CHAPTER 2

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

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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

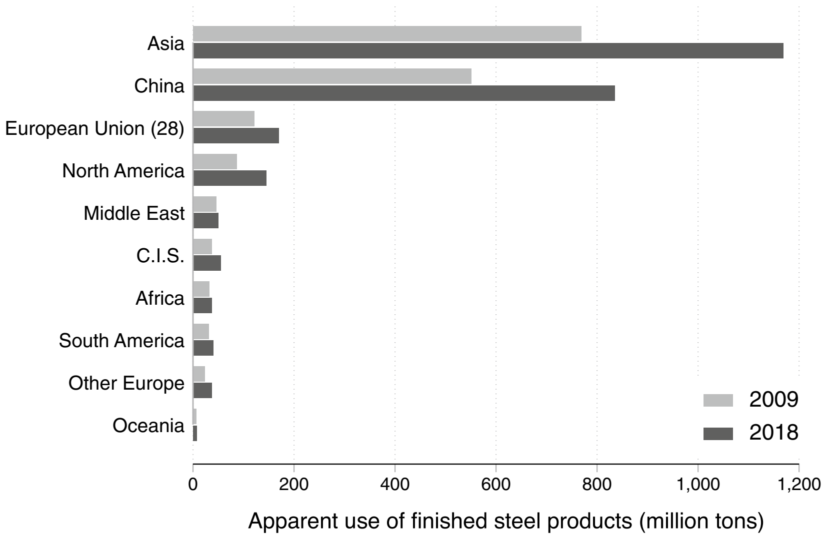

Fig. 1 Apparent use of finished steel products in million tons (*Note* C.I.S. indicates Commonwealth of Independent States. This figure presents the change in the apparent use of finished steel products from 2009 to 2018 for nine of the world's largest steel-consuming economies in Asia, Europe, the CIS 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,

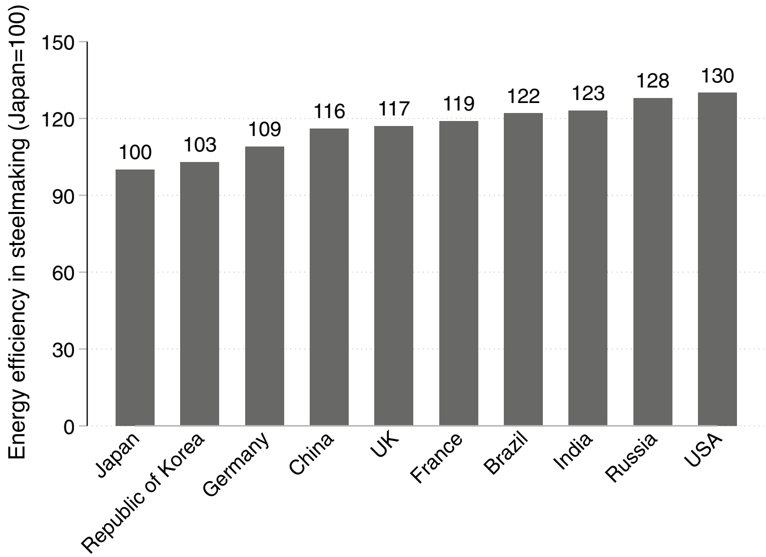

Fig. 2 Energy efficiency in steelmaking by country (2015) (*Note* This figure illustrates international comparisons of energy efficiency [sectors of electricity generation, iron, steel, and cement] and indexes with Japan set at 100. The original Japanese translation data and numerical values were provided 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)

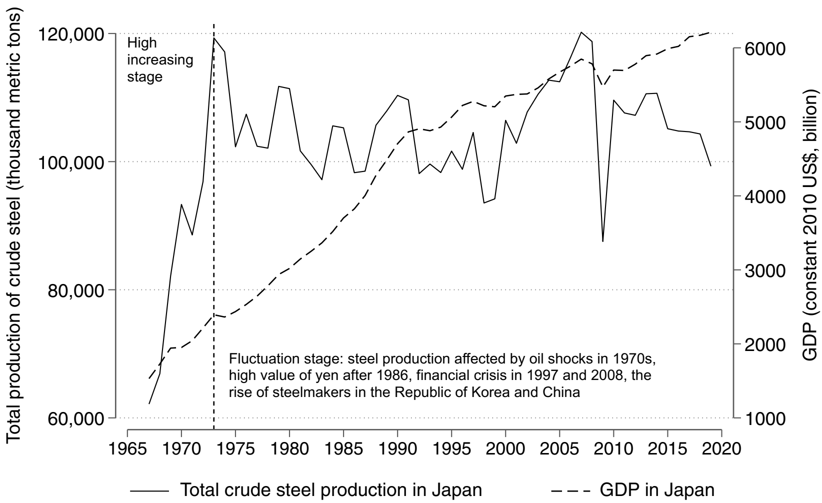

Fig. 3 Trend in total crude steel production in Japan, 1967–2019 (*Note* Data on GDP are in constant 2010 U.S. dollars and converted from domestic currencies using 2010 official exchange rates. *Source* The crude steel production dataset is from World Steel Association [1967–2019], and the GDP dataset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

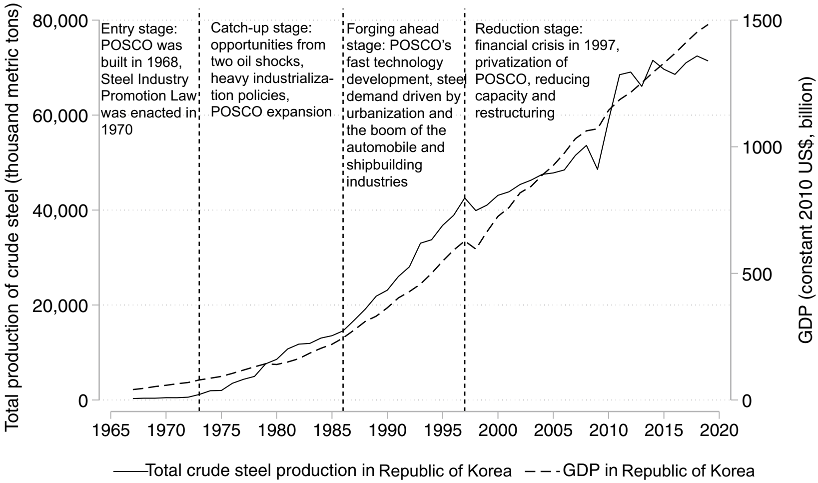

Fig. 4 Trend in total crude steel production in the Republic of Korea, 1967–2019 (*Note* Data on GDP are in constant 2010 U.S. dollars and converted from domestic currencies using official 2010 exchange rates. *Source* The crude steel production dataset is from World Steel Association [1967–2019], and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

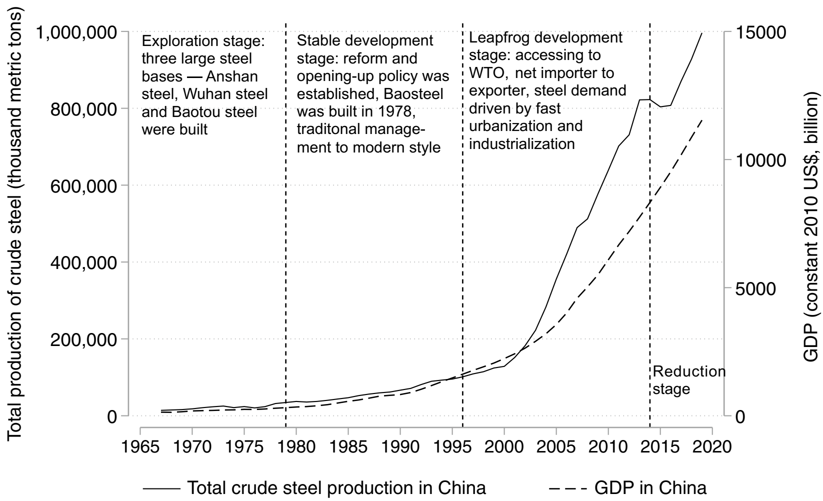

Fig. 5 Trend in total crude steel production in China, 1967–2019 (*Note* Data on GDP are in constant 2010 U.S. dollars and converted from domestic currencies using official 2010 exchange rates. Data on total crude steel production from 1967 to 1971 were estimated by World Steel. *Source* The crude steel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

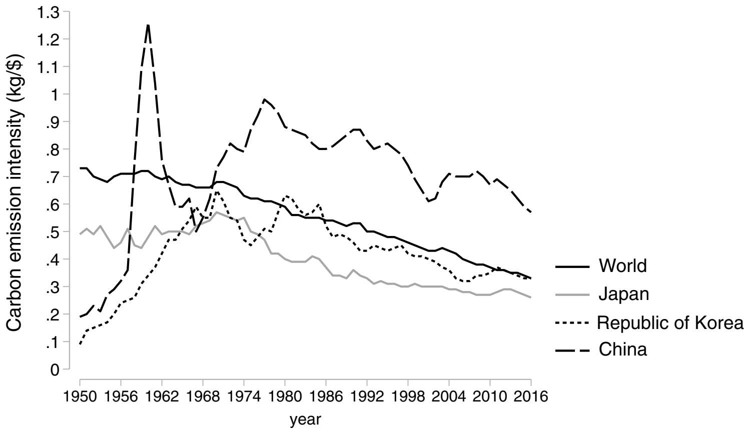

Fig. 6 Trend in carbon emission intensity in Japan, the Republic of Korea, and China (*Note* CO_2 intensity of the three East Asian economies measured in kilograms of CO_2 per dollar [kg/$] of GDP [measured in international dollars in 2011 prices]. *Source* This dataset is sourced from Our World in Data [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).

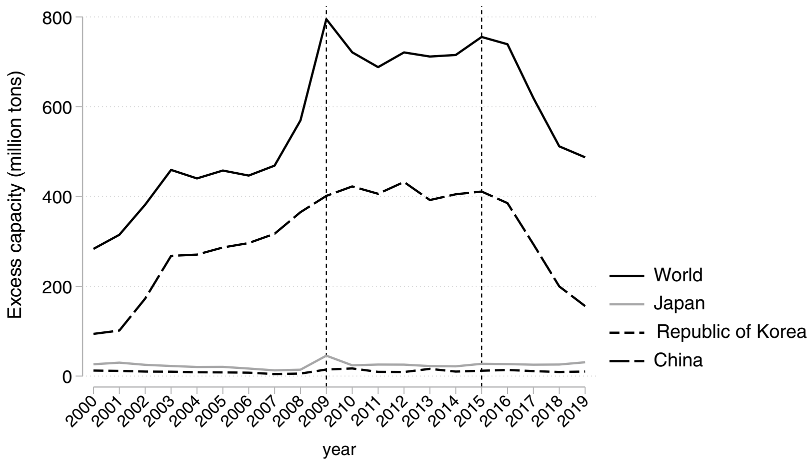

Fig. 7 Excess capacity in East Asia's iron and steel industry (*Note* This figure shows the trend in excess capacity in Japan, the Republic of Korea, and China from 2000 to 2019. Excess capacity in this study is calculated based on the following equation: excess capacity = steelmaking capacity-total 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

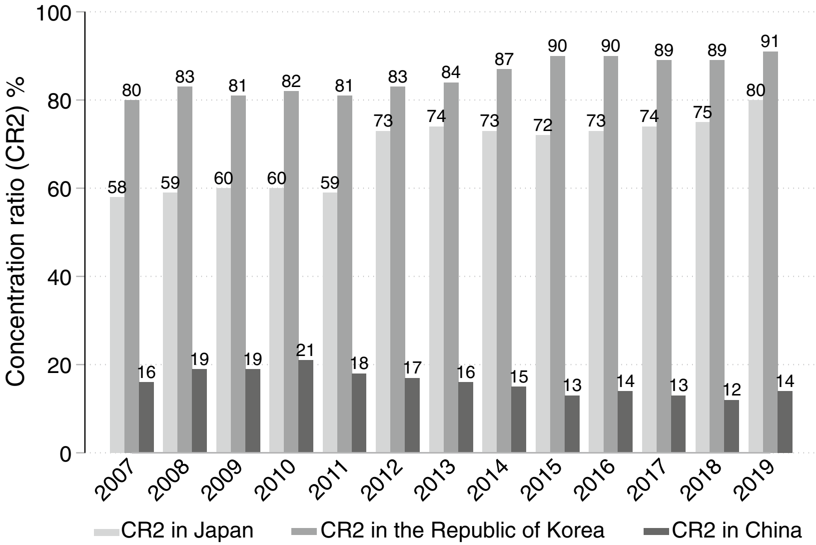

Fig. 8 The concentration ratio (CR2) in East Asia's iron and steel industry (*Note* The top two steelmakers in Japan are Nippon Steel and Sumitomo Metal Corporation [NSSMC] and JFE Steel Corporation. In the Republic of Korea, they are POSCO and Hyundai Steel Company. In China, they are Baowu Steel Group 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.

References

Brun, L. 2016. Overcapacity in steel: China's role in a global problem. Center on Globalization, Governance & Competitiveness, Duke University & Alliance for American Manufacturing.

Chen, W., Y. Lei, and Y. Jiang. 2016. Influencing factors analysis of China's iron import price: Based on quantile regression model. *Resources Policy* 48: 68–76.

China Association of Circular Economy. 2021. China's Baowu Steel Group plans to attain carbon neutral status by 2050. China Association of Circular Economy, 21 January.

China Iron and Steel Industry Association. 2019. China iron and steel industry thirteen five-year coal cap mid-term evaluation and later-term outlook. http://coalcap.nrdc.cn/Public/uploads/pdf/1559097268757375782.pdf. Accessed 28 December 2020.

Chung, C.H., and D.C. Sa. 2017. The Korean steel industry in retrospect: Lessons for developing countries. https://www.posri.re.kr/files/file_pdf/59/338/6867/59_3386867_file_pdf_1514351242.pdf. Accessed 30 December 2020.

Elbaum, B. 2007. How Godzilla ate Pittsburgh: The long rise of the Japanese iron and steel industry, 1900–1973. *Social Science Japan Journal* 10 (2): 243–264.

Hasanbeigi, A., N. Khanna, and L. Price. 2017. Air pollutant emissions projections for the cement and steel industry in China and the impact of emissions control technologies. Tech. rep., Lawrence Berkeley National Lab. (LBNL), Berkeley, CA.

Hong, J.H., J. Kim, W. Son, H. Shin, N. Kim, W.K. Lee, and J. Kim. 2019. Long-term energy strategy scenarios for South Korea: Transition to a sustainable energy system. *Energy Policy* 127: 425–437.

Iron and Steel Institute of Japan. 2020. Production and technology of iron and steel in Japan during 2019. *ISIJ International* 60 (6): 1063–1082.

Kawabata, N. 2017a. Where is the excess capacity in the world iron and steel industry? A focus on East Asia and China. https://www.rieti.go.jp/jp/publications/dp/17e026.pdf. Accessed 30 December 2020.

Kawabata, N. 2017b. The role of government in reducing excess capacity in the Japanese steel industry: Experiences from 1970s–2000s (Japanese). *TERG Discussion Papers* 371: 1–23.
Kim, J., Y. Ahn, and T. Roh. 2014. Low-carbon management of POSCO in circular economy: Current status and limitations. Towards a Circular Economy: Corporate Management and Policy Pathways. *ERIA Research Project Report* 44: 185–199.
Lee, T.Y. 2003. The Korean steel industry after the currency crisis. http://www.agi.or.jp/workingpapers/WP2003-36.pdf. Accessed 26 December 2020.
Lee, K., and J.H. Ki. 2017. Rise of latecomers and catch-up cycles in the world steel industry. *Research Policy* 46 (2): 365–375.
Lee, K., and F. Malerba. 2017. Catch-up cycles and changes in industrial leadership: Windows of opportunity and responses of firms and countries in the evolution of sectoral systems. *Research Policy* 46 (2): 338–351.
Lee, J.H., and J. Woo. 2020. Green new deal policy of South Korea: Policy innovation for a sustainability transition. *Sustainability* 12 (23): 10191.
Lee, H., E. Ramstetter, and O. Movshuk. 2005. *Restructuring of the steel industry in Northeast Asia*. London: Palgrave Macmillan.
Li, X. 2020. *The road map of China's Steel Industry*. Singapore: Springer.
Li, Y., Y. Wei, and Z. Dong. 2020. Will China achieve its ambitious goal?—Forecasting the CO_2 emission intensity of China towards 2030. *Energies* 13 (11): 2924.
Metal Bulletin. 2010. Metal bulletin's top steelmakers of 2010. https://www.metalbulletin.com/stub.aspx?stubid=12542. Accessed 25 December 2020.
Ministry of Economy, Trade and Industry. 2018. White paper on international trade 2018. https://www.meti.go.jp/report/tsuhaku2018/2018honbun/i2220000.html. Accessed 25 December 2020.
Ministry of Trade, Industry and Energy. 2014. Korea energy master plan: Outlook and polices to 2035. https://policy.asiapacificenergy.org/node/1358. Accessed 5 January 2021.
National Development and Reform Commission. 2005. China's steel and iron industry development policy (Chinese). https://www.shcs.com.cn/cn/laws/pdf/touzi/gangtiefazhan.pdf. Accessed 27 December 2020.
Nippon Steel Corporation. 2020. Nippon steel sustainability report 2020. https://www.nipponsteel.com/common/secure/en/csr/report/nsc/pdf/report2020.pdf. Accessed 3 December 2020.
Nolan, P., and G. Yeung. 2001. Large firms and catch-up in a transitional economy: The case of Shougang Group in China. *Economics of Planning* 34 (1): 159–178.
OECD. 2000–2019. OECD steelmaking capacity database, 2000–2019. https://stats.oecd.org/Index.aspx?DataSetCode=STISTEELMAKINGCAPACITY. Accessed 9 February 2021.

Our World in Data. 1950–2016. Carbon intensity data, 1950–2016. https://ourworldindata.org/grapher/co2-intensity?tab=table&time=1900.latest&region=World. Accessed 10 December 2020.

Oxford Economics. 2019. The role of steel manufacturing in the global economy. https://www.worldsteel.org/en/dam/jcr:fdf44918-de3b-455b-9083-f770afa4a214/OE%2520Executive%2520Summary.pdf. Accessed 10 December 2020.

Republic of Korea. 2020. 2050 carbon neutral strategy of the Republic of Korea. https://unfccc.int/sites/default/files/resource/LTS1_RKorea.pdf. Accessed 5 January 2021.

Ritchie, H. 2017. Carbon intensity in China's recent history—Politics matters a lot in achieving both prosperity and sustainability. https://ourworldindata.org/chinese-turbulence-how-periods-of-political-reform-affect-the-carbon-intensity-of-economies. Accessed 6 February 2021.

Shigeru, O., T. Hiroyuki, Y. Takao, and T. Nozomu. 2014. Environmental conservation and energy saving activities in JFE Steel. https://www.jfe-steel.co.jp/en/research/report/019/pdf/019-19.pdf. Accessed 16 December 2020.

Shin, K.H., and P.S. Ciccantell. 2009. The Steel and Shipbuilding Industries of South Korea: Rising East Asia and Globalization. *Journal of World-Systems Research* 15 (2): 167–192.

Smil, V. 2016. *Still the Iron age: Iron and steel in the modern world*. Butterworth-Heinemann

Tian, S., J. Jiang, Z. Zhang, and V. Manovic. 2018. Inherent potential of steelmaking to contribute to decarbonisation targets via industrial carbon capture and storage. *Nature Communications* 9 (1): 1–8.

United Nations Environment Programme. 2019. Emission gap report 2019. https://wedocs.unep.org/bitstream/handle/20.500.11822/30797/EGR2019.pdf?sequence=1&isAllowed=y. Accessed 11 January 2021.

Vercoulen, P., S. Lee, J.F. Mercure, S. Suk, Y. He, and K. Fujikawa. 2018. Decarbonizing the East Asian steel industry in 2050.

Wang, Y., H. Li, Q. Song, and Y. Qi. 2017. The consequence of energy policies in China: A case study of the iron and steel sector. *Resources, Conservation and Recycling* 117: 66–73, resource Efficiency in Chinese Industry.

Wilson, J. 2013. *Governing global production: Resource networks in the Asia-Pacific steel industry*. Springer.

World Bank. 1967–2019. World Bank GDP data, 1967–2019. https://databank.worldbank.org/indicator/NY.GDP.MKTP.CD/1ff4a498/Popular-Indicators. Accessed 09 February 2021.

World Steel Association. 1967–2019. Steel statistical yearbooks, 1967–2019. https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html. Accessed 11 December 2020.

Yu, B., X. Li, Y. Qiao, and L. Shi. 2015. Low-carbon transition of iron and steel industry in China: Carbon intensity, economic growth and policy intervention. *Journal of Environmental Sciences* 28: 137–147.

Zeng, S., Y. Lan, and J. Huang. 2009. Mitigation paths for Chinese iron and steel industry to tackle global climate change. *International Journal of Greenhouse Gas Control* 3 (6): 675–682.

Zhang, K., and Z. Wen. 2008. Review and challenges of policies of environmental protection and sustainable development in China. *Journal of Environmental Management* 88 (4): 1249–1261.

Zhou, K., and S. Yang. 2016. Emission reduction of china's steel industry: Progress and challenges. *Renewable and Sustainable Energy Reviews* 61: 319–327.