] For more detail with cases, see Byun (2020).

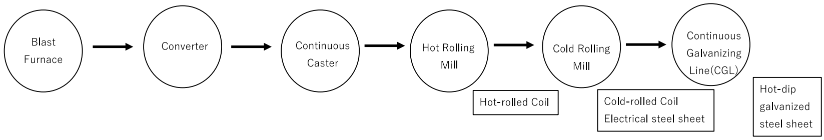

Fig. 1 Adding steel production processes

production up to this stage. However, when cold rolling and galvanizing processes are subsequently added, the difficulty suddenly increases. To produce cold-rolled coils, a cold rolling process is added. Then, to produce electrical steel sheets, an annealing process must be added after the cold rolling process. To produce hot-dip galvanized steel sheets, the final hot-dip galvanizing process must be added.

However, when production processes are sequentially added, both the added processes and the existing processes require operational coordination.

Notably, interdependence exists among processes, and the operational parameters of each process must be adjusted considering the requirements of the final product. For example, for the treatment and processing conditions, ingredient adjustments in the converter, reheating temperature changes in the hot-rolling process, variations in the hot-rolling speed, adjustments to cold rolling and plating amount changes are needed.

When expanding a production process, new operational knowledge and pattern knowledge, reflecting the so-called 'manufacturing recipe' for a new combination of operational parameters, must be acquired. For example, to produce hot-dip galvanized steel sheets, the contents of five major elements, namely C, Si, Mn, P and S, used by the converter are adjusted. Accordingly, in the subsequent rolling process, the reheating temperature and pressure are adjusted. Because there are variations in the task results, interprocess coordination is performed while sharing tolerance information for previous processes. Making adjustments with such causal knowledge is known as interprocess coordination. Figure 2 shows examples of typical operational parameters for each process and how the parameters among the processes are related.

If a pattern of interdependence among processes is identified, manufacturing operations can be managed based on an established plan. Such pattern recognition is often the focus of steel makers participating in the initial stage of new vehicle development with automobile makers.

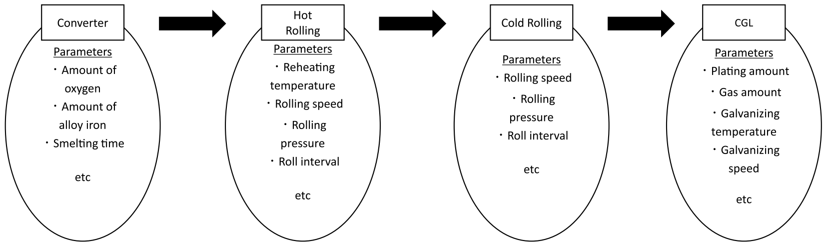

Fig. 2 Selecting and combining operational parameters

If patterns become completely stable, a steel maker can automate the operation.

By adding production processes, knowledge of the operational technologies used to manage connections and patterns is accumulated. If patterns are unclear, there is no knowledge regarding new combinations of operational parameters when adding production processes; thus, existing parameter combinations are maintained, and the only parameters of the new process are adjusted. Often, it takes some time before realizing that adjustments to existing parameters are necessary.

Once patterns are understood through trial and error, the next step in the operational process can begin. In addition to the parameters of the new process and the information from previous processes, multiple operational parameters must be combined and tried before production is successful. If coordination is generally understood, the burden of interprocess coordination can be predicted. Finally, the stages of standardization and automation are reached, and the load of interprocess coordination can be reduced. Combinations of operational parameters for each process are entered into the production system, and the parameters of the subsequent process are changed based on the operational conditions and results of previous processes.

Table 5 Examples of tolerance settings used in steelmaking processes

Name of process (name of equipment)	*Tolerance examples*
① material mix (blast furnace chute)	Size of iron ore and coal, amount moisture in cokes
② Iron making (blast furnace)	Internal temperature of blast furnace, temperature of molten iron, amount of impurities in molten iron
③ Steel making (converter)	Carbon amount in molten steel, amount of oxygen to eliminate impurities, amount of alloy iron to meet target composition
④ Hot rolling (hot roller)	Rolling speed, reheating temperature of intermediate products, thickness of products, cooling time
⑤ Cold rolling (cold roller, continuous annealing line)	Rolling speed of rolling machines, heating and reheating temperature of continuous annealing line, cooling time
⑥ Surface treatment (hot-dip galvanizing line)	Amount of zinc, galvanizing temperature

Sources Nippon Steel Corporation (2004, 2007, 2009)

5.2 Tolerance Management as an Example of Interprocess Coordination[9]

Tolerance is the difference between the maximum and minimum dimensions that can be allowed in terms of product functionality, as predetermined by a company for a particular design. Tolerance is a range-based concept. If the range is narrow and the tolerance is too strict, the number of internal defects will be high; conversely, under the opposite conditions, the number of external defects will be low.

Steel products are generally treated and processed in several steps at high temperatures and speeds. Each process is implemented with dedicated large equipment. An operator in the control room controls the parameters, sets the tolerances and manages the product quality. Table 5 illustrates the tolerance settings used in steelmaking.

For example, temperature is the most important factor in managing a blast furnace. A tolerance is set for the temperature inside the blast furnace to adjust the amount of oxygen and pulverized coal that is blown into the blast furnace, and the temperature must stay within the established

[9] For details on managing the tolerance stack-up problem, see Byun (2019).

tolerance range. Alternatively, in the steelmaking process, the operator controls the parameters, including the amounts of oxygen and alloy iron, among other things, so that the component values do not deviate from the tolerance. Thus, tolerance management is at the center of process management for any steel maker.

Normal-grade products with loose quality tolerances will not cause any major problems, even in subsequent processes, as long as the tolerance condition for each process is met.

However, in the production of high-grade products, such as automotive steel sheets, quality measurements may sometimes approach the tolerance limit in multiple processes, which frequently causes quality problems because of the cumulative effect. This is known as the risk of tolerance stack-up. In such cases, it is necessary to adjust and manage the tolerances among multiple processes. Cumulative tolerance that hinders the production of high-grade products is a technical problem and relates to interprocess coordination.

Managing tolerance stack-up is a technical issue as well as an organizational issue. Strictly setting a tolerance in each process increases the cost of dealing with defects in each process. Of course, setting tolerances for multiple processes requires adjustments and coordination between the processes and organizations.

5.3 *Technical Learning and Recognition Misalignment*

Findings can be obtained from existing studies related to the difficulties and biases of organizational learning, especially regarding factors that make interprocess coordination difficult. Senge (2006) explained the concept of the 'learning horizon' as one of the learning dilemmas of an organization. The learning horizon is the company's width of a company's field of view in time and space. One can evaluate their own work only within that frame. If the consequences of behavior are beyond one's learning horizon, it becomes impossible to learn directly from experience. In other words, when the results of one's actions appear temporally and spatially separated, it becomes difficult to understand the corresponding causal relationship, and learning by trial and error becomes challenging.

In interprocess coordination, if it is necessary to adjust parameters between separate processes instead of in adjacent pre- and postprocesses, it is necessary to learn knowledge about causal relationships from a perspective that goes beyond a single process.

Levinthal and March (1993) stressed temporal and spatial myopia as constraints in the learning process of organizations. Temporal myopia involves overlooking the distant future, and spatial myopia involves overlooking distant places. When manufacturing jobs are performed across multiple processes, the role of observing the entire process becomes crucial.

While the above research analyzed the difficulty of learning associated with large space and time distances, some other studies have focused on the information filter of a learning subject.

Henderson and Clark (1990) insisted that organizations with flooded information process this information through filters. Organizations create filters to identify the most important content as tasks become stable and clear (Arrow 1974; Daft and Weick 1984). In addition, according to Garvin (2003)'s study on the organizational learning process, when processing information, managers rely on factual, opinion and predictive information that they found useful in the past. These filters are often standardized and can be used unconsciously. In this approach, routines have the advantage of improving efficiency through standardization, but some side effects may occur. Starbuck and Milliken (1988)'s 'perceptual filters' and Shrivastava et al. (1987)'s 'organizational frames of reference' are also related to similar filter roles.

In the steel industry, if there are products that can be made with only the necessary equipment, there are also high-grade steel products that require integrated quality control through interprocess cooperation. Depending on the grade of products, advanced technology may not be required.

Such technologies include equipment-focused technology and interprocess coordination-focused technology. Figure 3 illustrates the relationships between the characteristics of technology and technology recognition for the introducing company.[10]

In Fig. 3, the cell on the upper right should be highlighted. In this case, the introducing company believes that they can make things if they establish the relevant processes with the necessary equipment. However, with this mindset, it becomes difficult to produce high-grade

[10] From process architecture theory and product architecture theory, equipment-focused technology is related to a modular architecture manufacturing process, and interprocess coordination-focused technology is related to an integrated architecture manufacturing process.

Technology recognition of introducing company	Characteristics of technology: Equipment-focus	Characteristics of technology: Inter-process coordination-focus
Equipment-focus	Accurate	Equipment dependence
Inter-process coordination-focus	Excessive cost	Accurate (learning time required)

Fig. 3 Characteristics of technology and technology recognition

steel products, such as automotive steel sheets, that require interprocess coordination. Since obtaining a technological overview is difficult for introducing companies, they tend to be overly dependent on manufacturing equipment, especially new equipment with expanded functions. With recognition lag, the company realizes the need for interprocess coordination, not equipment-focused technology.

After recognition lag is considered, the company tries to correct the misalignment issue in the upper-right cell and move to the lower-right cell. Although the recognition misalignment issue is alleviated, it still takes time to switch from the previous learning direction to a new direction and for relearning to occur.

Moreover, the upper-left cell means that an accurate recognition of equipment-focused technology is achieved. In the steel industry, such technology is required to produce steel that does not require advanced interprocess coordination.

Of course, it is difficult for the technology introducer to handle high-end products in the initial stage of introduction. Notably, the Korean steel maker POSCO did not have a continuous casting process or a cold rolling process at the beginning of operation, as shown in Table 2. At that time, intermediate products were supplied to meet the domestic demand as a substitute for imported products. However, after that, with the completion of the second steelworks, POSCO became serious about producing automotive steel sheets. The increase in the POSCO blast furnace volume has been progressing at an unprecedented pace. Notably, the production of automotive steel sheets began to take off in the 2000s, but it took a long time for the company to enter the high-grade steel market. Until 1990, normal-grade steel production accounted for more than 75% of total production, and it was not until the 2000s that the company embarked on organizational development.

For example, the Mega-Y-Project began in 2003. All organizational departments related to the production of automotive steel sheets were involved in production, and the department responsible for the final process could quickly respond to the detailed requirements of the automobile manufacturer while maintaining close communication with the managers of the previous process. Later, the research and development department and the marketing department, which deals directly with customers, also participated in this project.

Another organizational development was the integration of operations and maintenance in 2007. Gwangyang steelworks was reorganized in May 2007, and Pohang steelworks was reorganized in April 2010. The previously separated operation unit and maintenance unit were integrated. When the person who operates the equipment and the person who maintains the equipment acted separately, various problems occurred in real-time production control, and high-grade steel production was hindered. During this period, POSCO improved the quality of their automotive steel sheets and began supplying Toyota Motor Corporation.

6 Implications: The Differences in Catch-Up Speeds Within the Steel Industry

This study analyzes the challenges in technology transfer in the case of the steel industry. In extant research on technology transfer in capital-intensive industries, technology seems relatively easy to transfer because it is embodied in equipment, and companies that have introduced technology enjoy this benefit.

However, in the steel industry, which has a long history of technology transfer, manufacturers are particularly struggling to produce high-grade steel. Only a small portion of 200 steel makers in the world can produce high-grade steel. Steel makers that are able to produce automotive steel sheets are limited to 10% of all steel makers. In particular, there are few makers who are able to produce high-grade, hot-dip galvanized steel sheets. This study clarifies the reasons for the differences in catch-up speeds within the steel industry.

The economic backwardness of latecomers in the steel industry is found to be limited for two reasons. One reason is technological, the other reason is organizational, and these two reasons are not independent.

First, to produce high-grade steel products, interprocess coordination is crucial. When new production processes are added, the added process and the existing processes require coordination among operational parameters since interdependence exists among processes. The operational parameters of each process are adjusted considering the necessary composition of the final product.

Second, since companies introducing technologies lack knowledge of and experience with new technologies, the learning process and its effectiveness depend on how technologies are recognized and learned. After a company identifies recognition misalignment, they must work to correct the issue. As a result, the time required for correction is the sum of the time required to notice the issue, that is, the recognition lag, and the time required for relearning, that is, the learning lag.

It is not easy for companies that have introduced new technology to initially obtain a good overview of the technology and move on to high-grade steel production. Thus, this study identifies the following implications associated with technology transfer.

First, technology is both a learning object and a recognition object. Even with an incomplete understanding, it is necessary to correctly recognize whether the technology is equipment-focused technology or interprocess coordination-focused technology. Policy makers need to prepare for the unavoidable need to relearn by broadly analyzing the cases of companies that have introduced technologies. Technology transfer in the steel industry has a long history, but the frequency of transfer is so low that benchmarking can be difficult.

Second, it is necessary to clarify the target product group. Not all steel makers aim to produce high-grade steel, and high-grade steel is not necessarily a product that guarantees higher profits than other steel types. If a company specializes in low-margin, high-selling products, it will be important to consider introducing the appropriate equipment and technology.

Third, interprocess coordination requires not only high technical ability for operators but also a pool of seasoned veterans who coordinated connecting processes. If an operator is considered a within-process coordinator, the individuals connecting processes can be considered interprocess coordinators. However, as a manufacturer in an emerging country that has just introduced a certain technology, the pool of veterans will naturally be shallow, so it would be useful to use IT tools that support interprocess coordination.

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CHAPTER 7

Decomposing the Energy Impact of the Steel Industry in the Manufacturing Sector: Evidence from Japan and China

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1 Introduction

The multifaceted usage of iron and steel plays a leading role in a wide range of applications, such as construction and manufacturing. Consequently, sustainable development of a nation's financial system and economy depends specifically on the iron and steel industry (Christian

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et al. 2016; Skoczkowski et al. 2020; Stefan et al. 2020; Wang et al. 2020). Products made from steel are indispensable for daily life and contribute the largest share (approximately 27%) among all subsectors of carbon dioxide (CO_2) emissions from the global manufacturing sector (Gielen et al. 2007). Due to the continuous increase in energy demand worldwide, energy-related CO_2 emissions grew 1.7% from 2017 to 2018 (IEA 2019). The production process of iron and steel requires massive utilization of fossil fuels, with coking coal representing a major proportion of the energy use. The process employs high temperatures in a blast furnace for the transformation of raw materials to reduce iron ores (Quader et al. 2015; Mousa et al. 2016). Steel production employs mainly two approaches: the basic oxygen furnace (BOF) and electric arc furnace (EAF) methods. The BOF method, which is incredibly energy intensive, accounts for approximately 67% of world steel production, while the EAF method, which requires less energy, uses recycled scrap steel. A major share of global anthropogenic greenhouse gas (GHG) emissions (72%) comes from fossil fuel combustion and the largest share is that of China at 26%, whereas Japan accounts for only 3% (Olivier and Peters 2020). Recently, researchers have projected that the steel sector alone accounts for approximately 7% of total GHG emissions, resulting in environmental pollution, global warming and climate change (Moody's 2018).

According to the World Steel Association (2020), to meet demand for diversified applications, 1,868.8 million tons (Mt) of global crude steel were produced in 2019, representing an increase of 3.4% over the level in 2018. Concurrently, China alone produced 996.3 Mt, accounting for 53.3% of world steel production and holding the position of the world's largest steel producer since 1996. World total steel production increased by 850 Mt from 1990 to 2017, with 87% of this increase contributed by China (He et al. 2020). Among the significant producers, Japan was replaced by India as the second-largest producer. In 2019, Japan produced 99.3 Mt of crude steel, and production trended at approximately 100 Mt per annum in the late 1900s. This sector was one of the greatest contributors to manufacturing GDP, accounting for 7.2% in 2012. Japan maintained its domestic crude steel production through a corresponding increase in exports, as national consumption gradually weakened from 89.9% of total production in 1990 to 70.4% in 2018 (ISIJ 2020). By 2019, due to declines in both domestic and external demand, production of crude steel had decreased by 4.8% from its level in 2018.

In the present study, we focus on CO_2 emissions from the manufacturing sectors of Japan and China, specifically on the decline in emissions intensity or per dollar of output. Reducing the total CO_2 emissions intensity of the manufacturing sectors of Japan and China is a plausible strategy for reducing the sector's considerable proportion of total emissions. Researchers believe that technological innovation contributes to reducing CO_2 emissions by increasing energy efficiency and decreasing consumption (Wang and Zhu 2020). Recently, Chen et al. (2019) applied structural decomposition analysis (SDA) to investigate CO_2 emissions intensity in the Chinese construction industry and observed that CO_2 emissions declined between 2007 and 2012 through improving production technologies. Yang et al. (2020) found that economic activity is the greatest driver of carbon emissions, whereas energy intensity is the most important suppressor. According to Ahmed et al. (2016), technological innovation was a major factor in reducing CO_2 emissions in 24 European countries from 1980 to 2010. Moreover, innovative technology can promote the transition away from a coal-based economy by improving the energy consumption structure (Guo et al. 2016). Pollmann et al. (2018) explained how innovative recycling methodologies enable a circular economy through the recovery of metal from steel wastes (Gomes et al. 2018).

Zhang et al. (2019) performed a decomposition analysis to assess CO_2 emissions intensity by examining 41 influential manufacturing subsectors in China from 2000 to 2016. The authors inferred that energy intensity was the primary indicator in reducing CO_2 emissions. During recent decades, relative to research on Japan, research on CO_2 emissions in China has become of even greater importance for intensity reduction targets. The present study follows the decomposition analysis developed by Levinson (2009; 2015). We split the manufacturing sectors of Japan and China into two groups: CO_2 emissions from all manufacturing subsectors and CO_2 emissions from the manufacturing sector excluding the iron and steel industry since this industry produces a major share of CO_2 emissions. Our results help to evaluate whether the technology used in steel production by Japanese and Chinese industries is adequate or requires more augmentative measures to reduce CO_2 emissions. We believe that the present findings can provide policy implications to help lower CO_2 emissions while addressing the quality of the technologies used. Our reasoning will be clarified further in the remaining parts of this paper. The study is organized into eight sections as follows: Sect. 2

discusses Japan's and Sect. 3 China's efforts to reduce CO_2 emissions; Sect. 4 describes related studies employing the applied method; Sect. 5 elaborates on the method; Sect. 6 presents the results and Sect. 7 the discussion; and Sect. 8 offers the conclusion.

2 Japan's Efforts to Reduce CO_2 Emissions

Japan has been the target of international criticism on its climate efforts, receiving, for instance, the Fossil of the Day prize at the 25th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP25). The need to deal with increasingly serious environmental problems has given rise to strategies to mitigate CO_2 emissions. In 2018, the Japanese government adopted the 5th Basic Environmental Plan and 5th Strategic Energy Plan to outline the future direction of environmental policy development and the basic thrust of energy policy (ISIJ 2020). After switching off all domestic nuclear reactors soon after the Fukushima Daiichi nuclear disaster in March 2011, Japan began to depend mostly on fossil fuels for its energy. Following the incident, Japan's fulfillment of its commitment under the Copenhagen Accord from the 15th session of the Conference of the Parties to the UNFCCC (COP15) to cut GHG emissions by 25% from their 1990 level by 2020 became infeasible (Kuramochi 2015). According to the Ministry of Foreign Affairs of Japan, 90% of GHG emissions in 2015 were energy related. CO_2 emissions therefore surged, and it now seems very challenging to meet Paris Agreement targets. Japan has pledged to cut GHG emissions from their level in fiscal year 2013 by approximately 26% by 2030 and by 80% by 2050. To achieve these targets, some appropriate policy and legal frameworks have been designed targeting the transformation of the country's energy consumption structure (Yanagi et al. 2019).

In 2020, the Greenhouse Gas Inventory Office (GIO) of Japan reported that CO_2 emissions were approximately 1,240 Mt in 2018. This was a reduction from the peak of 1,410 Mt in 2013 and represented a decline for the fifth successive year, for a cumulative drop of 12%. In addition, government progress toward renewable approaches with continuous improvements in energy efficiency and distributed systems, usage of nuclear power, phasing-out of fossil fuel and introduction of new energy sources such as hydrogen are all under consideration to meet CO_2 reduction targets (Nguyen et al. 2019). In comparison with the commercial and residential sectors, manufacturing industries have made some progress in lowering their CO_2 emissions (Nippon Steel's environmental initiatives 2019).

Reducing CO_2 emissions from the ironmaking process requires sustained and focused effort since, in Japan, the iron and steel industry accounts for approximately 14% of total GHGs. To reduce CO_2 emissions, the Japanese iron and steel industry is making constant efforts to improve its technology, especially in relation to energy conservation, and modernize its facilities from diverse starting points. For instance, the Japanese steel industry has started a project called CO_2 Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50 (COURSE50), aiming to develop less carbon-intensive steelmaking technologies to mitigate CO_2 emissions by 30% (Tonomura 2013). The Technological Development of Ironmaking Process Utilizing Ferro-coke project was launched to reduce energy consumption and CO_2 emissions. Moreover, one effort by an individual steelmaker, Nippon Steel, was awarded for its incredible success in developing innovative technologies to utilize steel slag (Horii et al. 2015).

Japan has named eco-processes, eco-products, eco-solutions and innovative technology development as the four pillars of its commitment to a low-carbon society. An additional goal of Japan is to further improve its energy efficiency, which is already the highest in the world. In 2018, the Japan Iron and Steel Federation (JISF) expressed the Challenge Toward Zero-carbon Steel as a long-term strategy, and technology development based on the keyword "zero carbon steel" was specified as an Innovative Action Plan of the Progressive Environment Innovation Strategy under the jurisdiction of the Ministry of Economy, Trade and Industry (METI) in the supplemental budget for fiscal year 2019. Furthermore, science and technology-related matters such as advances in Internet of Things (IoT), artificial intelligence (AI), sensors, biometric authentication and robots have attracted attention in the Japanese steel industry (ISIJ 2020).

3 China's Efforts to Reduce CO_2 Emissions

China long avoided obligations to reduce GHG emissions in negotiations over the UNFCCC and Kyoto Protocol using common but different liability principles, historical responsibilities and development rights as an excuse. Conversely, in accordance with the requirements of its national sustainable development strategy, China has formulated and promulgated a series of policies and legislative measures related to climate change, the most important of which is the energy-saving and emissions-reduction policy. Since 2006, the Chinese government has successively formulated related legislation, including the National Plan for Addressing Climate Change, the Medium and Long-term Development Plan for Renewable Energy, the Eleventh Five-Year Plan for Renewable Energy Development, the Energy Conservation Law, the Renewable Energy Law and the Cleaner Production Promotion Law.

From approximately the 21st session of the Conference of the Parties to the UNFCCC (COP21) in 2015, China began to recognize its great responsibility as a major power. COP21 was the first climate conference that China's top leader attended, which indicated Beijing's acknowledgment of the rationality and necessity of a response to climate change. In addition, this participation represented China's commitment to including climate change in its ecology improvement program and pursuing a low-carbon society and economy. Thus, in recent years, China has changed its attitude toward actively working toward reducing greenhouse gas emissions (Gao 2017).

In 2017, China's CO_2 emissions per unit of GDP (hereinafter referred to as carbon intensity) declined by approximately 46% from their level in 2005, already beating the 2020 carbon intensity reduction target of 40%–45%, which preliminarily reversed the rapid growth trend of carbon emissions. In 2018, carbon intensity further decreased by 4.0% for a cumulative decrease of 45.8% from the level in 2005, equivalent to a reduction of 5.26 billion tons of carbon dioxide. Non-fossil energy accounted for 14.3% of total energy consumption. It seems that China's rapid growth of CO_2 emissions is ending (MEE 2018,2019).

The steel industry is one of the key sectors that has contributed to slowing down the growth of CO_2 emissions. China's steel industry has experienced rapid development driven by urbanization for decades. At present, the industry is facing problems such as overcapacity, uneven technological levels and low industrial concentration. Simultaneously, the steel industry consumes a great deal of energy, emits many pollutants and greenhouse gases and is one of the key sectors targeted for energy conservation and emissions reduction. There are three ways to save energy and reduce emissions in the iron and steel industry: capacity replacement, use of energy-saving emission reduction technologies and improvement of production processes. Against the background of overcapacity and limited domestic scrap resources, China has mainly adopted the method of eliminating outdated production capacity and promoting advanced energy-saving and emissions-reduction technologies.

In response to the low industrial concentration and small-scale and antiquated production technologies in China's steel industry, the National Development and Reform Commission formulated the Iron and Steel Industry Development Policy in 2005, which put forward clear and specific requirements for the steel industry to respond to climate change and implement low-carbon development. The Iron and Steel Industry Adjustment and Revitalization Plan promulgated in January 2009 also proposes to promote revitalization of the steel industry by focusing on total control, elimination of outdated production capacity, joint reorganization, technological transformation and optimization of layouts. As of the end of 2018, in accordance with the decisions and stipulations of the Party Central Committee and the State Council on supply-side structural reforms, all regions and relevant departments have steadily promoted the elimination of excess capacity in key areas and reduced the production capacity of crude steel by more than 150 million tons in 2018. Steel production capacity is over 35 million tons (MEE 2019).

We apply a decomposition analysis to separate the contributions of changes in output, industrial structure and emissions intensity to address CO_2 emissions reductions in the Japanese and Chinese manufacturing subsectors. In the present study, the effects on carbon emissions in Japanese and Chinese manufacturing were broken into three components: scale, composition and technique effects. We explain these effects in a later section.

4 Literature Reviews of the Method

Our analysis relies on the method developed by Levinson (2015). This method allows us to directly measure the technique effect. Levinson (2009; 2015) analyzed air pollution from US manufacturing and concluded that the technique effect was dominant for the reduction of US air pollution from the late 1990s and early 2000.The same method was applied by Brunel (2017) to EU air pollution and revealed that the EU has become more pollution intensive in terms of its manufacturing composition. Cole and Zhang (2019) were the first to apply this method to a developing country, China, based on data from 2003 to 2015. They found that the Chinese economy grew sixfold during this period, whereas SO_2 emissions from the manufacturing sector were only 1.5 times higher due to the extensive improvement of the technique effect. Furthermore, Bernard et al. (2020) and Holland et al. (2020) extended the method to analyze air and water pollution in the Canadian pulp industry and the US electricity industry in different ways. Recently, we applied the same method to analyze waste plastic pollution reduction in Japanese manufacturing and observed a larger contribution from the technique effect than from the composition effect (Yamamoto and Eva, unpublished data). The technique effect results in a reduction in pollution exclusively by reducing emissions intensity.

5 Decomposition of CO_2 from Manufacturing

5.1 Method

5.1.1 Scale, Composition and Technique Effects

In our analysis, the scale effect is driven by total economic growth or manufacturing output in a given year. The composition effect arises from shifts in the economic structure from more to less polluting sectors. The technique effect reflects changes in production methods, advanced technologies and innovations such as a mix of input substitution and process changes that usually lead to a reduction in emissions per unit of output (Liobikiene and Butkus 2019).

Following previous studies such as Levinson (2009; 2015), let P be total pollution and V total economic growth (or value added) from manufacturing. p_{it} denotes the pollution from industry i in year t and v_{it} the output of industry i in year t. θ_{it} is the share of industry i in year t in total output $\theta_{it}\left(= \frac{v_{it}}{V_t}\right)$. z_{it} is the emissions intensity or pollution per dollar of output $(= \frac{p_{it}}{v_{it}} \equiv z_{it})$, and total pollution from manufacturing in a given year t can be calculated as follows:

$$P_t = \sum_i p_{it} = \sum_i v_{it} z_{it} = V_t \sum_i \theta_{it} z_{it} \tag{1}$$

If we assume that the emissions intensity, z_{it}, is constant over time and denote it as $\bar{z}_i$, then the total emissions in year t,

$$\widehat{P_t} = V_t \sum_i \theta_{it} \bar{z}_i \tag{2}$$

are determined by economic growth ($= V_t$), in what is known as the scale effect, and changes in composition ($= \theta_t$), in what is called the composition effect. Furthermore, we can measure the technique effect by subtracting $\widehat{P_t}$ from the actual observation of P_t. Since this technique effect is defined by what cannot be explained by the scale effect and the composition effect, Levinson (2015) called it the indirect technique effect.

In vector form notation, (1) becomes the following:

$$P = V\boldsymbol{\theta}'\boldsymbol{z} \tag{3}$$

Totally differentiating the above equation, we obtain:

$$dP = \boldsymbol{\theta}'\boldsymbol{z}dV + V\boldsymbol{z}'d\boldsymbol{\theta} + V\boldsymbol{\theta}'d\boldsymbol{z} \tag{4}$$

The first term in (4) is the scale effect, which explains the change in pollution when the size of the manufacturing sector increases, holding the composition of industries and their pollution intensities fixed. The middle term is the composition effect, which accounts for the changing mix of industries, holding their scale and pollution intensities constant. The last term is the technique effect, which captures changes in pollution intensities, holding the scale and composition fixed. In the discrete expression, $P_t - \widehat{P_t}$ corresponds to the left-hand side (LHS) of (4) minus the first and second terms of the right-hand side (RHS). This allows us to indirectly derive the technique effect.

5.1.2 Direct Estimate of the Technique Effect

As a direct estimate of the technique effect, Levinson (2015) proposes two indexes, i.e., the Laspeyres index (I_L) and the Paasche index (I_P). Rather than holding the emissions intensity constant, the following indexes hold the composition of output fixed and show how pollution per dollar of output has changed. Given that the base year is 2008 for Japan and 2005 for China:

$$\text{Laspeyresindex}: I_L = \frac{\sum_i z_{it} \times v_{i1}}{\sum_i z_{i1} \times v_{i1}} \tag{5}$$

$$\text{Paascheindex}: I_P = \frac{\sum_i z_{it} \times v_{it}}{\sum_i z_{i1} \times v_{it}} \tag{6}$$

where z_{it} and v_{it} are the pollution intensity and output value of industry i in year t and z_{i1} and v_{i1} are the pollution intensity and output value of industry i in the base year. As Levinson (2015) points out, the Laspeyres index is smaller than the Paasche index if a subsector produces relatively less output with the fastest-falling pollution intensities (z_{it}) during the targeted time period, suggesting a larger technique effect. The Laspeyres value would be larger than the Paasche value if the output increases more in the sectors with the fastest-falling pollution intensities (z_{it}), suggesting a smaller technique effect.

5.2 Data of Japan

To compute the indexes introduced above, we need three types of information: (1) sector-specific output levels, (2) generation of CO_2 emissions by each sector and (3) sector-specific deflators to convert our economic variables from nominal to real.

First, we obtain data on manufacturing activity from the *Census of Manufacture*, published by the METI in Japan (METI 2020). The census contains the annual output (monetary base) of each of the 24 subsectors of manufacturing. This nominal output value is converted to real terms with the GDP deflator (base year = 2008), which supplies sufficient information to define the total output of the manufacturing sector, $V_t = \sum_{i=1}^{24} v_i$, covering the periods from 2008 to 2017. Information on CO_2 emissions is available from *Greenhouse Gas Emissions Data* by the Japan's GIO (GIO 2020). Dividing CO_2 emissions (p_{it}) by the output value shipped for each industry (v_{it}), we can obtain the subsector-specific pollution intensities ($\equiv z_{it}$) for each year.

5.3 Data of China

To estimate the CO_2 pollution intensity of the Chinese manufacturing sector, we use value-added data from the *China Statistical Yearbook*, National Bureau of Statistics of China; pollution data are taken from Shan et al. (2018; 2020). We use the industry-specific price index from the *National Bureau of Statistics of China* to deflate the nominal value to real terms. The value-added data for 2004 are missing, and the industry-specific price index has been precisely reported since 2004. Therefore, to avoid potential measurement error, we include data from 2005 to 2017. Considering the integrity of the data, we select 28 manufacturing subsectors following Yang et al. (2020). The total output of the manufacturing sector, $V_t = \sum_{i=1}^{28} v_i$ and the subsector-specific pollution intensities ($\equiv z_{it}$) were calculated as aforementioned. Since the data classifications are changed, we follow the adjustment procedure of Wei et al. (2020). For example, two independent subsectors, rubber products and plastic products, are merged to a unified rubber and plastic products category prior to 2011. Automobile, rail, marine, aerospace and other transportation equipment are merged to form the unified transportation equipment category after 2011. In addition, the iron and steel industry in Japan corresponds to the ferrous metal smelting and rolling processing industry in China. In the remainder of the paper, we use the term iron and steel industry instead of ferrous metal smelting and rolling processing.

6 Results

6.1 Results for Japan

Decomposition of the scale, composition and technique effects on the CO_2 emissions of Japanese manufacturing sectors from 2008 to 2017 are shown in Fig. 1 (with all manufacturing sectors) and Fig. 2 (excluding the iron and steel industry). Inflation is adjusted for with the GDP price index (production side), and all figures are set equal to 100 in 2008.

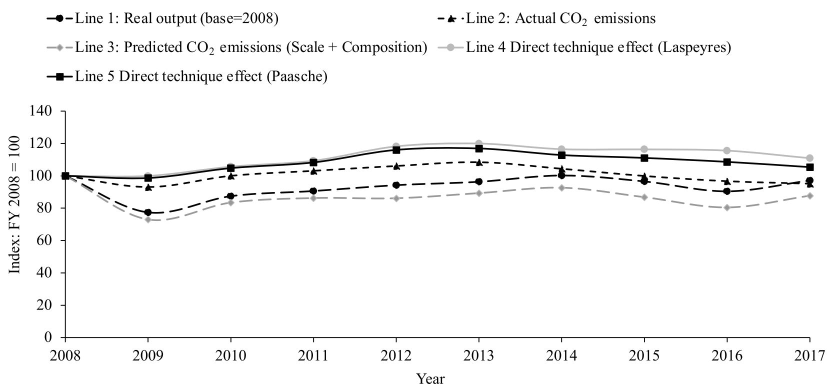

Fig. 1 Changes in Scale, Composition and Technique Effects of All Manufacturing Subsectors in Japan (*Source* Authors' own calculations and the original sources are METI [2020] and GIO [2020])

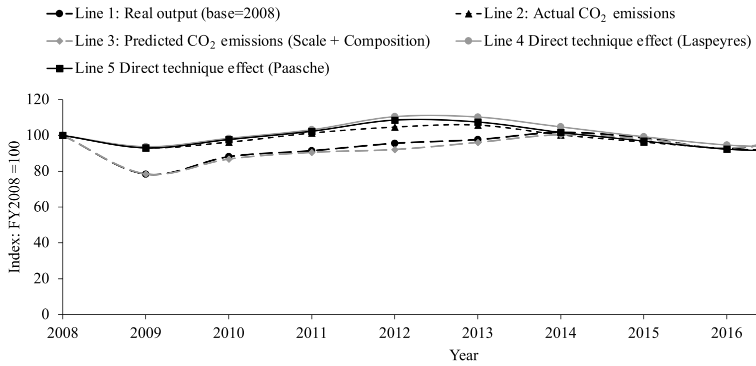

Fig. 2 Changes in Scale, Composition and Technique Effects in Japanese Manufacturing Excluding the Iron and Steel Industry (*Source* Authors' own calculations and the original sources are METI [2020] and GIO [2020])

In Fig. 1, line 1 depicts the scale effect. The sharp contraction of Japanese manufacturing from 2008 to 2009 improved immediately after the global financial crisis. Even the Great East Japan Earthquake (March 2011) did not pose further challenges. In a sense, line 1 represents how emissions would have developed had the composition of the manufacturing sector ($d\theta = 0$) and technology ($dz = 0$) remained constant. Line 2 demonstrates actual CO_2 emissions; the scale, composition and technique effects combined decreased pollution emissions by 4.8% (Table 1).

Table 1 Scale, Composition and Technique Effects for Japanese and Chinese Manufacturing

	(1)	*(2)*	*(3)*	*(4)*
	Scale (%)	Scale, composition and technique (%)	Scale and composition (%)	Cleanup due to composition (%)
Japan (All)	−2.84	−4.85	−12.27	−467.93
Japan (w/o iron and steel)	−0.64	−8.71	−0.16	5.91
China (All)	346.52	53.67	293.36	−18.15
China (w/o iron and steel)	365.36	30.95	376.71	3.4

Note (4) = [(1) − (3)]/[(1) − (2)]

The difference between the scale effect (line 1) and actual emissions (line 2) captures the cleanup of Japanese manufacturing sectors, accounting for 2.1% (Table 2). Line 3 expresses a 12.3% decrease in CO_2 pollution emissions from the combined effects of scale and composition; this is the pollution level predicted by Eq. (2). The difference between lines 1 and 3 indicates that the composition effect alone accounts for a 9.4% reduction. Since line 3 is always below line 1, the emissions changes from the combined scale and composition effects were lower than those from the scale effect alone.

Therefore, we can conclude that Japanese manufacturing sectors changed their economic structure by shifting toward less pollution-intensive subsectors relative to the composition in the base year (= 2008). Our findings show a remarkable disparity with the results of Brunel (2017) and Cole and Zhang (2019), who identified a diversion toward

Table 2 Cleanup of CO_2 in Japanese (2008–2017) and Chinese (2005–2017) Manufacturing

		All industries (%)			*Without iron and steel (%)*		
		(1) Cleanup	*(2) Technique effect*	*(3) Technique share*	*(4) Cleanup*	*(5) Technique effect*	*(6) Technique share*
Japan	Indirect	−2.07	7.63	−367.93	−8.12	−8.60	105.91
	Direct (Laspeyres)	−2.07	14.14	−681.84	−8.12	−6.38	78.58
	Direct (Paasche)	−2.07	8.45	−407.49	−8.12	−8.56	105.40
China	Indirect	−65.59	−53.68	81.85	−71.86	−74.30	103.40
	Direct (Laspeyres)	−65.59	−54.58	83.23	−71.86	−71.51	99.52
	Direct (Paasche)	−65.59	−60.93	92.91	−71.86	−72.53	100.93

Note Columns 1 and 4 show the difference between lines 1 and 2. Japan: (97.16−95.15)/97.16 (all industries) and (99.4−91.3)/ 99.4 (without iron and steel industry). China: (446.52−153.67)/446.52 (all industries) and (465.36−130.95)/465.36 (without iron and steel industry). First row of Column 2 is Column 1 times (1−4.68), and Column 5 is Column 4 times (1− (−0.059)); 4th row of Column 2 is Column 1 times (1−0.18), and Column 5 is Column 4 times (1− (−0.034)). The 2nd 3rd, 5th and 6th rows of Columns 2 and 5 are the percentile declines in the Laspeyres and Paasche indexes; Column 3 is the ratio of Columns 2 and 1; Column 6 is the ratio of Columns 5 and 4 pollution-intensive goods in the composition of EU and Chinese production, respectively. Our results are much more similar to those of Levinson (2015) on US production, in which compositional changes were associated with a 12% reduction in SO2 emissions from 1990 to 2008. The composition effect in Japan accounted for 468% of the 2.1% decline in CO_2 emission[1], signifying that approximately one-half of the cleanup was caused by changes in composition (Table 1). Considering that the approach calculates pollution from changes in scale and composition, holding technique fixed over time, the residual is attributed to the indirect technique effect.

The indirect technique effect is found to have increased CO_2 emissions by 7.6%, with the technique share being 368% (Table 2), the differences between lines 2 and 3. This positive result is much more intuitive than the findings of previous studies, where the technique effect was the main driver of the cleanup of manufacturing for the US, EU and China. To examine robustness, we use another approach to compute the technique effect directly using the base year industry composition based on the Laspeyres index, calculated with Eq. (5), and the final year industry composition based on the Paasche index, calculated with Eq. (6). The Laspeyres index value is 114%, and the Paasche index value is 108%. However, when we examine lines 4 and 5 of Fig. 1, the Laspeyres index appears to be 111% and the Paasche index 105%. Since the total real manufacturing output of each year is multiplied by the Laspeyres and Paasche index values to plot lines 4 and 5, respectively, the result is indexed so that 2008 = 100. This direct technique effect allows us to understand the predicted pollution from scale and technique effects alone by freezing the composition of production. Our results unequivocally show an increase in CO_2 emissions in lines 4 and 5, indicating that the reduction in pollution emissions was mainly driven by the composition effect in Japanese manufacturing. Table 2 shows the technique effect share in the cleanup of manufacturing using the two direct estimates. CO_2 emissions per dollar of output increased by 14.1% and 8.5% according to the Laspeyres and Paasche indexes, respectively, meaning that the technique effect increased CO_2 emissions by 682% and 407%.

[1] How can the composition effect account for more than 100% of the cleanup? Since the technique effect increased CO_2 pollution by 368% from 2008 to 2017, the composition effect is calculated as a 468% decline in CO_2 pollution: [(−2.84) − (−12.27)/(−2.84) − (−4.85)]*100.

Figure 2 excludes the iron and steel industry, helping to clarify the impact of the technique effect in this industry on the rest of the Japanese manufacturing sectors. There is no significant difference from the base year level, depicted by line 1, in the scale effect (with a decline of less than 1%) (Table 1). This result implies that the output of each sector, including the production techniques, remained nearly the same; therefore, total emissions did not change much. Furthermore, line 3 is the predicted pollution ($\widehat{P_t}$) that oscillates around line 1 without any clear, steady shift. Even though change occurred among the subsectors, pollution intensity remained nearly similar due to the negligible role of the composition effect. The results show that the composition effect increased CO_2 emissions by 5.9% (Table 1).

Line 2 in Fig. 2 is the actual CO_2 emissions; there is a decline of 8.7%, suggesting that pollution per dollar of output fell 8.1% (Table 2). The cleanup of 8.6% must be attributable to the residual or indirect technique effect, where the technique effect share is 106%. These results are confirmed using the results of the direct technique effect calculated from lines 4 and 5. Approximately 6% to 79% of the total decline in CO_2 emissions is accounted for by the Laspeyres index, while the Paasche index accounts for 9% to 105% of the total cleanup (Table 2).

6.2 *Results for China*

The decomposition of the scale, composition and technique effects on the CO_2 emissions of Chinese manufacturing sectors from 2005 to 2017 is shown in Fig. 3 (all manufacturing sectors) and Fig. 4 (excluding the iron and steel industry). Again, inflation is adjusted for, and the lines are all set to 100 in 2005.

Figure 3 depicts that line 1 is the scale effect, which increased by 347%—almost 3.5 times compared with that in the base year. Conversely, line 2 shows that actual CO_2 emissions increased by only 54%. Table 1 provides the result of the lines, which indicates that pollution per dollar of output fell by 65.6%, marking the difference between the scale effect (line 1) and actual emissions (line 2) (Table 2). We already know that line 3 is the plot of $\widehat{P_t}$, showing that CO_2 emissions increased by 293% over the base year level. The predicted pollution of the Chinese manufacturing sector shows an upward trend until 2015 and oscillates with line 1, which

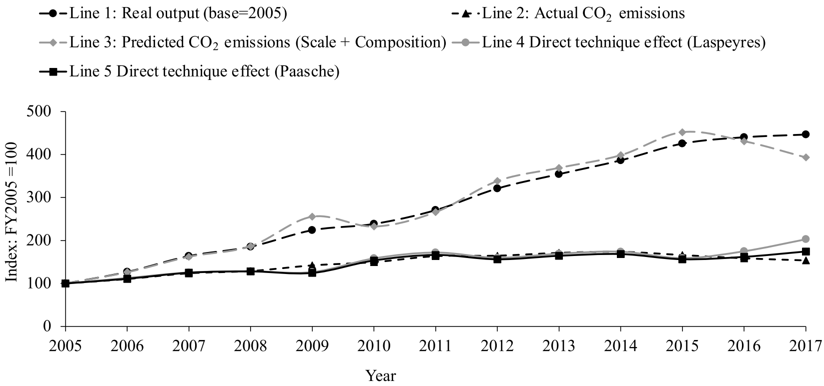

Fig. 3 Changes in Scale, Composition and Technique Effects of All Manufacturing Subsectors in China (*Source* Authors' own calculations and the original sources are National Bureau of Statistics of China [2005–2017], Shan et al. [2018; 2020])

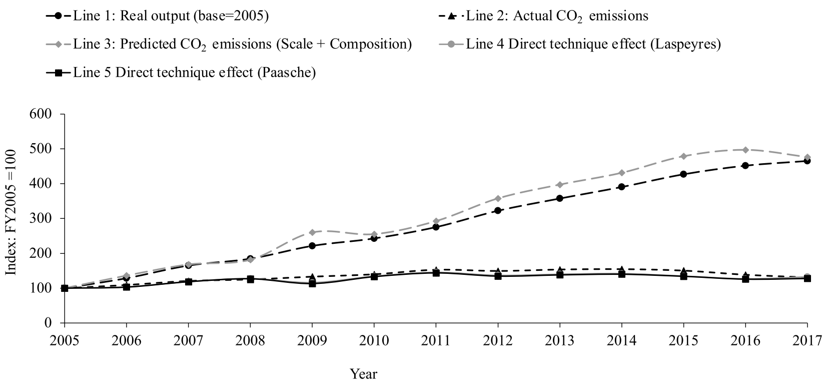

Fig. 4 Changes in Scale, Composition and Technique Effects in Chinese Manufacturing Excluding the Iron and Steel Industry (*Source* Authors' own calculations and the original sources are National Bureau of Statistics of China [2005–2017] and Shan et al. [2018; 2020])

dramatically declines in 2016. It seems that after 2015, Chinese manufacturing somehow significantly changed. As a result, compositional changes account for 18% of the total manufacturing cleanup of 65.6%. The indirect technique effect on the Chinese manufacturing sector contributed 54% of the decline in CO_2 emissions, where the technique share of 82% is displayed by the gap between lines 3 and 2. The direct estimates of the technique effect on CO_2 emissions decline by approximately 55% to 83% based on the Laspeyres index and 61% to 93% based on the Paasche index (Table 2).

In Fig. 4, we can see the result by excluding the iron and steel industry. The scale effect increased 365%, whereas actual CO_2 emissions increased by 31%, as depicted by lines 1 and 2. Line 3 is the $\widehat{P_t}$, showing that CO_2 emissions were set to increase by 377%. This result implies that the composition effect increased CO_2 emissions by 3.4% (Table 1) within the total manufacturing cleanup of 71.9%. The indirect technique effect accounts for 74% of the CO_2 emissions reduction; therefore, the technique effect share represents 103.4% of the total cleanup. In addition, the direct cleanup effect according to the Laspeyres index ranges from 72 to 100% and according to the Paasche index from 73 to 101% (Table 2). A similar result was obtained by excluding the iron and steel industry from Japanese manufacturing in the previous section. The overall summaries of the results for Japan (Figs. 1 and 2) and China (Figs. 3 and 4) are shown in Fig. 5.

7 Discussion

The total output of the iron and steel industry within Japanese manufacturing declined by 30% from 2008 to 2017, and we find a reduction in predicted CO_2 emissions. The declining output trend may have increased the share of cleanup through the composition effect. The driver behind this decline was uncertainty in the global economy and US-China trade issue (Nippon steel investor briefing 2020). In our case, we observe that the emissions intensity of the iron and steel industry increased in 2017 over its level in 2008 and $\widehat{P_t}$ is calculated by holding the base year emissions intensity constant over the period. Therefore, applying the Levinson (2015) method may exaggerate the role of the composition effect and understate the role of the technique effect. To date, we know that CO_2 emissions reached their apogee in 2013 after the Fukushima Daiichi nuclear disaster due to the maximum usage of fossil

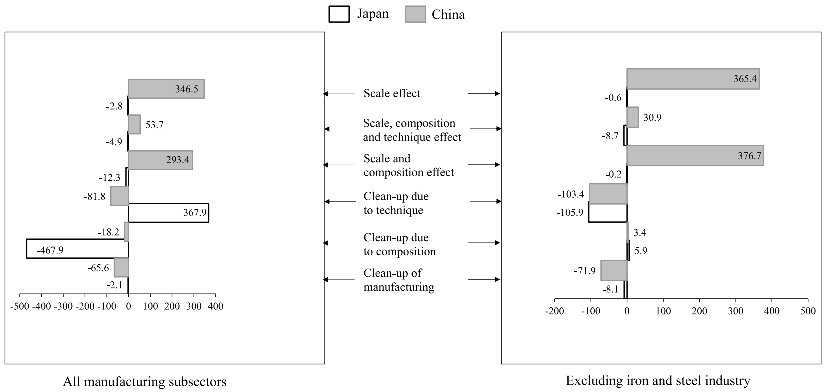

Fig. 5 Summary of Changes in Scale, Composition and Technique Effects in All Manufacturing Subsectors (*Source* Authors' own calculations and the original sources are METI [2020], GIO [2020], National Bureau of Statistics of China [2005–2017] and Shan et al. [2018; 2020])

fuel-dependent energy. Consequently, the transition to alternative energy has become more complicated (Kuramochi 2014). Recently, Liao and Ren (2020) found that the energy efficiency of Japanese manufacturing industries from 2003 to 2016 was volatile but has significantly improved, especially since 2014. The energy self-efficiency ratio of Japan was 6.4% in 2014 and increased to 9.6% in 2017. Considering the above, we turn to Figs. 6 and 7 to examine the more recent composition effect and emissions intensity trends by changing the base year to 2011.

The actual reduction in CO_2 emissions was 7.7% in all manufacturing subsectors and 9.9% after excluding the iron and steel industry (Table 3). A 2020 GIO report says that emissions declined sharply in 2014, which strongly aligns with our results. In addition, Levinson (2015) found that the composition effect accounted for only 12% and the technique effect 88% of the total cleanup of US air pollution. From our analysis, the technique and composition effect shares in the total manufacturing cleanup of 14% are 57% and 43%, respectively (Table 3 and 4). We can say that the contribution of the composition and technique effects is split in half for all manufacturing sectors in Japan. This finding further confirms the lack of technological improvement in the iron and steel industry. Levinson (2015) mentioned that securing a major share of cleanup from

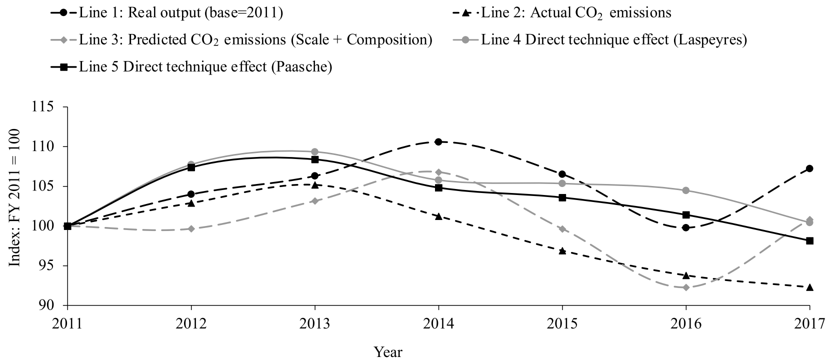

Fig. 6 Changes in Scale, Composition and Technique Effects of All Manufacturing Subsectors (2011–2017) in Japan (*Source* Authors' own calculations and the original sources are METI [2020] and GIO [2020])

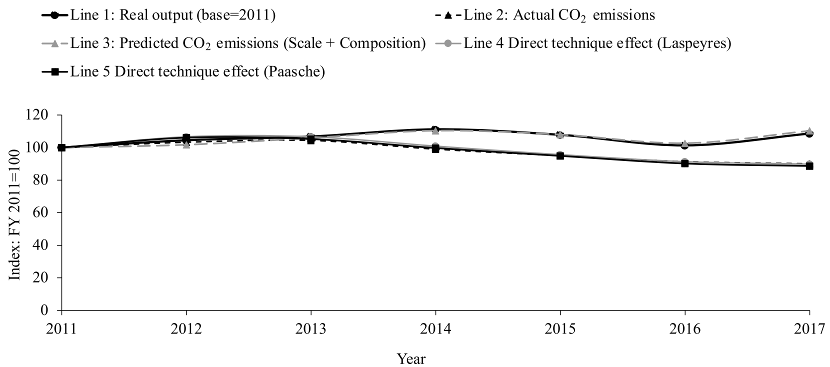

Fig. 7 Changes in Scale, Composition and Technique Effects in Japanese Manufacturing Excluding the Iron and Steel Industry (2011 to 2017) (*Source* Authors' own calculations and the original sources are METI [2020] and GIO [2020])

the technique effect rather than the composition effect is encouraging since technologies developed earlier by one country can be replicated in others.

Nevertheless, the overall cleanup of Japanese manufacturing occurred due to declining emission intensities in subsectors other than the iron

Table 3 Scale, Composition and Technique Effect in Japanese Manufacturing (2011–2017)

	(1)	*(2)*	*(3)*	*(4)*
	Scale (%)	Scale, composition and technique (%)	Scale and composition (%)	Cleanup due to composition (%)
All industries	7.23	−7.71	0.83	42.86
w/o iron and steel	8.63	−9.92	10.30	−9.03

Note (4) = [(1)− (3)]/[(1)− (2)]

Table 4 Cleanup of CO_2 within Japanese Manufacturing (2011–2017)

	All industries (%)			*Without iron and steel (%)*		
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
	Cleanup	Technique share	Technique effect	Cleanup	Technique share	Technique effect
Indirect	−13.93	−7.96	57.14	−17.08	−18.62	109.03
Direct (Laspeyres)	−13.93	−6.3	45.53	−17.08	−17.3	101.42
Direct (Paasche)	−13.93	−8.5	60.77	−17.08	−18.3	107.38

Note Columns 1 and 4 are the difference between lines 1 and 2; (107.23–92.29)/107.23 (all industries); (108.63–90.08)/108.63 (without iron and steel industry). The 1st row of Column 2 is Column 1 times (1−0.4), and Column 5 is Column 4 times (1− (−0.09)); the 2nd and 3rd rows of Columns 2 and 5 are the percentile decline in the Laspeyres and Paasche indexes; Column 3 is the ratio of Columns 2 and 1; Column 6 is the ratio of Columns 5 and 4

and steel industry. As can be seen in Figs. 2 and 7, the composition effect increases pollution when a major share of cleanup comes from the technique effect. As described in Tables 2 and 4, the iron and steel industry reduces the role of the true technique effect; as a result, the technique share is smaller for all manufacturing sectors. Finally, our main purpose is to show changes in the share of total manufacturing output ($= \frac{v_{it}}{V_t}$), CO_2 emissions ($= \frac{p_{it}}{P_t}$) and emission intensity ($= z_{it}$) of the iron and steel industry over the periods. This represents another way to understand

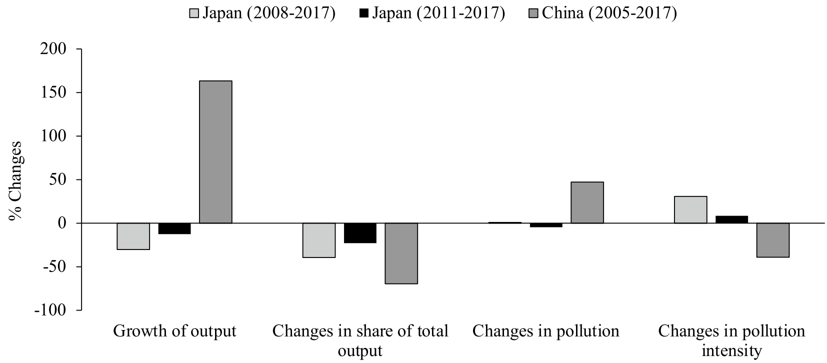

Fig. 8 Changes in the Iron and Steel Industry within Japanese and Chinese Manufacturing over the Sample Periods (*Source* Authors' own calculations and the original sources are METI [2020], GIO [2020], National Bureau of Statistics of China [2005–2017] and Shan et al. [2018; 2020])

what actually happens in different time periods[2] inside the iron and steel industry. Figure 8 shows that the Japanese iron and steel industry's share in output is weakening and that changes in total pollution and pollution intensity continue to increase. However, total pollution and the pollution intensity of CO_2 decline more when 2011 instead of 2008 is set as the base year, suggesting that the Japanese iron and steel industry is slowly improving. We provide some raw data for Fig. 8 in Table 5.

Conversely, the results for the Chinese manufacturing subsectors show that the total cleanup is almost entirely explained by the decline in pollution intensity in both the iron and steel industry and in overall manufacturing. Moreover, China's manufacturing sector shows an upward trend in $\widehat{P_t}$, with CO_2 emissions suddenly falling in 2016 and declining by 18%. In the 13th Five-Year Plan (2016–2020), China set peak targets for carbon emissions and energy and water consumption as well as goals for increasing the efficiency of industries and eliminating outdated or overcapacity production facilities, increasing energy production from renewables and developing green infrastructure. Regarding carbon emissions, China aimed to reduce carbon intensity by 18% from 2015 levels by 2020 (State

[2] As we discussed earlier, the results changed remarkably only for the iron and steel industry in Japan during the time period from 2008 to 2017 and 2011 to 2017.

Table 5 Changes in the Iron and Steel Industry (Japan and China)

	(1)	*(2)*	*(3)*
	Japan (2008–2017)	Japan (2011–2017)	China (2005–2017)
Growth in output (%)	−30.3	−12.7	163.3
Changes in share of total output (%)	−39.3	−22.8	−69.6
Changes in pollution (%)	0.9	−4.8	47.1
Changes in pollution intensity (%)	30.9	8.5	−39.2

Note The 1st row of Columns is (final year-base year)/base year; 2nd, 3rd and 4th rows of Columns are (final year-base year)/final year

Council of China 2016), in line with China's pledge to the UNFCCC at COP21 in Paris in December 2015.

Figure 8 presents the changes in the results on the share in total output, CO_2 emissions and pollution intensity between 2005 and 2017 for China. The iron and steel industry grew; however, the share in the output of overall manufacturing declined. The 13th Five-Year Plan stressed economic restructuring. Key priorities include resolving nationwide industrial overcapacity, promoting investment across sectors, strengthening property protections, supporting reform of state-owned enterprises and private sector development, reforming healthcare coverage and approval procedures, addressing licensing barriers, modernizing agricultural efficiency, encouraging workforce population rebalancing and rural area entrepreneurship, advancing technology innovation, emphasizing energy efficiency and reducing carbon emissions. The output share of iron and steel has declined under such economic restructuring.

Moreover, Fig. 8 shows that the pollution intensity decreased while the total pollution continued to increase. Cole and Zang (2019) also found similar results for SO2 and waste gas. The decline in emissions intensity from the iron and steel industry along with overall Chinese manufacturing is highly encouraging, although the actual total pollution is still increasing. China's steel sector has undergone a significant change under the 13th Five-Year Plan. The industry removed 200 million tons per year of excess capacity and upgraded 610 million tons per year of ultralow emissions capacity under the plan (MEE 2020). We can conclude that China currently must take more steps to reduce CO_2 emissions not only in the iron and steel industry but also in all manufacturing subsectors.

More attention should be paid to these trends of increasing CO_2 emissions, especially acknowledging the situation of the iron and steel industry in Japan, to reduce GHGs to the desired lowest level. This represents the main difference between Japan and China (shown in Table 5).

Recently, impact investors and other climate-aware organizations have focused their attention on the steel industry, as this sector needs to reduce its GHG emissions intensity by 65% from 2014 levels by 2050. Realizing the threat worldwide, a range of individuals and investors have begun a fossil fuel divestment movement that could lead to pressure on the steel business (Baron and Fischer 2015). In addition, it has been estimated that the increasing carbon price puts approximately 14% of steel companies' potential value at risk (CDP 2019). The Task Force on Climate-Related Financial Disclosures (TCFD), established by the Financial Stability Board, has recommended a framework to help businesses and investors for evaluating the potential risks and opportunities of a transition to a lower-carbon economy. Governance, strategy, risk management and metrics and targets are the core elements of the recommended climate-related financial disclosures. If steel industries adopt these measures and create an information framework, it would benefit investors and stakeholders in understanding how they evaluate climate-related issues on the business activities (TCFD 2017). The World Steel Association (2019) proposed the establishment of a baseline to understand considering environmental, social and governance (ESG) risks related to the steelmaking supply chain and the advance of a common approach to identifying potential opportunities for positive actions that the industry can adopt.

Even without the iron and steel industry, the predicted pollution of Chinese manufacturing subsectors is to increase, as is also the case in Japan. These results potentially indicate that declines in pollution emissions from Chinese and Japanese manufacturing subsectors other than the iron and steel industry have been accelerated by innovative improvements in production techniques and proper legal regulations. Our finding is in line with previous results based on the same method that confirmed technique effect was the main driver of reduced pollution emissions in, for instance, the US, the EU and China. Other studies have also found that environmental regulations have a strong, significant positive impact on technological innovation that can reduce CO_2 emissions (Hashmi and Alam 2019; Neves et al. 2020).

8 Conclusion

In this study, we decomposed the energy impact of the iron and steel industry of manufacturing subsectors from Japan and China. Our findings suggest that the technique effect has been the main driver of the overall manufacturing cleanup in industries other than the iron and steel industry. We observe that total pollution and pollution intensity increased in the iron and steel sector in Japan, although a decreasing trend occurred from 2011 to 2017. A similar tendency was observed in India, where total carbon emissions and emission intensity increased from 2007 to 2013 (Zhu et al. 2018). Whereas China's pollution intensity is decreasing, total pollution from overall manufacturing and the iron and steel industry is still increasing. In a recent study, the authors recommended some policies to mitigate CO_2 emissions, especially from the iron and steel industry, since regional heterogeneity decreases CO_2 considering environmental regulations in China (Chen et al. 2019). From our findings, it is clear that to transition toward a low-carbon economy and to mitigate CO_2 emissions, steelmakers must urgently deploy and commercialize radical technologies. Deep decarbonization in the iron and steel industry is feasible, as summarized by Skoczkowski et al. (2020). Thus, technology innovation systems require firm political support and intensive research and development financing to minimize business risk.

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CHAPTER 8

The Impact of Imports, Technological Progress and Domestic Demand on the Growth of and Structural Changes in China's Steel Industry

Jun Ma and Naoki Kakita

1 Introduction

Since the industrial revolution, the steel industry in most developed countries has grown along with the national economy. In this sense, the analysis of the growth process of a country's iron and steel industry usually promotes an understanding of the characteristics of the country's economic growth. China is no exception; its steel industry has grown

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significantly in line with economic growth since the reform and opening up that began in 1978.

In 1980, the world's total crude steel production was 715.6 million tons,[1] and China (excluding Taiwan and Hong Kong) produced 37.1 million tons, which accounted for approximately 5.2% of the world's total. In addition, although the production of iron ore in China (112.59 million tons) accounted for as much as 12% of the world's total production (931.38 million tons), the iron content of the iron ore mined domestically was very poor, and the smelting technology for crude steel was not highly developed.

However, by looking at the final consumption of finished steel products (apparent steel use), the total global consumption was 576 million tons, while the consumption of China was 33.7 million tons, which accounted for only 6% of the world total. Additionally, by examining the export volume of steel products, China exported only 398 thousand tons, which was negligible as a percentage of the world's total export volume (140.72 million tons); for imports, China imported 5.01 million tons, which was 3.5% of the world total (141.21 million tons).

As indicated in the statistics above, the Chinese steel industry had a very small presence in the world until the early 1980s, but by 2018, it had become the number one producer and consumer of crude steel to occupy half of the world's totals. Moreover, its iron ore imports came to represent half of the world's production, and it exported one-quarter of the world's production. China has become a considerably large steel-producing country.

Turning to the perspective of the East Asian region, after the end of World War II, Japan's steel industry grew significantly with the country's rapid economic growth, and in the 1970s, its production reached the top level in the world. Since then, however, production has been declining, and as of 2018, although production remained at a level of 100 million tons, it equaled only approximately one-ninth of China's production. However, continuous casting technology, which dramatically reduces costs through technological innovation, was adopted in Japan at the fastest pace in the world, and the resulting high-strength steel sheets made a significant contribution to lightweight automobiles. The steel industry of the Republic of Korea (ROK) also grew significantly from

[1] Unless otherwise noted, all statistics presented in this paper are adapted or calculated based on data from the World Steel Yearbook for each year.

the 1980s to the 1990s consistent with economic growth, and the ROK has become a top steel producer in terms of both production scale and productivity.

Although it initially lagged behind Japan's and the ROK's industries, China's steel industry has grown rapidly since the mid-1980s and surpassed Japan in crude steel production to become the top producer in 1996. However, its production scale and productivity improved significantly only when the automotive and railway industries in China began to grow rapidly after 2000.

Although the steel industries in these three East Asian countries have grown along with the countries' own economies, these countries currently hold the most important position in the world's steel industry, and the trade in steel products among them has become increasingly close.

In China, imports of steel products were mostly from Japan until the late 1980s, which accounted for 60% of China's total imports. Since 2000, the number of imports from Japan has been declining, and it currently stands at 20%, while imports from the ROK have gradually increased to approximately 20% of the total (see Figs. 1 and 2).

The above facts suggest that the growth of China's steel industry has largely been driven by the expansion of demand due to domestic economic growth since 2000 but has also been influenced by the trade relations with Japan and the ROK. In addition, China's steel industry has shifted from emphasizing scale expansion to promoting structural change.

Accordingly, there is a need to elucidate the mechanisms involved in the process of such growth, and an understanding of these mechanisms will contribute to understanding the growth of the overall economy in China.

Considering the above issues, this chapter seeks to describe the mechanisms by analyzing the impact of factors such as global iron ore price fluctuations, technological progress in China's domestic steel production, changes in the demand for final goods and changes in the trade relations with Japan and the ROK on the growth of China's steel industry.

2 Literature Review

Movshuk (2004) used a stochastic frontier model with panel data to evaluate the impact of major reform initiatives on enterprise performance in China's iron and steel industry and concluded that although the production possibility frontier of the examined enterprises was shifting upward,

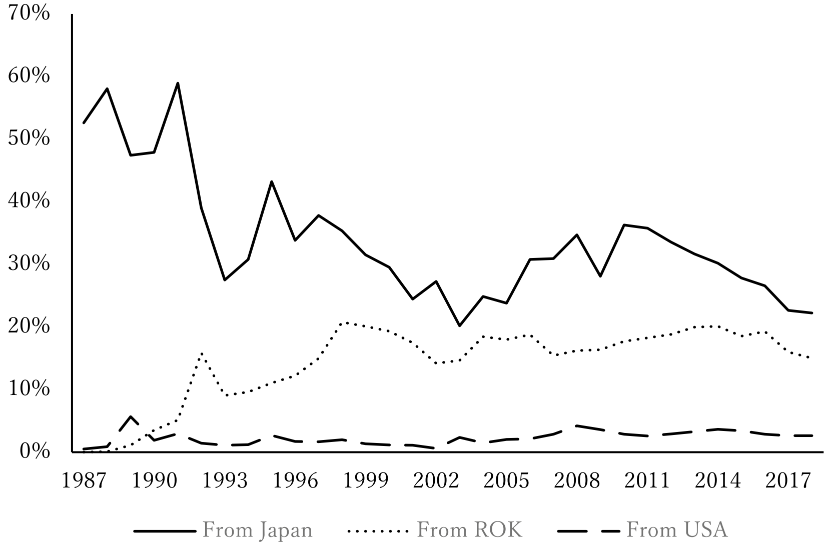

Fig. 1 Steel Import Rates of China from Japan, the ROK and the USA (*Source* Created by the author based on data from the United Nations [1980–2018])

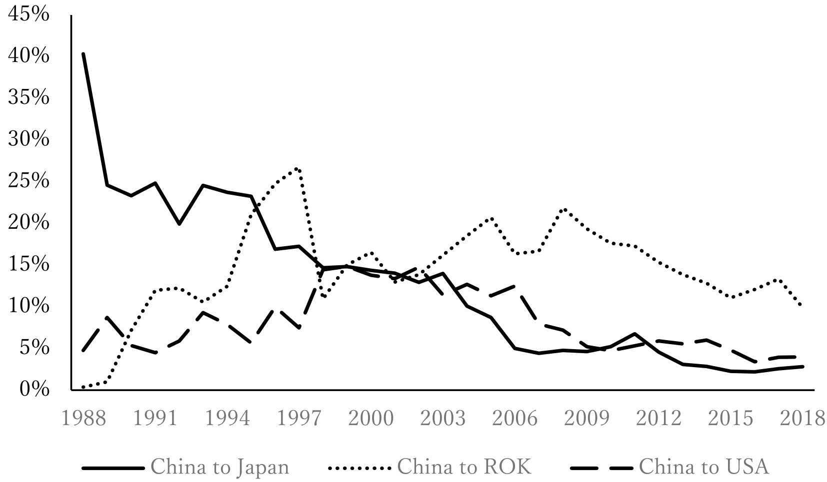

Fig. 2 Steel Export Rates from China to Japan, the ROK and the USA (*Source* Created by the author based on data from the United Nations [1980–2018])

their technical efficiency did not improve significantly and was even deteriorating in the mid-1990s. Moreover, the largest steel enterprises did not have a pronounced efficiency advantage over smaller enterprises, although the Chinese authorities considered large steel enterprises to be the core of ongoing centralized merger campaigns to create internationally competitive steel conglomerates.

Hernandez *et al* (2018) analyzed the most recent and most comprehensive data on the global steel industry and quantified the savings associated with energy- and material-saving measures. They reported that a global shift from average ore-based production to the best available operation methods could save up to 6.4 EJ/year in 2010.

Li *et al* (2018) analyzed the material and value flows of iron-containing commodities between China and other countries worldwide and revealed several facts. First, during the period from 2010 to 2016, the total number of iron materials imported to and exported from China increased by 224 million tons and 81 million tons, respectively. Second, 90% of the iron material imported by China consisted of iron ore and was imported from Australia and Brazil. More than 98% of the iron material exported from China consisted of rolled steel and IEPs (mainly engineering machinery and land vehicles) and was exported to Japan, the ROK and the US. Third, China had an international iron trade surplus, which increased from 31 billion USD in 2010 to 272 billion USD in 2016 at an average annual growth rate of 130%.

Sui *et al* (2019) focused on steel products in different stages of the industrial chain. They revealed various features of price transmission, calculated the Granger causality relationship between different steel products in different markets and in the midstream industry chain, and analyzed the network indicators. First, emerging economies play a major role in international steel product price transmission. Second, billets and plates of middle thickness are the components with the greatest price transmission in the steel market. Third, China imposes the broadest price transmission impacts in most regions. Finally, steel products at the end of the midstream steel industrial chain are "bridges" of price transmission activities.

However, previous studies, including those described above, have not analyzed the impact of global iron ore price fluctuations and technological advances in the steel industry on the production of steel products. This study focuses on these factors.

3 Theoretical Analysis

For the analysis, we use a vertically related market model introduced by Bernhofen (1995), who showed that the price dumping of an intermediate good arises from technological differences in final good production. Recently, Kuo *et al* (2016) analyzed the effects not only of antidumping duty but also of price policies by using a modified version of Bernhofen's model. We use a model similar to Kuo *et al* (2016) in this chapter.

By building on Kuo *et al* (2016), we use the following simple theoretical model. There are two countries, Country 1 and Country 2, and each has an upstream firm and a downstream firm. Each upstream firm produces an identical intermediate good, specifically, a steel product by using a primary good, namely an iron ore, imported from a world primary good market at a given price. Initially, each upstream firm of both countries uses one unit of the primary good to produce one unit of the intermediate good. Therefore, the production technologies of the upstream firms are the same initially. We assume that the upstream firm of Country 1 produces only for the domestic intermediate good market, but the upstream firm of Country 2 produces for both intermediate good markets, which enables us to analyze the trade of the intermediate good. We assume that both upstream firms compete in Cournot fashion in the intermediate good market of Country 1.

For the final good, we assume that each country has one downstream firm that uses one unit of the intermediate good to produce one unit of an identical final good. Thus, there is no difference in production technology. Both downstream firms produce final goods only for the final good market in Country 1, and they compete in Cournot fashion. Thus, the downstream firm of Country 2 exports all production to Country 1.

With this simple setting, we focus on analyzing the effects on the price of the intermediate good in Country 1, the production of the intermediate good of the upstream firm in Country 1, the export to Country 1 of the upstream firm in Country 2, and the supply of the final good in Country 1 due to the exogenous change of a primary good price in a world primary good market, the technological level of the upstream firm in Country 1, and the exogenous positive change in the demand of the final good in Country 1.

This chapter assumes the simple duopoly model in both the intermediate good market and the final good market. The profit functions of the upstream firms are as follows:

$$\pi_1 = (w_1 - kp_w)z_{11}, \tag{1}$$

$$\pi_2 = (w_1 - p_w)z_{21} + (w_2 - p_w)z_{22}, \tag{2}$$

where k is the necessary units of material to produce one unit of intermediate good, w_1 and w_2 are the prices of the intermediate good in Countries 1 and 2, respectively, p_w is a primary good price in the world primary market, z_{11} is the production of the intermediate good of the upstream firm in Country 1, and z_{21} and z_{22} represent the production of the upstream firm in Country 2 for each market.

The linear inverse demand function of the final good in Country 1 is

$$p_1 = a - b(x_{11} + y_{21}), \tag{3}$$

where p_1 is the price of the final good, a is the consumers' highest willingness to pay, $b \in [0, 1]$ is a constant slope of the inverse demand function in Country 1, and x_{11} and y_{21} represent the production of the downstream firm of Country 1 and Country 2, respectively.

The profit functions of the downstream firms are as follows:

$$\Pi_1 = (p_1 - w_1)x_{11}, \tag{4}$$

$$\Pi_2 = (p_1 - w_2)y_{21}, \tag{5}$$

where $x_{11} = z_{11} + z_{21}$, and $y_{21} = z_{22}$.

We assume that there is a two-stage game. In the first stage, both upstream firms simultaneously choose their optimal output in the intermediate good markets, and in the second stage, both downstream firms simultaneously choose their output in the final good market. Therefore, the subgame perfect Nash equilibrium is solved through backward induction.

In the second stage, the first-order conditions for the profit maximizations of the downstream firms are

$$\frac{\partial \prod_1}{\partial x_{11}} = a - b(2x_{11} + y_{21}) - w_1 = 0, \tag{6}$$

$$\frac{\partial \prod_2}{\partial y_{21}} = a - b(x_{11} + 2y_{21}) - w_2 = 0. \tag{7}$$

From these, we have solutions for the final good market in Country 1:

$$\begin{bmatrix} x_{11} \\ y_{21} \end{bmatrix} = \frac{1}{3b}\begin{bmatrix} a - 2w_1 + w_2 \\ a + w_1 - 2w_2 \end{bmatrix}. \tag{8}$$

Thus, considering that $x_{11} = z_{11} + z_{21}$ and $y_{21} = z_{22}$, we have the inverse demand functions for intermediate goods:

$$\begin{bmatrix} w_1 \\ w_2 \end{bmatrix} = \begin{bmatrix} a - 2b(z_{11} + z_{21}) - bz_{22} \\ a - b(z_{11} + z_{21}) - 2bz_{22} \end{bmatrix}. \tag{9}$$

In the first stage, the first-order conditions for the profit maximizations of the upstream firms are

$$\frac{\partial \pi_1}{\partial z_{11}} = a - 2b(2z_{11} + z_{21}) - bz_{22} - kp_w = 0, \tag{10}$$

$$\frac{\partial \pi_2}{\partial z_{21}} = a - 2b(z_{11} + 2bz_{21}) - 2bz_{22} - p_w = 0, \tag{11}$$

$$\frac{\partial \pi_2}{\partial z_{22}} = a - b(z_{11} + 2z_{21}) - 4bz_{22} - p_w = 0. \tag{12}$$

Thus, we have the equilibrium production of the intermediate good:

$$\begin{bmatrix} z_{11} \\ z_{21} \\ z_{22} \end{bmatrix} = \frac{1}{12b}\begin{bmatrix} 2a - 2(2k-1)p_w \\ a + (2k-3)p_w \\ 2a - 2p_w \end{bmatrix}. \tag{13}$$

Then, considering that $x_{11} = z_{11} + z_{21}$ and $y_{21} = z_{22}$, we have the equilibrium production of the final good:

$$x_{11} = \frac{1}{12b}\{3a - (2k+1)p_w\}, \tag{14}$$

$$y_{21} = \frac{1}{6b}(a - p_w), \tag{15}$$

We also have the equilibrium price of the final goods:

$$p_1 = \frac{1}{12}\{7a + (2k+3)p_w\}. \tag{16}$$

From Eqs. (9) and (13), we have the equilibrium prices of the intermediate good:

$$w_1 = \frac{1}{3}\{a + (1 + k)p_w\}, \tag{17}$$

$$w_2 = \frac{1}{12}\{5a + (5 + 2k)p_w\}. \tag{18}$$

By using the above equilibrium variables, we can summarize the results of the comparative statics in Table 1 assuming that initially, $k = 1$ for simplicity.

The main findings are as follows:

First, the effects of an exogenous positive change in a primary good price in a world primary good market are positive for the price of the intermediate good in Country 1, negative for the production of the intermediate good of the upstream firm in Country 1 and the export of the upstream firm in Country 2, and also negative for the supply of the final good in Country 1. Thus, the increase of a primary good price in a world primary good market shrinks the intermediate good market in Country 1, which brings a decrease in the demand for the final good.

Second, an exogenous positive change in the technological level of the upstream firm in Country 1 from an initial situation ($k = 1$) decreases the price of the intermediate good in Country 1. This change means that the upstream firm in Country 1 has the technological advance against the upstream firm in Country 2, which brings an increase in the production

Table 1 Results of the comparative statics

	dp_w	dk	da
$\boldsymbol{dw}_1$	$\frac{1}{3} > 0$	$\frac{1}{3}p_w > 0$	$\frac{1}{3} > 0$
dw_2	$\frac{7}{12} > 0$	$\frac{1}{6}p_w > 0$	$\frac{5}{12} > 0$
dp_1	$\frac{5}{6} > 0$	$\frac{1}{6}p_w > 0$	$\frac{7}{12} > 0$
$\boldsymbol{dz}_{11}$	$-\frac{1}{6b} < 0$	$-\frac{1}{3b}p_w < 0$	$\frac{1}{6b} > 0$
$\boldsymbol{dz}_{21}$	$-\frac{1}{12b} < 0$	$\frac{1}{6b}p_w > 0$	$\frac{1}{12b} > 0$
dz_{22}	$-\frac{1}{6b} < 0$	no effect	$\frac{1}{2b} > 0$
$\boldsymbol{dx}_{11}$	$-\frac{1}{4b} < 0$	$-\frac{1}{6b}p_w < 0$	$\frac{1}{4b} > 0$
dy_{21}	$-\frac{1}{6b} < 0$	no effect	$\frac{5}{12b} > 0$

of the upstream firm in Country 1 and decreases the production in the upstream firm in Country 2. In addition, the former effect is greater than the latter effect, which brings an increase in the supply of the final good in Country 1.

Third, the exogenous positive change in the demand of the final good in Country 1 positively affects all endogenous variables.

4 Empirical Analysis

Since the purpose of this chapter is to analyze the factors that affect the steel industry and the final goods industry related to steel products in China, we focus only on the results related to Country 1 in the variables analyzed by the theoretical model. Specifically, we examine the effects of the change in the world iron ore price, the demand change for final goods in China, the effects of technological progress of steel production in China on the import price and the quantity of steel products from Japan and the ROK, the production of steel products, and the production of the final goods related to steel products in China.

4.1 The Focus and Data Resources

The data used for the estimation were obtained from the following sources. First, the data for imports of iron ore and all steel products from other countries to China were obtained from the United Nations Comtrade database and based on the classification of SITC Rev.2. Second, the data for the production of iron ore and all steel products and final products related to steel in China were obtained from the National Bureau of Statistics of China (1980–2019), and the world price data of iron ore were from World Bank Commodity Price Data (The Pink Sheet) (World Bank 1980–2018). Third, the data concerning the production of iron ore and crude steel in each country that exports steel products to China were obtained from the World Steel Yearbook (World Steel Association 1980–2019) for each year from 1990 to 2018. Therefore, the data of the demand for final goods in the Chinese market were used as the data of final consumption from the National Bureau of Statistics of China (1980–2018). We matched the steel product data published in the China Industrial Statistics Yearbook with the data of the United Nations Comtrade database (United Nations 1980–2018) to obtain panel data on the steel products.

The codes, names and definitions of each steel product are shown in Table 2.

Table 2 Name, code and definition of steel products based on the CTD and CISY

Name of steel products	*Code and description in the SITC Rev.2*	*Name and definition in CISY*
Iron ore	281, Iron ore and concentrates	Iron ore
Pig iron	671, Pig and sponge iron, spiegeleisen, etc., and ferro-alloys	Pig iron
Ingots	672, Ingots and other primary forms of iron or steel	Ingots
Wire rods	6731, Wire rod of iron or steel	Wire rods
Light sections	67331, U, I, H sections, hot-rolled (not high carbon, alloy), of less than 80 mm	Light sections (< 80 mm)
Heavy sections	67332, U, I, H sections, hot-rolled (not high carbon, alloy), of 80 mm or more	Heavy sections (> 80 mm)
Plates and sheets	6744, Sheet, plates, rolled of thickness 4.75 mm or more of iron or steel 6745, Sheet, plates, rolled of thickness 3 mm to 4.75 mm of iron or steel 6746, Sheet, plates, rolled of thickness less than 3 mm of iron or steel	Heavy plate, medium plate and sheet
Railway tracks	676, Rails and railway track construction materials of iron or steel	Railway tracks
Tubes	678, Tubes, pipes and fittings of iron or steel	Tubes and fittings

Note CISY is an acronym for China Industrial Statistics Yearbook. Source Sorted by the author based on the United Nations (1980–2018) and National Bureau of China (1980–2019)

Additionally, the import prices of the iron ore and steel products exported from Japan and the ROK to China were divided by the respective import amounts to calculate the price of exports from each country to China.

Furthermore, according to the theoretical analysis, if China's technology for producing steel from iron ore is more advanced than the technology of exporting countries, then steel product imports will decrease, and production will increase. Specifically, if the amount of iron ore used to produce 1 unit of steel products in a country that exports steel products to China is one and the respective figure in China is k, then k is the relative productivity of China compared with the exporting country. In this case, to analyze the impact of the relative productivity of Chinese steel products, we set k to be a ratio of the amount of iron ore needed to produce one unit of crude steel between China and a country that exports steel products to China. If k is greater than 1, then China will increase imports instead of increasing its domestic production of steel products, while if k is less than 1, then China will increase its production of steel products instead of increasing imports.

However, there are two types of crude steel production processes. One is a process of melting iron ore, coke and limestone in a blast furnace, and the other is a process of melting iron scrap in an electric furnace. We use data that express the relative productivity of producing crude steel in blast furnaces because more than 90% of the crude steel in China is produced in blast furnaces. Specifically, we use the ratio as a proxy for China's technological progress, which indicates the total amount of iron ore (produced domestically or imported) needed to produce one unit of crude steel through oxygen-blown converters in China divided by the respective amount in the country that exports steel products to China in year t.

The data of crude steel production and iron ore production in each country were obtained from the World Steel Yearbook for each year from 1990 to 2017, and the yearly import amounts of iron ore were obtained from the United Nations Comtrade database.

In addition, China's accession to the WTO effective from 2002 is expected to have a significant impact on the steel industry and the industries engaged in the production of steel-related final goods. Therefore, we set a dummy variable for the years after 2002 to measure the effect of WTO accession.

The US and other OECD countries implemented anti-dumping measures against China's steel production in 2015, with a resulting impact on China's steel production since 2016. Therefore, we also introduce a dummy variable for the years after 2016 to represent the effect of the anti-dumping measures.

As an explained variable, first, the import price of steel products from Japan and other counties to China is calculated by dividing the total value of China's imports from a given country by the import quantity. Second, the production of other countries for the Chinese market is determined according to the amount that China imports from each country.

In addition, because steel products are widely used in many industries and there are a large number of related final goods, in this paper, we use the data of the steel-related final goods with a relatively high proportion of steel products in the total products.

Because the purpose of this paper is to analyze the impact of Japan and the ROK on Chinese steel products, which are in the same East Asian region and have close trade relations with China, in the next section, we focus on Japan and the ROK and estimate their respective impacts by using the panel data above. The descriptive statistics for each variable are shown in Table 8 of the Appendix.

4.2 Analysis of the Impact of the Import Prices from Japan and the ROK

The theoretical analysis suggests that the export price must be at least equal to the price in the steel product market of the target country when one country exports a steel product to another country's market. The price is positively influenced by the price of iron ore, the technical level of steel production and the demand for final goods in the target country.

Therefore, the estimation formula can be set based on the result of the theoretical analysis.

$$Ln(imp)_{i,t} = c_1 + \alpha_1 p_{wt} + \beta_1 a_t + \gamma_1 k_t + \sigma_1 (WTOd) + \tau_1 (ADd) + \mu_t \quad (19)$$

In the above formula, $Ln\ (imp)_{i,t}$ is the logarithm of the import price of steel products i (=Heavy section, Light section, Plate sheet, Railway track, Tube, Wire rod; the same applies hereafter) from Japan and the ROK to China. p_{wt} is the world price of iron ore, a_t is the demand for final goods in China, and k_t is the productivity of crude steel in China relative to Japan and the ROK in year t. Additionally, *WTOd* represents a dummy variable for China's accession to the *WTO*, and *ADd* represents a dummy variable for the anti-dumping measures against China.

Before conducting the estimation, we first tested for the existence of unit roots in the data on import prices from Japan and the ROK. Since no unit root was found, we adopted a linear model for estimation. To avoid the endogeneity problem associated with the iron ore price, we introduced a one-year lag of world iron ore production as an instrumental variable. After estimation, we performed Hausman's test on the result, and the estimation result for the random effects model was adopted. The estimation results are shown in Table 3.

The following estimation results were obtained. First, the coefficients for the world iron ore prices, the demand for final goods in China and the relative productivity of crude steel in China are all positive, and all values are significant except for the productivity of crude steel in China relative to Japan.

Table 3 Estimation results of the impact on the import price of steel products from Japan and the ROK

Variable	*Japan*	*ROK*
World iron ore price (p_w)	0.0067***	0.0081***
	(3.098)	(4.077)
Final consumption (a)	0.0003***	0.0002**
	(3.406)	(2.379)
Crude steel productivity (k)	0.0017	0.1112**
	(0.025)	(2.047)
WTO dummy (*WTOd*)	−0.3103*	0.0544
	(−1.780)	(0.317)
AD dummy (*ADd*)	0.4161	0.1987
	(1.639)	(0.825)
Const.	6.0360***	5.5514***
	(23.947)	(24.170)
Number of observations	165	162
Wald Chi2	152.58	174.805
sigma_u	0.3667	0.3199
Sigma_e	0.3667	0.3199
Rho	0.4191	0.3694
Hausman test p-value	0.9999	0.9980
	RE	RE

Note *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

Therefore, the estimation results for the import prices from Japan and the ROK almost match the results in the theoretical model.

In addition, the coefficient of the WTO dummy is significant and negative in the estimation for Japan. It can be observed that the import price of steel products from Japan was reduced after China entered the WTO.

4.3 Analysis of the Impact of the Import Quantity from Japan and the ROK

According to the theoretical analysis, the quantity of steel products (import quantity) provided by the steel producers of one country in the markets of the target country is positively impacted by the steel production technology and the demand for final goods in the target country. In contrast, the impact of iron ore prices depends on the technical level of steel production in the target country.

Therefore, based on the results of the theoretical analysis, the estimation formula can be set as follows:

$$Ln(imq)_{i,t} = c_2 + \alpha_2 p_{wt} + \beta_2 a_t + \gamma_2 k_t + \sigma_2(WTOd) + \tau_2(ADd) + \mu_t \tag{20}$$

In the above formula, Ln $(\text{imq})_{i,t}$ represents the logarithm of the quantity of the steel product i imported from other countries in the year t, and the definitions of the other variables are the same as in the estimation formula (19).

We tested for the existence of unit roots in the panel data for the import quantities from Japan and the ROK before estimation. Since the result indicated the existence of a unit root, we used a dynamic panel model with a one-year lag for the explained variable and all explanatory variables to estimate the panel data. To avoid an endogeneity problem with the explanatory variables, we introduced a one-year lag of world iron ore production as an instrumental variable in the estimation model. We ran a Sargan test on the estimated result to confirm that there was no overidentification problem. The results are shown in Table 4.

In this estimation, the following results were obtained. First, the coefficient value of the import amount of the previous year is significant and positive; therefore, the import quantity of the current year largely depends

Table 4 Estimation results of the impact of the import quantity of steel products from Japan and the ROK

Variable	*Japan*	*ROK*
Import qty ($Ln(imq)_{i,\ t}$)(-1)	0.4389***	0.3571***
	(8.567)	(2.703)
World iron ore price (p_w) (-1)	0.0011	0.00004
	(0.243)	(0.006)
World iron ore price (p_w)	−0.0010	−0.0048
	(−0.281)	(−0.696)
Final consumption (a) (-1)	0.0040*	0.0035*
	(1.890)	(1.735)
Final consumption (a)	−0.0041*	−0.0035*
	(−1.953)	(−1.958)
Crude steel productivity (k) (-1)	−0.5973	−1.1682***
	(−1.174)	(−2.789)
Crude steel productivity (k)	0.8125	0.9752***
	(1.577)	(2.702)
WTO dummy (*WTOd*)	0.7521**	0.4200
	(2.402)	(0.668)
AD dummy (*ADd*)	−0.2160	−0.6973*
	(−0.563)	(−1.887)
Const.	1.9279***	3.1661***
	(2.667)	(3.213)
Number of observations	153	151
Wald Chi2	833.47	52408.78
Arellano-Bond test AR(1) P-value	0.0556	0.0990
Arellano-Bond test AR(2) P-value	0.1892	0.0452
Arellano-Bond test AR(3) P-value		0.3425
Sargan test p-value	0.1089	0.2568

Note *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

on the import quantity of the previous year. Second, regarding the coefficient of the world price of iron ore, no significant result is obtained for the previous year or the current year. In addition, the coefficient for the demand for final goods in China is significant in both the previous year and the current year, but the coefficient in the previous year is positive, and the coefficient in the current year is negative. Furthermore, the coefficient for the relative productivity of crude steel is not significant in either the previous year or the current year for Japan, while the coefficient in the estimation for the ROK is significantly negative in the previous year but significant and positive in the current year. Finally, the WTO dummy is significant and positive in the estimation for Japan, but the AD dummy is significant and negative in the estimation for the ROK.

From this result, we first learn that a theoretical analysis that uses the comparative statistics model does not always accurately reflect reality, which entails dynamic changes. The following can be said from the estimation results of the dynamic model.

First, fluctuations in the world price of iron ore did not affect the import of steel products from Japan and the ROK. Second, the imports of steel products increased due to the increase in the demand for final goods in the previous year and conversely, decreased due to the increase in the demand in the current year. Third, the imports from Japan and the ROK are decreasing due to the improvement in the relative productivity of crude steel in China. Moreover, China's accession to the WTO increased the imports of steel products from Japan but did not affect China's imports from the ROK. However, the anti-dumping measures reduced imports from the ROK.

Considering the above estimation results, steel products imported from Japan would be considered complementary goods that are not produced in China, but steel products imported from the ROK would be substitutes for goods that are produced in China.

4.4 Analysis of the Effects of the Production of Chinese Steel Products

According to the theoretical analysis, the production of steel products in China has a negative effect on the world price of iron ore and the productivity relative to the exporting country but a positive effect on the domestic demand.

Based on the theoretical analysis, the estimation formula can be set as follows:

$$Ln(prz)_{i,t} = c_3 + \alpha_3 p_{wt} + \beta_3 a_t + \gamma_3 k_t + \sigma_3(WTOd) + \tau_3(ADd) + \mu_t \quad (21)$$

In the above formula, $ln\ (prz)_{i,\ t}$ represents the logarithm of the production volume of Chinese steel product i in year t, and the definitions of the other explanatory variables are the same as in formula (19).

Before estimation, we first conducted a unit root test on the data for the production of Chinese steel products, and the existence of a unit root was not confirmed. Therefore, we used a linear model for the estimation.

In addition, to avoid the endogeneity problem associated with the world iron ore price, we introduced a one-year lag of global iron ore production as an instrumental variable.

Furthermore, import prices from other countries are thought to have an impact on domestic production. Therefore, they were also added to the estimation formula as a control variable. Based on the results of the Hausman test, the fixed effects model was adopted for the estimation for Japan, while the random effects model was adopted for the estimation for the ROK. The results are shown in Table 5.

The following results were obtained in the estimations. First, the coefficients of the world price of iron ore are not significant, but both are positive. The demand for final goods and the relative productivity of crude

Table 5 Estimation results for steel product production in China

Variable	*Japan*	*ROK*
World iron ore price (p_w)	0.0011	0.0006
	(0.598)	(0.263)
Final consumption (a)	0.0005***	0.0005***
	(7.101)	(7.784)
Crude steel productivity (k)	−0.1828***	−0.165***
	(−3.476)	(−3.681)
Import price (ln) (p_{im})	0.1601**	0.1241
	(2.199)	(1.384)
WTO dummy ($WTOd$)	0.1271	0.057
	(0.905)	(0.402)
AD dummy (ADd)	−0.3227	−0.3258
	(−1.500)	(−1.497)
Const.	8.4241***	8.6827***
	(12.096)	(13.817)
Number of observations	162	159
Sigma_u	1.2484	0.8080
Sigma_e	1.2484	0.8080
Rho	0.9326	0.8539
Wald Chi2	604.00	578.06
Hausman test p-value	1.000	0.9998
	RE	RE

Note *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

steel in China are significant and positive. This result is almost consistent with the expectations of the theoretical analysis. Furthermore, in the estimation results for Japan, the coefficient of the import price of steel products from Japan is significantly negative.

These results suggest the following. The increase in the production of steel products is greatly affected by the increase in the demand for final goods and the improvement in the relative productivity of crude steel in China. High import prices of steel products from Japan also led to increased production in China. Furthermore, it seems that China's accession to the WTO in 2002 and the launch of anti-dumping measures in 2016 have had little impact on China's steel production.

4.5 Analysis of the Influence of the Production and Import of Steel Products on Final Goods Production in China

The theoretical analysis suggests that the production of steel-related final goods in China is negatively influenced by the world price of iron ore and the relative productivity of steel products in China compared to the countries that it imports from but is positively influenced by the demand for final goods in China. Based on the above results and Eq. (14), the estimation formula can be set as follows:

$$\begin{aligned} Ln(fgx)_{j,t} =& c_4 + \alpha_4 p_{wt} + \beta_4 a_t + \gamma_4 k_t \\ &+ \hat{\delta}_4 \widehat{\ln(prz)_{i,t}} + \hat{\theta}_4 \widehat{\ln(imq)_{i,t}} \\ &+ \sigma_4 (WTOd) + \tau_4 (ADd) + \mu_t \end{aligned} \tag{22}$$

Note that $Ln(fgx)_{j,\ t}$ in the above formula represents the logarithm of the production of steel-related final goods j (=Metal cutting machine, Tractor, Power equipment, Refrigerator, Car, Railway track, Oil and LNG pipeline, and Building area) in year t in China. The definitions of the other variables are the same as in the estimation formula (19).

Before conducting the estimation, we first tested for a unit root in the data for the production of steel products in China. Because no unit roots were present, a linear model was selected. To avoid an endogeneity problem with the world iron ore price, a one-year lag in world iron ore production was introduced as an instrumental variable.

We also added the estimated values of China's production of each steel product and imports from other countries, a dummy variable for membership in the WTO (*WTOd*) and a dummy variable for anti-dumping

(*ADd*) as control variables. The estimated results for the two countries are reported in Tables (6) and (7). Note that the tables show the values of the estimates adopted according to the results of the Hausman test for individual cases.

First, regarding the impact of changes in world iron ore prices, the estimates for Japan and the ROK are similar, and all are significant. The coefficient for the production of railway tracks is negative, while the coefficients for the other final goods are positive. The analysis of the theoretical model, however, suggests that the world price of iron ore has a negative impact on the production of the final goods related to steel products. Thus, the estimated results for the other final goods, excluding railway tracks, are contrary to the theoretical expectations.

Second, for China's demand for final goods, the results of the estimates for Japan and the ROK are similar, and all of the coefficients are significantly positive. This is consistent with the results of the theoretical analysis.

Third, for the productivity of crude steel in China relative to Japan and the ROK, the estimates for all final goods are negative. However, in both estimates, the estimates for refrigerators, cars, and oil and LNG pipelines and construction are significant. In addition, the estimates for railway tracks are significant in the estimates for Japan, and the estimates for cutting machines are also significant in the estimates for Korea. These estimates are broadly consistent with the theoretical analysis, but they also suggest that the relative productivity level of Chinese crude steel differs between Japan and the ROK.

Fourth, by viewing the estimated results for the fitted value of the production of Chinese iron ore products, which was estimated by using world iron ore prices, China's demand for final goods, the relative productivity of crude steel and the coefficients for the production of cutting machines, railway tracks and oil and LNG pipelines are significant in the estimations for both Japan and Korea. In particular, interestingly, the coefficient on railway tracks is positive, while the other coefficients are negative in both estimates.

Moreover, considering the estimates for the fitted value of imports from Japan and the ROK that have been estimated by using world iron ore prices, the demand for final goods and the relative productivity of crude steel in China, the results for all final goods are positive. In the estimation for Japan, the results for electric facilities, refrigerators, cars and

Table 6 Estimation results for the impact of the import of steel products from Japan on the production of Chinese steel-related final goods

	Metal_cut	*Tractor*	*Power equip.*	*Fridge*	*Car*	*Railway*	*Pipeline*	*Building area*
World iron ore price (p_{ww})	0.0083***	0.0123***	0.0138***	0.0086***	0.0085***	−0.0006***	0.0047***	0.0035***
	(4.854)	(3.747)	(4.300)	(6.420)	(3.025)	(−3.645)	(7.844)	(2.623)
Final consumption (a)	0.0008***	0.0012***	0.0007*	0.0008***	0.0010***	0.0002***	0.0006***	0.0007***
	(3.913)	(3.164)	(1.846)	(7.397)	(3.145)	(10.719)	(12.666)	(4.381)
Crude steel productivity (k)	−0.0753	−0.0748	−0.2162	−0.3989***	−0.6063***	−0.0235***	−0.2239***	−0.5311***
	(−0.843)	(−0.434)	(−1.286)	(−6.356)	(−4.097)	(−2.652)	(−8.022)	(−7.618)
Production of steel ($Ln(prz)$) (Fitted value)	−1.1403***	−0.8727	−0.9297	−0.4978**	−0.0328	0.0815*	−0.2732***	0.0522
	(−2.708)	(−1.076)	(−1.174)	(−2.106)	(−0.047)	(1.954)	(−2.599)	(0.159)
Import qty of steel ($Ln(imq)$) (Fitted value)	0.007	0.0534	0.1408**	0.0344**	0.2149***	0.0037	0.0101	0.0847***
	(0.215)	(0.846)	(2.290)	(2.284)	(3.969)	(1.131)	(1.510)	(3.319)
WTO dummy	0.8231***	0.0529	0.8396***	0.1702**	0.2391	−0.021**	0.0527	−0.1655**
	(8.790)	(0.293)	(4.768)	(2.066)	(1.542)	(−2.262)	(1.440)	(−2.266)
AD dummy	−0.396***	−0.4367*	0.1891	−0.2979***	−0.3338	−0.054***	−0.1566***	−0.3209***
	(−3.189)	(−1.825)	(0.810)	(−2.738)	(−1.624)	(−4.394)	(−3.237)	(−3.313)
Constant	12.9669***	8.8122	15.2143**	11.7341***	4.0322	1.0855***	3.3838***	11.109***
	(3.252)	(1.147)	(2.029)	(5.282)	(0.611)	(2.749)	(3.426)	(3.572)
Number of observations	159	159	159	159	159	159	159	159

(continued)

Table 6 (continued)

	Metal_cut	*Tractor*	*Power equip.*	*Fridge*	*Car*	*Railway*	*Pipeline*	*Building area*
Groups	6	6	6	6	6	6	6	6
Wald (Chi2(4))	55821.07	8758.89	84180.54	3885.42	43814.01	17900.00	9586.96	934807.38
F test P-value	0.3838	0.9217	0.3704		0.0335	0.5406		0.1290
Hausman test P-value	0.0000	0.0000	0.0005	0.6410	0.0000	0.0000	0.4000	0.0000
	FE	FE	FE	RE	FE	FE	RE	FE

Note *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

Table 7 Estimation results for the impact of the import of steel products from the ROK on the production of Chinese steel-related final goods

	Metal_cut	*Tractor*	*Power equip.*	*Fridge*	*Car*	*Railway*	*Pipeline*	*Building area*
World iron ore price (p_w)	0.0098***	0.0112***	0.0134***	0.0071***	0.0071***	−0.0008***	0.0041***	0.0016
	(5.554)	(4.019)	(4.856)	(5.523)	(3.167)	(−4.319)	(7.333)	(1.316)
Final consumption (a)	0.0011***	0.0013***	0.0008*	0.0008***	0.0011***	0.0002***	0.0007***	0.0006***
	(3.863)	(2.927)	(1.760)	(4.906)	(3.659)	(5.734)	(9.514)	(3.554)
Crude steel productivity (k)	−0.1956**	0.0222	−0.0695	−0.2488***	−0.3443***	−0.0024	−0.1751***	−0.3127***
	(−2.008)	(0.144)	(−0.457)	(−4.057)	(−3.237)	(−0.240)	(−6.613)	(−5.457)
Production of steel ($Ln(prz)$) (Fitted value)	−1.7441***	−1.0225	−1.0126	−0.3971	−0.201	0.1503**	−0.3315**	0.2699
	(−3.013)	(−1.117)	(−1.120)	(−1.172)	(−0.342)	(2.484)	(−2.266)	(0.852)
Import qty of steel ($Ln(imq)$) (Fitted value)	0.0507*	0.0833*	0.1822***	0.0356***	0.0679***	0.0028	0.0103*	0.0249**
	(1.822)	(1.893)	(4.190)	(2.643)	(2.908)	(0.976)	(1.774)	(1.976)
WTO dummy	0.6768***	0.2029	0.8606***	0.2131***	0.5684***	−0.0182	0.0591*	−0.0451
	(6.398)	(1.213)	(5.209)	(2.599)	(3.998)	(−1.642)	(1.670)	(−0.589)
AD dummy	−0.5306***	−0.5904**	0.1111	−0.3551***	−0.5489***	−0.0377**	−0.219***	−0.3732***
	(−3.091)	(−2.176)	(0.415)	(−2.998)	(−2.672)	(−2.101)	(−4.282)	(−3.371)
Constant	18.6119***	9.8355	15.6061*	10.591***	5.6781***	0.4254	3.8633***	9.0155***
	(3.423)	(1.144)	(1.838)	(3.331)	(1.030)	(0.748)	(2.813)	(3.033)
Number of observations	157	157	157	157	157	157	157	157

(continued)

Table 7 (continued)

	Metal_cut	*Tractor*	*Power equip.*	*Fridge*	*Car*	*Railway*	*Pipeline*	*Building area*
Groups	6	6	6	6	6	6	6	6
Wald (Chi2(4))	44625.71	10447.26	97501.19	263432.22	3315.24	12800.00	10719.35	4137.89
F test P-value	0.1583	0.6518	0.0182			0.3853		
Hausman test P-value	0.0000	0.0000	0.0000	0.2551	0.1193	0.0000	0.9950	0.1040
	FE	FE	FE	RE	RE	FE	RE	RE

Note *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$

building area achieve significance, while the results for Korea are significant for all of the dependent variables except railway tracks. In particular, by observing the values, it becomes apparent that the imports of steel products from Japan and Korea contribute significantly to the production of electric power equipment, and imports from Japan contribute significantly to the production of cars compared to other final goods in China.

Additionally, in the estimates for both countries, the WTO dummies are positive for all final goods except for railway tracks and construction, and significant estimates are obtained for cutting machines, power equipment, refrigerators, automobiles and pipelines. That is, accession to the WTO has increased the production of many final goods, but it has had no impact or even a negative impact on railway and building production in China. In contrast, regarding anti-dumping, the imposition of anti-dumping measures appears to have had a suppressive effect on the production of most steel product-related final goods in China since significant and negative results are obtained for all products except power equipment.

5 Conclusion

From the above findings, the following conclusions can be derived. First, of the three influencing factors (world iron ore prices, the relative productivity of crude steel in China and the demand for final goods in China), the increase in the demand for final goods in China is the largest factor that has led to higher prices and lower import volumes of steel products from Japan and the ROK and an increase in the domestic production of steel products and final goods related to steel products in China.

Second, the improvement in the relative productivity of crude steel in China compared to the ROK has also contributed significantly to the increase in the production of steel products and final goods related to steel products in China and a decrease in the price and volume of steel products imported from the ROK. Subsequently, the world price of iron ore increased the price of steel products imported from other countries and thereby increased the domestic production of steel products and further boosted the production of final goods related to steel products in China. This result is not consistent with the results of the theoretical analysis perhaps because China's demand for final goods has grown too large. In this sense, the traditional comparative statistics model may have limitations in interpreting China's economic growth.

Third, overall, the growing demand for final goods in China has contributed significantly to the rising price and increasing volume of steel products imported from Japan and the ROK and to the increasing production of steel product-related final goods in China, but the contribution differs according to the product category. Steel products imported from Japan have contributed the most to China's production of cars, followed by power equipment, buildings and refrigerators, but not to the production of cutting machines, tractors, railway tracks and pipelines. Steel products imported from the ROK have contributed the most to the production of power equipment, followed by tractors, cars, cutting machines, refrigerators, construction and pipelines, and they contribute the least to the production of railway tracks. If these results are considered to be linked to the second conclusion noted above, then the steel products imported from Japan are mainly for the production of cars and electric equipment that cannot be produced in China, while the steel products imported from the ROK are primarily used to meet the demand for the final goods that can also be produced in China.

Fourth, in response to structural shifts in the demand for final goods, the domestic production and import volumes of various types of steel products have changed. Specifically, the production of steel products required for the production of cutting machines, pipelines and refrigerators has decreased, while related imports have increased. On the contrary, the steel for railway construction is mainly supplied by domestic production.

Fifth, with China's accession to the WTO, the import of steel products from Japan and the ROK and the production of steel products within China have increased. The production of many final goods related to steel products has also increased, but there has been a rather negative impact on industries such as railway construction and construction, which have grown significantly in China. This is a new finding contributed by this study and should be further analyzed in the future.

Finally, although the imposition of anti-dumping measures has had very little direct impact on the imports and production of steel products, it has had a negative effect on the production of many final goods related to steel products in China.

It should be noted that the accuracy of the estimated results for the panel data is not sufficiently high because the items of trade and the items of domestic production for steel products in China do not exactly match. It is necessary to better match these items for a more accurate estimation in the future.

Appendix

See Table 8

Table 8 Descriptive Statistics

Variable	*Number*	*Unit*	*Mean*	*Std. Dev.*	*Min*	*Max*
1.World iron ore price (p_w)	165	US$/dmt	64.687	45.612	26.470	167.754
2.Crude steel productivity (k) (CN/JP)	165	Index Japan = 100	2.309	0.848	1.375	4.134
3.Crude steel productivity (k) (CN/ROK)	164	Index KR = 100	2.509	1.105	1.298	4.735
4.Import amount of steel (from JP to CN)	165	1000US$	383,038	718,163.5	77.152	3,660,988
5.Import quantity of steel (from JP to CN)	165	Kiloton	407.671	747.046	0.064	3,019.170
6.Import price (from JP to CN)	165	1000US$/Kiloton	1,093.032	1,110.544	147.958	5,301.443
7.Import amount of steel (from ROK to CN)	164	1000US$	194,486	422,715	1.453	2,075,125
8.Import quantity of steel (from ROK to CN)	164	Kiloton	238.797	509.359	0.000	2,105.517
9.Import price (from ROK to CN)	164	1000US$/Kiloton	1,045.726	1,054.614	125.648	8,648.761
10.Production of steel (CN)	162	Kiloton	32,919.2	36,606	1,340	153,834
11.World production of iron ore	165	Kiloton	1,365,668	458,393	884,044	2,162,524
12.Final consumption (a) index (CN)	165	1980 = 100	1,231.087	973.093	210.670	3,665.990

(continued)

Table 8 (continued)

Variable	*Number*	*Unit*	*Mean*	*Std. Dev.*	*Min*	*Max*
13.Metal cutting machine (CN)	165	10th Unit	44.815	26.897	11.910	88.680
14.Tractor (CN)	165	10th unit	22.396	22.069	3.770	68.820
15.Electric equipment (CN)	165	10th kw	7,070.803	5,574.997	1,164.2	15,053.02
16.Refrigerator (CN)	165	10th Unit	3,717.317	3,197.540	463.060	9,255.740
17.Car (CN)	165	10th Unit	430.998	466.506	3.500	1,248.310
18.Railway (CN)	165	10th km	7.919	1.981	5.780	12.700
19.Pipeline (CN)	165	10th km	4.918	3.389	1.590	11.930
20.Building area (CN)	165	10th m^2	175,402.7	140,525.6	19,552.5	423,357.3
21.WTO dummy (CN)	165		0.564	0.497	0	1
22.AD dummy (CN)	165		0.055	0.228	0	1

Source Calculated from 1989 to 2017, based on the data from United Nations (1980–2018), World Bank (1980–2018), World Steel Association (1980–2019), National Bureau of Statistics of China (1980–2018, National data), and National Bureau of Statistics of China (1980–2019, China Industrial Statistics Yearbook), respectively

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PART III

The Impact of the Growth of China's Steel Industry

CHAPTER 9

Effectiveness and Policy Analysis of International Capacity Cooperation of China's Steel Industry

Zhongyuan Zhang and Guoqing Zhao

1 Current Situation of China's Steel Industry

Over the past two decades, China's steel industry has seen rapid growth in its production capacity. Within this period, a complete industrial system has been developed that consists of sectors such as mining, sintering, coking, iron smelting, steelmaking, and steel rolling. The industry has also facilitated the development of ferroalloy, refractories, carbon products, geological prospecting, engineering design, construction, scientific research, and other related products or industries. At the beginning of the twenty-first century, China entered a high-growth stage, which dramatically drove up the demand for steel and promoted the rapid development of the steel industry. Since 2012, however, the growth in demand for steel

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products has significantly slowed down due to the lower rate of national economic growth. This, coupled with the declining demand from the international market, led to a lower utilization rate relative to China's steel production capacity. In 2016, China produced 808 million tons of crude steel, far below its capacity of 1.2 billion tons; the capacity utilization rate was only 67%, indicating serious overcapacity. The continuous efforts devoted to de-capacity since 2013 removed excess capacity by close to 200 million tons. In 2017, the total steel production was 831 million tons, indicating a utilization rate of 76% (see Table 1). The overcapacity persisted. The total production in 2018 was 928 million tons or 78% of the total capacity. Despite the slight increase in the utilization rate, the industry still has an overcapacity (Xin and Chen 2019).

At present, the overcapacity of China's iron and steel is not only absolute overcapacity, but also structural overcapacity. From the perspective of product classification structure, the low-end and rough processing fields have excess capacity, while the high-tech and high-value-added fields have insufficient capacity (see Table 2). During the first 8 months of 2019, the total crude steel production was 665 million tons, a year-on-year increase of 9.1%; the average comprehensive price index published by the China Iron and Steel Association (CISA) was 108.89, a year-on-year decrease of 5.33%. Overall, the steel price declined. The financial performance across the industry also declined, with a profit rate of only 4.88% for CISA members, representing a year-on-year decrease of 2.66 percentage points (see Fig. 1). On the surface, the rising price of iron ore has been the ostensible main reason for the phenomenon of profits not growing with production. Since 2019, the price of imported iron ore has been increasing, driving up the cost of steel by approximately 240 yuan per ton. The fundamental cause, however, is still supply and demand: The excess production has led to the declining profits. For instance, Ma (2017) used data from China's industrial firms to analyze the changes in the utilization rate of the steel industry and the relationship between firm type and performance. The research found that the capacity utilization rate is the dominant factor that affects firms' profit rates in the steel industry. Firms' capacity utilization rates and profit rates demonstrate similar trends of change; however, state-owned firms have significantly lower capacity utilization rates and profit rates than non-state-owned firms.

Zhang et al. (2018) estimated the long-term domestic demand for China's steel products and found that the per capita steel stock in use

Table 1 Overview of China's steel industry

Indicator	*Unit*	*1995*	*2000*	*2005*	*2010*	*2015*	*2016*	*2017*
1. Number of firms in the industry		1,639	2,997	6,686	12,143	9,540	8,498	7,712
2. Revenue from main operations	100 million yuan (RMB)	4,047.46	4,732.9	21,247.82	57,832.91	63,001.33	61,986.59	64,571.78
3. Volume of major products:								
Steel	10, 000 tons	9,535.99	12,850	35,323.98	63,722.99	80,382.5	80,760.94	83,138.09
Pig iron	10, 000 tons	10,529.27	13,101.48	34,375.19	59,733.34	69,141.3	70,227.33	71,361.93
Steel products	10, 000 tons	8,979.8	13,146	37,771.14	80,276.58	103,468.41	104,813.45	104,642.05
Iron ore (Quantity in raw ore)	10, 000 tons	26,191.86	22,256.19	42,049.28	108,016.1	138,128.9	127,173. 09	122,937.33
Coke	10, 000 tons	13,501.83	12,184.12	25,470.89	39,166.82	44,822.54	44,911.48	43,142.55
Ferroalloy	10, 000 tons	431.88	402.92	102.2	2435.5	3,666.4	3,554.65	3,288.68
Carbon products	10, 000 tons	169.36	261.11	138.21	205.59	366.39	378.11	411.63
Refractories	10, 000 tons	1,755		2,276.36	2,808.06	2,615.19	2,391.24	2,292.54
4. Continuous casting ratio	%	46.48	87.3	96.98	98.12	99.65	99.66	99.64
5. Investment in fixed assets	100 million yuan (RMB)	576.75	366.96	2,583.37	3,494.24	5,622.90	5,139.78	4,555.39

Source China steel statistical yearbook (2018)

Table 2 Capacity of main products of members of the China iron and steel sssociation (2013–2017) (unit: 10,000 tons)

Product	*2013*	*2014*	*2015*	*2016*	*2017*
1. Iron ore mining (raw ore)	32,068	33,483	35,968	47,556	45,297
2. Iron ore processing	35,245	37,778	40,456	40,526	39,426
3. Iron ore sintering	98,731	105,776	108,736	105,528	102,828
4. Iron ore pellets	16,881	18,025	17,154	16,302	16,201
5. Pig iron	76,942	78,830	80,104	75,285	71,713
6. Direct reduced iron	30	300	30	30	30
7. Crude steel	84,293	86,561	88,098	82,602	78,316
8. Continuously cast steel billets	83,962	86,640	89,470	86,358	82,824
9. Steel products	83,166	86,848	88,497	87,183	83,360
10. Steel wire and its products	500.85	500.09	315.98	311.98	329.86
11. Ferroalloy	132.45	126.96	88.89	92.09	110.35
12. Coke	14,508	14,403	15,345	16,018	15,131

Source China steel statistical yearbook (2018)

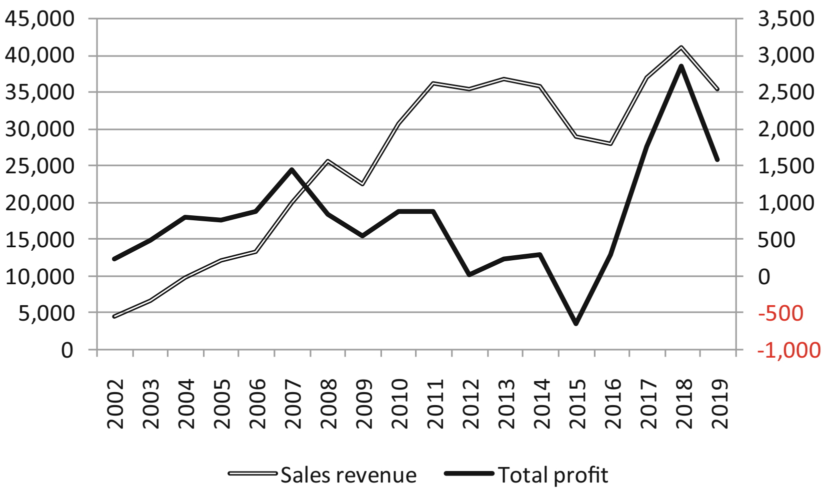

Fig. 1 Sales revenue and profits of CISA members (2002–2019) (unit: 100 million yuan) (*Source* CEIC database. The 2019 data are from January to October)

as of 2014 was 4.57 tons, almost halfway to the saturation level of developed countries. They predicted that domestic consumption of final steel products would peak at 670 million tons in 2020 and decline to 420 million tons by 2040. Based on the current requirements on de-capacity of the steel industry, by 2020 the production capacity for crude steel will be reduced to 1–1.05 billion tons; as a result, the utilization rate is expected to return to above 80%. In the long term, however, with China's urbanization wrapping up by mid-century, the per capita steel stock in use will approach saturation and the decline in domestic demand is invariable. Overcapacity will be a long-term issue facing the steel industry.

2 Analysis of Causes of Overcapacity in China's Steel Industry

Since the 2008 international financial crisis, various countries have rolled out economic stimulus policies to cope with the economic slowdown. Worldwide, however, the countercyclical effect of these policies is diminishing, the structural issues are becoming increasingly prominent, and overcapacity has evolved into a global problem. In 2018, ArcelorMittal, the world's largest steelmaking company, which is based in Luxembourg, reported a total crude steel production of 98.088 million tons, accounting for 5.89% of the global production. This was almost the sum of the total production of the second largest steel producer, Nippon Steel & Sumitomo Metal, and the third largest producer, HBIS Group. In the same period, ArcelorMittal reported a profit of $22 million. As of the third quarter of 2019, however, the firm recorded a net loss of $700 million, four times higher than the forecast. According to reports of Nihon Keizai Shimbun, Nippon Steel & Sumitomo Metal estimated a consolidated profit of over 300 billion yen for the 2015 fiscal year (up to March 2016), a year-on-year decrease of 30%. The previous profit forecast was 370 billion yen or a decline of 18%. Nippon Steel & Sumitomo Metal indicated that the demand for steel in the international market, where China was a major trader, had declined significantly, and profit-making was becoming increasingly difficult. Within Japan, meanwhile, the recovery of the steel market, which had mainly targeted the automobile and construction industries, had been slow, and demand was difficult to shore up. In November 2019, the largest steelmaking company in the United States (headquartered in Pittsburgh) also reported a loss, with a net loss of $173 million in the third quarter and a year-on-year decrease of a quarter of the total shipment, to 3.9 million tons.

In 2011, China's steel industry also entered a difficult period of operation marked by overcapacity and disorderly competition. The capacity utilization rate decreased to below 75%, and the decline continued. Firms' performance continued to deteriorate. In 2016, the global crude steel production was 1.629 billion tons, of which 54.1% was from China (44.8% in 2015). The product quantity and quality, as well as the deployment of the steel industry, had experienced significant improvement. China had developed a steel industry with the most complete industrial chain across the globe. However, with the transformation of China's economic growth mode, the issues that hindered development of China's steel industry, which was characterized by extensive development, became more prominent. Those issues included fierce homogeneous competition, overcapacity, insufficient innovation capacity, and environmental restrictions. By 2016, the overcapacity of the steel industry had evolved from regional and structural overcapacity to absolute overcapacity (Wang and Chen 2018). Currently, among all industries with overcapacities, the steel industry accounts for the largest total assets, employs the most workers, and has the most widespread involvement in socioeconomic activities in China. Consequently, this industry is the most representative in regard to de-capacity.

The steel industry's overcapacity is a result of both the general laws of the market economy and China's specific economic system. In terms of the influences of the market economy, the overcapacity of China's steel industry has demonstrated evident cyclical fluctuations that are common to the market economy. During high economic growth periods, investment in infrastructure increases, and so does the demand for steel; as a result, investment in the steel industry rapidly grows, and production capacity is inflated. With economic fluctuations, infrastructure investment slows down, and so does the demand for steel products. Consequently, the issue of overcapacity arises. In terms of economic management, China has adopted a decentralized public finance system. Local governments are tempted to increase investments and taxes, and they take various measures, such as favorable policies, to increase local investments. This leads to repetitive development and production overcapacity. Some data and phenomena indicate that imbalance in supply and demand in the steel industry is still likely to occur. During the first half of 2019, the crude steel production of CISA member firms increased by 5.64%, while that of non-CISA member firms increased by 24.08%, showing a significantly higher growth rate than that of member firms. Overall, non-CISA member firms accounted for 56.2% of the total production growth.

With the transition from a growth-centered economy to a quality-centered economy, China's steel industry has had to face a variety of difficult tasks, including eliminating the excess capacity, speeding up technological progress and innovation, and enhancing the industry's overall competitiveness (Xin and Chen 2019). Wang and Tong (2017) found that technological progress in China's steel industry has a significant impact on de-capacity, and accelerating technological progress is the right approach to fundamentally alleviate the overcapacity. Ma et al. (2018) noted that utilization rates in China's steel industry are not completely procyclical; in addition to the market factors, the utilization rates of firms in the steel industry are also influenced by nonmarket factors, such as financial support, sunk costs, the firm's scale, the elasticity of employment, and government subsidies. Ma and Dou (2017) found that economic fluctuations, local government investments, and capital intensity are positively correlated with overcapacity, while demand does not have a significant impact on overcapacity. Ma and Tian (2018) argued that market isolation can effectively control the pressure from external competitors on the local market and alleviate the overcapacity issue in the short term; in the long term, however, the protection of local steel firms' market share through market isolation is unsustainable. Such protection will gradually backfire after three years and turn the positive effects into negative ones. The isolation strategy adopted in China's regional competitions is short-sighted and will aggravate firms' overcapacity in the long term. From an industry policy perspective, Wang (2018) analyzed the causes of the steel industry's overcapacity in Japan and the United States, the measures taken to resolve the issue, and the effects. The research revealed that overcapacity is not limited to specific regions; it varies with development stages and can happen in a wide range of industries. In the process of removing excess capacity, industry policies should meet the following criteria: Policies should be consistent to be applicable to different economic cycles, although the targets of the measures may vary; the policies should consist of a comprehensive set of measures but should also accommodate different approaches to resource allocation in the local economy; policies should be developed from the perspective of the entire industrial chain and focus on technological innovation; policies should take into consideration the restrictions of resources and the environment and try to utilize the market participants' innovative ideas and actions; and policies should target key areas and regions and focus on international cooperation. In the future, to achieve the goal of removing the excess capacity, China should focus on the following areas when developing its industry policies: transformation and upgrading industrial structures; fostering firms' innovation capacity; resource endowment and the external environment; the development of policy systems and support measures; rejuvenation of small and mid-sized local businesses; and international capacity cooperation.

From the perspectives of the domestic manufacturing industry value chain, the global value chain, and the trade structure of the industry, Wang and Chen (2018) examined the formation of overcapacity in a context in which China's steel industry is locked at the low end of the value chain. Their study found that the steel industry is near the bottom of China's manufacturing value chain, and there is still a sizable gap between China and developed countries despite the enhancement of the overall value-added capacity and the continuing extension of the industrial chain; China's steel industry has been squeezed at home and abroad, and its overcapacity and its position at the bottom of the value chain reinforce each other. The rapid growth of the steel industry laid a foundation of industrialization for China's economic take off. However, the industry's development has been afflicted by a plethora of issues, such as overcapacity, low utilization rates, environmental pollution, and resource pressure. The traditional growth mode characterized by high input and high consumption is facing mounting challenges. Meanwhile, China's economy has entered a stage of high-quality growth and is undergoing a transformation from factor and investment-driven development to innovation-driven development. Nationwide, infrastructure development has slowed down, and the previously high demand for steel has also eased. Consequently, there is an urgent need for de-capacity and high-quality development in the steel industry. De-capacity has become imperative to allow the steel industry to enhance innovation capacity and improve competitiveness and the ability for sustainable development.

3 De-Capacity Policies of China's Steel Industry and Their Effect

Since 2011, the issues of low utilization rates and overcapacity in China's steel industry have become increasingly prominent. The entire sector is even facing the specter of operational losses. The steel industry is a key target of China's supply-side structural reform. To achieve de-capacity goals, the Chinese government has rolled out a set of policies to control and guide the industry.

3.1 Major De-Capacity Measures in the Steel Industry

First, the top-down policy design was streamlined. In February 2016, the State Council issued the Opinions on De-capacity, Predicament Alleviation, and Development of the Steel Industry (referred to as "Opinions" hereafter) (The Chinese Central Government 2016). This policy directive lays out the overall requirement, major tasks, and policy measures for the steel industry to remove excess capacity, alleviate predicaments, and achieve development. The document strictly prohibits the addition of new capacity and requires that laws, regulations, and industry policies regarding environment protection, energy consumption, quality control, safety, and technology be strictly followed. Steel production capacity that does not meet these requirements must be removed. The policy encourages firms to remove part of their production capacity through capacity reduction on their own initiative through mergers and restructuring, the transformation of production, relocation, and renewal, and international capacity cooperation. The document clearly declares that, building on de-capacity achieved over the past several years, starting in 2016, the overall production capacity of crude steel should be reduced by 100–150 million tons in 5 years. Ultimately, the implementation of this policy will achieve the following goals: substantial progress in mergers and restructuring; optimization of the industrial structure; improved efficiency of energy consumption; more reasonable capacity utilization rates; and significant increases in production quality and the capacity to supply higher-end products.

In 2017, de-capacity was the top priority of the supply-side structural reform in the steel industry. The National Development and Reform Commission clearly indicated that substandard steel products would be completely prohibited by June 30 of that year. In the same year, the Report of the 19th National Congress of the Chinese Communist Party established supply-side structural reform as a priority for the development of China's modern economic system and insisted on "de-capacity, de-inventory, de-leverage, reducing costs, and improving weak areas." This policy provides clear policy directions for the steel industry to implement supply-side structural reform and prioritizes de-capacity. In April

2018 and May 2019, six ministries of the central government, including the National Development and Reform Commission and the Ministry of Industry and Information Technology, jointly issued the Priorities of De-capacity for the Steel Industry for the respective year (referred to as "Priorities" hereafter). The 2018 Priorities listed 19 priorities for de-capacity in the steel industry, including setting goals and tasks for the year, firmly dealing with "zombie enterprises," and shutting down outdated production facilities in accordance with laws and regulations. "Zombie enterprises" in the steel industry were the major target of de-capacity in 2018, and the policy required that exits and shutdowns of these firms be accelerated. The 2018 Priorities also specified five types of steel capacity that do not meet the requirements of laws, regulations, and industry policies regarding environmental protection, quality control, energy consumption, water consumption, and safety, and they required facilities to be shut down in accordance with laws and regulations. The 2019 Priorities listed 20 priority areas and proposed the achievements of the de-capacity targets by 2019. The policy also required the following measures to be put in place: strengthening cooperation with the State Grid and the Southern Power Grid and monitoring power use by steel companies and related firms for the timely identification of construction and production activities that are against laws and regulations; facilitating the orderly relocation of steelmaking facilities in key areas, such as Beijing, Tianjin, and Hebei; reducing the total regional production capacity; and optimizing the spatial distribution of capacity.

Second, each province (autonomous region or directly administered municipality) also developed policies on de-capacity (see Table 3). For instance, in August 2016, the government of Anhui Province issued the Opinions on the Implementation of Measures for Reducing Overcapacity in the Steel Industry, Alleviating Predicament, and Facilitating Development. The policy required that between 2016 and 2020, the province should reduce its production capacity by 3.84 million tons for pig iron and 5.06 million tons for crude steel and arrange re-employment for 29,000 workers who would be displaced by the de-capacity measures. The policy proposed that, by 2020, firms in the steel industry would realize a productivity of 1,000 tons per employee. To achieve these goals, Anhui Province categorically prohibited any region or government department from approving steelmaking projects that would add capacity, no matter what justification the project sponsor may propose. For the Magang (Group) Holding Company, the province-controlled

Table 3 Merger and restructuring plans for the top 10 crude production provinces

Province	*Crude production as a proportion of national production (%)*	*Requirements of the master plan for the region*	*Local plan (as of 2020)*
Hebei	25.60	Capacity reduction and restructuring	Form a "2310" industry development layout led by HBIS Group and Shougang Group, supported by three local steel companies—Qian'an, Fengnan, and Wu'an—and supplemented by 10 specialty steel companies
Jiangsu	11.30	Capacity reduction and restructuring	Form a "134" industry development layout comprising one super-large steel company—Shagang Group (50 million tons); three extra-large steel companies—Zenith Steel Group, Yanhai Group, and Xuzhou Group (over 20 million tons); and four large specialty steel companies—Nanjing Iron and Steel Group, Xingcheng Special Steel, Tiangong Group, and Delong Steel

(continued)

Table 3 (continued)

Province	*Crude production as a proportion of national production (%)*	*Requirements of the master plan for the region*	*Local plan (as of 2020)*
Shandong	7.80	Capacity reduction and restructuring	Further reduce steel production capacity; full implementation of a circular economy; production capacity along the east coast to account for approximately 40% of total capacity
Liaoning	7.40	Regional integration and reduction in the number of firms	Active promotion of the integration of strong firms and striving to form one or two super-large and industry-leading groups with international influence
Shanxi	5.80	Regional integration	Overall goal of reducing the number of steel companies from 27 to 10 through mergers and integration
Anhui	3.40	Regional integration	Efforts to reduce overcapacity and encourage province- and city-controlled firms at the high and low ends of the industrial chain to merge and restructure through market-oriented measures, such as asset restructuring, cooperation on equity, asset swapping, strategic alliances, and joint development

Province	*Crude production as a proportion of national production (%)*	*Requirements of the master plan for the region*	*Local plan (as of 2020)*
Hubei	3.30	Regional integration	Reasonable adjustment of the scale and structure of the steel industry; efforts to increase the levels of resource utilization, energy conservation, and emission reduction; upgrades to the equipment of steel companies through restructuring
Henan	3.10	Regional integration	Reduction in the number of firms in the steel industry in Anyang from 11 to 4 to form a well-functioning industrial group comprising raw material supply, melting, rolling, and deep processing
Guangdong	3.10	Developing production bases along the coast and receiving production capacity shifted from the northern part of the province	No new steel projects will be built; by 2020, all firms in the steel industry will complete facility renewal to achieve the goal of super-low emissions; production bases will be developed along the coast
Jiangxi	2.70	Regional integration	Basically, complete relocation and renewal of heavily polluting firms in major urban areas

Source Sohu.com (2018)

steel company, Anhui Province required the firm to speed up the development of a modern enterprise system and improve its competitiveness (People.com.cn 2016). In accordance with the Implementation Plan for Steel Companies to Reduce Overcapacity, Alleviate Predicament, and Achieve Development (2016–2020) issued by the general office of the Hui Autonomous Region of Ningxia in 2016, during the next 5 years, Ningxia would encourage firms to exit the industry on their own initiative and facilitate mergers and restructuring. The government would employ a set of measures, including market, legal, financial, technical, and administrative measures, to lead and guide firms in the following categories to gradually exit the industry: firms that had not been in operation or had only been in partial operation for a long time; firms that had been suffering operational losses for a long time; and firms that do not have the prospect of making a profit (Economic Daily 2016). Hebei Province forced the elimination of overcapacity by implementing standards on environmental protection, energy and water consumption, quality control, technology, and safety. In 2019, a total of 14.02 million tons of steelmaking capacity was reduced in Hebei. The capacity of Langfang Steel was completely removed. Hebei Province planned to reduce its steelmaking capacity by 14 million tons in 2020 (official website of the CISA 2020).

Third, efforts were made to strictly crack down on capacity that is in violation of laws and regulations and to enhance the accountability mechanism. The measures that have been taken are as follows: complete prohibition of new capacity—under no circumstance and for no reason will a region or government department be allowed to approve or file any new steel production projects that will add to the existing capacity; removal of outdated production facilities—all government departments must more strictly follow the standards on environmental protection, quality control, technology, energy consumption, safety, and credibility and reduce capacity in accordance with laws and regulations. Of the measures, prohibition of new capacity is the key to ensuring the success of de-capacity policies. It is critical to strictly monitor and control the processes involved in capacity swapping and project filing to prevent a scenario in which "capacity increases while being decreased." It is necessary to standardize the processes of project filing and capacity swapping and prohibit any region from filing new steel melting projects that will add capacity; for projects that are deemed absolutely necessary, before the filing, the revised requirements on capacity swapping must be strictly followed, and the project must be made public and subjected to the public's scrutiny. Various levels of government must conduct self-examination and rigorously investigate unapproved projects, illegal capacity swapping, and project filing. Issues identified in the investigation should be addressed in a timely manner. In September 2017, the State Council planned and implemented random inspections for the de-capacity tasks of the steel industry in accordance with the predefined acceptance criteria, and accountability mechanisms were implemented accordingly. The State Council dispatched teams to conduct field inspections. The teams were tasked with pinpointing the barriers and difficulties in the process of implementing de-capacity policies and, building on the findings, developing effective measures to address the issues. All steel companies required to reduce capacity were inspected. Further, measures were implemented to phase out outdated facilities and technologies, eliminate development projects that are in violation of laws and regulations, and jointly enforce the laws on specific tasks.

Fourth, technological progress in the steel industry was enhanced. Measures toward this policy direction include adhering to the innovation-driven development strategy; encouraging firms in the steel industry and scientific research institutions to actively explore and effectively unleash the innovation potential of all kinds of talents; and enhancing the passion and enthusiasm for innovation. This policy also requires firms to focus on the stability of steel quality; advanced and high-end steel products; new energy-conservation and environment-protection technologies; key common technologies; basic research; frontier processes, technologies, and equipment; strengthening research and development; and quickly achieving breakthroughs. Due to the lengthy steel production process and the many pollutant-producing steps it involves, the steel industry is still a large emitter. In 2018, the steel industry accounted for approximately 7% of the sulfur dioxide, 10% of the nitrogen oxide, and 20% of particulate matter that was emitted nationwide. Over recent years, China's environmental supervision of the steel industry has become increasingly stringent. In April 2019, five departments of the central government, including the Ministry of Ecology and Environment, jointly issued the Opinions on the Implementation of Ultra-low Emission in the Steel Industry. The policy proposed that, in principle, newly constructed (or relocated) steelmaking projects should meet low-emission standards; it also required that, by the end of 2020, 60% of the capacity should be produced in facilities that have been reconfigured for low emissions.

3.2 Main Successes in De-Capacity in the Steel Industry

First, a large amount of excess capacity has been reduced, and firms' performance has become stable and is improving. Since 2017, the HBIS Group has reduced its iron-making capacity by 3.46 million tons and its steelmaking capacity by 5.02 million tons, equivalent to 1/10 of its original capacity (The HBIS Group 2019). In 2016, a total of 65 million tons of iron and steel production capacity was cut nationwide, far exceeding the original target of cutting 45 million tons of crude steel capacity. Building on this, in 2017, over 50 million tons of iron and steel production capacity was cut. Between January and July of 2018, 24.7 million tons of capacity were further cut. The target of cutting 140 million tons of crude production capacity during the 13th Five-year Plan was achieved ahead of schedule. Between 2011 and 2016, the utilization rate of crude steel capacity hovered around 73%. With the continuous de-capacity efforts, the utilization rate continued to grow and gradually returned to a reasonable range. By September 2018, the utilization rate had increased steadily to 78.7%, and the overcapacity issue was effectively alleviated. Meanwhile, the operational performance of the steel industry was improving. During the first half of 2018, there were 5,011 firms in China's steel industry, and they recorded a total revenue from main operations of 3,052.5 billion yuan (RMB), a year-on-year increase of 15.8%. The operational performance and profit-making of firms in the steel industry continued to improve.

Second, transformation and upgrading are forced upon firms in the steel industry. The goal of building a nation with a strong manufacturing sector has placed increasingly high requirements on steel products. Firms in the steel industry must transform themselves from mere suppliers of material to service providers that can provide materials, recommend solutions, and provide future processing and use designs and other extended services. After de-capacity, firms in the steel industry gradually rejected the traditional ideas of prioritizing quantity and started to pursue high-quality development. As a result, new technologies continuously emerge in the steel industry, and the industry's innovation capacity is growing increasingly stronger. For instance, HBIS Group strengthened innovation to enter the medium and high-end markets. In 2015, it opened access to the steel market for high-end appliances by holding Haier Special Steel. It collaborated with top automobile companies internationally, such as Mercedes-Benz and BMW; as a result, its automobile steel products have evolved from a single product to a series of products and from regular steel to all manner of super-strong steel products. The Baowu Steel Group adheres to technology innovation and has developed a series of high-end products represented by steel used for automobile and nuclear power, silicon steel, steel for 100-m heavy rails, and special materials for aviation and aeronautics. TISCO Group independently developed a 600-mm-wide, ultrathin steel product (referred to as a "hand-transportable steel sheet"), which can be widely used in aviation and aeronautics, the petrochemical industry, and electronics (Liu 2019). Magang Group and TISCO Group jointly developed wheels for high-speed trains with a maximum speed limit of 350 km per hour. A 60-million-km operation test has been completed for the material used for the axles, laying a solid foundation for the domestic manufacturing of axles for high-speed train wheels. The EH36 steel plate independently developed by Xingcheng Special Steel is only 250 mm thick and has been successfully used on Offshore Oil 162, the first mobile production platform, which is in trial operation. This represents a break of foreign monopoly and a landmark development in China's steel industry.

Nonetheless, controversy remains regarding whether the de-capacity policies are effective. Deng et al. (2018) used 2001–2016 provincial panel data and the breakpoint regression method to perform empirical analyses. The research found that if the year 2013 was set as the policy breakpoint, the de-capacity policies would be effective in the short term but not in the long term. Wang and Chen (2018) argued that under the set of policies that limit and reduce capacity, including supply-side reform and the policy of "de-capacity, de-inventory, de-leverage, reducing costs, and improving weak areas," the steel industry may have ended the industry-wide operational loss but failed to address the fundamental aspects of the overcapacity issue. Endogenous factors, such as distorted management systems and mechanisms, are the main cause of the steel industry's overcapacity. The long-term lock down of China's steel industry at the bottom of the value chain has aggravated the issue. As a result, the task of transforming and upgrading the industry is still challenging. Coordinated efforts from all parties involved are required to enhance merges, restructuring, and technological innovation; streamline industry standards and the oversight system; strengthen openness and international cooperation; solidify the results already achieved; and promote the high-quality development of the steel industry (Liu and Liu 2019).

4 Analysis of the Effect of International Capacity Cooperation on China's Steel Industry

4.1 Current Situation of International Capacity Cooperation

First, exports of steel products: As of the end of 2016, China's crude steel production was 808 million tons, of which net export was 98.55 million tons, or 12.2% of the total crude steel production, amounting to a year-on-year decline of 4%. Based on statistics from China Customs, total exports of iron and steel in 2015 were 100.368 billion tons, an increase of 22.3% from 2014; the monetary worth of the total exports in 2015 was $49.219 billion, a decline of 11.3% from 2014. The total export of iron and steel in 2016 was 97.001 billion tons, a decline of 3.4% from 2015; the monetary worth of the total exports in 2016 was $43.2626 billion, a decline of 12.1% from 2015. The export of finished steel products mainly comprises plates, rods, and wires, with plates accounting for approximately half of the exports and rods and wires accounting for over 30%. The export destination countries are mainly those surrounding China, including the Republic of Korea, Vietnam, the Philippines, Thailand, Indonesia, and Pakistan (see Table 4). The top five export destination countries are Republic of Korea, Vietnam, Thailand, the Philippines, and Indonesia. Export to Thailand has had the highest growth since 2015, with total volume increasing by 35.2% and total monetary worth increasing by 18.8%. Export to India has had the largest decline since 2015, with total volume decreasing by 35.5% and total monetary worth decreasing by 33.8% (Zhao and Li 2018).

Second, overseas building of plants by firms in the steel industry: In recent years, Chinese firms in the steel industry have sped up investing overseas. After many years of development, Hebei Province has established a relatively complete steel industry, with the world's leading technology and equipment and a large reserve of industrial workers. Their steel products have significant advantages in segmented markets. The province's steel industry has developed a solid foundation for its global expansion and the ability to allocate resources worldwide. In recent years, Hebei Province has been promoting international collaboration on production capacity. In May 2019, information released at the Hebei Iron and Steel Enterprises International Cooperation Platform Promotion and Exchange Meeting indicated that, in recent years, firms in Hebei's steel industry had sped up the adoption of the "going out" strategy

Table 4 Exports by country or region (2016–2017)

Item	*2016*		*2017*	
	Volume (10,000 tons)	*Monetary worth ($10,000)*	*Volume (10,000 tons)*	*Monetary worth ($10,000)*
Total exports	10,849.15	5,448,191.72	7,541.35	5,450,430.01
1. Republic of Korea	1,433.65	651,927.09	1,139.66	721,845.81
2. Vietnam	1,166.48	481,446.97	762.95	458,987.48
3. The Philippines	651.88	262,589.89	406.60	236,235.40
4. Thailand	620.75	289,194.00	313.78	218,912.55
5. Indonesia	582.92	227,283.93	289.64	179,670.39
I. Rods and wires	4,125.82	1,387,796.05	1,607.50	842,967.71
1. Republic of Korea	451.45	160,379.59	327.79	165,139.53
2. The Philippines	379.47	119,350.93	129.56	57,977.37
3. Indonesia	430.01	134,518.07	129.01	62,141.73
4. Thailand	381.59	124,682.97	115.29	61,303.67
5. Hong Kong	186.00	63,722.50	110.48	49,059.19
II. Angle profiles	502.16	204,841.55	322.37	178,558.57
1. Republic of Korea	94.55	35,605.14	51.61	26,637.89
2. The Philippines	41.48	19,567.13	42.98	23,748.60
3. Hong Kong	23.57	9,924.50	26.24	14,172.77
4. Malaysia	31.48	11,387.43	25.28	12,767.06
5. Myanmar	27.61	9,788.55	25.17	12,713.50
III. Plates	4,802.73	2,467,743.48	4,319.34	2,940,356.22
1. Republic of Korea	809.18	384,400.55	686.55	449,128.38
2. Vietnam	828.55	341,201.10	623.00	360,145.45
3. The Philippines	187.03	92,329.76	185.24	114,560.03
4. Pakistan	202.79	81,179.59	172.46	95,307.12
5. Thailand	174.90	99,176.04	166.13	122,680. 24
IV. Tubing material	967.12	784,761.84	874.88	840,532.08
1. India	52.70	49,659.36	48.10	55,176.80

(continued)

Table 4 (continued)

Item	*2016*		*2017*	
	Volume (10,000 tons)	*Monetary worth ($10,000)*	*Volume (10,000 tons)*	*Monetary worth ($10,000)*
2. Republic of Korea	48.93	38,552.80	44.95	42,978.02
3. Kuwait	44.21	29,944.57	41.57	30,455.56
4. The Philippines	32.25	20,765.08	35.92	28,231.84
5. United Arab Emirates	39.94	28,202.93	31.17	26,363. 28

Source China steel statistical yearbook (2018)

and implemented eight international collaboration projects on production capacity with a total capacity of over 6 million tons (Xinhuanet 2019). According to the 2019 White Paper on International Production Capacity Cooperation of Hebei Province released by the province's Reform and Development Commission, Hebei has been encouraging firms in the steel industry to build iron-making and steelmaking bases through greenfield investments and contracting projects in countries in Southeast Asia and Africa as a means of extending the firms' industrial chain of smelting and processing and expanding sales and trade. In central and eastern European countries, the firms also choose existing steel companies with good conditions and market potential and collaborate with them through acquisitions to expand the European market. In December 2019, HBIS Group signed a memorandum of understanding with POSCO of Republic of Korea to establish a joint venture in China for the research and development (R&D), production, and sale of high-end steel boards for automobiles. The parties will build on the cold rolling project of HBIS Group in Leting and develop a new company to produce high-strength steel boards for automobiles as well as high-grade automobile panels (official website of HBIS Group 2019).

Overseas factories are mainly located in the countries surrounding China, and countries in Southeast Asia are the main destinations. Examples of these factories include the one-million-ton whole-process steel project built by Nanjing Iron and Steel Group, the 300,000-ton ferronickel smelting project of Qingshan group, and the 200,000-ton steel pipe plant of Xinya Metal of Bazhou in Indonesia, the 600,000-ton hot-rolled narrow strip steel project of Delong Steel in Thailand, the medium-sized steel plate project of Jigang Group in Malaysia, and the 500,000-ton steel project of Kunming Steel Group in Laos. Currently, China has developed more than 150 economic and trade cooperation zones in 50 countries. Over recent years, many steel projects have been relocated from China to these cooperation zones. These projects include the 3.5-million-ton steel project of Shanghai Baoye Group in the Malaysia-China Kuantan Industrial Park of Malaysia, the 200,000-ton round steel project of Zhenzhen Steel in Ethiopia's Eastern Industry Zone, the color steel plate project of Bsteel in the Ussuriysk Industrial Park in Russia, and the steel project in the China-Nigeria Economic & Trade Cooperation Zone of Nigeria. The Indonesian Morowali Industrial Park has become an important base from which Chinese firms producing ferronickel and stainless steel can manage global deployment and realize industrial agglomeration.

According to a 2017 semi-annual report released by the Research Institute of Metal Industry Development under the Ministry of Industry of Ethiopia, foreign firms have become the mainstay of the country's metal industry. Currently, Ethiopia has more than 400 firms in the metal industry; 85% are owned by native investors, and the rest are owned by foreign firms or are joint ventures. China has 35 firms in the metal industry in Ethiopia, and they account for the largest share of the steel bar market in this country (Economic and Commercial Office of the Embassy of the People's Republic of China in the Federal Democratic Republic of Ethiopia 2017).

Third, the strengthening of cooperation on iron ore: China has a large deposit of iron ore; however, there are more lean ore mines than rich ones, and the purity is low. Lean ore accounts for 80% of China's iron ore, and the average iron content is approximately 18%. In comparison, the iron ore in Brazil and Australia contains over 60% iron (see Table 5). Chinese firms rely on foreign supply for 70% of their iron ore. Three giant iron ore mines—Vale of Brazil, BHP Billiton Ltd. of Australia, and Rio Tinto Group of Britain—control the majority of the iron ore resources and monopolize 75% of the global iron ore market. The high price of raw material leads directly to razor-thin profits or even operational losses for Chinese firms in the steel industry. To reduce the cost of raw materials, between 2006 and 2016, China invested in close to 40 iron ore projects overseas. For instance, Wugang Group acquired approximately

Table 5 Iron ore import by source country (2016–2017)

Country	*2017 (10,000 tons)*	*2016 (10,000 tons)*	*Percentage of total imports (%)*		*Change from 2016 to 2017*	
			2017	*2016*	*Increase in volume (10,000 tons)*	*Percentage increase (%)*
Total	107,473.69	102,421.20	100.00	100.00	5,052.49	4.93
Australia	66,848.76	63,987.59	62.20	62.47	2,861.16	4.47
Brazil	22,909. 57	21,469.38	21.32	20.96	1,440.19	6.71
South Africa	4,510. 89	4,485.18	4.20	4.38	25.71	0.57
Iran	1,954. 22	1,462. 27	1.82	1.43	491.96	33.64
Sierra Leone	697. 89	410.29	0.65	0.40	287.60	70.10
Ukraine	1,087.05	1,478. 86	1.01	1.44	– 391.80	– 26.49
Chile	938. 25	1,127.16	0.87	1.10	– 188.91	– 16.76
Canada	669.90	904.57	0.62	0.88	– 234.67	– 25.94
Peru	1,148. 25	1,088.66	1.07	1.06	59.59	5.47
Mauritania	817. 52	954.45	0.76	0.93	– 136.93	– 14. 35
Malaysia	259.48	229.57	0.24	0.22	29.91	13.03
India	2,506. 85	1,556. 37	2 . 33	1.52	950.48	61.07
Mongolia	658.10	624.06	0 . 61	0.61	34.04	5.45
Russia	485.78	628.59	0.45	0.61	– 142. 81	– 22.72
Indonesia	58 . 17	255.90	0.05	0.25	– 197.73	– 77.27
Kazakhstan	132.29	128.81	0 . 12	0.13	3.47	2.70
Pakistan	19.81	10.73	0.02	0.01	9.08	84.64
Myanmar	255. 08	142. 82	0.24	0 . 14	112.26	78.61
North Korea	165.66	163.55	0 . 15	0.16	2.10	1.29
Liberia	0.00	32 . 82	0.00	0.03	– 32.82	– 100.00
United States	73 . 14	65.79	0.07	0.06	7 . 35	11 . 17
New Zealand	281.73	310.41	0.26	0.30	– 28.68	– 9.24
Venezuela	380. 36	527.04	0.35	0.51	– 146.67	– 27.83
Vietnam	351.26	94.81	0 . 33	0.09	256.45	270.48

Source China steel statistical yearbook (2018)

21.5% of shares of the Brazilian company MMX, thereby obtaining the rights to 600 million tons of iron ore. Shandong Steel acquired mining rights to the Salinas iron ore project in Brazil. Ansteel acquired lifetime mining rights to 30 million tons of magnetite from Australia's Gindalbie

Metals Ltd. Chongqing Iron and Steel Group invested in a 1.78-billion-ton magnetite project in Australia. China Railway Materials acquired a 12.5% share of African Minerals and obtained 20 years of iron ore mining rights in the Tonkolili project.

Fourth, working with developed countries and enhancing technological cooperation: Currently, developed countries such as Japan and those in Europe and North America are renewing their infrastructure. For instance, countries like the United States and Canada recorded a tremendous net import of steel products over the past couple of years, and these countries have advanced steel production technologies and environmental protection technologies. Countries in Europe and North America have well-developed technologies and standards for the treatment of emissions such as smoke, sulfur dioxide, and nitrogen oxide. Japan owns numerous patents on steel production and has been a leader in technological innovation. By reaching out internationally, Chinese firms can learn from the experience and standards of developed countries and acquire higher-level technologies. These advanced technologies not only help to reduce firms' costs but also improve the entire industry's standards regarding product quality and environmental protection. On December 4, 2019, Baosteel Europe R&D Center was established in Munich, Germany. Europe leads the world in technology, talent, and the market and has been at the forefront of steel technology development. After more than ten years of international cooperation, Baosteel has laid a solid foundation in Europe. The European R&D center will enable Baosteel to continue its regional cooperation, utilize Europe's high-quality resources, better integrate into the innovation system in Europe, and promote more in-depth technological cooperation and exchanges with top scientific research institutes in Europe (official website of CISA 2019).

4.2 Achievements of China's Production Capacity Cooperation

Overcapacity is a serious issue facing China's steel industry, and international capacity cooperation is one of the main approaches to reducing the excess capacity. China's steel industry has the ability to "go out." From export to capital investment to international advantageous production capacity cooperation, these efforts represent important steps in enabling China's steel industry to enter the middle and high end of the global value chain. During this process, there is a need to transform the traditional business model of "manufacturing-trade" to the new business model, in which core resources, technologies, supply chain management, and value added from services constitute the main contents; it is also necessary to further improve independent innovation capacity and the value added to products, strengthen international capacity cooperation, and develop good partnerships by integrating the upstream and downstream of the industrial chain.

The supply-side structural reform and Belt and Road Initiative (BRI) provide strong support for the international capacity cooperation of China's steel industry. The BRI provides valuable opportunities for China's steel production capacity to "go out" and provides opportunities for steel trading for the countries along the BRI route. The countries along the BRI route have relatively weak industries but good development potential. Of the more than 60 countries along the route, more than 70% have steel product net imports. The empirical analyses of Liu et al. (2018) indicate that China has cascading advantages over the countries along the BRI route in regard to shifting the steel production capacity. China can promote international capacity cooperation through the BRI, transfer technologies and management experience to those countries, develop local talent in technology and management, promote local economic development, and reduce China's excess capacity. Yan et al. (2017) forecasted the incremental international demand for China's steel products under the BRI and found that international capacity diversion can effectively alleviate the steel industry's overcapacity. Shi et al. (2017) found that countries along the BRI route have diversified steel trading, and geographically close countries tend to have close trade relations. China's major export destinations are in South and Southeast Asia. The competition in the steel market in the Middle East is extremely intense, and the demand is tremendous; therefore, this region is an important international market on which China should focus.

As a foundation of China's national economy, the steel industry provides solid support for infrastructure development. Since the 2008 financial crisis and the subsequent international trade protectionism and supply-side reform, China's steel exports continued to decline between 2016 and 2017. Meanwhile, overcapacity in the steel industry became a global phenomenon. To resolve their own issues, countries across the world pointed fingers at China, and steel trade disputes became increasingly frequent. In 2016, global crude steel production was approximately 1.6 billion tons, of which 600 million tons constituted excess capacity. In 2016, China exported close to 100 million tons of crude steel. The

European Union, the United States, and India staged anti-dumping and anti-subsidy investigations against China. Based on the China Trade Remedies Information, between 2001 and 2015, there were 706 anti-dumping cases filed against China, of which 78 were related to steel products, accounting for 11% of all cases. In 2016, there were 117 anti-dumping and anti-subsidy cases filed against China worldwide, of which 49 were related to steel products, accounting for 42% of all cases. Since 2014, the European Union has filed 15 cases of trade remedy investigation, of which eight are related to steel products, accounting for 53.3% of the cases. In April 2016, India launched an anti-dumping and anti-subsidy investigation regarding hot-rolled coils, stainless steel plates, and other steel products originating in China. Nine steel industry associations in North America and Europe jointly issued a statement claiming that China is the major driver of global steel production overcapacity, and opposing China automatically accorded the market economy status. Since taking power, President Trump of the United States has claimed that China's overcapacity in the steel industry led to lower steel prices across the globe and forced some steel mills in the United States to close; he emphasized bringing the manufacturing sector back to the United States multiple times. As a result, China's steel industry is among the industries that have most frequently been subject to anti-dumping investigations by the United States.

Against the backdrop of global overcapacity in the steel industry and the United States imposing duties on steel products, major steel product-exporting countries are competing more intensely outside of the United States. They strive to acquire a market share through various measures, including price reduction. Feng and Li (2019) used the monthly HS10 data for steel products involved in anti-dumping cases initiated by the United States against China in 1995–2015 and analyzed six stages—before the filing, after the filing, before the preliminary decision, after the preliminary decision, before the final decision, and after the final decision. The research found that the export of Chinese products involved in these cases to third-party markets will increase and that exports are primarily diverted toward developing countries, not developed ones. Xiang (2019) found that the trade potential of China's steel products is mainly concentrated in Southeast, South, and West Asia, largely coinciding with the regions where India, Japan, and Republic of Korea have large trade potential; China's regions of trade potential have relatively little overlap with those of Germany and Russia. Regarding price competitiveness, India is relatively more competitive with China than other countries are in regard to steel exporting.

In October 2019, the Global Forum on Steel Excess Capacity (GFSEC) held its third Ministerial meeting in Tokyo, Japan. China was the only GFSEC member that set de-capacity targets and had taken measures to reduce capacity. Since 2016, China has reduced steel capacity by over 150 million tons. To this end, it has arranged re-employment for up to 0.28 million displaced steelworkers, exceeding the number of workers in the steel industry in the United States, Europe, or Japan. China's steel market has significantly improved, and the utilization rate of crude steel capacity has returned to a reasonable range of above 80%. Although China accounts for half of the global steel capacity and production, it also accounts for half of the global steel consumption. Currently, domestic consumption accounts for 93% of China's steel production, and exports only account for 7%. Excess capacity is a challenge facing the entire world. The fundamental reason for this round of excess steelmaking capacity is the global economic recession and depressed demand for steel caused by the 2008 international financial crisis. Excess capacity is a common, cyclical, and structural issue in economic development (Economic Daily 2019).

In the future, reducing excess capacity, alleviating predicaments, and realizing development will be the top priorities of China's steel industry. However, these goals cannot be obtained using only traditional approaches. Especially in the context of the deepening global division of labor, improving the steel industry's position in the value and industrial chains is both the means and end to de-capacity in China. The ability of China's steel industry to provide added value has increased, and the industrial chain is also being extended; in comparison with its counterparts in the United States, Japan, and Republic of Korea; however, China's steel industry has low value added and is less competitive. The industry's profits are squeezed by both international and domestic forces, and the industry faces a strong pressure to upgrade. Value-added trade between China's steel industry and developed countries is characterized by a high amount of import and low amount of export and by large amounts of import and export, and the trade surplus is significantly overestimated. As a large steel producer, China still relies on import for high-tech steel products; its product structure needs to be optimized. The industry's ability to negotiate and produce profits is generally low. China's steel industry must undergo restructuring and upgrading to eliminate excess capacity and optimize production (Wang and Chen 2018).

5 Concluding Remarks

The fundamental goal of de-capacity in China's steel industry is to promote restructuring and upgrading of the industry and high-quality development. The industry must consider the global market, improve quality through innovation, and plan production based on demand. Further, the government needs to provide guidance on capacity planning, and all stakeholders should do their part. Only when all these efforts are in place will the steel industry realize high-quality development.

First, the industry should strengthen openness and international cooperation. China's steel industry should take global competition into consideration in its development plans, further strengthen cooperation and exchanges with its counterparts in other countries, adopt and introduce advanced technologies and management experience, and enhance international capacity cooperation. The industry should take advantage of the opportunities brought about by the BRI and optimize international deployment of its capacity. Under the guidance of the BRI, firms should be the major players in these efforts. In accordance with the principle of mutual benefits and win–win situations, and following the theme of infrastructure development and trade and investments, firms should strive for in-depth cooperation with countries along the BRI route to optimize global deployment of their steelmaking capacity and hasten the industry's upgrading, orderly diversion of capacity, market expansion, and restructuring. China's steel industry should not regard the expansion of exports as its goal. Under pressures related to de-capacity and the environment, firms must tightly restrict exports of resource-intensive products with low value added; develop reliable overseas supply systems for energy and resources; actively explore bilateral cooperation mechanisms, such as engaging in transnational cooperation and introducing strategic investors; improve the openness, joint-venture development, and international cooperation of the industry; encourage exports of high-value-added products; and improve the industry's international competitiveness.

Second, the steel industry should focus on improving innovation capacity and use this as the driving force for healthy and sustainable development. De-capacity is not simply a matter of reduction; it is more a matter of realizing the industry's healthy and sustainable development.

Therefore, firms should adhere to an innovation-driven strategy and improve innovation capacity and core competitiveness. Firms upstream and downstream of the industrial chain, steelmaking firms, and research institutes should actively collaborate, increase R&D input into core areas and key projects in the steel industry, promptly improve innovation capacity, and realize high-quality development. De-capacity does not only refer to the elimination of outdated, low-end, and inefficient capacity; firms should also focus on how to optimize the deployment of capacity and transform low- and medium-end capacity into high-end capacity through technological innovation. Further, they should enhance R&D ability by focusing on new technologies that conserve energy and protect the environment; high-quality, high-end steel products; key common technologies; frontier processes, technologies, and equipment; and basic research. In addition, it is necessary to actively explore the development of a smart manufacturing system for the steel industry and establish a platform that integrates procurement, products, and sales. Further, firms should develop a whole-process management system to improve the standardization and intellectualization of management and management efficiency.

Third, the steel industry should follow the laws of the market economy and develop a market-oriented sustainable development mechanism. The excess capacity in the steel industry results from both cyclical and structural aspects of economic growth. Market-based de-capacity means comprehensively employing the fair market mechanism to determine whether firms should exit or remain in the market and forcing firms—with the "invisible hand" of the market—to undergo transformation and upgrading through innovation to improve the productivity and competitiveness of the entire industry. De-capacity in accordance with the law means utilizing the "visible hand" of government; introducing indicators of environment protection, energy consumption, and safety to solve problems related to eliminating excess capacity; and guiding market behavior through legal measures. In achieving the goals of de-capacity and sustainable development while seeking to fulfill the de-capacity quota, the industry should increase its focus on balancing demand and supply to avoid significant price fluctuations, actively foster a fair, competitive market, and develop and improve a market-based mechanism for planning capacity and production.

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CHAPTER 10

Labor Productivity and Surplus Labor in Chinese Iron and Steel Firms

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1 Introduction

In China, during the planned economy period, all firms, including firms in the iron and steel industry, were state-owned enterprises (SOEs) managed by the government. Since 1978, the Chinese government has implemented market-oriented economic reforms. Non-SOEs (i.e., privately owned enterprises: POEs; foreign-owned enterprises: FOEs) have developed as a result of the implementation of the opening-up policy and SOE reform.[1] However, the ownership reform was incomplete, the governance of large SOEs and monopoly industries has scarcely changed, and these entities remain controlled (managed) by the government (Lin et al. 1996; Zhang and Xue 2008; Ye et al. 2011; Ma 2017, 2018a; b, c; Iwasaki et al.

[1]At the end of the 1990s, the government introduced the SOE reform, and the majority of medium-sized and small SOEs were privatized, while large SOEs continued to be controlled (or managed) by the government, which is called "Zhuada Fangxiao" in Chinese.

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2020). For example, based on the "Guiding Opinions on Adjusting State-Owned Capital and Promoting Mergers and Acquisitions of State-Owned Enterprises" promulgated by the State Council in December 2006, the State Assets Control Commission stated that "the state-owned sector should absolutely control seven industries that are vital to national security and the national economy (i.e., the military industry, electric power, petroleum and petrochemical industry, telecommunications industry, coal industry, aviation industry, and transportation industry) and should have relatively strong control over nine industries (i.e., the equipment manufacturing industry, vehicle manufacturing industry, electronic information industry, construction industry, steel industry, colored metal industry, chemical industry, inspection and design industry, and science and technology industry)." Thus, in China, large SOEs in the steel industry sector continue to be managed by the government.

There remain many problems, such as agency problems (Berle and Means 1932) and information asymmetry problems, that may cause the low performance of SOEs (Iwasaki et al. 2020). It is argued that because SOEs operating at a loss can obtain government financial support (i.e., government subsidies and rent from state-owned banks), the majority of SOEs are zombie firms. From the neoclassical economics perspective, based on the market mechanism, in a profit-maximizing firm, the wage level of a worker should be equal to the marginal labor productivity in a firm; the number of employees should be based on the market equilibrium mechanism. Thus, surplus labor should not persist in a firm with high efficiency and productivity.

It has been argued that the Chinese iron and steel industry has been plagued by a severe surplus production problem among SOEs since the 2000s. The government implemented a set of policies to improve the performance of firms in the steel industry during the 2000s (Li 2017). To understand the performance of Chinese steel firms, the following questions should be investigated: What is the labor productivity of Chinese iron and steel firms? Is there still surplus labor in Chinese iron and steel firms? Does the amount of surplus labor differ between SOEs and non-SOEs in the steel industry sector? To the best of our knowledge, empirical studies on these issues are scarce. This study can fill this gap.

Using data from the Chinese Large and Medium-sized Manufacturing Enterprises Survey (CLMMS), this study attempts to estimate the marginal productivity of labor (MPL) and surplus labor in Chinese iron and steel firms and compares these values for SOEs and non-SOEs. The findings indicate that in the steel industry sector, the MPL exceeds wages for both SOEs and non-SOEs; the MPL is lower than wages in both large SOEs and small SOEs. The results suggest that there may still be surplus labor in large and small iron and steel firms. This does not appear to be the case for medium-sized firms. Thus, the majority of large SOEs in the steel industry sector are likely to be zombie companies.

The remainder of this paper is organized as follows: Sect. 2 presents the methodological framework for the empirical analysis, including the models and data. Section 3 reports and explains the estimated results. Section 4 summarizes the conclusions.

2 Methodology

2.1 Model

Based on the Lewisian dual economy model,[2] we calculate the MPL based on the results of the production elasticity of labor from the appropriate production function and average labor productivity (APL). We compare the average MPL and average wage of workers. A lower average MPL than average wage of workers indicates that firms may maintain surplus labor. We use the Cobb-Douglas production function to estimate the production elasticity of labor and capital, which is expressed as follows:

First, the ordinary least squares (OLS) regression model is expressed in Eq. (1)

$$lnY_{it} = \alpha + \beta_L lnL_i + \beta_k lnK_i + \beta_x X_i + v_i \quad (1)$$

where $lnY.$ denotes the logarithm of gross value added (annual sales value), i represents the firm, L denotes the labor force (number of employees), and K stands for capital (fixed assets). a is a constant, and

[2] The Lewisian dual economy model assumes the coexistence of a "capitalist sector" and a "subsistence sector". The former is characterized by the profit-maximizing behavior of capitalists, while in the latter, the marginal productivity of labor (MPL) is smaller than wages, which are determined by the subsistence level (SL) predominant in society. In general, they are represented by urban industries and agriculture. The labor force of the subsistence sector is supplied to the capitalist sector at a constant SL (unlimited supply of labor). When the MPL increases and reaches the SL, profit-maximizing behavior begins to occur, and the labor force of the subsistence sector becomes available only by increasing wages (limited supplies of labor). This point in time is the "turning point".

v is an error term. β_L and β_k express the production elasticity of labor and capital, respectively.

It is argued that there are time-invariant factors such as unobserved firm characteristics (i.e., a firm's management culture) that may affect firm outcomes. It is thought that the bias associated with unobserved heterogeneity may be present in the results obtained via OLS. To address this problem, fixed effects (FE) or random effects (RE) models are utilized as follows:

$$lnY_{it} = a + \beta_L lnL_{it} + \beta_k lnK_{it} + \beta_x X_{it} + u_i + \varepsilon_{it} \quad (2)$$

where i denotes the enterprise and t the year. u stands for unobserved firm characteristics, and ε is the real error term. Because u may be time invariant or appear randomly, an FE model and an RE model are utilized.

Although FE and RE models can address unobserved heterogeneity, the problems of initial dependence and the other endogeneity may remain. The generalized method of moments (GMM) can be used to address these econometric problems. GMM can produce consistent parameter estimates for a finite number of time periods (T) and a large cross-sectional dimension (n) (see Arellano and Bond 1991; Arellano and Bover 1995; Blundell and Bond 1998). Because we utilize short-term panel data (four waves), a one-step GMM is used in this study. One-step GMM can utilize the lagged variables (from period t−1) as instrumental variables to address the endogeneity problem.

Based on Arellano and Bond (1991), the one-step GMM can be represented as follows:

$$n(\frac{1}{n}\sum_{i=1}^{n} lnY_{i,s}\left[\left(lnY_{i,t} - lnY_{i,t-1}\right)\beta\right] = 0 \quad (3)$$

$s = 0, 1, \ldots, t-1, t = 2, 3, \ldots, T$

When the lagged dependent variables used as instrumental variables are not correlated with lagged ε, the dynamic panel data analyzed with one-step GMM can be expressed as follows:

$$\Delta lnY_{it} = \beta_{yt1-1} lnY'_{i,t-1} + \beta_{L'}\Delta lnL'_{i,t-1} + \beta_{K'}\Delta lnK'_{i,t-1} + \beta_{X'}\Delta X'_{i,t-1} + \Delta\varepsilon_i \quad (4)$$

$i = 1, 2, \ldots N$

In Eqs. (3) and (4), Δ stands for changes in variables between two periods, which are calculated by "Difference = $variable_{i,t} - variable_{i,t\_1}$"

3 Data

This study uses data from the CLMMS for 2004–2007, which is fairly similar to the Longitudinal Research Database (LRD) maintained by the U.S. Census Bureau. Our dataset comprises all state-owned firms and non-state-owned firms with sales exceeding 5 million RMB (approximately US $650,000). The sample consists of the number of employees (labor), fixed assets (capital), wages and other firm-level information. The samples for each survey year are 263,861 in 2004, 257,990 in 2004, 282,063 in 2006 and 312,206 in 2007. Enterprises that did not have complete information on the main regression variables were deleted. According to the enterprise regulations, a firm with fewer than eight employees is considered in the self-employment category and is therefore omitted. Observations in the one-percent tails of each of the regression variables are omitted to control for the potential influence of outliers. The CLMMS is not a panel survey, so we utilized the information on the firms' address, telephone number and industry code to construct an enterprise panel dataset. The unbalanced panel covers four waves (2004, 2005, 2006, and 2007); the number of observations that appeared in four waves, three waves, two waves and one wave is 167,493, 67,274, 59,680 and 93,554, respectively, and the matched total number of observations in the panel dataset sample is 388,001. The cross-sectional dataset is used for the OLS, and the unbalanced panel dataset is utilized for the analyses based on the FE model, the RE model and one-step GMM.

We selected firms in the ironmaking, steelmaking, steel casting and manufacturing, steel rolling and ferroalloy smelting industry sectors from the CLMMS dataset to represent Chinese steel firms. The total sample includes 34,753 iron and steel firms from 2004 to 2007 (8,562 in 2004, 8,065 in 2005, 8,715 in 2006 and 9,411 in 2007).

Ownership is classified into five types based on the dataset: state-owned enterprises (SOEs); collectively owned enterprises (COEs); privately owned enterprises (POEs); foreign-owned enterprises (FOEs); Hong Kong and Taiwan-owned enterprises (HTOEs); and other types of enterprises (Other). The public sector comprises SOEs and COEs, and the private sector includes POEs, FOEs and HTOEs. The non-SOEs include POEs, FOEs and HTOEs.

The dependent variable is constructed as the logarithm of gross value added (annual sales value). The dependent variables in the production function include (1) the number of employees (labor), (2) the value of fixed assets (capital), (3) the three kinds of inputs for intermediate goods (intermediate goods for manufacturing: inter_manu; intermediate goods for administration: inter_admin; and intermediate goods for operation: inter_op), (4) an export dummy variable (1 = export firm, 0 = otherwise), (5) firm welfare, which is a variable representing the average social insurance contributions paid by a firm for employees, and (6) survey year dummies (from 2004 to 2007). The values from 2004 to 2007 are adjusted using a price index (the base year is 2004) published by the Chinese National Bureau of Statistics.

4 Employment, Wages and Labor Productivity in Chinese Iron and Steel Firms

Based on the data from the CLMMS for 2004–2007, we calculated the distributions of the number of firms, average annual sales values, average number of employees, average wage and average productivity of labor (APL) by ownership type, and the results are presented in Table 1 and Figs. 1–4.

First, during the period from 2004 to 2007, the proportion of firms in the public sector was less than 10% (SOEs 4.6%, COEs 4.9%), while it was

Table 1 Distribution of the number of iron and steel firms by ownership type

	2004–2007	*2004*	*2005*	*2006*	*2007*
SOEs	4.6	6.0	4.6	4.3	3.6
COEs	4.9	0.8	0.7	9.4	8.2
POEs	43.6	0.0	6.8	79.6	81.5
HTOEs	1.7	0.0	0.0	3.0	3.1
FOEs	1.9	0.0	0.6	3.7	3.6
Other	43.2	93.2	87.3	0.0	0
Total	100.0	100.0	100.0	100.0	100.0
Observations	34,753	8562	8065	8715	9411

Note SOEs: state-owned enterprises; COEs: collectively owned enterprises; POEs: privately owned enterprises; FOEs: foreign-owned enterprises; HTOEs: Hong Kong and Taiwan-owned enterprises; Other: other types of enterprises

Source Created by the author based on data from the CLMMS for 2004–2007

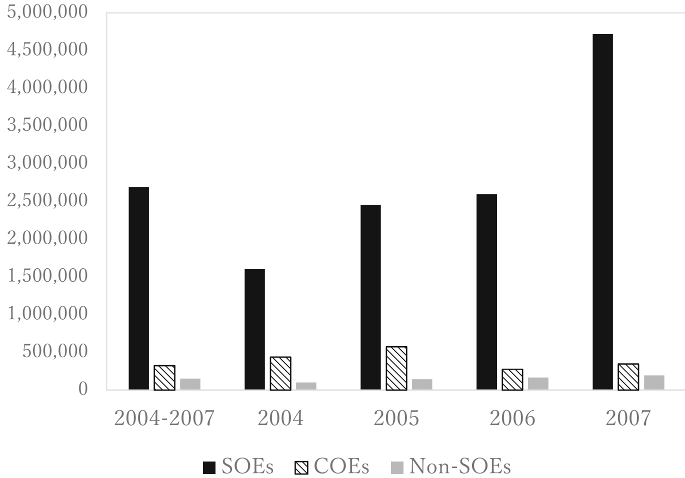

Fig. 1 Annual sales values of iron and steel firms by ownership type (unit: yuan) (*Source* Created by the author based on data from the CLMMS for 2004–2007)

larger for firms in the private sector (POEs 43.6%, HTOEs 1.7%, FOEs 1.9%, other 43.2%) (see Table 1). This suggests that as market-oriented economic reforms progressed, firm ownership in the steel industry sector privately expanded considerably. It can be assumed that a dramatic increase in POEs may influence management systems and determine the mechanism of labor and capital, which could increase the efficiency and productivity of both SOEs and non-SOEs in China.

Second, Fig. 1 shows that the average annual sales values of steel firms by ownership type are greater for SOEs than for non-SOEs. Although there are fewer SOEs than non-SOEs, the latter perform well in terms of value added (firm outcomes). This finding suggests that the SOEs in the iron and steel industry sector are large firms and occupy a greater share of production in China. Since the 1990s, although the Chinese government has deregulated entry into the iron and steel industry sector for non-SOEs, government financial support (i.e., government subsidies and rent from state-owned banks) is still focused on SOEs, which allows SOEs to maintain a leading position in iron and steel production.

Third, Fig. 2 displays the labor force of iron and steel firms by ownership type and shows that SOEs have a larger average number of employees than non-SOEs. Specifically, during the period from 2004 to 2007, SOEs

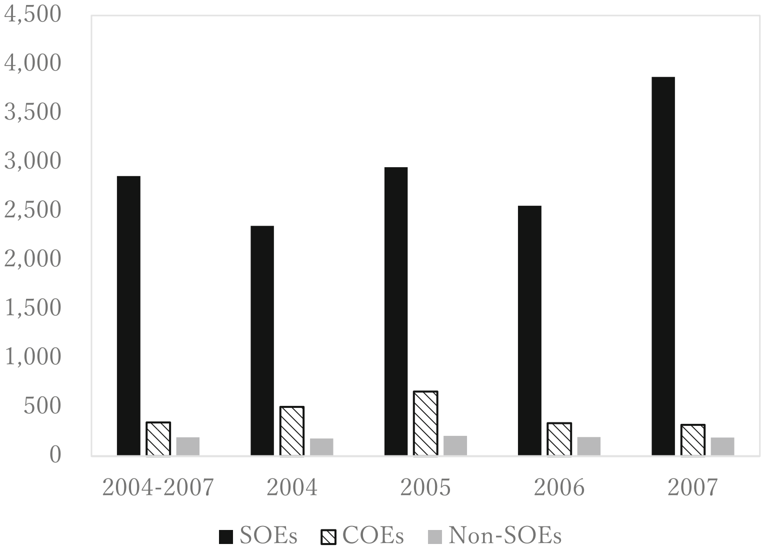

Fig. 2 Number of employees of iron and steel firms by ownership type (*Source* Created by the author based on data from the CLMMS for 2004–2007)

had 2,860 employees on average, while non-SOEs had 194. This indicates that in the Chinese iron and steel industry, the majority of SOEs are large firms, while the majority of non-SOEs are small firms. In addition, compared to the period from 2004 to 2006, the number of employees in SOEs increased in 2007.

Fourth, based on the value added and number of employees, we calculated the APL of steel firms by ownership type. The results are shown in Fig. 3. During the period from 2004 to 2007, APL was higher for SOEs than for non-SOEs, and the difference in APL between SOEs and non-SOEs increased from 2004 to 2007. It seems that the Chinese government's reform and reconstruction of SOEs in the steel industry in the 2000s improved the APL of state-owned iron and steel firms.

Fifth, based on labor costs (wages) and the number of firm employees, we calculated the average wage of Chinese iron and steel firms by ownership type. The results in Fig. 4 suggest that the average wage level is higher for SOEs than for non-SOEs. The results are consistent with those based on data from the Chinese Statistical Yearbook published by

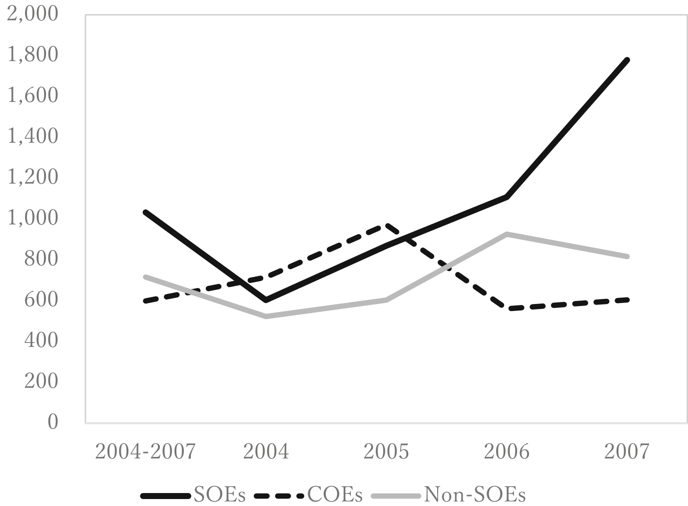

Fig. 3 Average productivity of labor of iron and steel firms by ownership type (unit: thousand yuan) (*Source* Created by the author based on data from the CLMMS for 2004–2007)

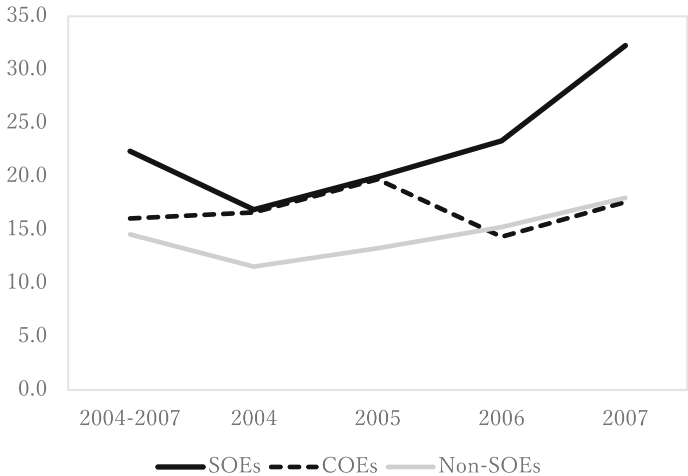

Fig. 4 Average wage of iron and steel firms by ownership type (unit: thousand yuan) (*Source* Created by the author based on data from the CLMMS for 2004–2007)

the National Statistics Bureau, which notes that "SOEs increased while non-SOEs decreased" (*Guojin Mintui* in Chinese) (Ma 2018a).

Although these statistical results suggest that the labor force, APL and average wage levels differ by firm ownership type, it is unclear whether Chinese steel firms maintain surplus labor. The results based on the econometric analysis in the following section can answer this question.

5 Econometric Analysis: Results

5.1 Basic Results of the Chinese Iron and Steel Firm Production Function

The results of the iron and steel firm production function for the full sample are summarized in Table 2 (OLS model) and Table 3 (FE model, RE model and GMM model).

First, the results using cross-sectional data show that the elasticity of labor is 0.370–0.380; in the results using the panel data, it is 0.370 (FE model), 0.466 (RE model) and 0.294 (GMM), and these results are statistically significant at the 1% level.

Second, for the other factors, (1) the elasticity of capital is 0.202–0.204 in the OLS model, 0.202 in the FE model and 0.025 in GMM, which is smaller than the elasticity of labor, and these results are statistically significant at the 1% level. (2) The input of intermediate goods positively and significantly affects firm production. (3) Production is greater for firms assessed as making larger social insurance contributions for their employees. This can be explained by the efficient wage hypothesis; employees may devote greater effort when firms pay higher labor costs (i.e., higher wage levels and higher social insurance contributions) (Ma and Cheng 2019). (4) When the other factors (i.e., labor, capital and intermediate goods input) were held constant, the production of iron and steel firms from 2004 to 2007 increased.

Third, regarding the appropriateness of these models, the results of the F-test (F(10,489, 13,456) = 7.18, Prob > F = 0.000) and BP test (chibar2(01) = 8825.37, Prob > chibar2 = 0.000) indicate that both the FE model and the RE model are more appropriate than the OLS model. The results of the Hausman test (chi2(10) = 2184.83, Prob > chi2 = 0.000) suggest that the FE model is more appropriate than the RE model. In addition, based on the results of the Sargan test for overidentifying restrictions, overidentifying restrictions do not pose a significant problem

Table 2 Production function results for Chinese iron and steel firms (OLS model)

	Model 1			*Model 2*			*Model 3*		
	Coef		*t-value*	*Coef*		*t-value*	*Coef*		*t-value*
Labor	0.370	***	56.78	0.374	***	57.94	0.380	***	57.16
Capital	0.202	***	52.12	0.203	***	52.78	0.204	***	52.91
Inter_manu	0.235	***	59.70	0.231	***	59.06	0.224	***	57.62
Inter_admin	0.122	***	24.56	0.121	***	24.56	0.118	***	23.96
Inter_op	0.103	***	29.12	0.107	***	30.55	0.109	***	30.94
Export				– 0.469	***	– 19.20	– 0.495	***	-20.27
Firm welfare				0.004	***	6.55	0.004	***	6.49
Survey year (Ref. = y2004)									
y2005	0.068	***	4.56	0.066	***	4.50	0.075	***	5.18
y2006	0.104	***	7.22	0.102	***	7.14	0.114	***	8.10
y2007	0.229	***	16.05	0.224	***	15.85	0.238	***	17.01
Region	No			No			Yes		
Constant	4.013	***	152.13	4.021	***	153.70	3.935	***	123.65
Observations	23,885			23,885			23,885		
Adj R-squared	0.759			0.763			0.771		

Note ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$; the OLS model is used
Source Created by the author based on data from the CLMMS for 2004–2007

Table 3 Production function results for Chinese iron and steel firms (FE, RE and GMM models)

	(1) FE			(2) RE			(3) GMM		
	Coef		*t-value*	*Coef*		*t-value*	*Coef*		*t-value*
t–1 values							0.257	***	7.00
Labor	0.370	***	56.78	0.466	***	65.27	0.294	***	18.30
Capital	0.202	***	52.12	0.156	***	37.86	0.025	***	3.33
Inter_manu	0.235	***	59.70	0.166	***	49.73	0.067	***	14.43
Inter_admin	0.122	***	24.56	0.098	***	23.33	0.045	***	7.66
Inter_op	0.103	***	29.12	0.088	***	28.22	0.046	***	10.01
Export				–.176	***	–6.29	0.067		1.39
Firm welfare				0.004	***	7.31	0.004	***	3.97
Survey year	Yes			Yes			Yes		
Region	No			Yes			No		
Constant	4.013	***	152.13	4.594	***	139.69	5.392		14.73
Number of obs	23,885			23,885			7,502		
Number of groups	0.759			0.466			4,593		
R-sq: within	0.483			0.742					
between	0.701			0.701					
overall	0.719			0.756					

	(1) FE		(2) RE		(3) GMM	
	Coef	*t-value*	*Coef*	*t-value*	*Coef*	*t-value*
Hausman test						
BP test						
F-test	F (10,489, 13,456) = 7.18 Prob > F = 0.000					
Sargan test of overidentifying restrictions					chi2(2) = 11.988 Prob > chi2 = 0.0025	

Note ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$; FE: fixed effects model, RE: random effects model, and GMM: generalized method of moments
Source Created by the author based on data from the CLMMS for 2004–2007

in the GMM model. Therefore, we use the FE and GMM models to estimate the elasticity of labor by ownership type in the following.

6 Results of the Chinese Iron and Iron and Steel Firm Production Function by Ownership Type

The production function results by ownership type are presented in Table 4 (FE) and Table 5 (GMM). The results for the elasticity of labor differ by model. Specifically, the results in Table 4 indicate that the elasticity of labor is 0.516 for SOEs, 0.281 for COEs and 0.435 for non-SOEs, and these findings are statistically significant at the 1% level. In contrast, the results in Table 5 suggest that the coefficient of the labor force is not statistically significant for firms in the public sector (both SOEs and COEs), while it is significant for firms in the private sector (non-SOEs). The results indicate that after addressing the endogeneity problem, labor productivity is lower for firms in the public sector than for firms in the private sector. It can be assumed that lower labor productivity may be responsible for the existence of surplus labor in SOEs.

7 MPL and Wage of Chinese Iron and Steel Firms

Does surplus labor persist in Chinese steel firms? Does the amount of surplus labor differ between SOE and non-SOE iron and steel firms? Based on the empirical method proposed by Minami (1968, 1973),[3] wecalculate the MPL based on the average productivity of labor (APL) and elasticity of labor estimated by the production functions. The results, including the MPL and wage, are summarized in Tables 6 and 7. We compare the values of the MPL and average wage; when the value of the MPL is lower than the average wage, there may be surplus labor.

First, regarding the differences by ownership type (Table 6), the results indicate that for firms in both the public and private sectors, the MPL is higher than the average wage (the ratio of the MPL to the average wage is 1.170 for SOEs, 1.236 for COEs and 1.421 for non-SOEs). It seems that there is no surplus labor in either SOEs or non-SOEs in the Chinese steel industry.

[3] For empirical studies of surplus labor in the Chinese agricultural sector, please refer to Minami and Ma (2010, 2014).

Table 4 Production function results for Chinese iron and steel firms by ownership type (FE model)

	(1) SOEs			*(2) COEs*			*(3) Non-SOEs*		
	Coef		*t-value*	*Coef*		*t-value*	*Coef*		*t-value*
Labor	0.516	***	7.71	0.281	***	4.01	0.435	***	32.89
Capital	0.089	**	2.41	0.057	***	1.33	0.091	***	13.36
Inter_manu	0.143	***	6.92	0.076	***	3.76	0.145	***	33.42
Inter_admin	0.059	**	2.48	0.064	***	2.42	0.100	***	17.95
Inter_op	0.123	***	6.75	0.073	***	3.50	0.097	***	22.75
Export	1.292	***	6.26	0.190	***	0.62	0.043		1.00
Firm welfare	0.008		1.37	0.014	***	2.10	0.010	***	9.03
Survey year	Yes			Yes			Yes		
Region	No			No			No		
Constant	5.305		9.76	7.405	***	15.19	5.543	***	72.16
Number of obs	1,128			1,060			21,768		
Number of groups	510			718			9863		
R-sq: within	0.378			0.221			0.380		
between	0.848			0.750			0.699		
overall	0.864			0.746			0.705		
F-test	F(509, 611) = 9.51			F(717, 335) = 8.72			F(9862, 11,898) = 5.34		
	Prob > F = 0.000			Prob > F = 0.000			Prob > F = 0.000		

Note ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$; the fixed effects model is used

Source Created by the author based on data from the CLMMS for 2004–2007

Table 5 Production function results for Chinese iron and steel firms by ownership type (GMM)

	(1) SOEs		*(2) COEs*		*(3) Non-SOEs*	
	Coef	*t-value*	*Coef*	*t-value*	*Coef*	*t-value*
t–1 values	0.398	1.33	0.314	0.80	0.267 ***	7.09
Labor	0.254 **	2.33	0.333 ***	4.29	0.288 ***	16.70
Capital	− 0.016	− 0.27	0.034	1.04	0.025 ***	3.07
Inter_manu	0.100 ***	3.42	0.036 **	2.51	0.069 ***	13.76
Inter_admin	− 0.012	− 0.33	0.049 **	2.28	0.047 ***	7.39
Intert_op	0.038	1.59	0.059 ***	3.87	0.045 ***	8.98
Export	0.911 *	1.83	0.180	1.06	0.047	0.92
Firm welfare	0.001	0.08	0.007	1.32	0.004 ***	3.86
Survey year	Yes		Yes		Yes	
Region	No		No		No	
Constant	4.939	1.68	4.520	1.23	5.296	14.07
Number of obs	1,128		641		6,455	
Number of groups	510		425		3993	
Wald chi2(10)	116.220		304.570		3394.880	
Prob > chi2	0.000		0.750		0.699	

Note ***p < 0.01, **p<0.05, and *p<0.1; GMM is used
Source Created by the author based on data from the CLMMS for 2004–2007

Table 6 MPL and wage of Chinese iron and steel firms by ownership type

	Average productivity of labor (APL)	*Production elasticity of labor*	*Marginal productivity of labor (MPL)*	*Wage*	*MPL/Wage*
SOEs	1,032	0.254	262	224	1.170
COEs	599	0.333	199	161	1.236
Non-SOEs	716	0.288	206	145	1.421

Note ***p < 0.01, **p < 0.05, and *p < 0.1; the production elasticity of labor is calculated based on the results of the production function using the GMM model
Source Created by the author based on data from the CLMMS for 2004–2007

Table 7 MPL and wage of Chinese SOE iron and steel firms

	Average productivity of labor (APL)	*Production elasticity of labor*	*Marginal productivity of labor (MPL)*	*Wage*	*MPL/Wage*
Large SOEs	1,548	0.015	23	224	0.103
Medium-sized SOEs	371	0.602	223	161	1.385
Small SOEs	106	0.602	64	145	0.441

Note ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$; the production elasticity of labor is calculated based on the results of the production function using the GMM model; firm size is determined based on the number of employees
Source Created by the author based on data from the CLMMS for 2004–2007

Second, regarding the differences by firm size in the SOE group, we compare the MPL and wages of large, medium-sized and small SOE firms (Table 7). We classified firms into three types based on the number of employees.[4]

The MPL is lower than the average wage for both large SOEs and small SOEs, while the MPL is higher than the average wage for medium-sized SOEs. Thus, surplus labor might be present in large and small state-owned iron and steel firms, while this might not be the case for their medium-sized counterparts. As the ratio of the MPL to wages is smaller (0.103) for large firms than for small firms (0.441), there might be considerable surplus labor in large state-owned iron and steel firms.

8 Conclusion

Using data from the CLMMS for 2004–2007, this study attempts to answer two questions: (1) Is there surplus labor in Chinese iron and steel firms? (2) Does the amount of surplus labor differ between the public and private sectors? We calculated the elasticity of labor based on firm production functions using an FE model, an RE model and GMM.

The main results are summarized as follows: first, both the wage level and labor productivity increased from 2004 to 2007 for both SOEs and

[4]The firms in the third, second and first quartiles in the number of employees are defined as large, medium-sized and small firms, respectively.

non-SOEs, but the extent of the increase in both wage and labor productivity is greater for SOEs than for non-SOEs. Second, the results based on the Cobb-Douglas production function indicate that the elasticity of marginal labor productivity is statistically significant for firms in the private sector (non-SOEs), while it is not significant for firms in the public sector (SOEs and COEs), according to the GMM estimates. Third, when we compare wages and marginal labor productivity, we find no surplus labor in the iron and steel sector overall, but there might still be surplus labor in both large and small SOEs, particularly in large state-owned iron and steel firms. The results indicate that the majority of large SOEs in the iron and steel industry sector are likely zombie firms. Why are these zombie firms supported by the Chinese government? This can be explained by the multiple purposes the government has for retaining state-owned firms, such as maintaining a leading position in sectors related to national security, stabilizing employment and reducing unemployment (Iwasaki et al. 2020). Thus, to improve the effectiveness and productivity of SOEs, including SOEs in the iron and steel industry, the cooperative governance reform of Chinese firms should be pursued.

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CHAPTER 11

On the Electoral Consequences of Increasing Chinese Imports: Insights from the Japanese Lower House General Elections, 2009–2017

Gaku Ito

1 Introduction

How does increasing import competition shape domestic politics? Given China's increasing economic growth and exports, the last several decades have witnessed a flourishing debate on how international trade affects domestic politics and local labor markets, both in academia and in the realm of policy. However, despite the existence of an established body of literature on international trade, the presence and directions of causality in this context remain largely disputed. For example, as highlighted in Autor et al. (2013), the observed evidence on international trade flows already shows that the increasing exports from China to the United States are strongly and negatively associated with US manufacturing employment at the community-zone level. This observed correlation, however, does not necessarily reflect an underlying causality if, for example, localities that

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already have declining manufacturing employment tend to be exposed to trade flows from China, which sustain their local economies.

One of the central threats to causal identification in the context of this debate is spurious correlations in the absence of experimental data. The widely employed gravity model of trade, namely the "workhorse" of empirical investigations of international trade (Head and Mayer 2015, 132), reveals empirical regularities in the observed trade flows in tandem with theoretical foundations. However, although the estimated parameters derived from gravity equations may well describe associations between, for example, the geographic distance between a pair of countries and trade flows, they do not necessarily capture causal quantities when not coupled with credible identification strategies.

Most of the empirical investigations into the impacts of increasing trade flows on related economic and political outcomes primarily rely on nonexperimental, observational data and thus face this identification challenge. Here, credible identification strategies play a central role in revealing the causal effects underlying the observed patterns of international trade. Given this challenge, Autor et al. (2013, 2020) recently proposed an innovative identification strategy to uncover the domestic economic and political outcomes of the increasing trade flows from China to the United States. This innovation involves the use of the observed imports from China to other high-income countries to exploit the *supply*-driven component, rather than the *demand*-driven component, of the increasing trade flows from China to the US. The empirical results in the work of Autor et al. (2013) reveal that an increase in Chinese exports to the US indeed increases the unemployment rate, decreases labor force participation, and decreases wages in labor markets at the community-zone level. Autor et al. (2020) extend the original analysis to investigate the political consequences of the increasing Chinese imports and demonstrate that increased exposure to Chinese imports is associated with increased ideological polarization and ideological rightward shifts in the US presidential elections between 2000 and 2016. Primarily focusing on the manufacturing sector, Taniguchi (2019) applies the proposed IV strategy to examine the effects of increased trade flows from China on prefecture-level labor markets. Somewhat in contrast to the earlier findings of Autor et al. (2013), the results in Taniguchi (2019) suggest that first, trade flows from China increase employment in the manufacturing sector, and second, this association is stronger in the context of intermediate products.

This chapter adopts the empirical strategy proposed by Autor et al. (2013, 2020) to explore the domestic political consequences of the increasing trade flows from China to Japan. Specifically, this chapter broadly applies the research design of Autor et al. (2013, 2020) to examine the impacts of the increasing Chinese imports to Japan, both the steel industry-specific increases and the increases in all the manufacturing sectors, on the outcomes of the four national Lower House (*Shūgiin*) General Elections in Japan between 2009 and 2017.

Although the present analysis might suffer from several methodological concerns, which are described below, the estimation results suggest two important patterns at the prefecture level. First, a naive comparison and coefficient estimates derived from ordinary least square models suggest that there is a positive association between increased import exposure in the steel industry and the vote shares of the ruling coalition and the Liberal Democratic Party. Second, and somewhat in contrast to the naive OLS estimates, this positive association becomes invisible once instrumented. In other words, while the naive comparisons are consistent with popular accounts and suggest evidence of rightward ideological shifts within heavily exposed prefectures, the detected association may not reflect an underlying causality. These results are somewhat consistent with the earlier findings in the work of Taniguchi (2019) and contribute to the growing debate in the political economy literature by providing another piece of evidence on the domestic political consequences of exposure to international trade.

2 Research Design

The current empirical analysis broadly follows the instrumental variable (IV) design of Autor et al. (2013, 2020), and utilizes a dataset containing prefecture-level records of the election results of the four national Lower House general elections between 2009 and 2017 and the international trade flows during the same period.

The records of international trade flows are based on the "BACI: International Trade Database at the Product-level" dataset (2020 version) developed by the Centre d'Etudes Prospectives et d'Informations Internationales (CEPII; Gaulier and Zignago 2010).[1] The individual records

[1] Available at http://www.cepii.fr/CEPII/en/bdd_modele/bdd_modele.asp. Accessed February 2, 2021.

of trade flows in the BACI are coded at the annual dyadic (bilateral) level, while the related products are coded according to the Harmonized System (HS) Code system. As discussed in detail below, the current analysis relies on the HS 1992 (HS92/HS0) system to ensure consistency with the coding systems of other sources taken from official governmental statistics below.

The following sections describe the details of the product coding of the trade flows and the measurements of the key variables. I then lay out the IV design based on the approach of Autor et al. (2013, 2020).

2.1 Dependent Variables

Recall that the current analysis primarily focuses on the possible impacts of increasing Chinese imports on political outcomes in Japan. The data for the primary outcome variables, namely the prefecture-level vote shares of the Liberal Democratic Party (LDP) and the ruling parties (LDP and *Komeito party*) in the four national Lower House general elections in 2009, 2012, 2014, and 2017 (the 45th to 48th general elections), come from the Ministry of Internal Affairs and Communications (MIAC).[2]

I obtained prefecture-level vote count records for both the single-seat and large-bloc proportional representation districts. Given the redistricting of single-seat districts during the study period, the current analysis exclusively focuses on each party's vote share relative to the total vote counts at the prefecture level.[3] The resultant dataset contains the vote shares of the individual parties across different prefectures in the four general elections between 2009 and 2017. The two dependent variables take the inter-election equivalents of first differences for the two subsequent elections. Specifically, the dependent variables, $\Delta\text{Share}_{it}^{\text{LDP}}$ and $\Delta\text{Share}_{it}^{\text{RP}}$, measure the change in the vote shares of the LDP and the two ruling parties, respectively, between the elections in years $t-1$ and

[2] Available at https://www.soumu.go.jp/senkyo/senkyo_s/data/shugiin/ichiran.html. Accessed February 2, 2021. The electoral system of the Lower House of Japan comprises single-seat constituencies and proportionally represented multiple-seat constituencies. The vote count records for individual constituencies have been publicly available since the 2009 general elections.

[3] Another reason for this focus on the prefecture level is the availability of the covariates and variables used to compute the trade exposure measure and the instrument specified below. Several key sources of these variables are only available at the prefecture level.

t, rather than the raw vote shares in the individual elections in prefecture i. For example, during the 2012 general election, $\Delta\text{Share}_{it}^{\text{LDP}}$ reflects the change in the LDP's vote share relative to its vote share in the 2009 general election in prefecture i.

2.2 Chinese Import Exposure

The coding of the key independent variable follows the work of Autor et al. (2013) and measures the extent of a region's exposure to Chinese imports scaled and weighted by its labor force and employment structure:

$$\text{Exposure}_{it}^{\text{Japan}} = \sum_j \frac{L_{ijt}}{L_{jt}} \frac{\Delta M_{jt}^{\text{Japan}}}{L_{it}}, \tag{1}$$

where i indexes a prefecture, j an industry, and t a period (election year) of observation. ΔM_{jt} is the recorded change in imports from China between years $t-1$ and t for industry j, and L_{it} denotes the total number of workers in prefecture i during year t. L_{ijt} and L_{jt} capture the number of workers in industry j within prefecture i and Japan, respectively, during period t.

Since the import growth M_{jt} is fixed across the prefectures for a given year t and industry j, the prefecture-level variation in Exposure_{it} arises from the differences in employment structure across the prefectures. Specifically, as stated in Autor et al. (2013), the variation in the weighted and scaled prefecture-level exposure to Chinese imports stems from two sources (p. 2128). First, the variation arises from prefecture-level differences in the degree of concentration in the manufacturing sectors relative to total employment (manufacturing and nonmanufacturing sectors). The more centralized a prefecture's employment is in the manufacturing sector, the greater its weighted exposure to Chinese imports becomes. Second, the exposure measure also reflects prefecture-level differences in the share of each industry relative to the national employment of that industry $\left(\frac{L_{ijt}}{L_{jt}}\right)$. Put another way, $\text{Exposure}_{it}^{\text{Japan}}$ measures the per-worker exposure to increases in Chinese imports for a given product category weighted by the share of the corresponding manufacturing sector in the employment structure of a prefecture.

2.3 Instrumental Variable

The specification of the instrument also generally follows Autor et al. (2013) and is defined analogously to the trade exposure measure:

$$\text{Exposure}_{it}^{\text{OECD}} = \sum_j \frac{L_{ijt-1}}{L_{jt-1}} \frac{\Delta M_{jt}^{\text{OECD}}}{L_{it-1}}. \quad (2)$$

Following Autor et al. (2013, 2129–2130), the instrument differs from the trade exposure measure in Eq. (1) in two ways. First, $\text{Exposure}_{it}^{\text{OECD}}$ replaces the measure of the change in the imports of each industry with observed records of Chinese imports to other Organization for Economic Cooperation and Development (OECD) countries, $\Delta M_{jt}^{\text{OECD}}$. The intuition behind this strategy to exploit the variation in the realized imports of China to other high-income countries is that it reflects the same supply-driven component of the Chinese imports, but it is not a function of a demand-driven component other than the common demand shocks across the OECD countries. Second, the expression of $\text{Exposure}_{it}^{\text{OECD}}$ replaces the employment-related terms in the trade exposure measure with temporally lagged variables to mitigate simultaneity bias.

2.4 Other Variables and the Coding of the Product Categories

I also compile a series of prefecture-level attributes to construct the trade exposure measures above and the covariates included in the estimation model below. The original prefecture-level statistics include population estimates from the MIAC; the Census of Manufacturers done by the Ministry of Economy, Trade and Industry (METI); and the Labor Force Survey done by the Statistics Bureau of Japan. I obtain prefecture-level counts of the labor force, the employment in different manufacturing sectors, and the total population and unemployment rate during the study period.

Recall that the examined records of international trade flows are based on the BACI data with individual trade flows coded according to the HS92/HS0 system. Thus, we need an accurate and disaggregated correspondence table to combine the trade flow records with the prefecture-level attributes to construct the import exposure measure and the instrument specified above. As the prefecture statistics of the METI and Statistics Bureau are coded according to the Japan Standard Industrial Classification (JSIC, Rev. 13), I first create two correspondence tables to match the product codes across the different datasets in two steps. First, I combine the MIAC's correspondence table for JSIC coding and International Standard Industrial Classification (ISIC) with the correspondence table for ISIC versions 3, 3.1, and 4 provided by the UN Statistics Division.[4] The resultant correspondence table provides a concordance list that can be used to link a given product code in the JSIC to the corresponding ISIC code. Second, I rely on the product concordance tables provided in the World Integrated Trade Solution data of the World Bank to match the individual ISIC codes to the HS coding system.[5] Then, I simply combine the JSIC-ISIC correspondence table with the ISIC-HS table, using ISIC as the common key to match the records of international trade flows (coded in the HS system) to the prefecture-level labor market structure (coded in the JSIC system).

The JSIC classification system divides the manufacturing sectors in Japan into 24 mutually exclusive categories, including the steel industry (*Tekko-gyo*). The classification of manufacturing industries in the current analysis follows the JSIC system used to measure industry-specific imports and employment.

2.5 Model Specification

According to the key measures defined above, the main IV estimation reported below builds on the following two-stage specification:

$$\text{Exposure}_{it}^{\text{Japan}} = \gamma \text{Exposure}_{it}^{\text{OECD}} + \mathbf{X}_{it}'\boldsymbol{\beta} + \phi I_t^{2012} + e_{it}, \tag{3}$$

$$Y_{it} = \tau_{\text{IV}} \widehat{\text{Exposure}}_{it}^{\text{Japan}} + \mathbf{X}_{it}'\boldsymbol{\eta} + \zeta I_t^{2012} + u_{it} \tag{4}$$

where Y_{it} represents one of the outcome variables, $\Delta\text{Share}_{it}^{\text{LDP}}$ and $\Delta\text{Share}_{it}^{\text{RP}}$. $\mathbf{X}_{it}$ is a vector of covariates, $\boldsymbol{\beta}$ is the corresponding coefficient vector including intercepts, and I_t^{2012} is a dummy variable that is equal to 1 for 2012 and 0 otherwise. For simplicity, given the limited number

[4] Available at https://www.soumu.go.jp/toukei_toukatsu/index/seido/sangyo/index.htm and https://unstats.un.org/unsd/classifications/Econ. Accessed February 3, 2021. The correspondence table for the different ISIC versions (Revisions 3, 3.1, and 4) is also provided by the UN Statistics Division.

[5] Available at https://wits.worldbank.org/product_concordance.html. Accessed February 3, 2021.

of observations ($47 \times 3 = 141$), $\mathbf{X}_{it}$ only includes the logged unemployment rate and the logged proportion of the population that voted, along with logged total vote counts in the proportional representation districts in prefecture i, in the election in year t. I_t^{2012} denotes the change in the ruling parties from the government coalition led by the Democratic Party of Japan (DPJ) to the 2012 general election and the LDP-led coalition afterward.[6] The number of observations remains at 141, rather than $47 \times 4 = 188$, given that I take the equivalents of the first differences between the subsequent two elections. To account for possible spatial and temporal autocorrelations in the regression residuals, I report the standard errors robust to multiway clustering at the prefecture and year levels.

Our primary variable of interest is τ_{IV}, which captures the local average treatment effect (LATE) of exposure to Chinese imports on the election outcomes. For comparison, I also report the corresponding, uninstrumented ordinary least square estimates. Given the focus of this volume, I also replicate the estimation separately for the steel-related industries and for all the manufacturing industries. The current analysis follows the recommendation of Angrist and Pischke (2008, 197–205) and builds on two-stage least square (2SLS) models rather than nonlinear models, which require additional estimation assumptions.

3 Results

Table 1 reports the main estimation results with the change in the vote share of the ruling coalition (LDP and *Komeito*) in the proportional representation districts as the dependent variable. Columns (1) to (3) report the first- and second-stage results of the IV-2SLS estimates of the import exposure in all the manufacturing sectors along with the uninstrumented OLS estimate, and columns (4) to (6) display the corresponding estimates with the import exposure measure replaced with the steel-related industry exposure measures. Table 2 replicates these regression estimates with the change in the LDP's vote share in the proportional representation districts as the dependent variable.

[6]The 2012 general election was the first Lower House election after the 2011 *Tōhoku* earthquake and tsunami, which is one of the strongest earthquakes in the recorded history in Japan.

Table 1 Chinese imports and the change in the ruling coalition's vote share, 2009–2017

	Dependent variable: $\Delta Share_{it}^{RP}$					
	OLS (1)	*First stage* (2)	*IV-2SLS* (3)	*OLS* (4)	*First stage* (5)	*IV-2SLS* (6)
$\text{Exposure}^{\text{Japan}}$	−0.001 (0.005)		0.028 (0.044)			
$\text{Exposure}^{\text{Japan, steel}}$				0.013^{**} (0.006)		0.02 (0.017)
$\text{Exposure}^{\text{OECD}}$		0.546^{**} (0.209)				
$\text{Exposure}^{\text{OECD, steel}}$					0.699^{***} (0.237)	
Covariates	✓	✓	✓	✓	✓	✓
Observations	141	141	141	141	141	141
Adjusted R^2	0.181	0.94		0.224	0.879	
F-statistic (weak instrument)		6.804	6.804		8.718	8.718
Stock and Yogo's critical value		16.38	16.38		16.38	16.38

Notes $^{*}p < 0.1$; $^{**}p < 0.05$; and $^{***}p < 0.01$. Reported in parentheses is standard errors adjusted for two-way clustering at the prefecture and year levels

3.1 Electoral Consequences of the Increasing Chinese Imports in Japan

Two patterns are visible in the regression estimates with different model specifications. First, the uninstrumented OLS estimates (columns 1 and 4 in Tables 1 and 2) suggest a positive association between the increasing Chinese imports in the steel industry and the change in the vote shares of the ruling coalition and the LDP. The coefficients of $\text{Exposure}^{\text{Japan, steel}}$ are consistently positive and are statistically significant at the conventional 5% level. In contrast, the coefficient estimates of the import exposure measure, $\text{Exposure}^{\text{Japan}}$, which accounts for all the manufacturing industries, remain small and statistically indistinguishable from zero. In other words, the naive regression results indicate that the increasing imports in the steel industry, if not in the whole industry, are associated with increased support for the ruling coalition led by the conservative LDP.

Second, the IV-2SLS estimates suggest a different picture that undermines the naive interpretation of the OLS estimates as causal effects. As

Table 2 Chinese imports and the change in the LDP's vote share, 2009–2017

	Dependent variable: $\Delta Share_{it}^{LDP}$					
	OLS *(1)*	*First stage* *(2)*	*IV-2SLS* *(3)*	*OLS* *(4)*	*First stage* *(5)*	*IV-2SLS* *(6)*
$\text{Exposure}^{\text{Japan}}$	−0.002 (0.004)		0.016 (0.027)			
$\text{Exposure}^{\text{Japan, steel}}$				0.008*** (0.003)		0.012 (0.009)
$\text{Exposure}^{\text{OECD}}$		0.546** (0.209)				
$\text{Exposure}^{\text{OECD, steel}}$					0.699*** (0.237)	
Covariates	✓	✓	✓	✓	✓	✓
Observations	141	141	141	141	141	141
Adjusted R^2	0.205	0.94		0.241	0.879	
F-statistic (weak instrument)		6.804	6.804		8.718	8.718
Stock and Yogo's critical value		16.38	16.38		16.38	16.38

Notes $^{*}p < 0.1$; $^{**}p < 0.05$; and $^{***}p < 0.01$. Reported in parentheses is standard errors adjusted for two-way clustering at the prefecture and year levels

reported in columns (3) and (6) in Tables 1 and 2, the coefficients of the import exposure measures, for both the steel industry and all the manufacturing industries, fail to retain substantial and statistical significance regardless of the outcome variables examined. The coefficients remain small and statistically insignificant at the conventional 5% level. Although the IV-2SLS should be interpreted with caution given the relatively weak first-stage associations, these contrasting results warn of the potential endogeneity biasing the naive comparisons. The OLS estimations suggest a systematic correlation between the increasing Chinese imports and the vote shares of the ruling coalition and the LDP; however, this correlation may not reflect an underlying causality.

3.2 Notes on the Remaining Methodological Concerns

Other than the difference in the estimands (average treatment effect (ATE) in the OLS estimations and LATE in the IV designs), the discrepancy between the OLS and the IV-2SLS estimates may reflect bias remaining in the OLS estimates, the IV estimates, or both. First, as mentioned above, the OLS estimates might be biased due to omitted confounding, simultaneity, and other sources of endogeneity. For example, the OLS estimates could suffer from upward bias if the exposure to Chinese imports is severer in prefectures with high baseline tendencies of support for the ruling coalition and the LDP than in other prefectures.

Second, the IV-2SLS estimates might also be biased or inconsistent due to the weak first-stage associations and potential violation of the exclusion restriction assumption induced by instrument-outcome confounders and mediators (Garabedian et al. 2014). For example, if the current analysis fails to adjust for any omitted variables that affect the instrument (namely, Chinese imports to OECD countries other than Japan) and the outcome (IV-outcome confounder) or that are affected by the instrument while influencing the outcome (IV-outcome mediator), these unadjusted factors would introduce bias into the IV-2SLS estimates by violating the exclusion restriction assumption.[7] As noted above, the IV estimates might also suffer from a lack of instrument relevance, as the F-statistics failed to reach Stock and Yoga's (2005)'s critical value of against the null hypothesis that the instrument is weak.

Admittedly, the present analysis is inadequate to allow us to interpret either the OLS or the IV-2SLS estimates as unbiased causal effect estimates. Focused investigations into the remaining methodological concerns and falsification tests are beyond the scope of the current volume. However, the discrepancy between the reported OLS and the IV-2SLS estimates is still capable of serving as a warning that underlines the inadequacies of naive comparisons to guide policy efforts.

4 Conclusion

How do increasing Chinese imports shape political outcomes in Japan? Due to the lack of experimental data, any empirical investigation into the impacts of these increasing trade flows faces the ever-present challenge of spurious correlations and other forms of endogeneity. Despite related scholarly and policy interests, the potential political consequences of trade flows remain largely disputed. This chapter has followed the recently proposed IV design of Autor et al. (2013, 2020) to examine how

[7] See, for example, Imbens (2014), Garabedian et al. (2014), and Davies et al. (2017) for identification checks for IV designs.

exposure to increasing trade flows from China affects electoral outcomes in Japan.

While several identification concerns remain in the present analysis, this chapter suggests two empirical patterns that carry important implications for future studies and policymakers. First, the naive comparisons of the OLS estimates suggest a positive association between exposure to Chinese imports and electoral support for the ruling coalition and the LDP in the four general elections of the Lower House in Japan. Second, and somewhat in contrast to the OLS results, the IV-2SLS estimates fail to uncover a similar positive association between the local geography of import exposure and electoral outcomes. Naive comparisons and popular accounts might suggest that increasing trade exposure causes rightward ideological shifts; however, the empirical analysis in this chapter fails to support such predictions. Several remaining methodological concerns, which are highlighted in the previous section, and other possible consequences of Chinese imports in Japan, are open for future studies.

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PART IV

Closing Remarks

CHAPTER 12

Closing Remarks: Toward Sustainable Growth of the Steel Industry in East Asia

Masashi Yamamoto and Jun Ma

This book summarizes East Asia's steel industry from its catch-up stage to becoming a world-leading player. Each chapter explains key factors that have allowed the steel industry in China, Japan, and the Republic of Korea (ROK) to be successful in the last 50–60 years from different perspectives. It was not our original intention to look back to the past and summarize the steel industry in East Asia, but we believe this is the best time to do so for the following reasons.

Just one year ago, COVID-19 was widespread in all three of these East Asian countries. As the following pandemic restricted most people in various ways, such as city lockdowns and travel bans, the world economy slowed to an unprecedented pace. Since steel products play a major role in

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many industries in our modern economy, this stagnation severely affected the industry, which was already suffering from overcapacity problems before the pandemic. In fact, the production of crude steel decreased by approximately 11% in the EU and 17% in the US, according to the World Steel Association (2021). Japan and the ROK also reduced their crude steel production by 16% and 6%, respectively, while total production in Asia increased by 1.5% due to 5% growth in China.

The overcapacity issue in the steel industry has been discussed repeatedly in this book, but the issue is so complicated that we cannot derive a simple solution. One reason for the difficulty is that the steel industry, especially because of its need for towering blast furnaces, needs long-term investment to build, which makes it difficult to exit the business. Another reason is the ineffectiveness of domestic subsidies. As the steel produced by each of three East Asian countries becomes closer in terms of quality, the competition among them is becoming closer to Cournot competition, where one country's gain is other countries' loss. In such a competitive environment, as Mai and Hwang (1988) argued, a welfare-maximizing national government tends to expand subsidies when its domestic industry is more competitive than the same industry in exporting countries. When China, Japan, and the ROK specialized in producing steel products of different qualities in "segregated" markets, industrial policy through subsidization or its equivalent could result in mutual prosperity among the three countries. However, in the current competitive situation and with similar quality, the competition to subsidize a country's own industry could end in a so-called race to the bottom with the consequence that no one wins. It seems that the pandemic has made an already complicated problem more complicated. The longer the steel industry in East Asia stagnates, the more likely it is that it will not stand on its accomplishments over the last 50 years but will transform them into a new business model with fewer demands for steel products.

The role of national governments should be reevaluated in the new business model. The overcapacity problem will become increasingly serious if governments simply put in place policies to increase the competitive advantage of their own steel industry. It will be necessary for governments to collaborate with each other to establish policies for how companies can grow sustainably in a good competitive environment based on competitive and dependency relationships in the international market for steel products and steel-related final products, with a view to not only quantitative adjustments but also structural adjustments in the value chain.

In addition, companies in the ROK and China have achieved competitive advantages by continually engaging in government-sponsored catch-up innovation activities. However, companies need to voluntarily change from learning innovation to creative innovation, as Japan Steel has done, if they are to maintain their leadership position in the global steel industry.

Late in 2020, the environment surrounding the steel industry became increasingly complicated due to the declaration of carbon neutrality by national leaders in many countries in the world. Following these statements, including one by ArcelorMittal, POSCO, and Nippon Steel, which are the leading steel producers in ROK and Japan, respectively, announced in December 2020 that they would commit to carbon neutrality by 2050. In January 2021, the Baosteel Group, the second-largest steel producer in China, also announced its commitment to carbon neutrality by 2050.

Steel production is carbon intensive in the process of extracting iron from ore. Towering blast furnaces need to be heated to over 1,000 degrees Celsius to remove oxygen molecules from iron oxide. Along with the energy input for heating, a large amount of CO_2 must be generated as a by-product of this reaction. This means that carbon neutrality cannot be achieved without drastic changes in the way steel is produced.

Major steel producers aim to achieve carbon neutrality by adopting carbon-capturing technology and hydrogen reduction methods (instead of using coke) as well as introducing more electric furnaces that use renewable energy. All of these alternatives are associated with problems that must be solved before they can be launched as real alternatives to current business operations. For example, electric furnaces cannot always produce the quality required for certain applications, such as trains and automobiles, and scrap supplies in many areas are currently very limited.

These changes will demand huge investments for steel producers. ArcelorMittal, a leading steel producer in the world, estimates it will need between 15 and 40 billion euros to decarbonize its facility by 2050,[1] while Nippon Steel announced that it will need an investment of between 4 trillion yen and 5 trillion yen[2] along with a 20% reduction in production capacity. Obviously, not all of the current steel producers can afford this level of investment.

[1] Pooler (2021).

[2] Yumae and Morikuni (2021).

The four issues discussed in this book, restructuring of international value chains, sustainable use of resources, environmental protection, and overcapacity, are common issues among the three countries. In the interviews that we conducted with representative steelmakers and related organizations in the three countries during the research period, these four issues were frequently mentioned as common topics. However, the fact remains that protectionism and political relations among the three countries have hampered the resolution of these issues.

In the future, it will be necessary for the government of each country to cooperate with the others to build a good competitive environment in the international market and to formulate policies that promote international cooperation at the corporate level in each country.

Whether these governments want it or not, the shrinking demand following the COVID-19 pandemic and the world commitment to carbon neutrality will force the steel industry to drastically reshape its business operations. In the next ten to twenty years, the steel industry will become very different, especially in East Asia. It is obvious that maintaining not only the same production capacity but also the same methods of production is not realistic. In studying the new trend of the industry that has recently emerged, we believe that this book, a summary of what Chinese, Japanese, and ROK steel producers have experienced, can provide various implications to prepare for the new road ahead.

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