Catch-Up of the Steel Industry in Non-OECD Countries in the 21st Century: Developments in Steel Trade and the Role of Technology

Doctoral Dissertation

Catch-Up of the Steel Industry in Non-OECD Countries in the 21st Century: Developments in Steel Trade and the Role of Technology

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Chapter 1. Introduction

1.1 Research Background

The world economy has undergone multiple transformations in the 21st century, including the growth of emerging/developing economies, exemplified by non-Organisation for Economic Co-operation and Development (OECD) countries.[1] The robust growth of non-OECD countries has resulted in growing shares in the global economy and rising per capita income has accelerated their catch-up with richer countries.[2] The increasing prominence of Brazil, Russia, India, China and South Africa, particularly China and India, has driven the rapid development of non-OECD countries in the global economy. Thus, the rise of non-OECD countries is receiving considerable attention, and further research on the development of non-OECD countries could provide vital insights into the evolution of the world economy.

The circumstances in the global steel industry in the 21st century are notable from an industrial development perspective since the steel industry in latecomer countries has reformed the industry's structure. In the 21st century, the global steel market has developed significantly, primarily driven by the economic development and industrialisation of non-OECD countries, leading to radical changes in the structure of the global steel supply. The steel industry in OECD countries, major suppliers in the 20th century, has been challenged by non-OECD countries in terms of steel supply in this century. More specifically, the evolution of steel firms in non-OECD countries has fundamentally changed the landscape of the global steel industry over the last 20 years due to significant investments in steelmaking capacity, stemming from a sharp increase in steel-intensive economic activities, such as construction and infrastructure-building. While the growing prominence of the steel industry in non-OECD countries is seen as one of the most significant changes in the global steel industry today (OECD, 2015a, p. 7), despite being in the spotlight, very little is known about this development in the 21st century in economic literature.

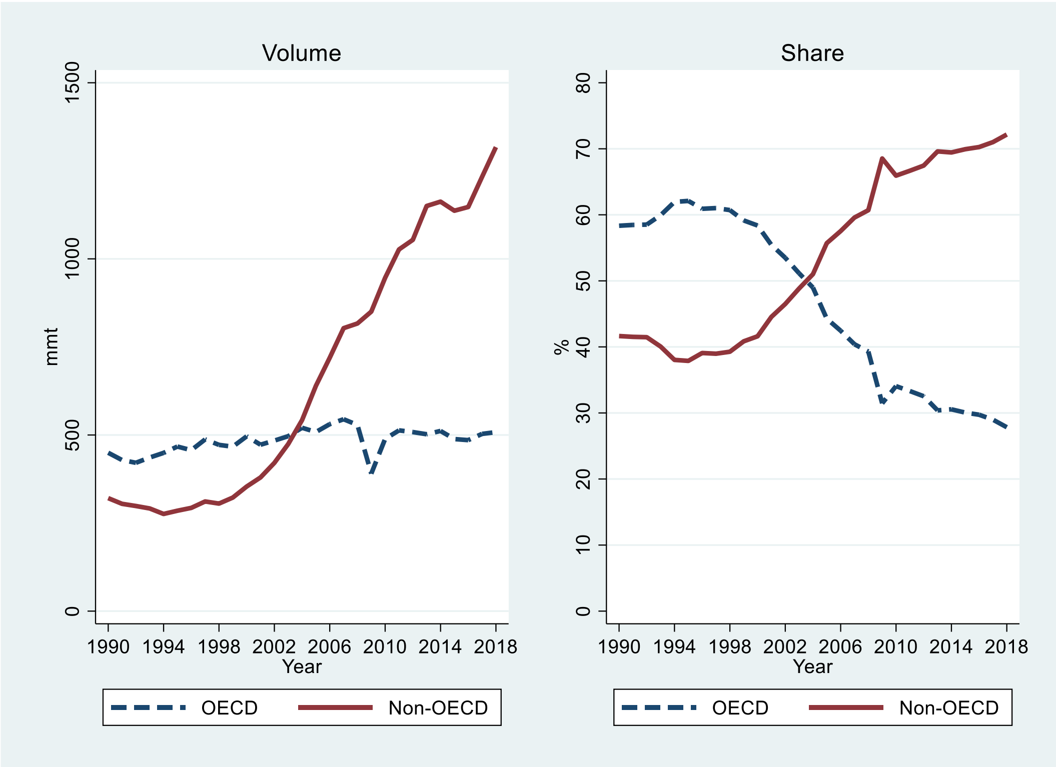
Focusing on steel production could provide important insights into the dynamics of the global economy, given that shifts in steel output are a significant indicator of the changing national and global

[1] This paragraph is based on Dahlman and Wermelinger (2015).

[2] According to data from the World Bank (2021), non-OECD countries surpassed the OECD's gross domestic product (GDP) at purchasing power parity in 2014.

economic landscape (Smil, 2016, p. 66). Crude steel output is one of the most important indicators for measuring the development of each steel industry and clearly reveals the development of the steel industry in non-OECD countries.[3] In the 21st century, crude steel output in OECD countries appears to remain relatively stable, whereas it has grown considerably faster in non-OECD countries in comparison (Figure 1.1, left panel). The steel industry in non-OECD countries surpassed OECD countries' crude steel output in 2004, with their share of world crude steel output increasing from 41.6% in 1990 to 72.2% in 2018 (Figure 1.1, right panel), dramatically transforming the structure of the global steel industry.

Figure 1.1 Global crude steel output (1990–2018)



Source: Author's calculation based on data from the World Steel Association (various years)

The concept of 'catch-up' is a key consideration in industrial development literature to illuminate latecomer countries' development paths, and many researchers in industrial development studies have discussed and attempted to elucidate catch-up trajectories at the national, industry and firm levels.[4] The

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[3] The World Steel Association (2021g) noted that 'Crude steel is steel in its first solid (or usable) form: ingots, semi-finished products (billets, blooms, slabs) and liquid steel for castings'.

[4] In economic literature, the concept of catch-up in latecomer countries can be examined at the national, industry and firm levels (Sato & Sato, 2016, p. 6); the present research investigates catch-up at the industry level.

steel industry is a suitable example for investigating non-OECD countries' catch-up at an industry level because it has been closely associated with national economic prowess since the Industrial Revolution (Shin, 2015, p. 66) and is a strategic industry that is crucial to latecomer countries' economic development (Mattera & Silva, 2018, p. 5). Indeed, several studies have analysed and discussed the catch-up of latecomer countries in the steel industry (Amsden, 1992; Kawabata, 2005, 2016a; Lee & Ki, 2017; Sato, 2013, 2016; Shin, 2015).

Based on the discussion above, it is crucial to examine non-OECD countries' catch-up trajectory in the global steel industry, and such research could provide a more comprehensive understanding of industry dynamics on a global scale, thus contributing to more thorough industrial development study. Therefore, analyses of the catch-up of the steel industry in non-OECD countries could offer a suitable approach for investigating the world economy from the perspective of the steel industry.

The remainder of this chapter is organised into five sections. Section 1.2 provides a literature review, primarily focusing on the concepts of comparative advantage and competitiveness at the industry level and catch-up industrialisation. Section 1.3 identifies research gaps based on the existing economic literature and presents the research questions. Section 1.4 provides an analytical framework, illustrating a hypothetical catch-up model, while Section 1.5 summarises some stylised facts regarding the steel industry, including the steelmaking process and pathways in steelmaking technologies. Section 1.6 presents the structure of this research.

1.2 Literature Review

1.2.1 Comparative advantage at the industry level

The 21st century is an era of post-Cold War global competition in which goods and services are traded worldwide due to decreased international trade barriers, transportation costs and information transmission costs.[5] Integration of Western and Eastern bloc countries has intensified international cost competition between higher-wage advanced countries (e.g. the United States, the EU and Japan) and lower-wage emerging/developing countries (e.g. China and India). Firms in advanced countries with a huge

[5] This paragraph is based on Fujimoto (2018, p. 6) and Fujimoto and Ikuine (2018, p. vii).

international wage handicap have faced challenges in enduring cost competition, primarily due to China's entrance into the global market.

This background leads to the following questions: How can we understand global competition at industry level since the end of the Cold War? Is there a theory to help us better understand international competition between advanced and emerging/developing countries?

The principle of comparative advantage—introduced by David Ricardo two centuries ago—could help us better understand the global competition between advanced and emerging/developing countries from the industry perspective (Fujimoto, 2018; Fujimoto & Shiozawa, 2012). In economic literature, the principle has been one of the most fundamental trade theories for explaining the mechanism of international trade (Deardorff, 2011; Kowalski & Stone, 2011; WTO, 2008).[6] Trade literature presents two major models of comparative advantage: the Ricardian model and the Heckscher–Ohlin model. While the Ricardian model highlights relative productivity differences across countries, differences between countries' relative factor endowments are at the heart of the Heckscher–Ohlin model (WTO, 2008, pp. 29–32).

This research adopts the Ricardian model based on the assumption that it is easier to understand comparative advantage in terms of productivity when discussing international trade at the industry level, including the steel industry. In the Ricardian model, countries' productivity is the key to understanding comparative advantage in international trade. Ricardo argues that it is not absolute differences but relative differences in productivity between countries that matter in explaining international trade (Deardorff, 2011, p. 28). In short, the relative productivity differences within each industry across countries determine which country has a comparative advantage.

Although comparative advantage is a classical theory, it continues to have a pivotal role in understanding complex contemporary international trade (Kowalski & Stone, 2011), providing important implications for the global competition between advanced and emerging/developing countries in the 21st

[6] The WTO (2008) explains the differences between 'absolute advantage' and 'comparative advantage' using the following example. Consider two countries (A and B), two goods (logs and steel bars), and one single input (labour). Here, technology in the two countries is summarised by labour productivity in the production of logs and steel bars, and unit labour requirements represent labour productivity. In this example, unit labour requirements for the logging and the steel industries are lower in Country A than in Country B, indicating that both industries have higher labour productivity. Thus, Country A has an absolute advantage in both industries. If the ratio of labour required for producing one log to that required for producing one steel bar is lower in Country A than in Country B, Country A has a comparative advantage in the logging industry. In contrast, if the ratio of labour required to produce one steel bar to that required for producing one log in Country B is lower than in Country A, Country B has a comparative advantage in the production of steel bars (pp. 29–30).

century (Fujimoto, 2018; Fujimoto & Shiozawa, 2012). Fujimoto and Ikuine (2018) assumed, 'In the era of global competition, *comparative advantage* still remains one of the key principles to analyse trade and industrial structures' (p. vii). In addition, Fujimoto and Shiozawa (2012) asserted, 'We anticipate that Ricardo's 19th century theory of comparative advantage will increase its importance in the globalised economy in the 21st century' (p. 193).

According to Fujimoto and Shiozawa (2012), it is possible to reinterpret the Ricardian model as a model of comparative product costs at the manufacturing site level. From this perspective, comparing international wage and productivity gaps is the key to understanding the model, which explains firms' capability-building competition amid intense global cost competition (Fujimoto & Ikuine, 2018, p. ix).[7]

While the above discussion suggests that the principle of comparative advantage could help us better understand international competition at the industry level, the following questions arise: How can we interpret global competition at the industry level using the principle, and how can industries in high-income countries overcome the huge international wage gap? From emerging/developing countries' perspectives, how can their industries acquire or maintain a comparative advantage to compete with high-income countries?

Fujimoto and Shiozawa (2012) explain international competition at the industry level using the four variables, the wage rates, w_J and w_C, and labour input coefficients, a_{Ji} and a_{Ci}, of the two countries (Country *C* and Country *J*) producing the same good.[8] These are variables that an industry member (a corporate manager or a factory leader) can estimate production cost per unit. The following inequalities are presented based on the four variables.

$$w_J a_{Ji} < w_C a_{Ci} \tag{1}$$

or

$$a_{Ji}/a_{Ci} < w_C/w_J \tag{2}$$

[7] Fujimoto (2018) defined capability-building competition as a circumstance by which, 'manufacturing sites compete to be selected by the firms to which they belong by improving their productive performance, such as production lead times, physical productivity, and manufacturing quality' (p. 11).

[8] The explanation of the model is based on Fujimoto and Shiozawa (2012, p. 198). For a more detailed explanation of the model, see the literature cited above.

When the two countries' wage rates are given, inequality (1) indicates that Country *J* has a lower cost than Country *C* for producing good *i*. In this case, Country *J* has a comparative advantage in good *i*, thereby exporting the product. Inequality (2), which is equivalent to (1), suggests that Country *J* must maintain productivity a_{Ji}/a_{Ci} times more than that of Country *C* to compete with Country *C*. For instance, Country *J*'s productivity must be ten times higher than that of Country *C* when country *C*'s wage rate is 1/10th of Country *J*'s wage rate.

To sum up, comparative advantage at the industry level can be determined by examining differences in production costs based on wage rate and productivity in the same industry between two countries. Macro factors (e.g. wage rate) are given to firms and manufacturing sites, whereas micro factors such as productivity are not given but variables that can change over time (Fujimoto & Shiozawa, 2012). Therefore, capability-building efforts for productivity improvement are crucial for firms and manufacturing sites that face intense global cost competition (Fujimoto & Ikuine, 2018, p. ix). In short, productivity improvement is the ultimate generator of comparative advantage at the industry level (Fujimoto, 2018, p. 13); thus, capability-building competition for improving productivity has been observed at this level.[9]

Based on the above observations, this research assumes that comparative advantage in the steel industry is not given but can be acquired through steel firms' technology choices and productivity improvement. This is consistent with the argument that enhancing the competitiveness of a country's steel industry results from the acquisition of comparative advantage through increased productivity (Marukawa, 2018).

1.2.2 Competitiveness at the industry level

The discussion regarding comparative advantage at the industry level suggests that firms and industries can overcome huge wage handicaps and remain competitive through capability-building efforts to improve productivity.[10] Hence, it is valuable to consider what competitiveness looks like at the industry level. Competitiveness at the industrial level can be defined as a subject's ability to be selected, including

[9] Fujimoto (2013, p. 3) explains international competition using Japan and China as an example. Although manufacturing sites in Japan rarely lose to overseas manufacturing sites in terms of productivity, they sometimes lost to China due to its huge wage gap. More specifically, Japan has been able to continue to export coordination-intensive (integral architecture) products such as automobiles based on the superiority of its manufacturing sites. In contrast, many coordination-saving (architecturally one-modular) products in Japan declined due to wage handicaps. For further discussion regarding architecture, see, for example, Fujimoto (2018, pp. 22–32).

[10] This paragraph is based on Fujimoto (2018, pp. 19–20) and Fujimoto et al. (2019, p. 1).

i) productive performance of manufacturing sites (deep-level competitiveness), ii) market performance of products selected by product market (surface-level competitiveness) and iii) profit performance of firms selected by capital markets. These performances interact with one another.

There are three layers of competitiveness at the industry level.[11] First, 'organisational capability' determines productive performance, strengthening a manufacturing site's potential for selection as a surviving facility by a firm (e.g. productivity).[12] This performance is called 'deep-level competitiveness' because it demonstrates the development and production ability that customers cannot observe. Second, 'market performance' is a product's potential for selection on the product market or the attractiveness of the design information embodied in the product (e.g. price). Since customers can observe or evaluate the performance, it is called 'surface-level competitiveness'. Deep-level competitiveness determines surface-level competitiveness, whereas surface-level competitiveness is also affected by various factors, including the appeal of products' characteristics and advertising and promotion. Finally, 'profit performance' is a firm's potential for selection on the capital market (e.g. profit margin) or its attractiveness in investors. Overall, firms and industries must strengthen productive performance (deep-level competitiveness), link to market performance (surface-level competitiveness) and lead to profit performance.

To summarise, it is reasonable to assume that each industry's productivity determines deep-level competitiveness. While it defines surface-level competitiveness, the differences in productivity (i.e. deep-level competitiveness) and wage of the entire economy affect surface-level competitiveness. In this case, comparative advantage corresponds to surface-level competitiveness. This research assumes that the productivity of a country's steel industry defines its deep-level competitiveness, and deep-level competitiveness can be improved through technology choice and productivity enhancement.

1.2.3 The relationship between the growth of industrial output and industrial productivity

The discussion about comparative advantage at the industry level suggests that productivity plays a vital role in industrial competitiveness. An important question that arises when discussing productivity in the industry is whether changes in output are associated with increased productivity.[13] The notions of the

[11] This paragraph is based on Fujimoto (2007, pp. 7–10) and Fujimoto (2018, pp. 19–20).

[12] Fujimoto (2018) defined organisational capability as 'a set of organisational routines that control and improve the flows of design information in that manufacturing site' (p. 12).

[13] This paragraph is based on Kaldor (1966) and Thirlwall (1983).

Verdoorn law and cumulative causation discussed by Kaldor (1966) have important implications to consider the relationship between the growth of industrial output and the growth of industrial productivity.[14] There are three growth laws in the Kaldorian model. Kaldor regards the manufacturing industry as the engine of economic growth (Kaldor's first law), and his second law suggests that manufacturing output growth induces productivity growth within the manufacturing sector itself owing to static and dynamic economies of scale or increasing returns (also known as Verdoorn's law). This suggests that i) the growth of manufacturing output leads to ii) the growth of productivity in the manufacturing industry, and iii) the productivity growth in the manufacturing industry promotes iv) the further growth of the manufacturing output. In short, there exists a cumulative process or virtuous circle of the growth of output and productivity in the manufacturing industry. In addition, the linkage between output growth and productivity growth leads to the faster growth of exports.

Based on the above observations, this research assumes a positive causal relationship between output growth and productivity growth as well as productivity growth and export growth when analysing the development of the steel industry in non-OECD countries.

1.2.4 Global competition in the steel industry

Operating costs and steel prices are essential elements closely linked to competitiveness in each country's steel industry. In the short term, steel prices are influenced by capacity utilisation, and steel firms aim to maintain a high utilisation rate to cover operating costs (D'Costa, 1999, p. 125). Input costs in the steel industry vary across countries due to the supply of raw materials, energy and labour costs, and these costs tend to differ depending on the types of technologies selected (OECD, 2012, p. 4). The steel industries in some non-OECD countries (e.g. Russia, China and Brazil) have lower operating costs than those of OECD countries (OECD, 2012, p. 4; Wood Mackenzie, 2018, p. 8), leading to competitiveness in the global steel industry. Operating costs for steel production are generally reflected in steel prices. Suzuki (1991) noted,

[14] For detailed information on the notions of the Verdoorn law and cumulative causation, refer to Kaldor (1970), Thirlwall (1983) and Verdoorn (2002).

> The steel industry is an industry with a low degree of product differentiation, particularly in mass-production goods, and in such an industry, competition normally occurs with regard to price. Price, in turn, is determined by the costs of raw materials, wages, and capital (p. 13).[15]

It is worth investigating how the global steel industry has evolved since the post-war period to better comprehend the competition between advanced and emerging/developing countries in the steel industry.[16] The industry has undergone significant changes, and at least three major transformations have been observed in the post-war period. First, the distribution of steel production capacity has shifted to latecomer countries; steel production is no longer confined to traditional steel-producing countries, such as the United States and Western European countries. Second, disequilibrium in the global steel industry has occurred due to the emergence of new technologies, challenging traditional large-scale integrated steel firms through the establishment of mini-mills.[17] Finally, institutional changes have been observed in the global steel industry, with entrepreneurs and the private sector increasingly entering the steel industry.[18]

Kawabata (2000) developed a framework of global competition based on the advantages implied by the backwardness and maturity hypotheses to analyse the competition between advanced and emerging/developing countries in the global steel industry.[19] The former emphasises the possibility of rapid growth in emerging/developing countries' steel industries, exploiting the advantage of the backwardness.[20] At the same time, the latter highlights the life cycle of the steel industry in advanced countries that have faced maturity.[21] Suzuki (1991) claimed,

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[15] Indeed, price competition has been observed in the steel industry, and trade friction frequently occurs in the global steel market (Kawabata, 2000, p. 136). According to the WTO (2021), base metals (including steel) have the highest antidumping cases among 19 sectors, accounting for 32.1% of global anti-dumping initiations during 2001–2018.

[16] This paragraph is based on D'Costa (1999, p. 2).

[17] For a detailed explanation of mini mills, see p. 30 in this chapter.

[18] In the steel industry, state-owned enterprises (SOEs) had a significant role until the 1990s. Indeed, SOEs accounted for about 70% of global steel production in the mid-1980s (Toda, 1987, p. 57). However, state ownership declined rapidly until the 2000s, primarily due to privatisation in Europe, followed by privatisation waves in former Soviet Union countries. Moreover, a privatisation wave also occurred in Brazil and in South America (Mattera & Silva, 2018, p. 17). In 2016, SOEs represented 37% of global steel output (World Steel Association, 2018, p. 26).

[19] This paragraph is based on Kawabata (2000, pp. 136–137).

[20] For a detailed explanation of the advantage of the backwardness, see pp. 14–15 in this chapter.

[21] A mature industry is in the process of losing its former comparative advantage. The major factor of maturity includes the standardisation of technology and products on the supply side and the market's economic slowdown or contraction on the demand side (Kawabata, 2003a, p. 3).

> The steel industry in developing countries could catch up with and outrun advanced countries in productivity levels by introducing the newest equipment, or by having the advantage of low-cost labour and capital. In other words, the steel industry of the leading countries is inevitably outrun by others. If so, it is not enough to examine the steel industry of advanced countries only in terms of new investments or the introduction of new technology, because such measures are more or less temporary in the long run (p. 13).[22]

If the advantages of the backwardness and maturity hypotheses apply, production capacity in the global steel industry is likely to shift from advanced to emerging/developing countries due to divergence in production costs.[23] However, the steel industry's competitive advantage has been established through technological change with the coordination of various institutions (e.g. behaviours of entrepreneurs and policy interventions) as opposed to price mechanisms. In sum, the hypotheses of advantage of the economic backwardness and maturity only provide probabilities regarding potential events, suggesting that not all steel industries in emerging/developing countries can catch-up, and not all steel industries in advanced countries will fall into decline. The development paths of firms and industries can be determined through institutional coordination to advance innovation and restructuring.

Given the above observations, it seems necessary to focus on at least three perspectives in this research. First, it is essential to bear in mind that competition among the steel industries of advanced and emerging/developing countries has emerged in the global steel industry. Second, technology choice is crucial for the steel industries in both advanced and emerging/developing countries. Finally, the steel industries in advanced and emerging/developing countries have faced different issues—maturation (advanced countries) and catch-up (emerging/developing countries).

[22] At the 27th International Conference of Business History, based on Suzuki (1991), Kawabata (2003a) pointed out that 'In the logic of a firm, unlike the steel industry, diversification and disinvestment are not necessarily the evidence of decline. Instead, they may be the best strategic option for the steel firm. In the discussion, however, participants [of the conference] emphasised that mobilising the accumulated capability in the steel industry was important for successful diversification (Suzuki and Abe 1991). To accumulate capabilities for the growth of the firm, it is necessary to keep competitiveness and profitability of the mature steel industry at a certain level' (p. 3).

[23] This paragraph is based on Kawabata (2000, pp. 137–146).

1.2.5 Technology choice in latecomer countries

The perspective of technology choice—the act of domestic/foreign entrepreneurs and producers selecting and adopting technology (Otsuka, 1990, p. 11)—has crucial implications when considering latecomer countries' industrial development (Gemma & Yoshino, 2012, pp. 1–2). Indeed, technology choice is a key consideration in the catch-up of latecomer countries at firm and industry levels (Sato, 2016, p. 159). Economic literature has highlighted the role of technology in latecomer countries' catch-up, suggesting that technology helps latecomer countries facilitate economic and industrial development (Kim & Nelson, 2000; Perez & Soete, 1988).

A critical issue to keep in mind is that technology choice has the nature of path dependence (Araujo & Harrison, 2000; Simeonov, 2020).[24] Since technological capabilities are path-dependent, past technology choice accumulation could affect future technological choices (Shibata & Kodama, 2004, p. 14). The technologies that firms have accumulated through past technological development choices and activities tend to influence future activities to search in terms of technological opportunities and results (Nelson & Winter, 1985), and the ability to absorb and use external knowledge depends on prior field capabilities and knowledge (Cohen & Levinthal, 1990).

In sum, technology options and exploration can be locked in as an extension of firms' existing technology (Shibata & Kodama, 2004, p. 14), suggesting that technology choice determines the development paths of firms and industries. A country's existing technology may not be easily switched due to the path-dependent nature of previous choices; thus, steel firms' past technology choices could affect current technology options, which is reflected in the production systems of each steel industry.

1.2.6 Technology choice in the steel industry

Technology choice has a pivotal influence in the steel industry. Technological advances and innovation help boost productivity and introduce high value-added steel products (Silva & de Carvalho, 2016, p. 6), and technology choice can lower production costs and enhance competitiveness in the steel industry (D'Costa, 1999, pp. 125–128). Production technology can impact long-term cost competitiveness, contributing to price competition in the steel industry (D'Costa, 1999, p. 125).

[24] Simeonov (2020) argues, 'A path dependence phenomenon is primarily a constructive approach for understanding the centrality of decision making on technology adoption' (p. 309).

Technology choice is a vital strategic element of structural change and a driver of growth in the steel industry in advanced and emerging/developing countries.[25] For the steel industry in advanced countries, efforts to make technological progress are crucial, such as the development of new steel products and manufacturing methods and innovation in facilities. In contrast, the industry in emerging/developing countries must determine which existing technology to use for steel production. For such countries, steel production indicates a catch-up experience because it reflects capital accumulation, technological progress and changes in the industrial structure.

1.2.7 Catch-up of latecomer countries and state-of-the-art technology

Economic literature highlights international trade since exports have implications for countries' economic and industrial development (Hausmann et al., 2006; Lall, 2000a, 2000b; Rodrik, 2006; Schott, 2007). Indeed, the evidence in a number of studies indicates that latecomer countries' level of industrial development can be observed by examining export structures (Kumagai, 2014; Kumagai & Kuroiwa, 2020). Therefore, research regarding industrial development must assume an international trade perspective.

Upgrading export structure has been a key agenda for the development of emerging/developing countries (Zhu & Fu, 2013, p. 221), which is relevant to investigations regarding comparative advantage in international trade. Export upgrading, such as export sophistication and export diversification, has attracted considerable attention in economic literature and provides important insights into how comparative advantage changes in emerging/developing countries. A broad consensus in the literature indicates that export sophistication and diversification are important for emerging/developing countries' progress, advancing faster and sustainable economic growth, and levels of economic development are closely related to export upgrading (Agosin et al., 2011; Cadot et al., 2011; Hausmann et al., 2006; Hesse, 2008; Lall, 2000a; Lall et al., 2006; Rodrik, 2006; Schott, 2007). Export upgrading is a means for an emerging or developing country to transform itself into a modern economy capable of producing and exporting goods similar to developed country exports (Chandra et al., 2007, p. 1). This argument in the literature suggests that the dynamic shift of comparative advantage could be a driver for emerging/developing countries of export upgrading through export sophistication and diversification.

[25] This paragraph is based on Sato (2010, p. 327) and Sato (2014, p. 10).

Economic literature explains changes in comparative advantage (Akamatsu, 1962; Vernon, 1966) and discusses how comparative advantage is acquired and then transmitted between advanced and emerging/developing countries through investment and trade (Meier, 1995, p. 456). The 'flying-geese' theory of economic development, introduced by Akamatsu (1962), is a well-known economic theory that explains the sequential development of manufacturing industries in latecomer countries. The main contentions of the model are: i) a basic pattern of an industry that grows tracing out the three successive curves of import, production and export, and ii) a variant pattern that industries diversify and upgrade from consumer goods to capital goods and from simple to more sophisticated goods (Kojima, 2000, p. 376).[26] The model was expanded by Kojima (2000), suggesting that comparative advantage shifts from labour- to capital-intensive products as a reflection of capital accumulation. Based on the flying-geese model, Widodo (2009) suggests that as latecomer countries' economies develop, they can improve trade balance (international competitiveness) while acquiring comparative advantage for a wide variety of goods.

Based on the above discussion, it seems reasonable to elucidate the shifts of comparative advantage as follows.[27] On the one hand, it is a process of industrial upgrading in a country through shifts in industries' comparative advantage. On the other hand, it is the industry's propagation from forerunner countries to latecomer countries. Therefore, the flying-geese model presents a theory for explaining the dynamic trajectory of comparative advantage.

The discussion about dynamic changes in comparative advantage is closely related to the concept of economic catch-up, providing important insights into how industries in latecomer countries can alter their structures from comparative disadvantage to comparative advantage through the introduction of technologies. Economic literature suggests that it is possible for industries in latecomer countries to reduce productivity gaps with methods in forerunner countries, as the former can easily import technology and access the benefits of international technological spillovers (Giuliani et al., 2012, pp. 3–4). Suehiro (2008) asserted,

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[26] Vernon's (1966) product cycle model explains why US firms shift to multinationalisation and overseas production. The model is an international spillover mechanism of industrialisation from developed countries that overlaps with Akamatsu's (1962) arguments (Suehiro, 2008, pp. 39–40).

[27] This paragraph is based on Kawabata (2005, p. 2).

> Catch-up industrialisation is a pattern of industrialisation frequently, indeed necessarily, adopted by late-industrialising countries and late-starting industries. It is an essential aspect of any attempt to reduce the gap in national wealth between developing and developed countries (p. 3).

The concept of catch-up emphasises the development and upgrading of industrialisation, particularly in the manufacturing industry, and mainly examines production technology, manufacturing know-how, institutions, systems and organisations that facilitate industrialisation.[28] The theory has two characteristics. First, latecomer countries can use technologies and knowledge systems developed by previously industrialised countries; thus, they are able to save time and capital by adopting the existing necessary technology and know-how. Second, latecomer countries usually start by importing most industrial products, often launching a domestic production policy and import substitution to reduce import dependency. Overall, a cycle from importing to domestic production, exporting and re-importing is evident. Latecomer countries tend to introduce trade policies related to import substitution and export promotion and industrial policies to protect and foster domestic industries. Hence, Suehiro (2008) asserted, 'In short, trade and industry are inextricably interlinked' (p. 4).

The above observations suggest that the flying-geese model and the catch-up industrialisation model have a high correlation. Overall, catch-up industrialisation is a model in which latecomer countries aim to catch-up with forerunner countries through industries that already exist in forerunner countries, rather than pursue development by promoting new industries.

To fully understand the catch-up mechanism in latecomer countries, it is important to highlight the work of Gerschenkron (1962), which discussed the possibility of a surge in industrialisation through exploiting the advantages of backwardness—an opportunity to leverage the backlog of technologies developed by countries that already industrialised.[29] Gerschenkron (1962) argued,

[28] This paragraph is based on Suehiro (2008, pp. 3–4).

[29] Gerschenkron (1962) posits that latecomer countries need to meet certain conditions to enjoy the advantages of backwardness. For instance, latecomer countries require specific industrialisation ideologies or strong ideological stimulus for industrialisation (Gerschenkron, 1962, p. 86). In addition, the author emphasises the role of government and financial institutions in advancing industrialisation (Gerschenkron, 1962, pp. 11–21).

> Industrialisation always seemed the more promising the greater the backlog of technological innovations which the backward country could take over from the more advanced country. Borrowed technology, so much and so rightly stressed by Veblen, was one of the primary factors assuring a high speed of development in a backward country entering the stage of industrialisation (p. 8).

Based on observations of European industrialisation in the 19th century, Gerschenkron (1962, p. 26) argues that latecomer countries tend to introduce large-scale plants based on the most modern technologies. A question arises: What kind of industries are relevant to Gerschenkron's hypothesis? Is the steel industry an industry in which latecomer countries can exploit the advantage of backwardness to catch-up with forerunner countries? According to Gerschenkron (1962),

> … a branch like iron and steel production does provide a good example of the tendency to introduce most modern innovations, and it is instructive to see, for example, how German blast furnaces so very soon become superior to the English ones, while in the early years of this century blast furnaces in still more backward southern Russia were in the process of outstripping in equipment their German counterparts (p. 10).

In addition, Shin (2015) asserted,

> … the Gerschenkronian strategy of establishing 'bigger and bigger' plants with latest technologies was effective when the pace of product and process innovation was not so rapid, when its direction was towards increasing economies of scale, and when technological progress was mostly embodied in capital equipment (p. 141).

Shin (2015, p. 141) cited the steel industry as a typical example of the assumption that technology is embodied in capital equipment, arguing, 'The iron and steel industry is a typical producers' goods industry on which Gerschenkron's schema is based' (p. 67). Here, the threshold level of technology for catching up is a critical issue as it relates to whether the steel industry is an industry in which latecomer countries can easily catch-up with forerunner countries. Shin (2015) observed, '… the threshold level played an important role in the catching-up in the semiconductor industry whereas it was not so significant in the iron and steel industry' (p. 142). In the case of the steel industry, where more known technologies than in other industries exist, technology transfer is easier than in other sectors; thus, latecomers can quickly catch-up (Toda, 1984, pp. 31–33).

As Gerschenkron emphasised, some studies argue that the large-scale plants based on state-of-the-art technology have played a significant role in the steel industry. Shin (2015) sheds light on the catch-up of the steel industries of Japan and South Korea during the post-war period as suitable examples of the Gerschenkron model.[30] The author argues that the steel industry in latecomer countries could catch-up with forerunner countries by establishing bigger and bigger plants based on state-of-the-art technology and exploiting economies of scale on the global level as a key factor of international competitiveness. Although there was a technological gap in the steel industries of Japan and Western European countries during the first half of the 20th century, the Japanese steel industry adopted a Gerschenkronian type strategy to catch-up with more advanced steel-producing countries. Japan's steel firms established large plants in coastal areas to enjoy economies of scale, enabling the export of products to the world market. In the South Korean steel industry during the post-war period, Pohang Iron & Steel Co, Ltd (now known as POSCO, the largest steel firm in the country) solely undertook the nation's catch-up, and the industry also adopted the Gerschenkronian type catch-up strategy and established bigger and bigger plants, contributing to its export activities. Shin (2015) observed,

> … the Gerschenkronian type of investment strategy, that is, the establishment of 'bigger and bigger' plants with the latest technologies, should have been a critical factor in POSCO's earlier attainment of international competitiveness and profitability (p. 107).

[30] This paragraph is based on Shin (2015, chap. 7).

The above discussion suggests that the steel industry is an industry to which Gerschenkron's hypothesis can be applied, given that technology is embodied in capital equipment.[31] While Gerschenkron's model argues that latecomer countries can achieve the catch-up with forerunner countries by introducing state-of-the-art technology, there is a debate on appropriate technology to fulfil local conditions. Thus, it is also imperative to examine the concept of appropriate technology to consider which approach is suitable for analysing the catch-up of the steel industry in latecomer countries.

1.2.8 Appropriate technology and innovation in emerging/developing countries

The concept of appropriate technology could provide important insights into the discussion of technology choice in emerging/developing countries.[32] An argument that introducing the latest technology in emerging/developing countries does not necessarily bring about superior results since the technological gap between advanced and emerging/developing countries is too wide. There is also a considerable gap in terms of factor endowments between them.

In economic literature, the concept of appropriate technology is traceable to Schumacher (1993), who used the term 'intermediate technology' to refer to the technology between advanced and indigenous technology. Schumacher (1993) argued,

> Such an intermediate technology would be immensely more productive than the indigenous technology (which is often in a condition of decay), but it would also be immensely cheaper than the sophisticated, highly capital-intensive technology of modern industry … The intermediate technology would also fit much more smoothly into the relatively unsophisticated environment in which it is to be utilised (p. 149).

In the 1970s, intermediate technology had become a highly debated issue in major international organisations such as the OECD, the United Nations Industrial Development Organisation and the

[31] Indeed, Gerschenkron's (1962) argument is suitable to examining capital-intensive industries such as the steel industry and can be used to investigate the possible development of the steel industry in emerging/developing countries (Kawabata, 2016a, p. 80).

[32] This paragraph is based on Marukawa (2016, p. 187).

International Labour Organisation.[33] These organisations argued that emerging/developing countries should adopt or develop technology suitable to their factor endowment and workforce skill and education levels. While there are numerous successful cases of intermediate and appropriate technology in emerging/developing countries, the discussion regarding appropriate technology suggests that technology does not operate well when it does not fit emerging/developing countries' conditions.

The discussion regarding innovation relevant to the debate on appropriate technology in emerging/developing countries has an increasingly prominent position in economic literature. It may be challenging for the technologically backward emerging/developing countries to develop novel technologies and products like firms in advanced countries, and their opportunities are also limited. Nevertheless, firms in emerging/developing countries can combine existing resources (e.g. capital, labour, technology and marketing) to gain competitiveness (Suehiro, 2008, p. 61).

The concept of disruptive innovation introduced by Christensen (2016) has implications for innovation in industries.[34] Christensen (2016) argues,

> Disruptive technologies change the value proposition in a market. When they first appear, they almost always offer lower performance in terms of the attributes that mainstream customers care about … But disruptive technologies have other attributes that a few fringe (generally new) customers value. They are typically cheaper, smaller, simpler, and frequently more convenient to use. Therefore, they open new markets. Further, because with experience and sufficient investment, the developers of disruptive technologies will always improve their products' performance, they eventually are able to take over the older markets (p. 232).

The theory of disruptive innovations suggests that such novelties can be applied to emerging/developing countries' markets, and disruptive innovations at the base of the pyramid have much greater potential than those in markets in advanced countries.[35] This is because business models in low-

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[33] This paragraph is based on Marukawa (2016, pp. 187–188).

[34] Christensen (2016) discusses disruptive innovations examining the cases of the disk-drive, excavator, steel and car industries.

[35] This paragraph is based on Hart and Christensen (2002, pp. 52–54).

income markets can be more profitable than high-income markets, and disruptive innovations can offer a product/service to low-income individuals who may otherwise be entirely left out of accessing existing products.

The concept of catch-down innovation introduced by Marukawa (2016) also provides insights for considering appropriate technology and innovation in emerging/developing countries.[36] Since the 2000s, the catch-up of firms in emerging/developing countries has been remarkable, with their unique technological progress attracting considerable attention. In particular, firms in China and India have developed a number of indigenous technologies that fulfil low-income demand, resulting in commercial success in these countries.[37] In sum, catch-down innovation encompasses intermediate and appropriate technology and new innovations in which firms in emerging/developing countries take the initiative.

While the discussion above suggests that emerging/developing countries do not always need the latest technology, whether the latest technology or the appropriate technology is suitable may differ depending on the industry type. Thus, it is necessary to consider this issue in the context of the steel industry.

The discussion regarding appropriate technology provides important insights into technology choice in the steel industry. First, the case of Malayawata Steel in Malaysia, presented by Yoneyama (1990), has implications for transferring appropriate technology in the steel industry. Malaysia constructed a small-scale integrated steel mill based on a blast furnace using rubberwood charcoal and local low-quality iron ore by transferring appropriate technology from Japan.[38]

Second, the case of Vietnam's two private steel firms, namely, Hoa Phat Group (HPG) and Hoa Sen Group (HSG), analysed by Kawabata (2020b), also has implications regarding appropriate technology in the context of the steel industry.[39] These firms have achieved leading positions in the long and flat steel sectors in the Vietnamese steel industry, taking advantage of innovation in the production system and

[36] This paragraph is based on Marukawa (2016).

[37] The cases included compact cars (India), DVDs (China), guerrilla mobile handsets (China), electric bicycles (China) and animation (China) (Marukawa, 2016).

[38] While the Malayawata project started from Malaysia's request to Japan's Yawata Steel to construct a large-scale integrated steel mill with a capacity of 1 million metric tonnes (mmt), Yawata Steel considered that it would be challenging to build such a steel mill due to its small domestic market. Instead of 1 mmt steel mill, a small-scale, 100,000-tonne integrated steel mill was constructed. The project used local natural resources (e.g. iron ore and rubberwood charcoal), and new technology which produces rubberwood charcoal for the blast furnace was invented. This unique production system fulfilled appropriate technology conditions (Yoneyama, 1990).

[39] This paragraph is based on Kawabata (2020b, pp. 263–265).

management that fulfils local market conditions and factor endowment.[40] Overall, the trajectory of these steel firms indicates that HPG selected appropriate technology and catch-down innovation (Marukawa, 2016) and HSG implemented a primitive stage of disruptive innovation (Christensen, 2016) and market creating innovation at the base of the pyramid (Hart & Christensen, 2002). This case implies that the latest technology is not necessary for success in the steel industries of emerging/developing countries.

The discussion regarding appropriate technology in the steel industry suggests that it is rational for firms in emerging/developing countries to apply innovation in the production system and management that fulfils local market conditions to capture the domestic market. In the case of the steel industry, steel firms in some countries can produce steel using appropriate technology to meet domestic steel demand. However, a question arises: Does the steel industry in these countries continue to use appropriate technology when shifting from the import substitution stage to the export industrialisation stage? [41]

When steel industries in these countries consider supplying steel products to the foreign steel market, they will be exposed to international competition. To supply steel products to other countries, the steel products produced must meet international standards to achieve a comparative advantage. In this case, production technologies may switch from appropriate technology to state-of-the-art technology, given that forming a large-scale integrated production system based on the latest technology appears to be important for international competitiveness in the global steel market. Based on the above discussion, a more in-depth analysis is needed to assess whether introducing state-of-the-art technology remains an effective approach for emerging/developing countries to accelerate their catch-up in the global steel industry.

1.2.9 Development patterns of latecomer countries in the steel industry

It is imperative to shed light on the development patterns of latecomer countries in the steel industry to better understand non-OECD countries' catch-up in the 21st century, and the discussion

[40] Adopting small-scale integrated facilities (e.g. three small-sized blast furnaces), with its own raw materials instead of large-scale facilities used in large steel-producing countries, enabled HPG to establish a leading position in the long products market due to its high cost competitiveness, resulting from a vertical integration strategy from raw materials to steel products. HSG explored the domestic market through its own a directly managed sales network across the country, contributing to its rapid market development. It targeted the construction steel market, particularly the private housing market and became the leading firm in the surface-treated steel sheet market (Kawabata, 2020b, pp. 263–265).

[41] The case of HPG in the Vietnamese steel industry has implications for the discussion regarding appropriate technology and state-of-the-art technology in the steel industry. It might be challenging for the steel firm to maintain its market share with only the current technology (i.e. appropriate technology), and thus it planned to install a large-scale integrated steel complex based on state-of-the-art technology (Kawabata, 2020b, p. 265).

regarding the flying-geese model (Akamatsu, 1962; Kojima, 2000) is closely related to the development patterns of the steel industry in latecomer countries. Suppose the steel industry in latecomer countries develops a flying-geese pattern. In that case, they are likely to adopt an import substitution strategy during industrialisation, and then their catch-up process shifts to domestic production and exports.

Economic literature discusses some typical development patterns of latecomer countries in the steel industry; for example; i) steel imports meet the steel demand for economic development and industrialisation if the steel industry in a country is not well developed; ii) steel demand shifts from low value-added steel products to high value-added products as the economy develops; iii) steel production begins when steel imports reach the minimum economic size; iv) steel exports start when steel production increases to a certain level and v) steel imports, steel production, and steel exports change from low value-added steel products to high value-added products (Toda, 1970, pp. 25–28).[42] In addition, the structure of the industry also shifts as an economy develops; i) from import substitution of downstream steel-producing facilities (i.e. re-rolling/surface treating facilities) to import substitution of upstream steel-producing facilities (i.e. ironmaking/steelmaking facilities); ii) from long to flat steel products; and iii) from low value-added to high value-added steel products (Sato, 2013, p. 177).

It is particularly crucial to focus on export competitiveness in the steel industry, based on the assumption that the industry develops in the order of import, production and export. Uncovering the historical development patterns of the steel industry in a specific country could help better understand the role of the overseas market in developing the steel industry. The cases of the steel industries of South Korea and Taiwan have implications relevant to considerations of the development patterns of latecomer countries in the industry. In economic literature, researchers have regarded these two countries as successful catch-up industrialisation cases (Sato & Sato, 2016, p. 1). From the steel industry perspective, they have at least three things in common; i) the domestic steel market's narrowness; ii) export-oriented strategy; and iii) the importance of integrated steel firms.

[42] Economic literature highlights the importance of linkage effects between the steel industry and steel-using industries (Jeon, 2018; Kawabata, 2003b, 2005; Mattera, 2018; OECD, 2017; Sato, 2014, 2016) focuses on the issue of Global Value Chains (GVCs) in the context of the steel industry, illustrating the linkage effects. Owing to high linkage effects with various sectors (e.g. automobile, shipbuilding and construction), steel consumption is closely linked to GDP (OECD, 2013d, p. 4). Indeed, high linkage effects are observed between the steel industry and steel-using industries (AISI, 2018; EUROFER, 2018; World Steel Association, 2019a, 2019b).

The South Korean steel industry's case suggests that an export-oriented strategy was recognised from the initial stage to avoid the narrowness of the domestic steel market. It could not have developed without export competitiveness in the international steel market, and an integrated steel firm had a significant role in its development. South Korea's largest integrated steel firm, POSCO, established in 1968, was the sole integrated steel firm until Hyundai Steel entered the blast furnace business in 2010.[43] POSCO set an export target and focused on exports for various reasons that included ensuring long runs and full-capacity use for all types of steel and driving a stake in the international market in anticipation of future capacity expansion (Amsden, 1992, p. 301; Shin, 2015, p. 106).[44] POSCO had also been active in exports since its establishment (Abe, 2008, p. 79). Some research (Amsden, 1992; Shin, 2015) considers the South Korean steel industry to be a successful example of the strategy of export promotion and import substitution from the beginning, relying on exports from the start to avoid the narrowness of the domestic steel market. The South Korean steel industry enhanced international global competitiveness through POSCO's integrated steelworks which have enjoyed economies of scale (Sato, 2014, p. 20). In addition, the export-oriented strategy enabled the South Korean steel industry to earn foreign currency and upgrade both technology and exports, leading to technological improvements in its steel industry through competition (Sato, 2014, p. 20).

The case of the Taiwanese steel industry also demonstrates the importance of export competitiveness in the global steel market when considering its development.[45] Like South Korea, the size of the domestic steel market in Taiwan has been modest; thus, steel exports (particularly flat products) have had a prominent place in its steel industry development. In the Taiwanese steel industry, the transportation equipment industry, such as automobiles, a major steel-using industry, was limited compared to those of Japan and South Korea. The underdeveloped automobile industry has been a major impediment to developing high value-added products; thus, exports in the flat products segment in the Taiwanese steel industry made up for its underdeveloped transportation equipment industry. Flat products such as cold-rolled sheets and surface treated sheets have been major production items in the Taiwanese steel industry, which developed relying on overseas demand. Since these products have been designed to

[43] Hyundai Steel fired up its two blast furnaces in 2010 and constructed a third in 2013 (Paul Wurth, 2020, p. 2).

[44] POSCO set an export target of 30% of its steel production (Amsden, 1992, p. 301).

[45] This paragraph is based on Sato Yukihito (2008).

primarily target overseas markets, the export ratios have been very high. In 1971, China Steel Corporation (CSC) was established as a steel firm integrated into the Taiwanese steel industry, and CSC contributed to developing the flat products segment in the Taiwanese steel industry as the sole integrated steel firm.[46]

Although the production/export ratio in the Chinese steel industry has been low, the industrial development literature suggests that export competitiveness is relevant to its development.[47] Some research provides insight regarding the overseas steel market with a focus on the Chinese steel industry, including important implications for its development (Marukawa, 2018, pp. 252–254; Marukawa & Hattori, 2019, pp. 32–36; Tanaka & Isomura, 2020, pp. 122–127). While China was declared the world's largest steel-producing country in 1996, the Chinese steel industry had not yet achieved the catch-up since it was a net importer of steel and thus was not internationally competitive at that time (Tanaka, 2008, pp. 20–22; Tanaka & Isomura, 2020, p. 127). In the 21st century, the Chinese steel industry has become a net exporter of steel (Marukawa, 2018, pp. 252–254; Marukawa & Hattori, 2019, pp. 32–33; Tanaka & Isomura, 2020, pp. 122–127), indicating the nation's significant development as a superpower in the global steel industry (Marukawa, 2018).

Based on the above discussion, export competitiveness appears to be closely related to the development of the steel industry. Nevertheless, it does not mean that all steel firms are capable of exporting steel products, and steel firms need to acquire comparative advantage by enhancing productivity to export steel products, which is in accordance with Fujimoto (2018) and Fujimoto and Shiozawa (2012). Therefore, it is important to determine how comparative advantage in the steel industry has been analysed in economic literature.

While the principle of comparative advantage is prominent in trade literature, it is also relevant to the international steel trade. de Carvalho and Sekiguchi (2015) discussed comparative advantage in the context of the steel industry, asserting, 'Steel trade is determined to a large extent by the comparative advantage of steel producers' (p. 27). Steel firms have a comparative advantage when the opportunity cost of production is low, and they tend to focus on specific steel products that have a comparative advantage (Mattera, 2018, p. 27). Thus, focusing on the specific steel products exported can identify where the

[46] Dragon Steel Corporation, a subsidiary of CSC, established No.1 blast furnace in 2010 and No.2 blast furnace in 2013 (Primetals Technologies, 2020a, p. 2).

[47] The export ratio (total steel exports/crude steel production) of the Chinese steel industry in 2001–2018 was 9.1%.

‘strengths’ of specific countries lie (de Carvalho & Sekiguchi, 2015; Mattera, 2018). Overall, the above literature suggests that the principle of comparative advantage can explain international steel trade, and steel firms tend to export steel products based on their comparative advantage.

Another significant issue in the steel trade is international competitiveness, which is also relevant to the discussion regarding emerging/developing countries’ catch-up in the global steel industry. Industrial development research has highlighted the international competitiveness of major steel-producing countries, such as China (Marukawa, 2018, pp. 252–254; Marukawa & Hattori, 2019, pp. 32–33; Tanaka & Isomura, 2020, pp. 122–127). These studies indicated how these steel-producing countries had evolved globally, providing important insights into catch-up dynamics.

The literature mentioned above suggests that the analysis of comparative advantage and international competitiveness in the context of the steel industry could provide important insights into international steel trade patterns and catch-up dynamics of the steel industry in non-OECD countries. Nevertheless, despite the importance of comparative advantage and international competitiveness in the global steel industry, there is limited economic literature regarding the two concepts; therefore, it is vital to analyse the international steel trade from the perspectives of comparative advantage and international competitiveness in the global steel industry to discuss non-OECD countries’ steel industry catch-up in the 21st century.

Some principal issues must be considered when analysing the development of latecomer countries in the steel industry, including i) production technology and firm types, ii) actors, iii) level of economic development and steel demand, iv) characteristics of steel supply and demand and v) import structure. For instance, it is crucial to focus on the kinds of production technology steel firms select, the level of steel demand and the absolute size of demand (Sato, 2008a, pp. 9–18).

Overall, this research investigates the evolution of the steel industry in non-OECD countries in the 21st century by focusing on steel exports while also considering other relevant factors (e.g. technology), based on the assumption that export competitiveness is a necessary condition for the development of the steel industry across countries.

1.3 Identifying Research Gaps and Presenting Research Questions

Identifying research gaps in the existing literature is crucial to formulating the research questions in this research. While economic literature is beginning to pay attention to non-OECD countries' growing prominence in the global steel industry, empirical analysis remains limited. Although important insights are contributed in the existing literature examining the development of emerging/developing countries in the steel industry, several gaps and avenues for further research remain. More research is needed to gain further insights into the catch-up of the steel industry in non-OECD countries.

First, there has been no comprehensive analysis examining the steel industries in all emerging/developing countries in existing economic literature; thus, the state of catch-up progress for the whole steel industry in non-OECD countries remains unclear. There are rich case studies investigating specific emerging/developing country's steel industry in industrial development studies, and several studies have highlighted the development of large steel-producing countries (e.g. the Chinese steel industry). Nonetheless, it is crucial to focus on the steel industry in countries of both large and small-medium scale production to assess the entire evolution of the steel industry in all non-OECD countries. Therefore, an extensive analysis is necessary to assess their catch-up in the 21st century.

Second, little attention has been paid to the issues of comparative advantage and international competitiveness in the context of the steel industry. Although these issues have a significant role at the industry level, empirical research into the steel industry remains limited, necessitating further investigation, as minimal attention has been devoted to factors that affect comparative advantage and international competitiveness of each steel industry. Based on the literature review, two factors—technology choice and the level of economic development—appear to be crucial to steel industry export patterns, and such an investigation could provide vital insights into the patterns of the global steel trade.

Third, there is limited research on the issue of export upgrading in the steel industry. While some research is gradually focusing on the discussion regarding GVCs in the context of the steel industry, no direct analysis of export upgrading, exemplified by export sophistication and diversification in the industry has been made thus far. If emerging/developing countries need to upgrade trade structures to catch-up, then analyses of export upgrading could provide a deeper understanding of the level of development in non-OECD countries.

Finally, few reports are available that focus on technology choice as a key factor that impacts the catch-up of steel industries in non-OECD countries. In particular, very little is known about when, or by whom, such decisions are made, and which production technology was chosen to accelerate the catch-up. It is essential to track non-OECD countries' evolution longitudinally using time-series analyses to deepen the discussion regarding the catch-up in the global steel industry. Technology choice may have occurred in the 20th century and is likely to have continued to develop over a relatively extended period. Focusing on technology choice and international trade dynamics over time provide a more comprehensive understanding of the evolution of the steel industries in non-OECD countries during the 20th and the 21st centuries, offering critical insights into the catch-up dynamics.

To fulfil these research gaps, this research aims to answer the following key question:

How has technology choice contributed to the catch-up of the steel industry in non-OECD countries in the 21st century as demonstrated through export performance? [48]

[48] It is important to note the usage of the term 'technology' in this research. While 'technology' and 'technique' are related, their meanings are different in economic literature. Hamaguchi (2004) explains the differences between 'technology' and 'technique'. For instance, 'technique' refers to individual specific skills, whereas 'technology' suggests a system of various skills. Also, technology implies applying scientific knowledge, whereas the technique is sometimes used independently of science (p. 135). In addition, 'technique' instead of 'technology' is used the production function, which calculates the output compared to its input in theoretical economics (e.g. Kaldor, 1961). Looking at dictionaries of economics, technology refers to 'The sum of knowledge of the means and methods of producing goods and services' (Bannock & Baxter, 2011, p. 381) or 'The body of knowledge about materials, techniques of production, and operation of equipment, based on the application of science' (Black et al., 2017, p. 518). Thus, the use of 'technology' is broad and diverse. There seems either 'technique' or 'technology' are used when analysing the choice of methods of producing goods in developing countries. For instance, to discuss methods of production to use in developing countries, Stewart (1972) used 'choice of technique', while Willoughby (1990) referred to 'technology choice'. It seems that the latter is related to the topic in this research, given that Willoughby (1990) discusses the Appropriate Technology movement in the 1970s. Given that comparison of 'state-of-the-art technology' and 'appropriate technology' is theoretically critical in this research, the research assumes that 'technology' is suitable when discussing activities to select specific types of production facilities in the steel industry in non-OECD countries. In addition, 'technology' is often used in path dependence literature (e.g. David, 2007; Liebowitz & Margolis, 1995), which is also linked to the topic of this research. Indeed, the term 'technology choice' appears to use production methods at the industry level. For instance, see, Csereklyei and Stern (2018) for the U.S. electricity industry, Amsalem (2003) for the textile, pulp and paper industries and Otsuka et al. (1988) for the Indian and the Japanese cotton textile industries. Indeed, 'technology' and 'technology choice' are used for selecting specific types of production facilities in the steel industry (e.g. Boyd & Karlson, 1993; D'Costa, 1999; Howell et al., 1988; Rimini et al., 2020; Shin, 2015; Silva & Mercier, 2020). Thus, this research defines 'technology choice' as the act of steel firms selecting specific types of upstream/downstream production facilities.

This research sets the following sub-questions to answer the main question:

1. *How are technology choice and the level of economic development associated with advantages in specific types of steel products, forming current global steel trade patterns?*
2. *To what extent has the steel industry in non-OECD countries caught up in terms of upgrading exports, in reference to export sophistication and diversification?*
3. *When and how were technology choices that affect comparative advantage and international competitiveness implemented among major steel industries in non-OECD countries?*

1.4 Analytical Framework

Before constructing a model for this research, it is crucial to summarise an overview of the a) production process; b) technology pathways in steelmaking; c) enlargement of production facilities; d) state-of-the-art technology and appropriate technology in the steel industry; e) types of steel firms; and f) the role of exports in the steel industry.

1.4.1 Production technologies, types of steel firms and the role of exports in the steel industry

a) Overview of the production process

Steel is primarily produced using two methods: the blast furnace–basic oxygen furnace (BF–BOF) route and the electric arc furnace (EAF) route (EUROFER, 2020; World Steel Association, 2013, 2021f). In general, there are three stages in steel production: i) ironmaking, ii) steelmaking and iii) finishing.[49]

There are two production facilities in the ironmaking process: the BF and the direct reduction of iron ore (DRI). A BF is a furnace used for smelting iron from iron ore; thus, iron ore and coal are major inputs.[50] The DRI process is an alternative to the BF route that principally uses natural gas as a reductant to produce solid iron from iron ore. The DRI is used as either a replacement or supplement for scrap in the EAF route (Midrex, 2018, p. 6).[51]

[49] The information on the steelmaking process is based on the EUROFER (2020), the OECD (2015c) and the World Steel Association (n.d., 2012, pp. 24–39, 2013, 2021f).

[50] For detailed information on raw materials in the steel industry, refer to the OECD (2014a) and the World Steel Association (2021e).

[51] DRI production occurs in areas close to abundant natural gas sources and rich iron ore (Silva & de Carvalho, 2016, p. 18).

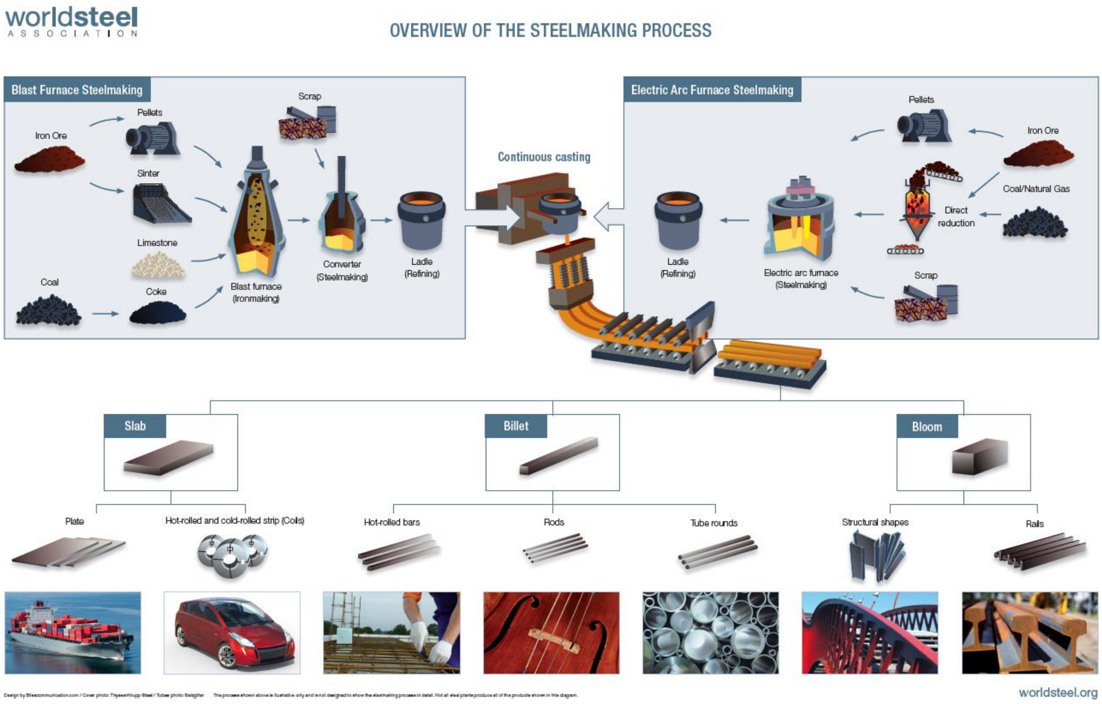
The BOF and the EAF are two main routes in the steelmaking process. The BOF route requires a BF since molten pig iron (sometimes referred to as hot metal) is input in this process, while scrap is used for the EAF route. An open-hearth furnace (OHF) route also exists in some emerging/developing countries, although this is outdated production technology compared to the BOF and EAF routes.

In summary, currently, the i) BF–BOF route, ii) EAF route and iii) DRI–EAF route exist in the steel industry. Thus, there are multiple routes in technology choice in the steel industry.

Figure 1.2 illustrates an overview of the steelmaking process. In the ironmaking process, oxygen is removed from the iron ore using coal to produce molten pig iron or hot metal, which is then delivered directly to a steelmaking plant. A BOF uses molten pig iron that has been produced in a BF. During the steelmaking process, oxygen is blown into the molten pig iron and carbon to remove other impurities (e.g. nitrogen, phosphorus, sulphur) from the molten pig iron and convert it to steel that contains less than 1.2% of carbon. The EAF route, alternatively, uses scrap as the main input with heat produced by electricity.[52] The EAF furnace is charged with material, and electrodes are lowered into it, creating an arc and generating the high temperatures required to melt the scrap. Then, the molten steel is cast and shaped into semi-finished products (i.e. billets, blooms and slabs) through a continuous casting machine, where steel is poured directly into the machine. A continuous casting process solidifies steel in the form of a continuous strand rather than ingots. From semi-finished products, steel products such as bars, rails, plates and hot-rolled coils are produced.

[52] DRI is also used for an input in the EAF route.

Figure. 1.2 Overview of the steelmaking process



Source: World Steel Association (2013)

b) Technology pathways in steelmaking technologies

Given that the BF–BOF route and the EAF route are major modern steelmaking technologies, it is particularly important to examine technology pathways focusing on these technologies to better understand historical development in the industry from a technological perspective.

In the 20th century, two steelmaking technologies—BOF and EAF processes—became the predominant production technologies over the OHF process introduced in the 19th century, enabling steelmaking to be faster and more energy-efficient, and allowing steel firms to re-use scrap as input material.[53] The BOF process was invented by Robert Durrer (Swiss) in 1948 and developed by VÖEST AG (now known as voestalpine AG).[54] Traditional integrated steel firms—large-scale plants combining iron smelting and steelmaking facilities based on the BOFs—require a BF to supply molten pig iron as input. While the EAF route first emerged at the end of the 19th century, its diffusion occurred in the 1960s, when

[53] This paragraph is based on the World Steel Association (2012, p. 24). For detailed technological pathways in the steel industry, see the literature cited above.

[54] This technology is also known as the LinzDonawitz (LD) process, after the Austrian towns in which it was first commercialised (World Steel Association, 2012, p. 24).

steel scrap from vehicles, home appliances and industrial waste became a cheap resource.[55] The EAF process was primarily used for speciality steels and alloys until the 1960s.[56]

In addition to these steelmaking processes, continuous casting—new ways to cast (pour) the molten metal into moulds—was developed in the steel industry.[57] Whereas steel was poured into stationary moulds forming ingots (large blocks) and then rolled into sheets or smaller shapes and sizes until the 1950s, liquid steel is now fed continuously into a mould in a conveyor belt type process in continuous casting, making a long strand of steel. Semi-finished products produced by continuous casting machines are much thinner than traditional ingots and easier to roll into finished products. Smil (2016) argued, 'Without exaggeration, swift diffusion of basic oxygen furnaces (BOFs) and of continuous casting have revolutionised the industry through higher efficiencies, reduced waste, and rising productivity' (p. 87).

c) Enlargement of production facilities

Since the 1950s, technological innovation has dramatically increased energy efficiency and productivity through the vertical integration of processes.[58] The importance of economies of scale through the rational arrangement and enlargement of facilities has expanded in the steel industry. The increase in the size of BFs was noticeable, especially in the 1960s, and EAFs also became larger, while OHFs disappeared in congruence with the diffusion of these new steelmaking technologies. In the global steel industry, large-sized BF technology was often introduced in the steel industries of in latecomer countries, including Japan and some emerging steelmaking countries (Toda, 1984, p. 5).[59]

Integrated steelworks based on large-sized BFs on the coast, with deep-water ports, are located where water transportation for raw materials and steel products is much more efficient than land

[55] The origin of the EAF route can be traced to the experiments of William Siemens in 1878 and 1879 (Smil, 2016, p. 103). The first commercial EAF plant, developed by Paul Héroult (French), was established in the United States in 1907 (World Steel Association, 2012, p. 51).

[56] Generally, EAFs are smaller and simpler to construct and operate and thus called 'mini mills'. While mini mills initially produced low value-added products (e.g. concrete reinforcing bars), compact strip production (CSP) has enabled them to produce flat products from thin slabs and enter the sheet-steel market (World Steel Association, 2012, pp. 34–35).

[57] This paragraph is based on the World Steel Association (2012, p. 25).

[58] This paragraph is based on Sato (2014, pp. 16–18).

[59] Generally, large-sized BFs denote an inner or working volume of more than 2,000 m^3 (see CISA, [various years] and KOSA, [various years]).

transportation than locations adjacent to raw material production areas.[60] These locations have maximised economies of scale and increased competitiveness. In the current technological paradigm, moving to the technological frontier, the ultimate goal is to produce steel based on large-sized BFs with BOFs. These are located on coasts, near deep-water and produce high value-added flat products.[61] Applying Gerschenkron's (1962) perspective to the modern steel industry, large plants with state-of-the-art technology could correspond to integrated steelworks based on large-sized BFs on the coast with deep-water ports.

d) State-of-the-art technology and appropriate technology in the steel industry

This research regards a large-scale integrated production system using the BF–BOF route as state-of-the-art technology, based on the above discussion, considering the BF–BOF route as the latest technology regardless of location to capture large-sized BFs in the steel industry in non-OECD countries.[62] Notably, not all BFs and BOFs are the latest technologies, since there are also small and timeworn facilities. This research assumes that technology choice followed by upgrading to state-of-the-art technology through accumulation is particularly important for developing the steel industry in non-OECD countries. Here, the state-of-the-art technology corresponds to large-sized BFs with either an inner or working volume of 2,000 m^3.

While the discussion regarding appropriate technology is essential when considering the issue of technology choice in the steel industry, it might be challenging to make the correspondence with specific types of production facilities. Although the EAF route is another major production route in the steel industry, this research does not regard the production technology as appropriate technology based on the assumption that 'appropriate' differs depending on the conditions of each steel industry.

[60] This paragraph is based on Sato (2014, pp. 16–18).

[61] There are various reasons for the widespread use of coastal steelworks, including increases in the size of vessels that carry raw materials such as iron ore and coal and the construction of port facilities with sufficient quay water depth (Sato, 2014, p. 31).

[62] Integrated steelworks located on coasts with deep-water ports have advantages in terms of importing raw materials and export-oriented strategies (Toda, 1984, p. 29). Despite this, steel industries in some countries (e.g. Russia and Ukraine) are highly export-oriented although many steelworks in those nations are located in landlocked areas (Toda, 1984, p. 29). According to the World Steel Association (2018, p. 19), globally, the shares of steel production are estimated at 72% (inland) and 28% (coastal), suggesting a relatively low share of steel production in coastal areas.

e) Types of steel firms

Understanding structure through a steel firm typology framework based on the production system defined by a steel industry's production technology/process is particularly important when analysing the global steel industry (Kawabata, 2005, chap. 1; Kawabata & Yin, 2020, pp. 4–19). In the steel industry, there are three types of steel firms: i) integrated firms, ii) EAF firms and iii) rolling firms (including surface treatment and pipe and tube making) (Sato, 2009, p. 7).

Integrated firms have three steel production stages (ironmaking, steelmaking and rolling, including surface treatment), and require a BF with a BOF to produce steel.[63] An integrated production system is suitable for relatively high value-added steel products mass-produced in large lots or for relatively large quantities of high value-added steel products.[64] The integrated production system enables steel firms to enjoy economies of scale by using large-scale production facilities, including a BF, BOF, and downstream facilities such as a hot strip mill, suitable for mass production. Generally, steel firms can control quality from the ironmaking process to the rolling process through the BF–BOF route, enabling them to produce high value-added products.

EAF firms are small-scale steelmaking plants based on EAF technology. Some EAF firms produce long products (carbon steel) used in civil engineering and construction in medium lots, while others supply speciality steel in different shapes in small lots.[65] In addition, the use of an EAF with compact strip production has enabled EAF firms to enter the sheet steel market.

Finally, rolling firms do not have ironmaking and steelmaking facilities, and they purchase intermediate inputs such as semi-finished products to produce some steel products (e.g. hot-rolled coils).[66] There are also steel firms that specialise in surface treatment (e.g. galvanising, colour-coating or tin-coating) or pipe and tube making. Downstream processes are more fragmented in the steel industry, and

[63] This paragraph is based on Kawabata and Yin (2020, pp. 11–14) and Sato (2009, p. 9).

[64] Indeed, integrated firms produce high value-added flat products, such as outer panels for automobiles (Kawabata, 2017, p. 9).

[65] This paragraph is based on Kawabata and Yin (2020, pp. 16–17) and the World Steel Association (2012, pp. 34–35).

[66] This paragraph is based on Kawabata and Yin (2020, p. 18) and Sato (2009, p. 8).

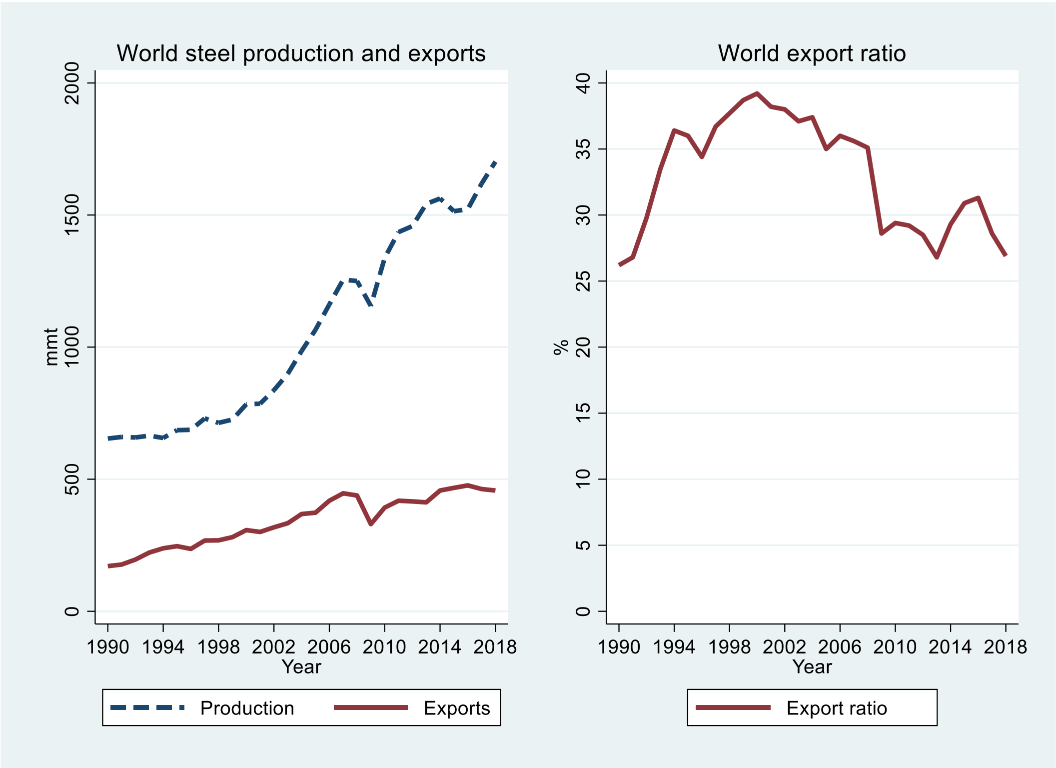
production facilities are more specialised; thus, the scale of production is relatively small. Many rolling firms are relatively small and produce small lots.

f) The role of exports in the steel industry

This research assumes that export competitiveness is a necessary condition for developing the steel industry in non-OECD countries. As pointed out by ITA (2016), 'Steel is a critical industry worldwide, and steel products are a heavily traded commodity' (p. 2); thus, trade has a significant role in the global steel industry. Since steel is a key input used for strategic industries such as automobiles and defence, it is often spotlighted during trade negotiations (IEA, 2020, p. 22).

Substantial amounts of steel products are traded on international markets as inputs for the production of goods and services in various industries. World steel exports increased from 171.0 mmt in 1990 to 457.2 mmt in 2018 (World Steel Association, 2021h, p. 24). In the global steel industry, around 30% of world steel output (finished steel products) is exported to trading partners (Figure 1.3).

Figure. 1.3 World steel production and export ratio (1990–2018)



Source: Author based on the World Steel Association (2021h)

Analysis of steel industry exports has at least three important implications.[67] First, the development pattern in the steel industry discussed in the literature review suggests that export could be an indicator of a steel industry's development. As the flying-geese model (Akamatsu, 1962; Kojima, 2000) illuminates, industries tend to demonstrate three successive patterns of i) import, ii) production and iii) export. Indeed, this development pattern can be observed in latecomer countries' steel industries, such as in Vietnam (Kawabata, 2016b, pp. 16–17).

Second, export itself could provide direct information about industrial competitiveness unless policies (e.g. export promotion and trade barriers) and government interventions distort market. According to Fujimoto and Shiozawa (2012), the possibility of exportation can be determined by differences in production costs based on wage rate and productivity. Therefore, if the steel industry in a country can export some steel products, then it is reasonable to suppose that the industry has strength in production costs due to wage rate or productivity.

Finally, trade data could provide critical insights into the types of steel products in each steel industry. Generally, the steel industry has a product hierarchy in terms of value creation, from long products to flat/pipe and tube products (Sato, 2013, p. 177), which has implications regarding a steel industry's upgrade. As a steel industry becomes more sophisticated, latecomer countries tend to alter the composition of the steel products produced (Nakaya, 2008, pp. 91–93). While understanding the product mix of countries is essential to assessing the development levels, it is challenging to obtain steel production data by product.[68] Therefore, trade data is used as a proxy for production data based on the assumption that

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[67] There are a variety of indicators when measuring catch-up. Catch-up can be measured by national income per capita at the national economic level. In addition, supply-side indicators are used at the industry level. They include production, productivity, exports, technology levels and production systems (Sato, 2012, pp. 33–34). Suehiro (2008) argued that '… a country's share of global markets for manufactured goods as the most important indicator of how far it has caught up on the industrial front' (p. 6). In the case of the steel industry, the Chinese steel industry had the highest share of crude steel output in the global steel industry in 1996. However, Tanaka (2008, p. 20) and Tanaka and Isomura (2020, p. 127) did not assess that the Chinese steel industry had achieved catch-up, as it lacked export competitiveness. Therefore, Tanaka and Isomura (2020) examined the catch-up of the steel industry in East Asia in terms of steel production and export competitiveness. This research assumes that export competitiveness is a necessary condition for the catch-up of the steel industry in non-OECD countries, apart from production performance. Thus, the research attempts to assess the catch-up of the steel industry in non-OECD countries, primarily focusing on export performance.

[68] The World Steel Association (various years) initially revealed production data by product in each country; however, since the scope and definition of reports of each product might have differed from country to country, it appears to have not accurately reflected actual production volumes. In addition, the organisation does not currently publish production data by product.

export data partially reflects the production system.[69] In addition, the Harmonised System (HS) code enables direct comparisons between countries using the same definitions.

1.4.2 Research method

This research examines the catch-up of the steel industry in non-OECD countries, primarily focusing on the international steel trade. Statistical analysis is performed using production and trade data to determine how the steel industry in non-OECD countries has evolved in the 21st century, based on the assumption that these data are suitable for assessing their catch-up under the same conditions.

The research investigates the production and export performance of the steel industry in advanced and emerging/developing countries applying the dichotomy between the 'OECD countries' and 'non-OECD countries', which is used as a proxy for the classification of 'advanced countries' and 'emerging/developing countries'. This classification could help better understand the development of emerging/developing countries in the global steel industry.[70] Therefore, this research examines the catch-up of the steel industry in non-OECD countries against that in OECD countries.

The research uses the dichotomy between 'BF–BOF-based' and 'EAF-based' countries when analysing the development of the steel industry in non-OECD countries. This research defines a BF–BOF-based country as one with a BF–BOF route share greater than 50% in total crude steel output. On the contrary, if a country's share of BF–BOF is below 50%, it is assumed to be an EAF-based country.

[69] The United Nations Economic Commission for Africa Office for North Africa (2013) indicated, 'The analysis of exports seems to be a good indicator of the production system given that exports make up that part of the production system that is entirely subject to international competition. In other words, exports, for which a country has comparative advantages in particular, are a genuine demonstration of a country's ability to raise the value of its production system on international markets. Moreover, from a practical viewpoint, export data is often more readily available and more coherent than production data and then it enables direct comparisons between countries' (p. 1).

[70] The OECD Steel Committee is a crucial forum for governments to come together with the cooperation of the industry to address challenges facing the global steel industry, such as the issue of excess global steel capacity. The OECD (2015b) released a position paper regarding the issue of excess capacity, providing a brief overview of the circumstances of global excess capacity, its effects and ways forward to address the challenge. It noted, 'The global steel industry's capacity to produce steel has increased rapidly since the early 2000s. Most of the growth in steelmaking capacity has occurred in non-OECD economies, to support growing construction and manufacturing activity, as well as to help build the infrastructure necessary for the economic development of these emerging economies' (p. 1). This indicates that the global steel industry has developed in the 21st century due to the growing economic prominence of the steel industry in non-OECD countries; therefore, it is critical to analyse the development of the global steel industry using the dichotomy between OECD and non-OECD countries.

1.4.3 Research model

Generally, latecomer countries' catch-up process follows this order: i) import of some goods; ii) production of goods (import substitution); and iii) export of goods (export industrialisation) (Suehiro, 2008, p. 130). Latecomer countries have the possibility of experiencing a big surge in industrialisation by exploiting the advantages of backwardness—an opportunity to use the knowledge and technologies developed by countries that are already industrialised (Gerschenkron, 1962), saving time and reducing expenditures. Therefore, technology choice could be an essential part of the catch-up of industries in latecomer countries. From the micro perspective of international trade at the industry level, productivity improvement by firms/industries can strengthen competitiveness (Fujimoto & Shiozawa, 2012).

During the industrialisation phase, steel demand may rise in response to industrial production growth, rising capital stock and the development of the infrastructure.[71] Countries usually require substantial amounts of steel for infrastructure in the initial stages. The level of economic development may partially affect the pattern of steel demand. In countries with a low level of economic development, the share of the construction industry's steel demand may increase, while the share of durable consumer goods is likely to rise as economic development progresses.

The historical pattern observed in the steel industry suggests that when countries undergo industrialisation with growth in steel demand, most steel requirements may initially be met through imports (OECD, 2013c, pp. 4–5). After several years of importing steel, steelmaking capacity is likely to grow (OECD, 2013b, p. 5). Steel firms in latecomer countries may increase production, reduce import dependency and initiate exports while improving productivity. The steel industry in some non-OECD countries could follow this pattern of moving away from imports towards domestic steel production and exports in the long term.

To investigate the development of non-OECD countries' steel industries, this research focuses on the following actors:

[71] This paragraph is based on the IEA (2020, p. 59).

- **Steel firm**: a firm that is involved in steel production/trade activities.
- **Country**: a country that reflects its steel market (i.e. steel demand) and steel firms' steel production/trade activities.[72]

Therefore, it seems reasonable to assume that the steel production and trade data of each steel industry reflects steel firms' production and trade activities, enabling the assessment of the catch-up of the steel industry in non-OECD countries. It is also assumed that countries can supply steel products to domestic and foreign steel markets if they have a comparative advantage. While supply to domestic markets is also important in the steel industry, this research focuses on the foreign steel market, based on the assumption that steel export could be the most reliable indicator for information on latecomer countries' capabilities to catch-up, enabling direct comparisons between countries using the HS code.[73]

The following four indicators are proposed to investigate the export performance of the steel industries in non-OECD countries.[74]

- **Revealed Symmetric Comparative Advantage (RSCA) index**: indicator to reveal a country's specialisation in a given steel product relative to the rest of the world.
- **Trade Balance Index (TBI)**: indicator to show whether a country is a net exporter or a net importer, which is used as a proxy for international competitiveness.
- **Export Similarity Index (ESI)**: indicator to exhibit the relative sophistication of a country's exports by comparing its export bundle with that of the whole OECD group.
- **Herfindahl Index (HI)**: indicator to measure a country's export diversification.

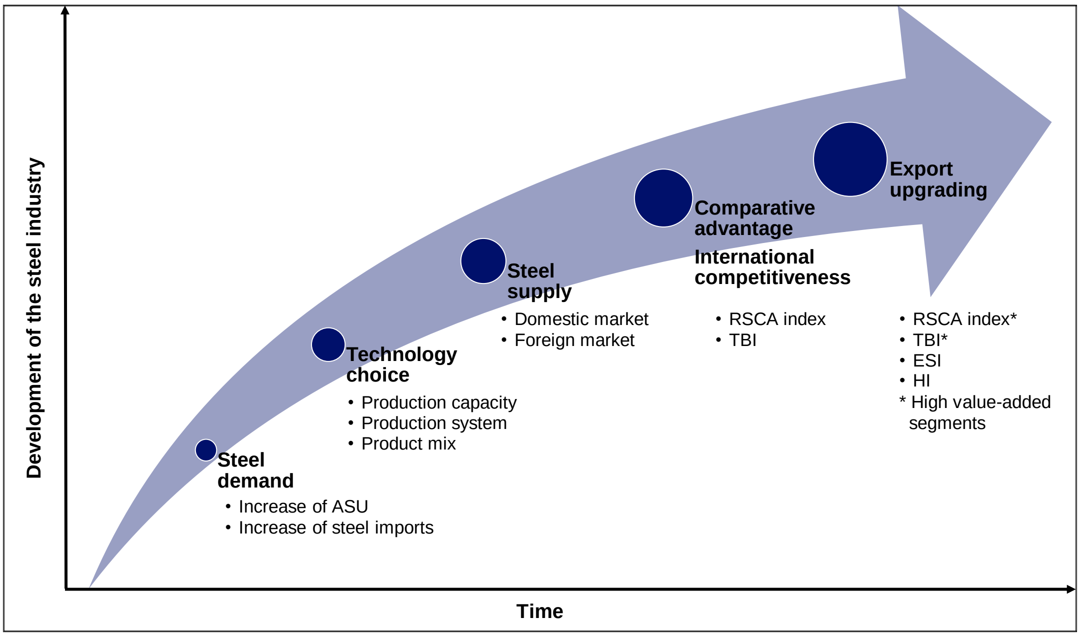
[72] Note that the trade activities (i.e. imports) reflect production/trade activities of steel firms in other countries.

[73] Ferrarini and Scaramozzino (2011) asserted, 'It is very difficult to measure capabilities directly, because of their complex nature. The recent analysis of capabilities and trade rests on the notion that the observed profile of trade specialisation of a country provides *indirect* information about its productive capacity … whilst it would prove problematic directly to measure capabilities, the actual trade flows can convey important information on countries' latent capabilities. In particular, export specialisation is seen as the most reliable indicator of a country's underlying capabilities' (p. 1).

[74] The Revealed Symmetric Comparative Advantage (RSCA) index is calculated based on the Revealed Comparative Advantage (RCA) index. The RCA index is defined as the ratio of two shares. The numerator is the share of a country's total exports of the commodity of interest, whereas the denominator is the share of the total world exports of the same commodity. Conversely, the Trade Balance Index (TBI) is defined as the trade balance (total exports minus total imports) as a fraction of the total trade (exports plus imports). The aforementioned explanations are based on the ESCAP (2009). For a detailed explanation of each indicator, see each chapter in this research.

This research proposes a model that highlights supply-side performance in the steel industry, and Figure 1.4 illustrates a hypothetical catch-up model to explain the development of the steel industry in a country. In the model, the horizontal axis represents time, and the vertical axis indicates the development of the steel industry. Circles represent significant events, and the affected items are listed below.

Figure. 1.4 Hypothetical catch-up model in the steel industry



Source: Author

An explanation of the model is provided below:

- The catch-up process begins with import substitution, which primarily stems from growing steel demand. High economic growth during industrialisation may lead to an increase in steel demand from domestic steel-using industries (e.g. construction and automobiles), triggering the growth of apparent steel use (ASU) and steel imports.[75] To fill the production/demand gap and supply steel products that meet the level of domestic demand, some steel firms may begin to consider local investment in production facilities and may contemplate the future possibility of export.
- Steel firms' technology choices have a vital influence on accelerating the catch-up process. Once a steel firm decides to invest in production facilities, upstream/downstream facilities are selected and

[75] The World Steel Association (2021a) noted, 'Apparent steel use (ASU) is one method of measuring steel demand, which is expressed in volume terms as deliveries minus net exports of steel industry goods'.

installed, increasing production capacity, forming production systems (i.e. BF–BOF-based or EAF-based countries) and defining the product mix for the entire domestic steel industry.

- In the next phase, the catch-up process shifts to steel supply. Following the installation of production facilities, production begins. Steel firms can improve productivity through capability-building efforts, leading to competitiveness in the market and the ability to supply the domestic market first and the foreign market later.[76]
- Increased steel production helps the domestic steel industry to acquire a comparative advantage and strengthen international competitiveness. If steel firms can further expand steel output, they can enjoy economies of scale and increase proficiency, contributing to productivity enhancement. A virtuous cycle may occur in which productivity is further improved by the increasing production volume. Steel firms may also have an opportunity to upgrade to large-scale production facilities in line with growing steel output. As the domestic steel industry develops, it can gain comparative advantage over other industries, increasing the RSCA index for the entire steel industry and reflecting productivity enhancement. In addition, imports may be substituted with domestic production, resulting in a rising proportion of exports to imports, leading to TBI improvement for the whole steel industry.
- The development of the domestic steel industry facilitates the upgrade of its steel export structure. As the domestic steel industry further develops, opportunities to upgrade the quality of its steel exports may arise. The domestic steel industry may demonstrate high RSCA and TBI values for high value-added segments (flat products, pipe and tube products). ESI values may also increase when the export structure of the domestic steel industry becomes sophisticated. Simultaneously, the domestic steel industry's export portfolio may diversify, reflecting low HI values.
- Other factors can affect steel export performance in the domestic steel industry. In addition to technology choice, countries' level of economic development may also be relevant to export patterns, as it is assumed to be related to domestic steel consumption patterns which impact the types of export products. Moreover, the magnitude of steel output may be related to export performance, given that there may be a close relationship between steel production and steel exports.

[76] In this research, productivity denotes 'labour productivity'. It is reasonable to focus on labour productivity herein as this aspect is compatible with the Ricardian and Kaldorian models.

This model suggests that the steel industry in non-OECD countries could develop through these steps: i) market expansion, ii) technology choice and productivity improvement, iii) production expansion and productivity improvement, iv) acquisition of comparative advantage, v) improvement of international competitiveness and vi) sophistication and diversification of the export structure. If each steel industry pursues the above process, there is a potential for developing steel industries over time.

Concerning the scope of this research, Chapter 2 corresponds to the acquisition of comparative advantage and international competitiveness, while the study in Chapter 3 investigates the sophistication and diversification of the export structures. Finally, the research in Chapter 4 explores the steel industry development steps described above.

Among the four indicators above (RSCA index, TBI, ESI and HI), this research primarily applies the RSCA index and the TBI; thus, it is imperative to highlight the difference between the two indicators. The research assumes that steel firms cannot export sustainably without productivity improvement, and increased steel production affects both the RSCA index and the TBI. However, the two indicators have distinct characteristics. The RSCA index identifies an industry/product in which a country has a comparative advantage relative to other industries/products and can identify industries/products with comparative advantages (e.g. Chinese bars over Chinese apparel). Thus, the RSCA index may be determined by relationships with other industries. Note that the RSCA index is calculated using export data and is not affected by imports. If a country's steel exports gain an advantage over other industries, the RSCA may improve. In contrast, the TBI identifies the advantages of an industry's product exports over the same product in other countries (e.g. Chinese bars over Russian bars). The development of steel demand and steel imports may significantly affect the evolution of the TBI value. This is because the TBI considers import data in addition to export data.

While a country's RSCA values improve due to the increasing comparative advantage of its steel industry over other industries, steel imports may increase if demand growth is greater than the change in production. In this case, the country's TBI values may not necessarily improve. In summary, TBI values may be determined by the balance between steel production/exports and steel demand/imports. If the increase in steel production and exports exceeds the increase in steel demand and imports, the TBI is likely to improve.

1.4.4 Hypothesis

Based on the observations of the literature review, production technology is assumed to have a pivotal role in the steel industry, and steel firms cannot export sustainably without improving productivity. It is particularly important for steel firms to upgrade to state-of-the-art technology through technology accumulation to achieve high export performance, including comparative advantage, international competitiveness and export sophistication and diversification. Therefore, steel firms' technology choices and capability-building efforts to enhance productivity are likely to be key elements of the development of the steel industry in non-OECD countries. These assertions yield the below hypothesis of this research.

Hypothesis: *Apart from steel firms' capability-building for productivity improvement to advance exportation, technology* choice *followed by upgrading to state-of-the-art technology through accumulation is necessary for the catch-up of the steel industry in non-OECD countries; these combined efforts result in demonstrating high export performance.*

1.4.5 Data

This research assembles a large-scale international steel trade dataset of all steel-producing countries by focusing on the HS 6-digit trade data of approximately 190 products to examine the evolution of the steel industry in non-OECD countries (see Appendix Table 1). The dataset could provide insights into the global steel industry's dynamics to enable international comparison between countries and investigate the evolution of the steel industry in non-OECD countries in the past 20 years. The primary trade data comes from the International Trade Centre (ITC)'s Trade Map (ITC, 2021), an online database of international trade data, unless otherwise indicated. While the dataset contains steel products at the six-digit HS code level by source country, trade values and quantities, trade data in value terms were used to calculate the four indicators (i.e. RSCA index, TBI, ESI, HI). In contrast, trade data in volume terms were used to assess the relationship between crude steel output and total steel exports. This dataset contains trade data for the years 2001–2018,[77] covering countries with available production data

[77] Although the author collected trade data from 2001 to 2020 using the ITC (2021) dataset, some countries' trade data for 2019–2020 appears to have been underestimated at the time of writing. For this reason, this research excluded data from 2019–2020 and used data from 2001–2018.

by process. The definition of steel products was based on the International Steel Statistics Bureau (ISSB, 2010). For other key steel-related data, figures for steel production and apparent steel use were retrieved or calculated based on the World Steel Association (various years).

1.5 Stylised Facts Regarding the Steel Industry

It is crucial to summarise stylised facts regarding the steel industry to better understand the characteristics of the industry.

a) The role of steel in the world economy and society, and steel consumption patterns

The steel industry has a profound impact on the world economy and society; global sales of steel products are estimated at USD 2.5 trillion, and the industry directly employs around six million people, contributing to the global economy and society (World Steel Association, 2019a, 2019b, 2020c). Steel remains at the heart of industrialisation and economic development as a basic material for advanced and emerging/developing countries. Steel production and trade has a number of advantages compared to that of other materials, including high strength, recyclability, durability and low cost (IEA, 2020, p. 17).[78] The World Steel Association (2019a) asserted,

> Steel plays a vital role in the modern world. In addition to being one of the most important materials for building and infrastructure, steel is the enabler of a wide range of manufacturing activities. It also creates opportunities for innovative solutions in other sectors and is indispensable in research and development projects around the world (para, 1).

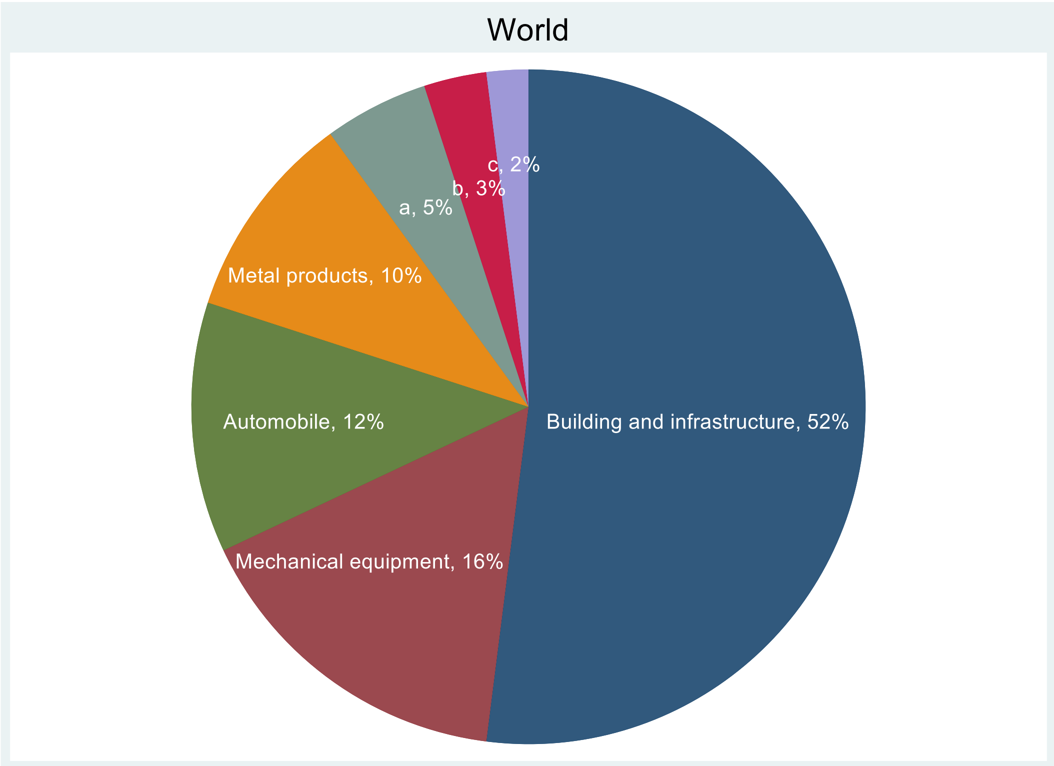
It is important to consider the industries that consume steel products, given their wide use as intermediate inputs. Globally, building and infrastructure have been the largest steel-using industries, accounting for more than 50% of world steel consumption (Figure 1.5). Buildings and infrastructure include, for example, bridges, power plants, pipelines and sanitation systems (IEA, 2020, p. 58). In

[78] Since 2018, steel prices have been in the range of USD 550–800 per tonne, while prices for aluminium and copper were USD 1,700–2,000 per tonne and USD 5,500–7,000 per tonne, respectively (IEA, 2020, pp. 19–20).

addition to buildings and infrastructure, steel products are used in various industries, such as mechanical equipment, automobile and metal products.

The steel industries in emerging/developing countries typically use a greater share of steel products in the construction industry compared to advanced countries (OECD, 2013b, p. 3). For instance, construction is one of the most important steel-using industries in Southeast Asian countries; more than 70% of the steel is consumed by the regional construction industry (SEAISI, 2020, p. 12).

Figure. 1.5 World steel consumption pattern (2019)



Note: a denotes other transport, b denotes electrical equipment and c denotes domestic appliances.
Source: Author based on the World Steel Association (2020a)

b) Types of steel products

This research classifies 16 product groups, including i) ingots/semi-finished products, ii) wire rods, iii) bars, iv) sections, v) rails, vi) hot-rolled sheets/strips, vii) plates, viii) cold-rolled sheets/strips, ix) galvanised sheets, x) tin plates and tin-frees, xi) other coated sheets, xii) electrical sheets, xiii) welded tubes, xiv) seamless tubes, xv) steel tube fittings and xvi) other steel products.

c) Uses of steel products

Steel products are intermediate inputs used in numerous industries, and the use of steel products is broad and diverse. For instance, steel products are used for a wide range of essential industries, from construction to home appliances, transportation and energy. Table 1.1 summarises the types and uses of steel products.[79]

Steel products can be divided into four broad groups: i) semi-finished products (including ingots), ii) long products, iii) flat products and iv) pipe and tube products. In the steel industry, semi-finished products (i.e. billets, blooms and slabs) are used as inputs to produce final products. Long products, such as bars, wire rods and sections, are predominantly used as construction materials. In contrast, the manufacturing industry uses various types of flat products. Within the flat products group, hot-rolled sheets/coils, cold-rolled sheets/coils and galvanised sheets are the major items used as inputs in the automobile and home appliances manufacturing. Pipe and tube products are used in a wide range of applications, including pipelines for oil and gas and oil drilling.

[79] Note that some steel products are also used as inputs for downstream production; for instance, cold-rolled sheets are produced from hot-rolled sheets and used as inputs for galvanised sheets.

Table 1.1 Types and uses of steel products

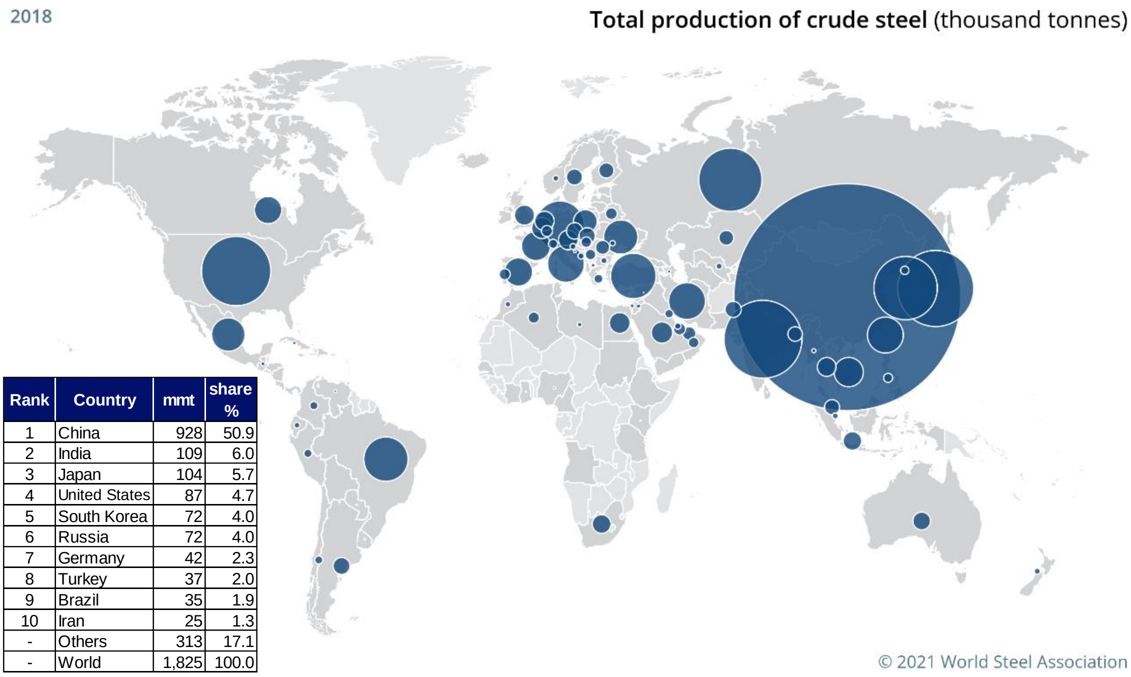
Broad category	Medium level detail	High level detail	Main usage
Semi-finished products	Semi-finished products	Billets	• Inputs to produce long products (e.g. bars, wire rods)
		Blooms	• Inputs to produce long products (e.g. rails, sections)
		Slabs	• Inputs to produce flat products (e.g. hot-rolled coils, plates)
Long products	Rails	Heavy rails	• Rails for bullet trains and conventional lines
		Light rails	• Rails for light railways
	Sections	H-sections	• Steel frames of high-rise buildings
		Heavy sections	• Channels, I-sections, angles, unequal leg and thickness angles
		Medium sections	• Angles
		Light sections	• Angles
		Cold-formed sections	• H-sections (thin thickness), angles, channels
		Sheet pilings	• Shore protection works
		Cold-formed sheet pilings	• Trench sheets
	Bars	Heavy bars	• Shafts, anchor bolts
		Medium bars	• Construction materials, road construction materials, structural materials
		Light bars	• Construction materials, bolts
	Wire rods	Bars in coil	• Nails, annealed iron wires, welded wire mesh
		Ordinary wire rods	• Construction materials, road construction materials, bolts
		Special wire rods	• Piano wires, steel cords, springs
Flat products	Plates	Plates	• Steel frames of high-rise buildings, ships, offshore structures, bridges, tanks, pressure vessels, nuclear power generation, thermal power generation, hydroelectric power generation
		Medium plates	• Switchboard outer panels, motor frames, tanks, strength parts
	Hot-rolled sheets/coils	Hot-rolled sheets/coils	• Compressor covers, automotive structural components, disc wheels, switchboard side panels, bicycle gears, product display racks
	Cold-rolled sheets/coils	Cold-rolled sheets/coils	• Refrigerators, cabinets, microwave ovens (doors, inner panels), home appliances, steel furniture
	Galvanised sheets	Hot dip galvanised sheets	• Automobiles, guardrails, ducts, washing machines, air conditioners
		Electro galvanised sheets	• Automobiles, air conditioners, oil heaters
	Electrical sheets	Grain-oriented electrical sheets	• Reactors, large rotating machines
		Non-oriented electrical sheets	• General-purpose motors, compressor motors, small precision motors
	Tin plates/tin-frees	Tin plates	• Food cans, beverage cans, pails, aerosol cans, crown caps of bottle
		Tin-frees	• Food cans, beverage cans, pails, aerosol cans, crown caps of bottle
Pipe and tube products	Seamless tubes	Seamless tubes	• Oil well pipes, boiler and heat exchanger tubes, pressure vessel pipes
	Welded tubes	Forging pipes	• Plumbing pipes, water pipes
		Electric resistance welded tubes	• Plumbing pipes, machine structural pipes, steel pipe piles
		Spiral weld pipes	• Steel pipe piles, general structural pipes, water pipes
		UO welded tubes	• Line pipes, gas transport pipes, pressure pipes

Source: Author based on Sato (2008b, p. x) *d) Locations of steel production*

Mapping the geographic distribution of crude steel output helps better understand where steel is produced globally, indicating that steel production is currently concentrated in Asia, with some large steel-producing countries such as China, India and Japan (Figure 1.6). China is the largest steel-producing country, with a dominant role in world steel production, accounting for 50.9% of global crude steel output in 2018. India overtook Japan to become the world's second-largest steel-producing country in 2018. In addition to these steel industries, Japan and South Korea are also large steel-producing countries in Asia. This indicates that Asia is currently the centre of steel production in the global steel market. Indeed, over 70% of global steel production occurs in Asia today (World Steel Association, 2021c, p. 2).

Apart from Asia, steel is produced in various regions such as North America and Europe, while the volumes of steel output in Oceania and Africa are minimal compared to those of other steel-producing regions. Apart from the steel industry in non-OECD countries, traditional steel-producing countries, such as the United States and Germany, remain among the major players in the global steel industry.

Figure. 1.6 Location of steel production (2018)



Rank	Country	mmt	share %
1	China	928	50.9
2	India	109	6.0
3	Japan	104	5.7
4	United States	87	4.7
5	South Korea	72	4.0
6	Russia	72	4.0
7	Germany	42	2.3
8	Turkey	37	2.0
9	Brazil	35	1.9
10	Iran	25	1.3
-	Others	313	17.1
-	World	1,825	100.0

Note: Bubble size represents the magnitude of crude steel output.
Source: Author's calculation based on data from the World Steel Association (2021g)

e) Top steel firms

Focusing on the world's major steel-producing firms could enable a more comprehensive understanding of the global steel industry's steel supply structure. Table 1.2 presents the world's top-50 steel firms in 2018, revealing the dominant role of steel firms in non-OECD countries (notably Chinese steel firms) in global steel production. Nevertheless, some OECD countries' steel firms have important roles in the global steel industry.

The steel industry is not as multinational as some other industries, such as machinery and electronics. In most cases, the headquarters country corresponds to the steel production country, although there is an important exception of ArcelorMittal, the world's largest multinational steel firm. For instance, many listed Chinese steel firms are located in China to produce steel.

The steel industry has a low degree of concentration. In 2018, the top 10 steel firms accounted for only 25.5% of global steel output, with the top 25 and top 50 accounting for 40.9% and 55.6%, respectively. Compared to iron ore and coal mining industries, the world steel industry is extremely fragmented (BlueScope Steel, 2010, p. 80). Indeed, in 2012, the top three and top 10 in the iron ore industry accounted for 35.2% and 50.8%, respectively (UNCTAD, 2013, p. 6). In addition, the degree of concentration in the steel industry is much lower than that of other industries, such as aluminium and energy (IEA, 2020, p. 24).

Table 1.2 Top steel firms (2018)

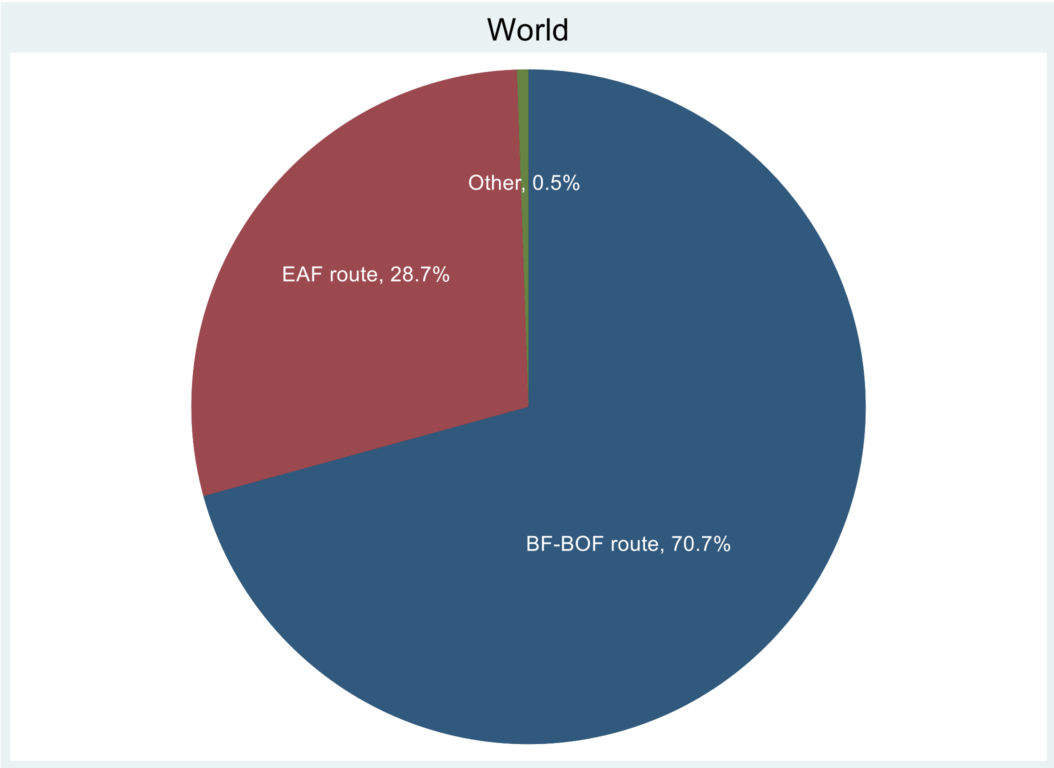
Rank	Firm	Country	Tonnage mmt	Share %	Rank	Firm	Country	Tonnage mmt	Share %
1	ArcelorMittal	Luxembourg	96.4	5.3	26	Baotou Iron & Steel (Group) Co., Ltd.	China	15.3	0.8
2	China Baowu Group	China	67.4	3.7	27	Rizhao Steel	China	15.0	0.8
3	Nippon Steel Corporation	Japan	49.2	2.7	28	Liuzhou Steel	China	13.5	0.7
4	HBIS Group	China	46.8	2.6	29	EVRAZ	Russia	13.0	0.7
5	POSCO	South Korea	42.9	2.3	30	Magnitogorsk Iron & Steel Works (MMK)	Russia	12.7	0.7
6	Shagang Group	China	40.7	2.2	31	thyssenkrupp	Germany	12.6	0.7
7	Ansteel Group	China	37.4	2.0	32	CITIC Pacific	China	12.6	0.7
8	JFE Steel Corporation	Japan	29.2	1.6	33	Severstal	Russia	12.0	0.7
9	Jianlong Group	China	27.9	1.5	34	Sanming Steel	China	11.7	0.6
10	Shougang Group	China	27.3	1.5	35	Shaanxi Steel	China	11.4	0.6
11	Tata Steel Group	India	27.3	1.5	36	Jingye Steel	China	11.3	0.6
12	Nucor Corporation	USA	25.5	1.4	37	Anyang Steel	China	11.0	0.6
13	Shandong Steel Group	China	23.2	1.3	38	Taiyuan Steel	China	10.7	0.6
14	Valin Group	China	23.0	1.3	39	Jinxi Steel	China	10.3	0.6
15	HYUNDAI Steel Company	South Korea	21.9	1.2	40	Nanjing Steel	China	10.1	0.6
16	Novolipetsk Steel (NLMK)	Russia	17.4	1.0	41	Metinvest Holding LLC	Ukraine	9.4	0.5
17	JSW Steel Limited	India	16.8	0.9	42	Xinyu Steel	China	9.4	0.5
18	IMIDRO	Iran	16.8	0.9	43	Tsingshan Stainless Steel	China	9.3	0.5
19	Steel Authority of India Ltd. (SAIL)	India	15.9	0.9	44	ERDEMIR Group	Turkey	9.1	0.5
20	Benxi Steel	China	15.9	0.9	45	Steel Dynamics, Inc.	USA	8.9	0.5
21	China Steel Corporation	Taiwan	15.9	0.9	46	Zenith Steel	China	8.7	0.5
22	Gerdau S.A.	Brazil	15.8	0.9	47	SSAB	Sweden	8.0	0.4
23	Fangda Steel	China	15.5	0.8	48	Donghai Special Steel	China	7.6	0.4
24	Techint Group	Argentina	15.4	0.8	49	Kunming Steel	China	7.3	0.4
25	United States Steel Corporation	USA	15.4	0.8	50	CELSA Steel Group	Spain	7.1	0.4
						Top 10		465.1	25.5
						Top 25		746.8	40.9
						Top 50		1,014.5	55.6

Source: Author's calculation based on data from the World Steel Association (2020d)

f) Steel production by process

While primary production routes vary geographically, the BF–BOF route accounted for 70.7% of global crude steel output in 2018 (Figure 1.7), the EAF technology production route represented 28.7% of global steel production. Other production processes, notably the OHF route, have been largely phased out due to their inferior energy performance (IEA, 2020, p. 30).

Figure. 1.7 Crude steel output by process (2018)



Source: Author's calculation based on data from the World Steel Association (2020b)

g) Initial investment costs and operation costs

In the steel industry, initial facilities investment costs and minimum efficient scales (the rate of output per year at which unit costs reach their minimum) are related to technology choice (Howell et al., 1988, pp. 20–23; Kawabata, 2005, pp. 26–39; Sato, 2013, pp. 167–168) and vary across production technologies (Table 1.3).[80] Steelworks based on BF–BOF technology require a more significant capital investment than EAF-based steel plants; the minimum efficient scale of an integrated mill with a large-scale BF is estimated at 3 mmt, with an initial investment cost of USD 4 billion. In addition to learning the operating technology of large-scale equipment and procurement of raw materials such as iron ore, it is important to secure demand commensurate with the production scale, given that it is technically difficult to control the operating rate of integrated production through the BF–BOF route.[81] Therefore, the barriers

[80] This paragraph is based on Sato (2013, pp. 167–168).

[81] For instance, the market size needs to be secured at 3 mmt for BF–BOF-based integrated steelworks (Kawabata, 2005, p. 31).

to entry with integrated steelworks based on the BF–BOF route may be high for some emerging/developing countries with small economies.

In addition to investment costs, operating costs affect technology choice and competitiveness in the steel industry (OECD, 2012, p. 4). Steel production is highly dependent on the cost of the main inputs; primarily the cost of iron ore, scrap and energy inputs. Energy and raw material inputs typically account for 60–80% of steel production costs (IEA, 2020, p. 30). Operating costs differ between the BF–BOF and EAF routes (Steelonthenet.com, 2021a, 2021b), although they depend on the development of key raw material prices.

Table. 1.3 Initial investment costs and minimum efficient production scales by production facilities

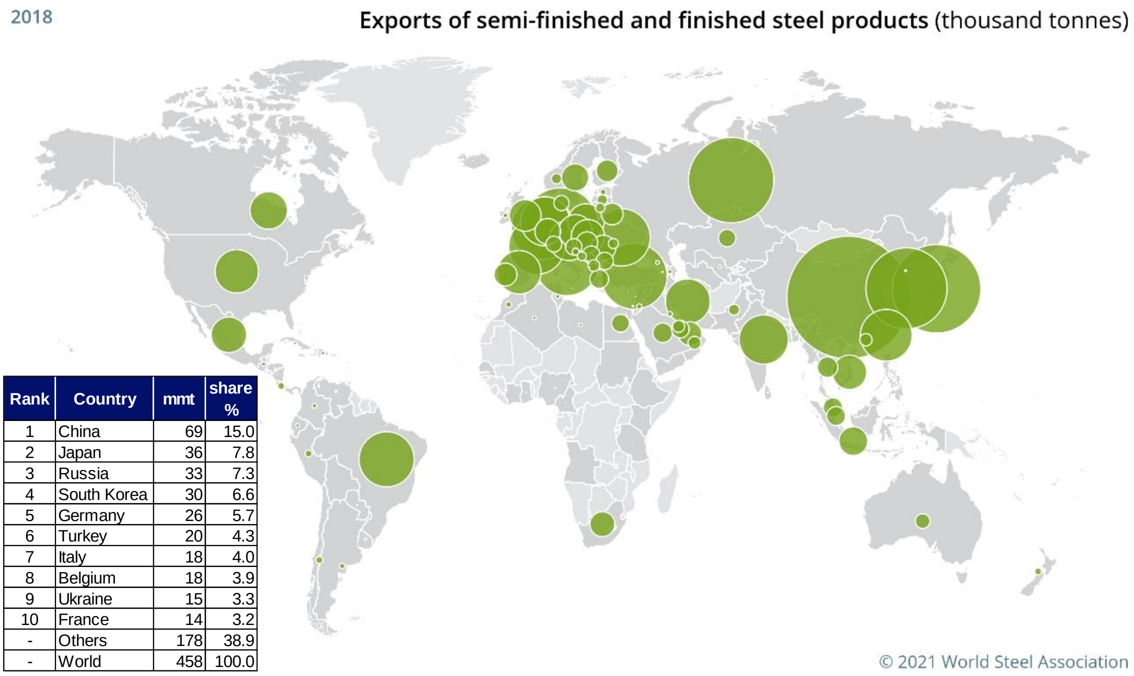
	Initial investment cost (Billion USD)	Minimum efficient production scale (Million tonnes)
Integrated steelworks based on the BF–BOF route	4.0–6.0	3.0
DRI plant	0.1–0.2	1.0
EAF equipped with facilities for long products	0.1	0.3
EAF equipped with facilities for flat products (thin slab caster, compact hot strip mill)	0.3	1.0
Facilities for long products	0.02	0.1
Facilities for flat products (hot strip mill)	0.4	2.0
Facilities for flat products (cold strip mill)	0.1	0.25

Source: Author based on Sato (2013, p. 167)

h) Location of steel exports

Mapping the geographic distribution of total steel exports reveals major steel-exporting countries, and Figure 1.8 indicates that such countries (e.g. China, India, Japan and South Korea) are located in Asia. Nevertheless, steel exports appear not to be as heavily concentrated in certain countries based on crude steel output. The structure of steel exports is relatively diverse compared to that of steel production. In addition to Asia, large steel-exporting countries are also present in the Commonwealth of Independent States region, such as Russia and Ukraine. Several European countries (e.g. Germany, Italy and France) have important roles in the international steel export market.

Figure 1.8 Location of steel exports (2018)



Rank	Country	mmt	share %
1	China	69	15.0
2	Japan	36	7.8
3	Russia	33	7.3
4	South Korea	30	6.6
5	Germany	26	5.7
6	Turkey	20	4.3
7	Italy	18	4.0
8	Belgium	18	3.9
9	Ukraine	15	3.3
10	France	14	3.2
-	Others	178	38.9
-	World	458	100.0

Note: Bubble size represents the magnitude of steel exports.
Source: Author’s calculation based on data from the World Steel Association (2021d)

i) World steel trade by area

Table 1.4 presents an overview of the world steel trade by area in 2018, demonstrating exceptionally large regional differences in magnitudes of steel trade. Countries in Asia tend to export to neighbouring countries, in particular others in Asia. Intra-regional trade appears to be significant in some regions. While the European Union is the largest export region, there are huge gaps in terms of steel trade volume between intra-regional trade and external regional trade. A similar regional pattern is also observed among North American Free Trade Agreement countries.

Table 1.4 World trade in steel by area (2018), mmt

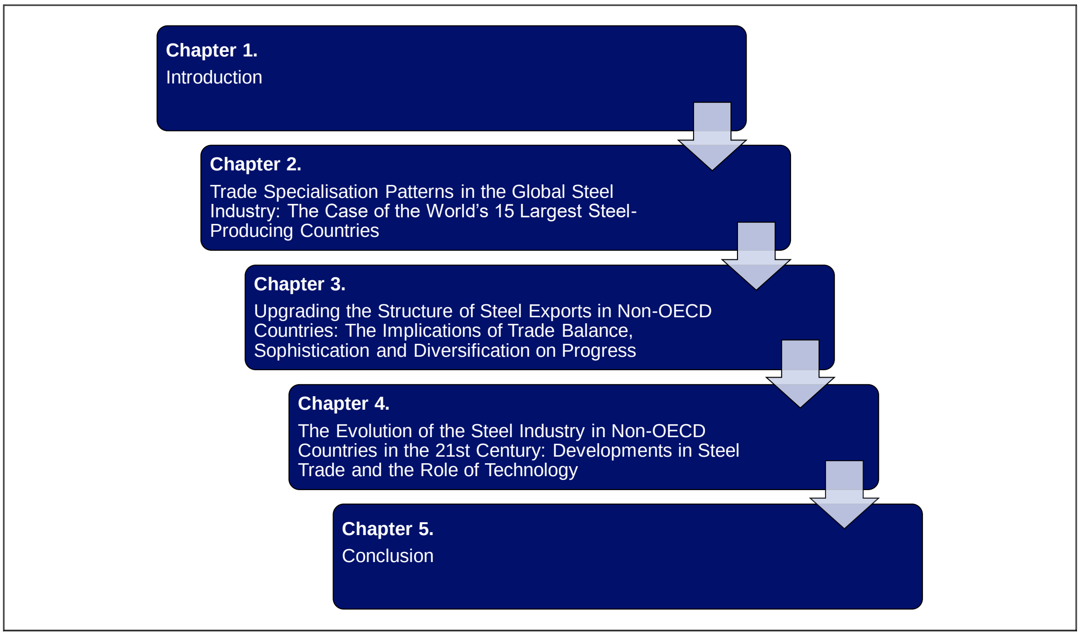
Exporting region / Destination	European Union	Other Europe	CIS	NAFTA	Other America	Africa and Middle East	China	Japan	Other Asia	Oceania	Total imports	extra-regional imports
European Union (28)	**118.5**	11.4	15.4	0.6	2.1	1.5	4.0	0.2	9.4	0.2	163.3	44.9
Other Europe	8.6	**0.6**	7.2	0.1	0.9	0.6	0.9	0.2	1.2	0.0	20.2	19.7
CIS	1.3	0.4	**9.2**	0.0	0.0	1.7	2.0	0.1	0.5	0.0	15.1	5.9
NAFTA	8.0	1.9	4.3	**16.7**	7.1	0.9	2.3	3.4	7.1	0.3	51.8	35.1
Other America	1.2	1.4	0.8	2.3	**3.8**	0.2	6.9	1.1	2.8	0.0	20.4	16.7
Africa	3.9	2.6	5.8	0.1	0.1	**3.2**	5.9	0.8	1.2	0.0	23.6	20.4
Middle East	1.6	3.4	3.0	0.1	0.2	**5.7**	5.6	0.8	2.9	0.1	23.5	17.8
China	1.5	0.0	0.1	0.1	0.1	0.1	-	5.4	7.1	0.0	14.4	14.4
Japan	0.1	0.0	0.0	0.0	0.0	0.0	1.0	-	4.8	0.0	5.9	5.9
Other Asia	2.0	1.7	6.9	0.5	0.8	7.9	39.3	23.6	**29.7**	0.3	112.8	83.1
Oceania	0.3	0.2	0.0	0.0	0.0	0.0	0.9	0.2	1.7	**0.2**	3.5	3.2
Total exports	146.9	23.6	52.6	20.5	15.1	21.8	68.8	35.8	68.2	1.2	**454.5**	267.1
Extra-regional exports	28.4	23.0	43.5	3.8	11.3	12.9	68.8	35.8	38.6	1.0	267.1	
Net exports	-16.5	3.4	37.5	-31.3	-5.3	-25.3	54.4	29.9	-44.5	-2.2		

Note: Internal trade is marked in light blue. Figure for the world in this table are different from Figure 1.8 owing to the difference in the source.
Source: The World Steel Association (2019c)

1.6 Structure of This Research

This study presents five chapters (Figure 1.9). The remainder of this research is structured into four chapters. Chapter 2 investigates trade specialisation patterns by investigating the world's 15 largest steel-producing countries to assess the association between technology choice and the level of economic development with advantages in specific types of steel products. Chapter 3 discusses non-OECD countries' upgrading the structure of steel exports to examine the extent to which the steel industry in non-OECD countries has caught up in terms of upgrading exports, referencing export sophistication and diversification. Chapter 4 focuses on the evolution of the steel industry in non-OECD countries in the 21st century to examine when and how technology choices that affect comparative advantage and international competitiveness were implemented among major steel industries in non-OECD countries. Chapter 5 concludes with a summary of the main findings, considering the remaining issues and suggesting potential avenues for further research.

Figure 1.9 Structure of this research



Source: Author

Chapter 2. Trade Specialisation Patterns in the Global Steel Industry: The Case of the World's 15 Largest Steel-Producing Countries

2.1 Introduction

Many countries and regions participate in trade activities in the global steel industry. While the steel industries in some countries specialise in low value-added steel products for the construction industry, others excel at supplying high value-added steel products used for manufacturing, such as the automobile and machinery industries. Based on the principle of comparative advantage, the steel industries in advanced economies and emerging/developing economies are likely to trade with each other. In spite of the importance of international trade in the steel industry, little is known about global steel trade patterns in economic literature.[82]

To elucidate global steel patterns, two perspectives appear to be important for analysing international steel trade. First, the trade specialisation approach could help us better understand global steel trade patterns by illustrating the countries that have strengths in specific steel products. Second, it is essential to shed light on the steel supply of large steel-producing countries, given that successful trade activities could determine global steel trade patterns.

A critical challenge is the determination of what factors should be considered when analysing the steel trade. Based on the hypothetical model presented in Chapter 1, two crucial factors—technology choice and the level of economic development—appear to be related to export patterns in the steel industry. Therefore, it is important to assess whether these factors are associated with the export patterns of large steel-producing countries.

Based on the above background, the research question in this chapter is: *How are technology choice and the level of economic development associated with advantages in specific types of steel products, forming current global steel trade patterns?*

The objective of this chapter is to examine the associations between the two factors (i.e. technology choice and the level of economic development) and steel export patterns. Focusing on these relationships

[82] The World Steel Association (2021c) noted that 'Steelmaking is a truly global industry, and raw materials (such as iron ore and scrap) and steel products are traded globally to a large extent' (p. 2).

through large steel-producing countries could elicit a more comprehensive understanding of global steel trade patterns. This analysis will be performed by investigating the world's 15 largest steel-producing countries, which represent nearly 90% of global steel production in 2016–2018. This chapter will offer crucial insights into the characteristics of steel supply for large steel-producing countries and how they are specialised in specific steel products in the international steel market.

The remainder of this chapter is structured into the following sections. Section 2.2 provides a brief literature review. Section 2.3 presents the analytical perspective of the study, including methodology, data and the list of the world's largest 15 steel-producing countries. Section 2.4 defines each steel product as either low or high value-added. Section 2.5 groups the 15 steel-producing countries based on technology choice and the level of economic development. Section 2.6 analyses the characteristics of steel exports for the 15 steel-producing countries focusing on the share of steel exports by product, and Section 2.7 presents the empirical results demonstrating comparative advantage and international competitiveness. Section 2.8 provides a summary and implications.

2.2 Literature Review

In economic literature, comparative advantage has been one of the most significant trade theories for explaining the mechanism of international trade (Deardorff, 2011; Kowalski & Stone, 2011). While the principle of comparative advantage has a crucial role in investigations of international trade, a key issue is determining how to analyse it when focusing on international trade between countries. Although comparing production costs is at the heart of comparative advantage (Fujimoto & Shiozawa, 2012), it is challenging to measure due to a lack of appropriate data (Balassa, 1965, p. 100). To address this issue, Balassa (1965) developed a proxy for measuring comparative advantage known as the 'Revealed Comparative Advantage (RCA) index', which defines a country's export share of each product compared to world shares of that specific product. Balassa (1965) argued,

> It is suggested here that "revealed" comparative advantage can be indicated by the trade performance of individual countries in regard to manufacturing products, in the sense that the commodity pattern of trade reflects relative costs as wells as differences in non-price factors (p. 103).

Balassa (1965) assumed that individual countries' export performance demonstrates the comparative advantage of the industry, suggesting that export performance could reveal various factors that indicate comparative advantage (Tamamura, 2016, p. 84). Researchers have used the RCA index in numerous empirical studies as a measure of international trade specialisation, which is characterised by a strong focus on one narrow area of activity and a less intense focus on others (Laursen, 2015, p. 100). Indeed, the RCA index has been used in several empirical studies, including for comparisons between industries within the same country or international comparisons between the same industries (Tamamura, 2016, p. 83). Dalum et al. (1998) and Laursen (2015) developed the 'Revealed Symmetric Comparative Advantage' (RSCA) index to make the RCA index symmetric.[83] Laursen (2015) asserted,

> Note that the RCA/RSCA is a measure of international specialisation and not of international competitiveness or any other concept indicating performance … RCA/RSCA is a measure of relative not absolute strength. The values of the measure imply that regardless of how poorly (or strongly) a country is performing, by definition the country will be specialised in something, and therefore will always have high values of RCA/RSCA for some sectors of the economy and low values for other sectors (p. 101).

Laursen's (2015) argument suggests that RCA/RSCA indices are suitable for measuring comparative advantage; however, they do not specify international competitiveness. With respect to trade balance (i.e. international competitiveness), the 'Trade Balance Index (TBI)' developed by Lafay (1992) has been used in the economic literature (Widodo, 2009).

With respect to comparative advantage in the context of the steel industry, de Carvalho and Sekiguchi (2015) analyse trade specialisation patterns for the ten largest steel-exporting countries using the RCA index, suggesting that comparative advantages of steel firms determine success in the steel trade. The authors also identify the strengths of the top ten steel-exporting countries finding a positive association

[83] Assume that the share of the export value of an industry in world export value is extremely small. In that case, the RCA index may elicit an extremely large value, and the comparative advantage of that industry may be overestimated. In the case of the RSCA index, the index falls between -1 and 1, which can avoid overestimating the comparative advantage of the industry (Kuwamori et al., 2014, p. 5). See Dalum et al. (1998) and Laursen (2015) for detailed discussions regarding the RSCA index.

between innovation activity and trade specialisation. Based on de Carvalho and Sekiguchi's (2015) results, Mattera (2018) examines the complexity in value-chains and sub-sectorial comparative advantage in the steel industry. In contrast, a number of studies find that TBI enables the investigation of countries' international competitiveness, suggesting the development level of steel industries (Marukawa, 2018, pp. 252–254; Marukawa & Hattori, 2019, pp. 32–33; Tanaka & Isomura, 2020, pp. 122–127).

While these studies provide important insights into comparative advantage and international competitiveness in the steel industry, they do not consider the associations with other factors (e.g. production technology or the level of economic development) and steel trade. Subsequent investigation is needed to better understand the associations between technology choice, the level of economic development and export patterns, including comparative advantage and international competitiveness.

While numerous studies have discussed the principle of comparative advantage in international trade, there remain minimal trade analyses focusing on emerging/developing countries from the perspective of comparative advantage and international competitiveness. One exception is Widodo's (2009) contribution, which analyses the Association of Southeast Asian Nations (ASEAN) development in terms of comparative advantage and trade balance (international competitiveness). The author introduces a framework entitled 'product mapping' to analyse ASEAN countries' development to discuss the catch-up of emerging/developing countries based on the flying geese model (Akamatsu, 1962; Kojima, 2000) using the RSCA index and TBI as indicators. The results suggest that a higher degree of comparative advantage raises the possibility of becoming a net exporter. A number of empirical studies use this framework to examine comparative advantage and international competitiveness of various countries and industries (e.g. Girik Allo et al., 2017; Setyastuti et al., 2018).

Based on the above observations, economic researchers appear to widely agree that the RSCA index and TBI are valuable indicators for examining comparative advantage and international competitiveness; therefore, this chapter uses the RSCA index and TBI to analyse global steel trade patterns.

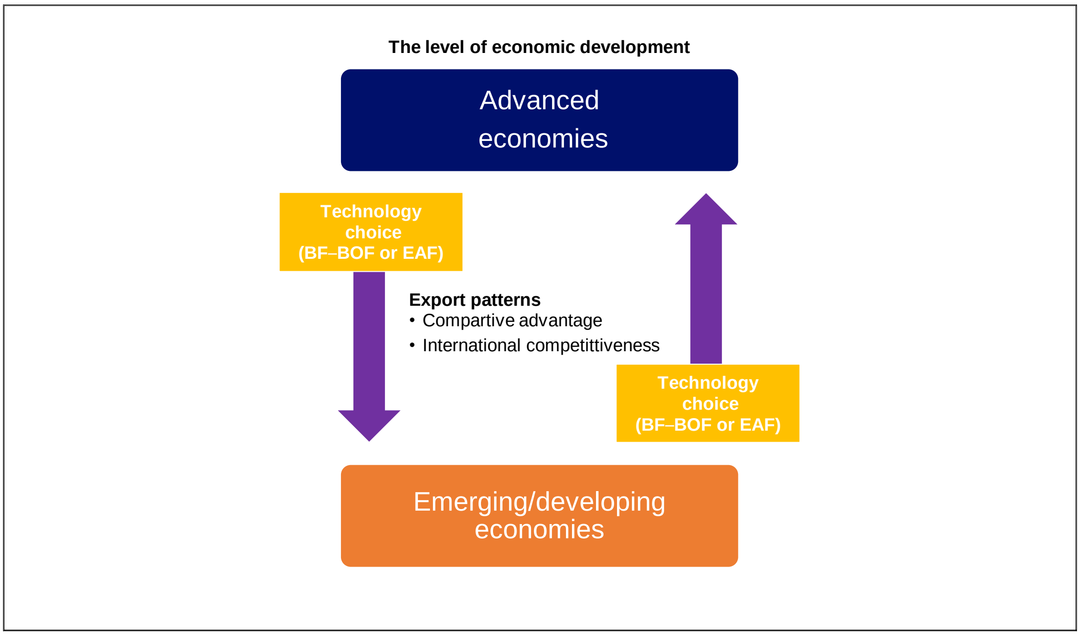
2.3 Analytical Perspective

2.3.1 Analytical Perspective

According to the hypothetical model presented in Chapter 1, technology choice and the level of economic development (i.e. advanced and emerging/developing economies) may impact the export patterns of large steel-producing countries, forming measurable global steel trade patterns. These factors could have important implications for the analysis of the international steel trade.

An international division of labour between advanced and emerging/developing economies, which is reflected by the level of economic development, is likely to exist in the global steel industry. Technology choice in the steel industries of advanced and emerging/developing economies to supply steel products to domestic or foreign steel markets involves either the blast furnace–basic oxygen furnace (BF–BOF) route or the electric arc furnace (EAF) route. Steel-producing countries' technology choices are likely to be reflected in export patterns. Countries' levels of economic development may also be relevant to export patterns, as it is assumed to be related to domestic steel consumption patterns, which ultimately impact the types of export products. This chapter examines whether the two factors of technology choice and the level of economic development are linked to international steel trade patterns. Figure 2.1 illustrates hypothetical global steel trade patterns.

Figure 2.1 Global steel trade patterns

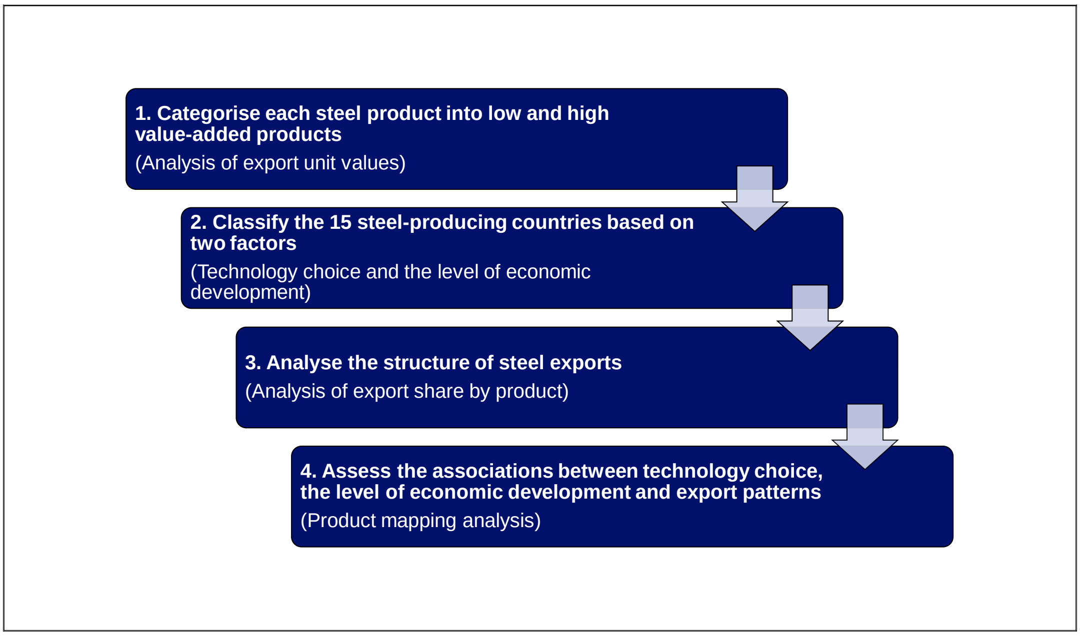


Source: Author

Figure 2.2 presents an overview of the flow of analysis and the analytical tools applied in this chapter.

1. This chapter examines the export patterns of the largest 15 steel-producing countries in terms of comparative advantage and international competitiveness at the product level. Consequently, it is critical to categorise each steel product into low and high value-added products, which will provide a more comprehensive understanding of the results of product mapping.
2. It is also crucial to classify the 15 steel-producing countries based on technology choice, which is reflected in countries' production system and the level of economic development as a first step prior to conducting a number of steel trade analyses. This grouping is expected to aid the assessment of the associations between technology choice, the level of economic development and export patterns.
3. Based on the above classification, it is important to elucidate the structure of steel exports in the 15 steel-producing countries by focusing on export share by product to identify the characteristics of each group's steel exports.
4. An in-depth investigation of the associations between technology choice, the level of economic development and export patterns can be conducted through a detailed product-level analysis by applying Widodo's (2009) framework, which enables the assessment of the comparative advantage and international competitiveness of the 15 steel-producing countries.

Table. 2.2 Overview of the flow of analysis and analytical tools



Source: Author

2.3.2 Methodology

Technology choice and the level of economic development

The World Steel Association (various years) releases data for crude steel output by process across each country's steel industry. This research assumes that steel firms' technology choices are reflected in countries' steel production by process. As presented in Chapter 1, the research classifies countries as either BF–BOF- or EAF-based countries to identify the characteristics of the production structure of each country.

Apart from technology choice, it is essential to focus on countries' levels of economic development, based on the assumption that it is another factor associated with the export patterns of each steel industry. In this chapter, while this research uses the dichotomy of OECD and non-OECD countries, IMF (2021b) classification is also used to indicate counties' levels of economic development.[84] The IMF (2021a) categorises the world into advanced economies and emerging market/developing economies based on i) per capita income level, ii) export diversification and iii) degree of integration into the global financial system.

a) Revealed Comparative Advantage index

Balassa (1965) proposed the RCA index, which is used to identify products with a comparative advantage in a country and has been widely used by researchers in the trade literature to identify specialisation patterns (Deardorff, 2011; Kowalski & Stone, 2011). If x_{ji} represents exports of product i from country j, then the RCA is expressed as follows:

$$RCA_{ji} = \frac{x_{ji} / \sum_i x_{ji}}{x_{wi} / \sum_i x_{wi}}$$

where the subscript w refers to world exports.

[84] The World Bank (2021) also classifies countries into income groups. Since it does not include data for Taiwan, the IMF (2021b) was used in this chapter.

b) Revealed Symmetric Comparative Advantage index

The distribution of the RCA index is asymmetric, varying from zero to infinity (Laursen, 2015). Dalum et al. (1998) and Laursen (2015) transformed this index into a symmetric RSCA index ranging from −1 to +1 ($-1 \leq RSCA_{ji} \leq +1$). The index is formulated as follows:

$$RSCA_{ji} = \frac{RCA_{ji} - 1}{RCA_{ji} + 1}$$

An $RSCA_{ji}$ greater than 0 for a given product *i* reveals a country's comparative advantage in its exports. In contrast, an $RSCA_{ji}$ less than 0 suggests a comparative disadvantage in a country's exports of a given product. Hence, values closer to 1 suggest a high degree of comparative advantage in the whole steel industry or some steel products.

c) Trade Balance Index

Lafay (1992) introduced the TBI as a measure to analyse whether a country is a net exporter or a net importer. The index is defined as follows:

$$TBI_{ji} = \frac{X_{ji} - M_{ji}}{X_{ji} + M_{ji}}$$

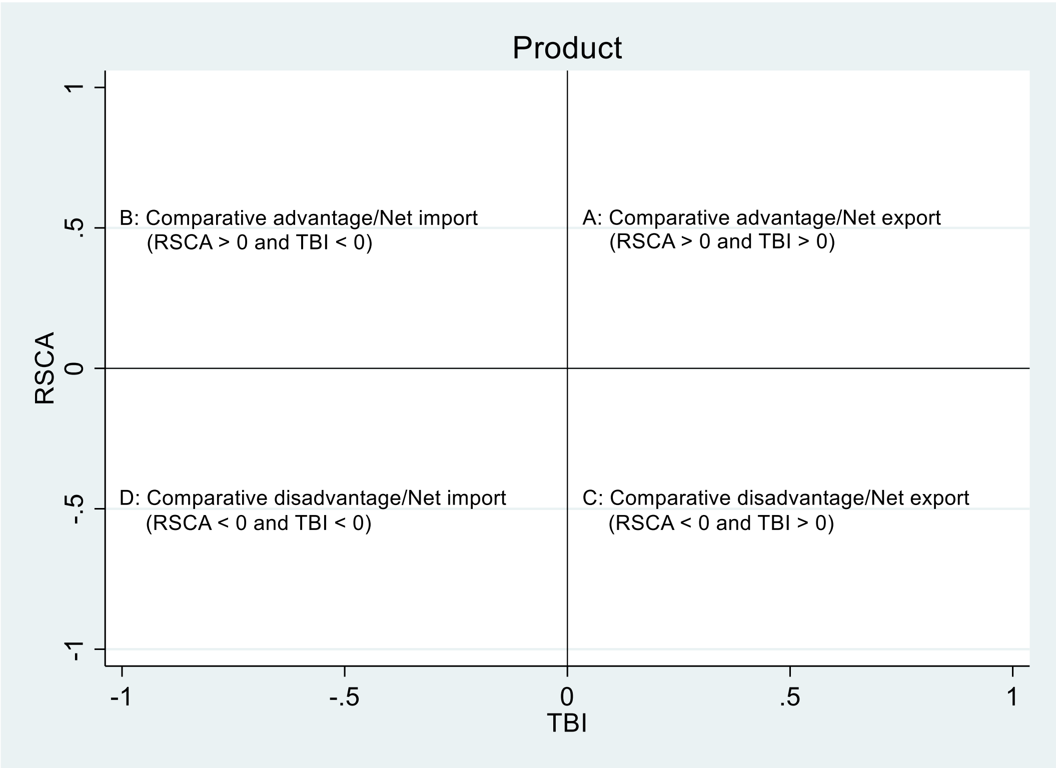
where TBI_{ji} represents the TBI of country *j* for steel product *i* and X_{ji} and M_{ji} denote the exports and imports of steel product *i* by country *j*, respectively. The index value ranges from -1 to +1 ($-1 \leq TBI_{ji} \leq 1$). A country is considered to be a net steel exporter if its TBI value is positive, whereas a negative TBI value indicates a net steel importer; hence, values closer to 1 indicate a high degree of international competitiveness in the whole steel industry or some steel products.

Product mapping

In this chapter, Widodo's (2009) product mapping can be applied to assess the comparative advantage and international competitiveness of the 15 steel-producing countries (Figure 2.3). In product mapping, TBI is on the x-axis and the RSCA index is on the y-axis. The upper right quadrants (A) present products with comparative advantage and net export positions. The upper left quadrants delineate products with comparative advantage that are in net import positions (B). The lower right quadrants show products that are in net export positions but have no comparative advantage (C). Finally, the lower-left quadrants represent products with neither comparative advantage nor net export position (D).

This research assumes that A (comparative advantage/net export) is the most competitive position, suggesting that the steel industry plays a vital role in a country or that a country has competitive steel products in international trade. The country may have comparative advantage in the whole steel industry or some products; however, the position may become B (comparative advantage/net import) when steel demand increases faster than steel production and when steel imports also increase. Because of its individual circumstances, its position may also become C (comparative disadvantage/net export). Conversely, D (comparative disadvantage/net import) is the least competitive position, indicating that the country has no comparative advantage/international competitiveness for the whole steel industry or specific steel products. Nonetheless, if the country gradually gains a comparative advantage in the whole steel industry or with regard to certain products, its position may shift from D to B.

Figure 2.3 Product mapping



Source: Author based on Widodo (2009, p. 67)

2.3.3 Data

The primary trade data comes from the International Trade Centre's Trade Map (ITC, 2021). Trade data in value terms are used to calculate the RSCA index and TBI. Definitions of steel products are based on the International Steel Statistics Bureau (ISSB, 2010). Data regarding steel production are taken or calculated from the World Steel Association (2020b).

2.3.4 List of the World's 15 Largest Steel-Producing Countries

This chapter focuses on the world's 15 largest steel-producing countries. These countries are selected according to the magnitude of crude steel output in 2016–2018. Based on the criteria, this chapter includes the 15 steel-producing countries presented in Table 2.1.

The table indicates that the Chinese steel industry has a dominant role in world steel production among the 15 steel-producing countries. Nevertheless, the supply structure appears to be relatively diversified when excluding the Chinese steel industry. The shares of steel exports in world steel exports in several large steel-producing countries tend to be higher than crude steel output, suggesting that steel exports have significant roles in each steel industry.

Table 2.1 List of the 15 steel-producing countries (2016–2018)

Rank	Region	Country	Country code (ISO)	Share of world crude steel output	Share of world steel exports in volume terms
				%	
1	Asia	China	CHN	50.2	17.8
2	Asia	Japan	JPN	6.0	8.1
3	Asia	India	IND	5.9	2.7
4	North America	United States	USA	4.7	2.0
5	CIS	Russia	RUS	4.1	6.8
6	Asia	South Korea	KOR	4.1	6.5
7	European Union	Germany	DEU	2.5	5.6
8	Other Europe	Turkey	TUR	2.1	3.6
9	South America	Brazil	BRA	2.0	3.0
10	European Union	Italy	ITA	1.4	3.9
11	Asia	Taiwan	TWN	1.3	2.6
12	CIS	Ukraine	UKR	1.3	3.5
13	Middle East	Iran	IRN	1.2	1.7
14	North America	Mexico	MEX	1.1	1.1
15	European Union	France	FRA	0.9	3.1

Source: Author's calculation based on data from the ITC (2021) and the World Steel Association (2020b)

2.4 Defining Low Value-Added and High Value-Added Products

While no industry-wide consensus has been reached regarding the definition of high value-added steel products in the steel industry, some characteristics have emerged, including high functionality, high added values and high unit prices (Kawabata, 2020a, p. 16). Subsequently, this chapter asserts that it is crucial to define low and high value-added steel products, as such classification will elicit a more comprehensive understanding of the export patterns of the 15 steel-producing countries under consideration.

The unit value of steel exports (nominal sales divided by tonnes of steel exported) helps illustrate values across steel products in the global steel industry, allowing for categorisation of steel products into low and high value-added delineations using export unit values. Table 2.2 summarises the definitions of low and high value-added products used in this research.

At a broad product level, the value of flat products is much higher than that of long products. The former is predominantly used as inputs for the manufacturing industry which requires high-quality, whereas the latter is primarily used in the construction industry. Regarding flat products, the value of the product group increases in each step of the process. For instance, product value tends to rise with the degree of processing: cold-rolled coils from hot-rolled coils, surface-treated sheets from cold-rolled coils and welded tubes from hot-rolled coils (Kawabata, 2017, p. 10). Among flat products hot-rolled flat products, such as hot-rolled sheets and plates, are relatively low value-added and are often used in the construction industry as well as the manufacturing industry.

Table 2.2 Definition of low value-added and high value-added products (2016–2018)

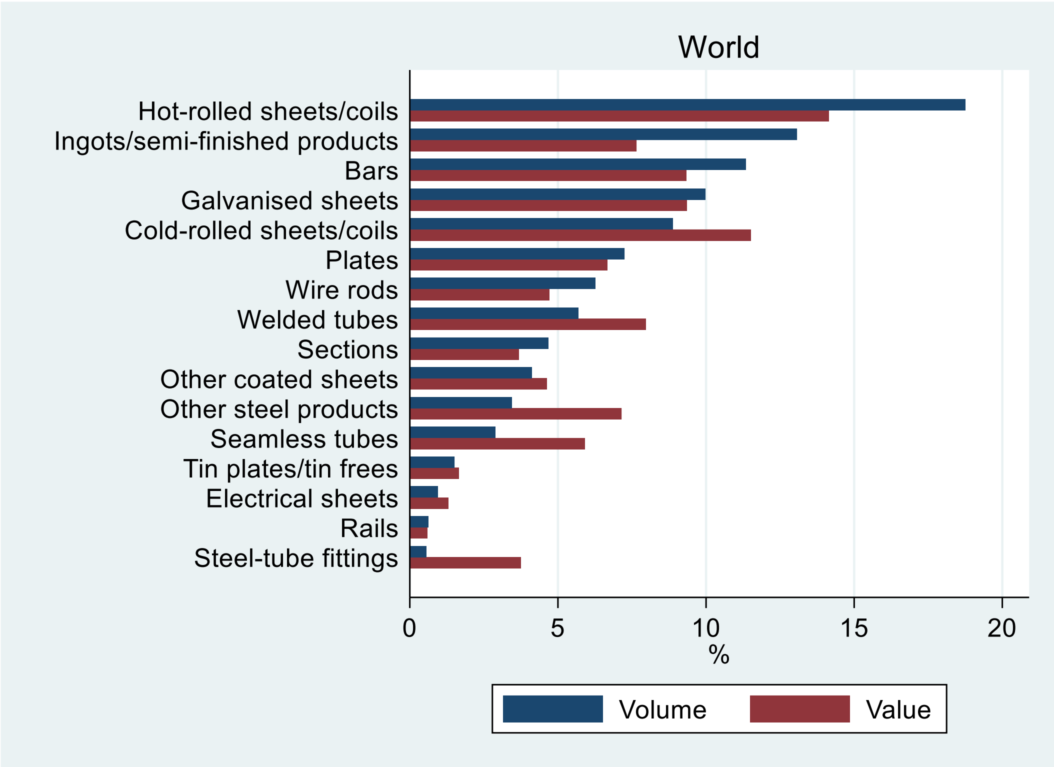
No	Category	Steel products	Unit value (USD/tonne)	Value
1	Semi	Ingots/semi-finished products	420	Low value-added products
2	Long	Wire rods	540	Low value-added products
3	Long	Bars	567	Low value-added products
4	Long	Sections	618	Low value-added products
5	Long	Rails	763	High value-added products
6	Flat	Hot-rolled sheets/coils	534	Low value-added products
7	Flat	Plates	609	Low value-added products
8	Flat	Cold-rolled sheets/coils	642	High value-added products
9	Flat	Galvanised sheets	736	High value-added products
10	Flat	Tin plates/tin frees	890	High value-added products
11	Flat	Other coated sheets	911	High value-added products
12	Flat	Electrical sheets	1,100	High value-added products
13	Pipe	Welded tubes	988	High value-added products
14	Pipe	Seamless tubes	1,265	High value-added products

Note: Alloy steel products are excluded from export unit values from the above table to make it easier to understand the value of each steel product. Regardless, alloy steel products are included in all analyses in this research.
Source: Author's calculation based on data from the ITC (2021)

Figure 2.4 presents the share of each steel product in world steel exports in 2016–2018. Among the all-steel product categories, hot-rolled sheets/coils were the largest export items, followed by ingots/semi-finished products, bars, galvanised sheets and cold-rolled sheets/coils. In contrast, steel products with high export unit values (e.g. electrical sheets and rails) had lower shares than other products.

The shares of world steel exports in volume and value terms differ widely across steel products, reflecting the value differences of each product category. Steel products such as hot-rolled sheets/coils and ingots/semi-finished products had much higher shares of exports in volume than the value in 2016–2018, suggesting that these products had lower values than other products. In contrast, some pipe and tube products generated much higher values than volume terms, which is congruent with the tendency of the product group having high export unit values.

Figure 2.4 Share of world steel exports by product (2016–2018)



Note: Alloy steel products are included.
Source: Author's calculation based on data from the ITC (2021)

2.5 Groupings

It is crucial to divide the 15 steel-producing countries into groups according to production systems based on steel firms' technology choices and the level of economic development to examine the associations between these two factors and export patterns.

Table 2.3 summarises the production system and the level of economic development for the 15 steel-producing countries. Production systems vary widely across geographies, reflecting each steel industries' diverse technology choice patterns. Regarding the level of economic development, there are some gaps in terms of OECD and IMF definitions. OECD member countries are generally considered to be developed countries, but some countries (e.g. Turkey and Mexico) are defined as emerging/developing economies according to the IMF's definition (IMF, 2021b). Although Taiwan is a non-OECD country, it is considered to be an advanced economy.

Table 2.3 Production systems and the level of economic development of the 15 steel-producing countries (2016–2018)

Country	Technology choice				The level of economic development	
	BF–BOF	EAF	Other	Production system	IMF's definition	OECD's definition
	Share of steel output, %					
China	91.2	8.8	0.0	BF–BOF-based country	Emerging/developing economy	Non-OECD country
Japan	76.2	23.8	0.0	BF–BOF-based country	Advanced economy	OECD country
India	44.4	55.8	0.0	EAF-based country	Emerging/developing economy	Non-OECD country
United States	32.2	67.8	0.0	EAF-based country	Advanced economy	OECD country
Russia	66.3	31.3	2.4	BF–BOF-based country	Emerging/developing economy	Non-OECD country
South Korea	67.7	32.3	0.0	BF–BOF-based country	Advanced economy	OECD country
Germany	70.0	30.0	0.0	BF–BOF-based country	Advanced economy	OECD country
Turkey	31.8	68.2	0.0	EAF-based country	Emerging/developing economy	OECD country
Brazil	76.8	21.7	1.5	BF–BOF-based country	Emerging/developing economy	Non-OECD country
Italy	20.8	79.2	0.0	EAF-based country	Advanced economy	OECD country
Taiwan	61.9	38.1	0.0	BF–BOF-based country	Advanced economy	Non-OECD country
Ukraine	70.4	7.1	22.6	BF–BOF-based country	Emerging/developing economy	Non-OECD country
Iran	10.5	89.5	0.0	EAF-based country	Emerging/developing economy	Non-OECD country
Mexico	24.6	75.4	0.0	EAF-based country	Emerging/developing economy	OECD country
France	67.8	32.2	0.0	BF–BOF-based country	Advanced economy	OECD country

Source: Author based on the IMF (2021b), the OECD (2020a, p. 23) and the World Steel Association (2020b)

Table 2.4 provides a grouping of the 15 steel-producing countries based on production system and the level of economic development. Broadly, the 15 steel-producing countries can be divided into four groups. First, the steel industries in Group I consists of four countries, China, Russia, Brazil and Ukraine; emerging/developing economies that mainly employ the BF–BOF route and are labelled 'BF–BOF-based emerging/developing economies'. Second, Group II includes the steel industries in five countries, Japan, South Korea, Germany, Taiwan and France, which are labelled 'BF–BOF-based advanced economies' since they are advanced economies that have the BF–BOF-based production structure. Third, the steel industries in Group III include four countries—India, Turkey, Iran and Mexico—labelled 'EAF-based emerging/developing economies', given that they are emerging/developing economies and produce steel mainly using the EAF route. Finally, the steel industries in Group IV include two countries—the United

States and Italy)—labelled 'EAF-based advanced economies'. They are advanced economies that produce steel mainly via the EAF route.

Based on the above classification, the 15 steel-producing countries were grouped into four groups. An important question that arises is whether each group has similar characteristics of the structure of steel exports.

Table 2.4 Groups based on production systems and levels of economic development

	Emerging/developing economy	Advanced economy
BF–BOF-based country	**Group I (BF–BOF-based emerging/developing economies)** • China • Russia • Brazil • Ukraine	**Group II (BF–BOF-based advanced economies)** • Japan • South Korea • Germany • Taiwan • France
EAF-based country	**Group III (EAF-based emerging/developing economies)** • India • Turkey • Iran • Mexico	**Group IV (EAF-based advanced economies)** • United States • Italy

Source: Author

2.6 The Characteristics of Steel Exports

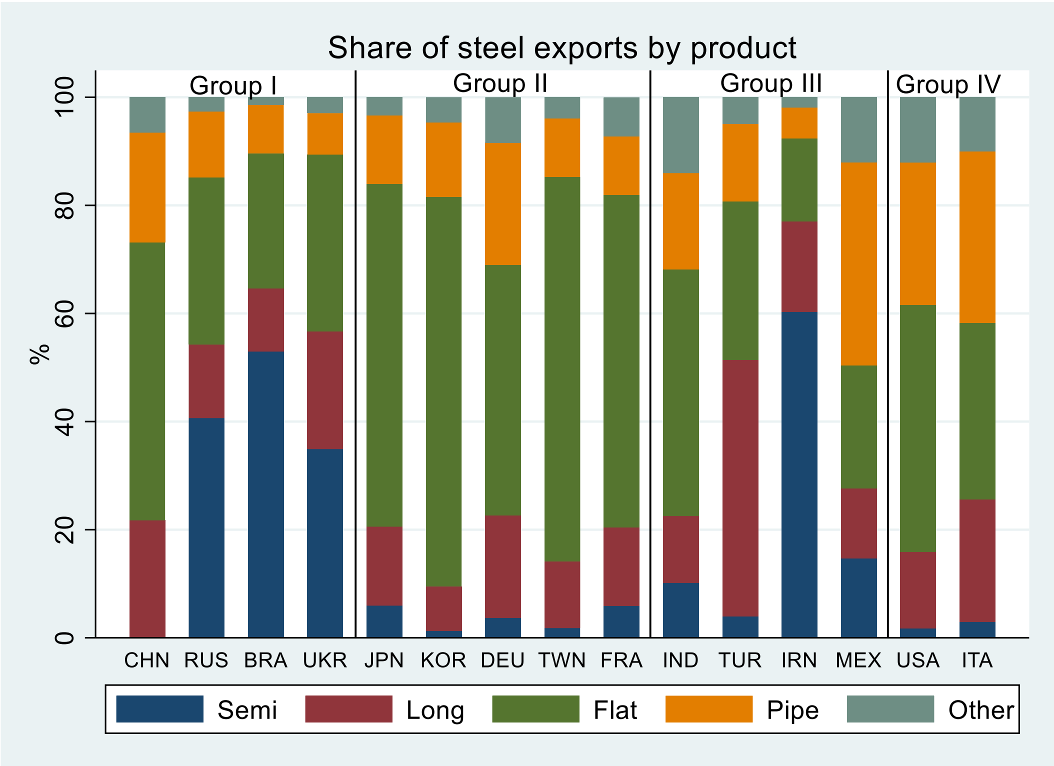
Understanding the overall structure of steel exports will provide a more comprehensive understanding of the steel supply characteristics of the 15 steel-producing countries. Figure 2.5 provides a cursory glance at the structure of steel exports in the 15 steel-producing countries in 2016–2018 in terms of relative shares.

There are notable variations in the structure of steel exports across the 15 steel-producing countries; however, some common patterns can be observed between them. The steel industry in each group appears to have relatively similar patterns of steel exports. For instance, ingots/semi-finished products are the largest export items in the steel industries in Group I, notably in Russia, Brazil and Ukraine, although the share of product category was very small in China.[85] Examining the products

[85] Nevertheless, ingots/semi-finished products were important export items in the Chinese steel industry. For instance, they were the largest export category in 2001, accounting for nearly 40% of its steel exports in 2001 in volume terms; however, since 2009, the share of ingots/semi-finished products was almost 0%. Market analysts have noted that such

exported by the steel industries in Group II, the main export category is flat products. In contrast, the steel industries in Group III appear to have different export structures, as each steel industry presents its own unique characteristics. For instance, the share of long products is very high in the Turkish steel industry, whereas the Iranian steel industry's main export products are ingots/semi-finished products. Regarding the steel industries in Group IV, the US steel industry's major export products are flat products, whereas pipe and tube products have a significant role in the Italian steel industry.

Figure 2.5 Structure of steel exports in value terms (2016–2018)



Source: Author's calculation based on data from the ITC (2021)

2.7 Comparative Advantage and International Competitiveness

To assess whether two factors of technology choice and the level of economic development are linked to the export patterns of each steel industry, an in-depth investigation of these potential linkages can be conducted through detailed product-level analysis using Widodo's (2009) framework. Analysing the

developments might have occurred in response to changes in the differential VAT rebates applied to steel exports, resulting in greater incentives to export, and most Chinese semi-finished products have shipped as finished products (CRU, 2016).

degree of specialisation and international competitiveness of the 15 steel-producing countries focusing on the associations between technology choice, the level of economic development and export patterns with detailed product data could reveal important insights into current global steel trade patterns.

RSCA index and TBI are calculated for selected steel categories, including i) total steel products, ii) ingots/semi-finished products, iii) wire rods, iv) bars, v) hot-rolled sheets/coils, vi) cold-rolled sheets/coils, vii) galvanised sheets, viii) tin plates/tin frees, iv) other coated sheets, x) electrical sheets, xi) welded tubes and xii) seamless tubes. Based on the definitions of Table 2.2, 11 categories are classified into low and high value-added products.

Overall, most of the 15 largest steel-producing countries tend to have a comparative advantage and international competitiveness for total steel products (i.e. the entire steel industry), indicating that the steel industry has a consequential role in trade for these countries (Figure 2.6). In contrast, two EAF-based countries (the United States and Mexico) have negative RSCA and TBI values; thus, their positions are D in the product mapping of all-steel products. Nevertheless, the results indicate notable variations in degrees of comparative advantage and international competitiveness at the detailed product level across groups/countries (Figures 2.7–2.10).

BF–BOF-based countries in Groups I and II tend to be in position A for various steel products, and Group I (excluding China) in particular appears to be extremely specialised in specific products, such as ingots/semi-finished products. In addition, Group I has high RSCA and TBI values for a number of low value-added products such as wire rods, bars and hot-rolled sheets/coils. This suggests that Group I countries have advantages in supplying low value-added products in global steel markets. Nevertheless, Group I (excluding Russia) also tends to be specialised in some high-value-added products such as seamless tubes.

Group II includes strong exporters in the flat products category and is specialised in a large number of low value-added products (e.g. wire rods and hot-rolled sheets/coils) to high value-added ones (e.g. tin plates/tin frees and electrical sheets). The steel industries in Japan, South Korea and Taiwan are quite specialised in major flat products, such as hot-rolled sheets/coils, cold-rolled sheets/coils and galvanised sheets, suggesting that they have a key role in supplying flat products in the international steel market. Notably, all the steel industries in Group II are in an A position for some high value-added products, such as tin plates/tin frees and electrical sheets.

The patterns of trade specialisation and international competitiveness in EAF-based countries (Groups III and IV) significantly vary between countries. Overall, no group in EAF-based countries is in position A at the product level except bars in Group III (excluding Mexico). Generally, EAF-based steel firms have strength in long products; thus, it is natural for some EAF-based countries to have strength in supplying long products. In particular, the steel industry in some countries (e.g. Turkey) in Group III is quite focused on bars. Turning to Group IV, they tend to be ranked in position D for a number of product categories, since the US steel industry elicits neither a comparative advantage nor international competitiveness in any categories.

Figure 2.6 Product mapping of total steel products

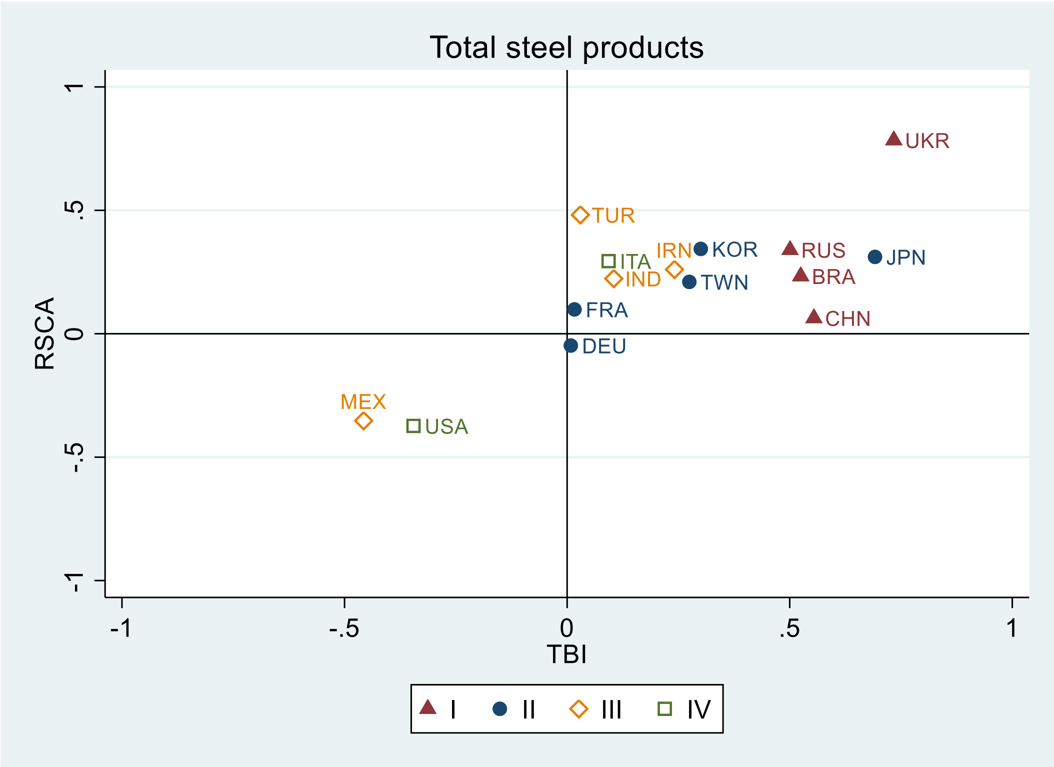


Figure 2.7 Product mapping of ingots/semi-finished products and selected long products

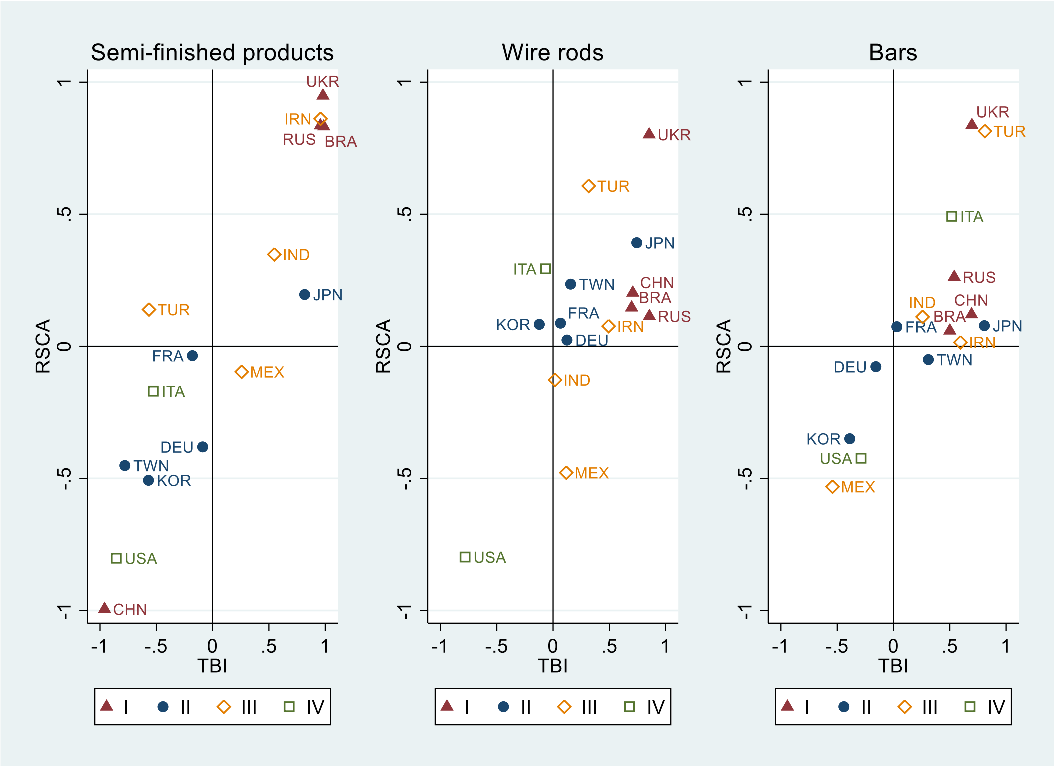


Figure 2.8 Product mapping of selected flat products (1)

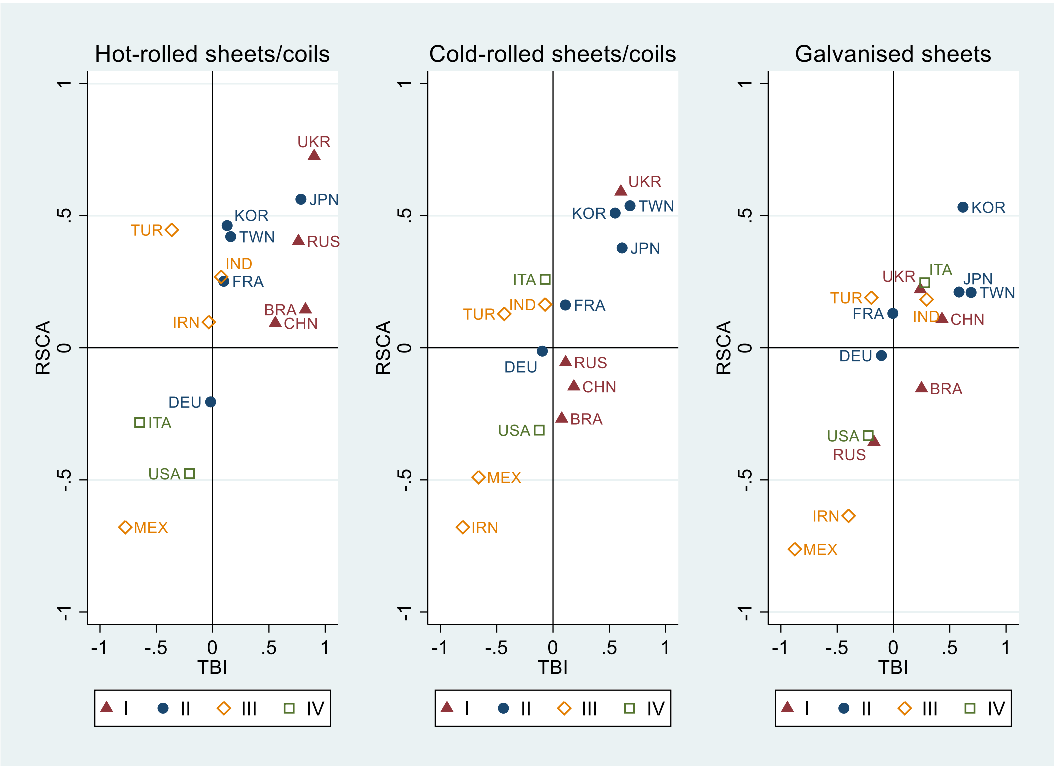


Figure 2.9 Product mapping of selected flat products (2)

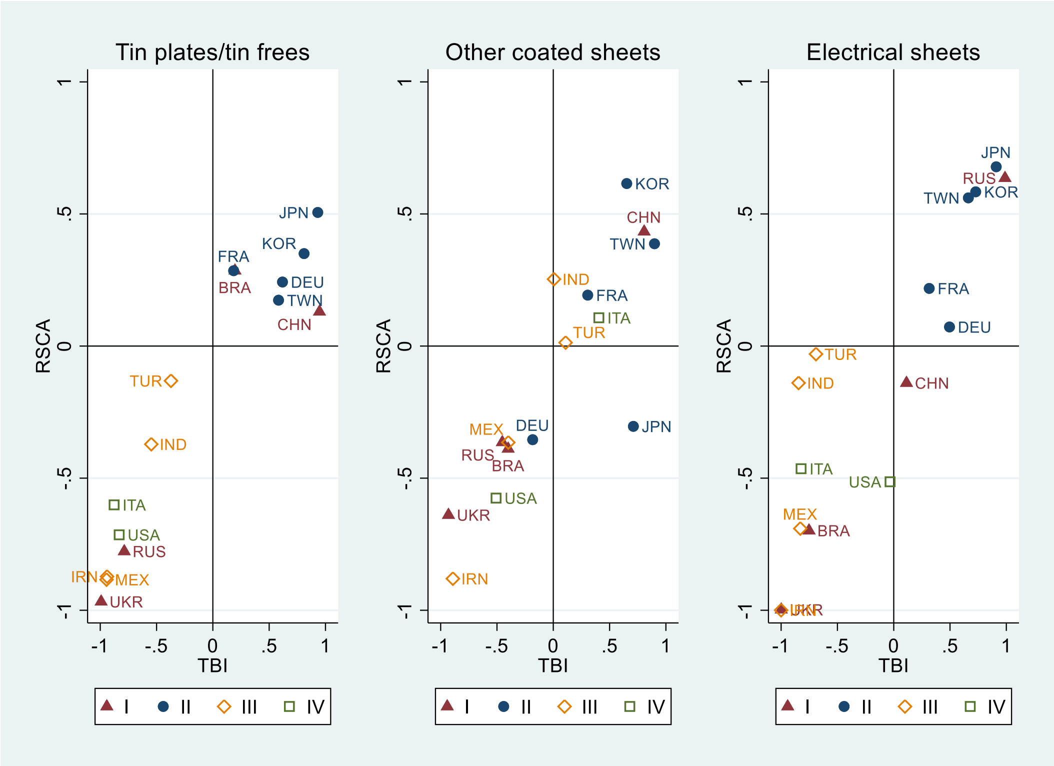
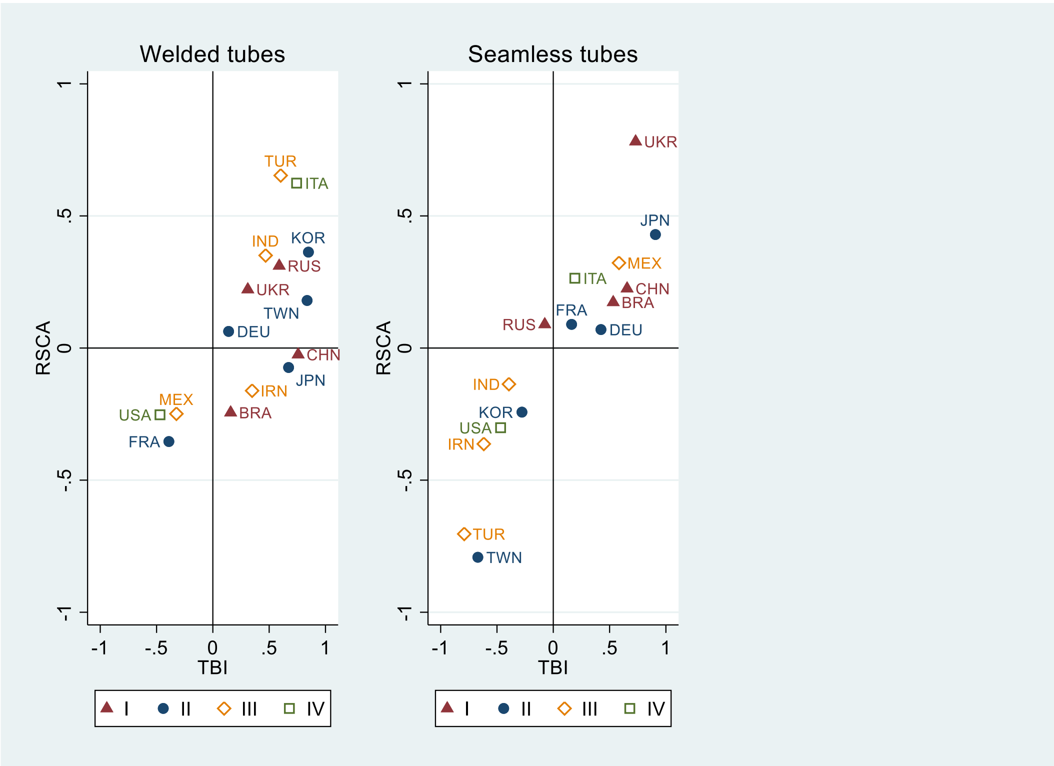


Figure 2.10 Product mapping of selected pipe and tube products



Source: Author's calculation based on data from the ITC (2021)

It is crucial to assess the results of product mapping for the 15 steel-producing countries, and Table 2.5 provides a summary of the analysis in 2016–2018. Overall, the results suggest that the steel industry has a vital role in international trade in these countries, so it seems natural for these to represent the world's 15 largest steel-producing nations. Nevertheless, the steel industry in some countries (notably the US steel industry) does not elicit a comparative advantage or international competitiveness, although it is a major steel-producing country.

There are notable variations in degrees of comparative advantage and international competitiveness at the product level in each steel industry. While both Groups I and II have advantages in supplying various types of products, there are substantial differences in those two groups in terms of supplying steel products that have comparative advantage and international competitiveness. Group I has positive RSCA and TBI values for several low value-added steel products, such as ingots/semi-finished products and long products (e.g. bars and wire rods). In contrast, Group II is in position A for both low and high value-added products, suggesting advantages in supplying specific steel products. In particular, advantages are demonstrated in some high value-added products (e.g. tin plates/tin frees and electrical sheets). Regarding the steel industries in EAF-based countries, specialisation patterns are found to be far from homogeneous across countries, suggesting that there is less association of EAF production systems with steel export patterns than BF–BOF-based production systems. Group III has a comparative advantage and international competitiveness only for bars, while Group IV is not ranked in position A for most product categories.

Table. 2.5 Summary of product mapping (2016–2018)

	Broad product category	Detailed product category	Unit value		Product mapping			
					A	B	C	D
			USD/tonne	Value	Comparative advantage/ Net export (RSCA > 0 and TBI > 0)	Comparative advantage/ Net import (RSCA > 0 and TBI < 0)	Comparative disadvantage/ Net export (RSCA < 0 and TBI > 0)	Comparative disadvantage/ Net import (RSCA < 0 and TBI < 0)
1	Total	Total steel products			**I, II** (excl. DEU), **III** (excl. MEX)	-	-	-
2	Semi	Ingots/semi-finished products	420	Low	**I** (excl. CHN)	-	-	**II** (excl. JPN), **IV**
3	Long	Wire rods	540	Low	**I, II** (excl. KOR)	-	-	-
4	Long	Bars	567	Low	**I, III** (excl. MEX)	-	-	-
5	Flat	Hot-rolled sheets/coils	534	Low	**I, II** (excl. DEU)	-	-	**IV**
6	Flat	Cold-rolled sheets/coils	642	High	**II** (excl. DEU)	-	**I** (excl. UKR)	-
7	Flat	Galvanised sheets	736	High	**II** (excl. FRA, DEU)	-	-	-
8	Flat	Tin plates/tin-frees	890	High	**II**	-	-	**III, IV**
9	Flat	Other coated sheets	911	High	**II** (excl. JPN, DEU)	-	-	**I** (excl. CHN)
10	Flat	Electrical sheets	1,100	High	**II**	-	-	**III, IV**
11	Pipe	Welded tubes	988	High	**II** (excl. JPN, FRA)	-	-	-
12	Pipe	Seamless tubes	1,265	High	**I** (excl. RUS), **II** (excl. KOR, TWN)	-	-	**III** (excl. MEX)

Note: While alloy steel products are excluded for export unit values from the above table, they have been included in the product mapping analysis.
Source: Author

2.8 Summary and Implications

The analyses of the steel trade through the lens of comparative advantage and international competitiveness presented in this chapter provided important insights into the associations between technology choice, the level of economic development and export patterns in the global steel industry. Results of these analyses are an essential step in the development of a more comprehensive understanding of the structure of steel supply in the global steel industry.

The chapter formulated a hypothesis that technology choice and the level of economic development impact large steel-producing countries' export patterns, revealing patterns in contemporary global steel trade. The results demonstrate that these two factors are associated with advantages in specific types of steel products in the international steel trade.

This chapter demonstrated that some large steel-producing countries have high degrees of comparative advantage and international competitiveness for a wide range of steel products. While BF–BOF-based countries are more likely to retain a specific comparative advantage and maintain international competitiveness for a variety of steel products, they differ widely according to levels of economic development. BF–BOF-based emerging/developing economies are likely to be associated with higher degrees of comparative advantage and international competitiveness for low value-added products compared to BF–BOF-based advanced economies. In contrast, BF–BOF-based advanced economies are associated with higher degrees of comparative advantage and international competitiveness for both low and high value-added products than those in emerging/developing economies. EAF-based countries tend to have more diverse structures in terms of export patterns than BF–BOF-based countries. Although some EAF-based countries tend to be extremely specialised in some low value-added products (i.e. long products), EAF-based production systems appear to be less linked to steel export patterns compared to the BF–BOF-based production systems.

Overall, this chapter infers that contemporary production systems based on past technology choice are closely associated with advantages in specific types of steel products, in addition to the level of economic development. Given the close relationship between production systems and export patterns, the

BF–BOF route appears to be more likely to determine the development patterns of each steel industry than the EAF route.

This chapter provided important insights into the associations between technology choice, the level of economic development and export patterns (i.e. comparative advantage and international competitiveness) for large steel-producing countries. Nevertheless, the results raise a number of questions that require further research. First, it is important to focus on the export performance of the steel industry across all steel-producing countries to assess the catch-up of the steel industry in non-OECD countries. While this chapter focused on only large steel-producing countries, more work is needed to investigate the export performance of non-OECD countries' steel industries, including small and medium-sized steel-producing countries. Second, it is essential to assess the differences in export performance between steel industries within non-OECD countries, as well as the differences in steel industries in OECD and non-OECD countries, to identify the characteristics of the industry in non-OECD countries. Finally, understanding the development of the export structure of steel industries in non-OECD countries in terms of export upgrading could offer more thorough insights into their current level of catch-up, given that they may need to develop trade structures to achieve this. Thus, more detailed research is required to fully understand the characteristics and catch-up of non-OECD countries in the global steel industry.

Chapter 3. Upgrading the Structure of Steel Exports in Non-OECD Countries: The Implications of Trade balance, Sophistication and Diversification on Progress

3.1 Introduction

Upgrading export structures, in reference to export sophistication and diversification, has attracted attention in the trade literature over the past decade (Hausmann et al., 2006; Hesse, 2008; Schott, 2007). These issues are particularly relevant to the progress of emerging/developing countries in the world economy. Economic literature suggests that emerging/developing countries should upgrade export structures to advance economic growth and industrialisation (Kumagai, 2014; Kumagai & Kuroiwa, 2020). Major international agencies, such as the United Nations Industrial Development Organisation, the United Nations Conference on Trade and Development and the World Trade Organisation have introduced various technology and capacity building programmes to aid emerging/developing countries to increase the value-added content of exports and diversify export portfolios (Zhu & Fu, 2013, p. 221).

Based on the above, export upgrades could be directly associated with the economic catch-up of emerging/developing countries, and such an investigation could provide vital insights into the level of development in non-OECD countries. Therefore, analyses of the state of international trade could offer a suitable approach for investigating the progress of the steel industry in non-OECD countries.

Examination of export upgrading is particularly relevant to the steel industry. Adding value to products and diversifying product portfolios could help steel industries in non-OECD countries to catch-up with those of more advanced steel-producing nations, which would ultimately help the industry become more economically viable. Indeed, improved steelmaking quality and upgrade, rather than increased quantity, is a prominent issue facing the contemporary steel industry, and steel exports could benefit from upgrading production activities (Mattera, 2018; OECD, 2017).

It is essential to understand the current level of steel industry export sophistication and diversification in non-OECD countries as a first step in considering the upgrade of industry structure, which could provide a more comprehensive understanding of existing levels of progress in the global steel industry.

The research question for this chapter is: *To what extent has the steel industry in non-OECD countries caught up in terms of upgrading exports, in reference to export sophistication and diversification?*

To answer this question, this chapter endeavours to assess the current progress of export upgrades in the steel industry in non-OECD countries. Understanding the degree of export upgrading is important for quantifying differences in the export performance of non-OECD countries from that of OECD countries and to what extent it varies. More specifically, this chapter defines and investigates two aspects of export upgrading, primarily examining the extent of export quality (export sophistication and diversification) in non-OECD countries. The chapter also highlights steel exports from the perspective of quantity, in reference to the extent of trade balance. The chapter also attempts to link the discussions of the quantity and quality of steel supply.

The remainder of the chapter is organised into the following sections. Section 3.2 presents a literature review. Section 3.3 details the analytical perspective used in the study, focusing on the link between technology choice and export performance. Section 3.4 provides an overview of technology choice as reflected in steel production systems and discusses the differing production structures in the steel industries of non-OECD and OECD countries. Section 3.5 analyses the distribution of trade balance, export sophistication and diversification to assess the progress of steel industry catch-up in non-OECD countries in comparison to OECD countries, followed by an analysis of the relationship between trade indicators in non-OECD countries. Section 3.6 presents a summary and suggests potential avenues for further research.

3.2 Literature Review

Economic literature suggests that it is essential to investigate export upgrading in considerations of overall industrial upgrading in emerging/developing countries.[86] The notion of the middle-income trap (Gill & Kharas, 2007) is relevant to the progress of industrial upgrading, and enhancing export structure is crucial to the advancement of emerging/developing countries. Indeed, high-income countries tend to export more sophisticated goods than those experiencing the middle-income trap. In contrast, trapped countries remain dependent on the export of primary commodities.

Researchers have acknowledged that export portfolios impact economic development, suggesting that export sophistication promotes more expedient and sustainable economic growth (Hausmann et al., 2006; Lall, 2000a; Lall et al., 2006). The implication is that export sophistication has a significant role in

[86] This paragraph is based on Kumagai (2014) and Kumagai and Kuroiwa (2020).

the economic progress of emerging/developing countries. Various indicators have been used to measure countries' export sophistication (Hausmann et al., 2006; Rodrik, 2006; Schott, 2007).[87] For instance, Schott (2007) assesses the relative sophistication of China's manufacturing export bundle in terms of its similarity to that of aggregate OECD countries referencing Finger and Kreinin's (1979) export similarity index (ESI). da Silva et al. (2011) assume the same approach, using the ESI to assess the relative sophistication of countries' exports by comparing the export bundles with those of aggregate OECD countries. As this chapter investigates only steel export data, as opposed to all trade in goods data, the methodology proposed by Schott (2007) and da Silva et al. (2011) appears to be suitable for measuring non-OECD countries' steel industry export sophistication, as it facilitates the measurement of export sophistication using only steel trade data.

Another consideration in the trade literature is export diversification, suggesting that advanced countries have more diversified export structures than emerging/developing countries and export diversification is essential to economic growth (Agosin et al., 2011; Cadot et al., 2011; Hesse, 2008). This implies that export diversification is vital for emerging/developing countries. While different indicators are used to measure export diversification (e.g. Gini Index, Herfindahl Index, Theil Index,), the Herfindahl Index (HI) is the most commonly used measure (Chandra et al., 2007, p. 2); therefore, it is reasonable to use the HI to measure export diversification in the international steel exports.

Discussions regarding the upgrade of production and export structures in the steel industry appear to have drawn researchers' attention amid the circumstances of global steel excess capacity.[88] Mattera (2018) analysed steel exports in the context of global value chains based on input–output data, asserting that the steel industry has a complex value chain and a gap exists between steel production in emerging/developing countries and that of advanced nations.

While economic researchers are beginning to focus on the importance of upgrading in the steel industry, no direct research exists on the issues of export sophistication and diversification in the context of the steel industry. Assessment of export upgrading in terms of export sophistication and diversification

[87] For instance, Hausmann et al. (2006) developed an index to assess the sophistication of individual export goods (PRODY) using exporting countries' income data. The researchers then use PRODY to calculate an index of the sophistication of the overall export structure (EXPY).

[88] In the last couple of years, the global steel industry has faced excess capacity challenges due to the rapid expansion since the early 2000s (OECD, 2015a, 2015b).

can provide important insights for the analysis of the industry. Understanding the degree of export upgrading could advance the comprehensive understanding of the extent the current level of catch-up in the steel industry in non-OECD countries; thus, this chapter presents a detailed analysis of export sophistication and diversification of non-OECD steel industries.

3.3 Analytical Perspective

3.3.1 Analytical perspective

Based on the hypothetical model presented in Chapter 1, it is necessary to focus on steel industry export upgrading in non-OECD countries to analyse progress. Chapter 2 examined the export patterns of major steel-producing countries, indicating that technology choice and the level of economic development are systemically linked to global steel trade patterns. This chapter sheds light on the steel industry in non-OECD countries by investigating the technology choice factor, as most non-OECD countries can be considered emerging/developing nations. Given the significance of technology in the steel industry, it is essential to understand the nexus between technology choice and export performance. Technology choice in the steel industry in non-OECD countries presents at least three potential implications for the analysis of the steel trade.

First, technology choice may be related to the magnitude of steel output, steel exports and ultimately trade balance. This chapter assumes that the Trade Balance Index (TBI) is an appropriate indicator to assess countries' trade balance, as it presents a valuable assessment of the quantity of steel exports of each steel industry. If the blast furnace–basic oxygen furnace (BF–BOF) route represents a suitable technology for mass production, BF–BOF choice may lead to a larger volume of steel exports and higher TBI values in the steel industry in non-OECD countries.

Second, technology choice, which is linked to export sophistication, may be relevant to the quality of steel products. A more sophisticated steel industry export structure in non-OECD countries implies the production and export of more sophisticated steel products. The steel industry in some non-OECD countries which previously only exported low value-added products for the construction industry, may export high value-added steel used for the manufacturing industry as it progresses. While measuring export sophistication is challenging, based on the literature review, this research assumes that export structures are relatively sophisticated if there are similar export structures throughout the whole OECD steel industry. The export sophistication of each steel industry can be measured using the ESI, which is linked to investigations of steel export quality. If the BF–BOF route is appropriate for producing higher value-added products, BF–BOF-based countries may be an indicator of high ESI values.

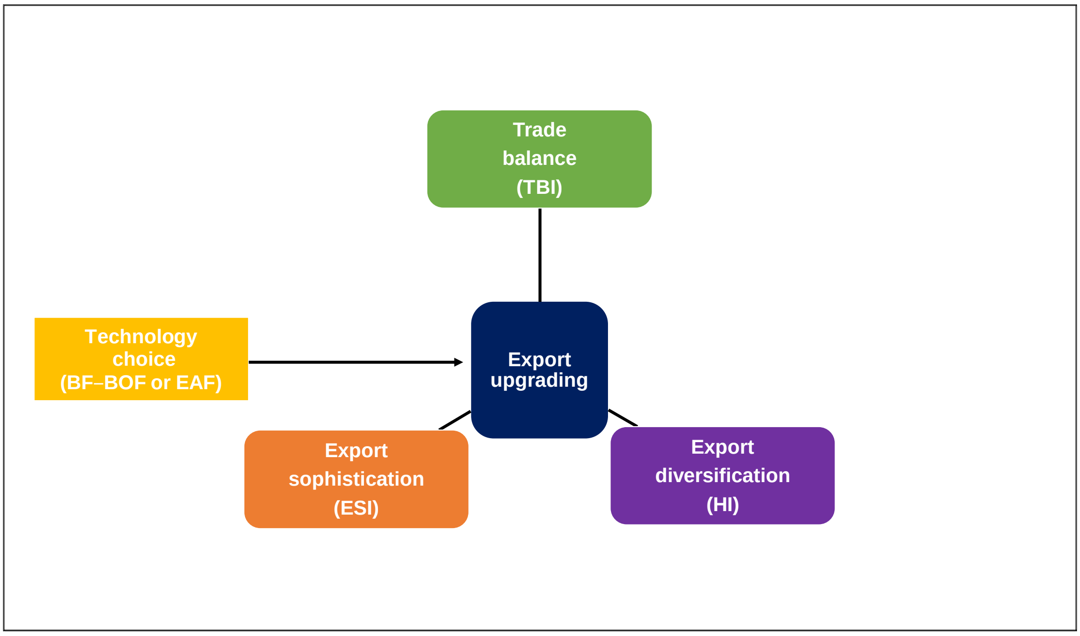
Finally, technology choice may also be associated with the existing product portfolio. Diversification of exports suggests that the steel industry in non-OECD countries can export larger varieties of steel products than ever before.[89] The steel industry in some non-OECD countries exporting limited kinds of products may begin exporting flat and pipe tube products as it develops. This chapter assumes that the HI is suitable for identifying countries' export diversification and the potential quality of steel exports. If the BF–BOF route is suitable for supplying a wider variety of steel products, BF–BOF-based countries are likely to export various products.

Overall, the TBI helps assess steel exports from the quantity side, while ESI and HI are linked to the quality side of steel exports. If technology choice impacts these three indicators (TBI, ESI, HI) within the steel industry in non-OECD countries, they could correlate with each other.

Based on the above observations, this chapter verifies a hypothesis that technology choice in non-OECD countries is linked to export upgrading. More specifically, it investigates whether technology choice reflected in the production system of each steel industry is correlated with its trade balance, export sophistication and export diversification. It assumes that the magnitude of steel production impacts export performance, as discussed in the model in Chapter 1. Figure 3.1 illustrates hypothetical export upgrading in the steel industry.

[89] In the steel industry, steelmaking has multistage processes (see Figure 1.2 in Chapter 1). The steel industry has some noteworthy characteristics. For instance, economies of scale occur particularly in the upstream process (Kawabata, 2020b, p. 16). In addition, the downstream process is more fragmented than the upstream one (Kawabata & Yin, 2020, p. 18). As the production facilities in the upstream process become larger and more modern, mass production becomes possible, lowering the crude steel production cost, which, in turn, lowers the cost of producing a variety of steel products in the downstream process. In short, economies of scope also play a role in the production of a variety of steel products. Therefore, as the facilities develop increasingly with respect to size and modernity in the steel industry, various steel products gain a comparative advantage and international competitiveness, leading to steel export diversification.

Figure 3.1 Export upgrading in the steel industry

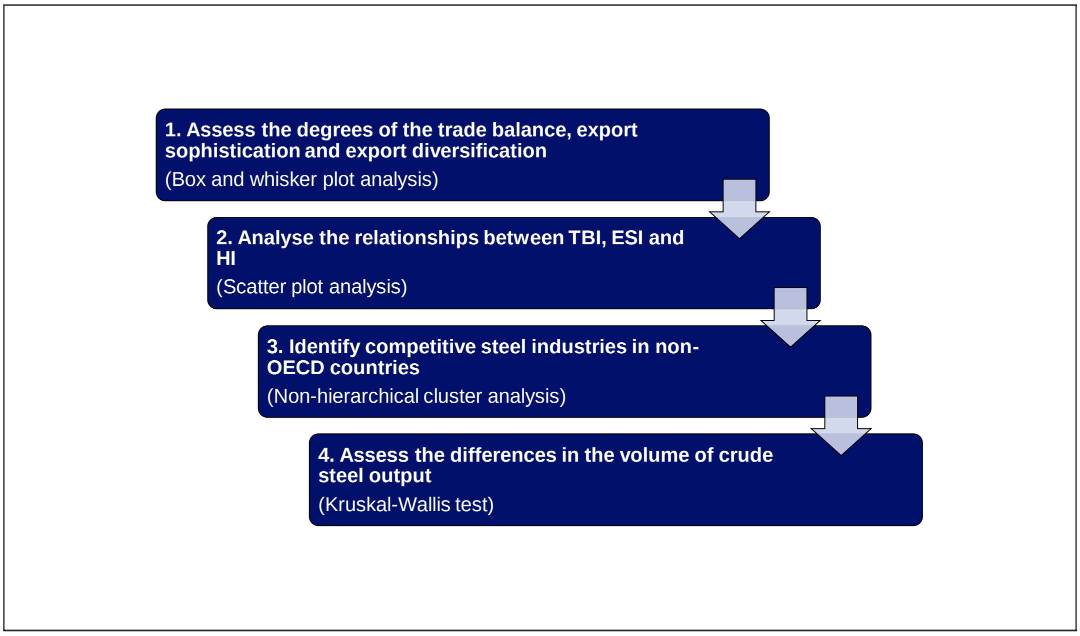


Source: Author

The next important question is how to analyse these three measures of export performance in the global steel industry. Figure 3.2 presents an overview of the flow of analysis and analytical tools used in this chapter.

1. To assess the degrees of the trade balance, export sophistication and export diversification in the steel industry of non-OECD countries, this chapter uses TBI, ESI and HI to compare the measures in OECD countries. The analysis can be performed with a box-whisker plot.
2. It is important to analyse how these three indicators (TBI, ESI, HI) are related to each other. Scatter plot analysis is suitable to analyse the relationships between the indicators.
3. As this chapter seeks to shed light on the steel industry in all non-OECD countries that participate in steel production activities, it is crucial to identify competitive countries. Based on the production system and trade performance (TBI, ESI and HI), non-hierarchical cluster analysis can be performed for such categorisation.
4. Export performance might significantly differ between steel industries in non-OECD countries. Since the magnitude of crude steel output appears to be an important determinant that impacts export performance, the Kruskal–Wallis test assesses the differences in the volume of crude steel output in steel-producing non-OECD countries.

Figure 3.2 Overview of the flow of analysis and analytical tools



Source: Author

3.3.2 Methodology

a) Trade Balance Index

Prior to assessing each nation's steel industry export sophistication and diversification, this chapter uses the TBI to assess whether a country is a net exporter or a net importer in the global steel industry.[90] This research presumes that TBI indicates steel exports from the quantity side, given that it focuses on the balance of steel export value and steel import value.

b) Export Similarity Index

This chapter uses the ESI introduced by Finger and Kreinin (1979) to measure the export sophistication of each steel industry in non-OECD countries. The index can be used to determine the relative sophistication of a country's exports by comparing its export bundle with that of OECD nations (da Silva et al., 2011; Schott, 2007). Aside from relative sophistication, the ESI can be used to show the level of a country's catch-up with other countries (da Silva et al., 2011, p. 4). The ESI can provide indirect information about export sophistication in the steel industry in non-OECD countries. The

[90] A detailed explanation of TBI is available in Chapter 2.

calculated ESI also implies that countries compete more directly with the OECD. The ESI is formulated as follows:

$$ESI_{jc} = \sum_{i} \min\left(\frac{x_{ji}}{Xj}, \frac{x_{ci}}{Xc}\right)$$

where ESI_{jc} is the ESI between countries *j* and *c*, and x_{ji}/Xj and x_{ci}/Xc are the shares of steel product *i* in the total steel exports of countries *Xj* and *Xc*, respectively. The ESI ranges between 0 and 1 ($0 \leq ESI_{jc} \leq 1$). An ESI value of 1 corresponds to identical export structures and a value of 0, to completely dissimilar export structures.

c) Herfindahl Index

This chapter also uses the HI developed by Herfindahl and Hirschman to indicate each non-OECD country's steel industry export diversification.[91] In the industrial organisation study, the HI, which indicates the degree of market concentration, has been used to reflect the competitive market structure. The index measures the concentration of the number of firms that manufacture products in each industry. This index can be applied to the analysis of international trade to indicate export diversification; thus, this research uses this measure to analyse the steel trade. Here, the shares of each firm in a market used in the industrial organisation study correspond to the shares of each steel product in a country's total steel exports to the world market. Lower values of HI in steel exports suggest that the structure of steel exports in a given country is not concentrated on specific steel products. Conversely, the country has a concentrated steel export structure if its HI values are high.

The HI can convey indirect information about export diversification in the steel industry in non-OECD countries by calculating the market concentration/diversification of steel products. The index is formulated as follows:

[91] There is a generally universal definition in the case of steel products, and unless exports are zero, there might not be a significant difference in the number of items.

$$HI = \sum_i \left(\frac{x_{ji}}{Xj}\right)^2$$

where x_{ji}/Xj is the share of total steel exports attributed to the *i* group of steel products and the HI ranges between 0 and 1 ($0 \leq HI \leq 1$). Lower values of the index represent more diversification; thus, countries with highly diversified export baskets are likely to have lower values.

ESI/HI and challenges

While ESI and HI provide important implications for the catch-up and the characteristics of the steel industry in non-OECD countries, there seem to be some noteworthy caveats. First, the issue of export sophistication and diversification is generally discussed in merchandise trade, including many products of various industries. This chapter discusses the case of an industry, namely, the steel industry; thus, it is important to note that the results may be applied to this industry alone. Second, the values of ESI and HI may vary depending on the way of aggregation of steel products. While this chapter calculated these indexes based on HS 6-digit trade data level, the results should be different using other classifications.[92] Thus, they are subject to an aggregation bias. It is important to keep these caveats in mind when analysing export performance in the steel industry in non-OECD countries.

Nevertheless, these indicators are calculated using only steel trade data and could be useful point when considering the issues of export sophistication and export diversification in the steel industry of non-OECD countries.

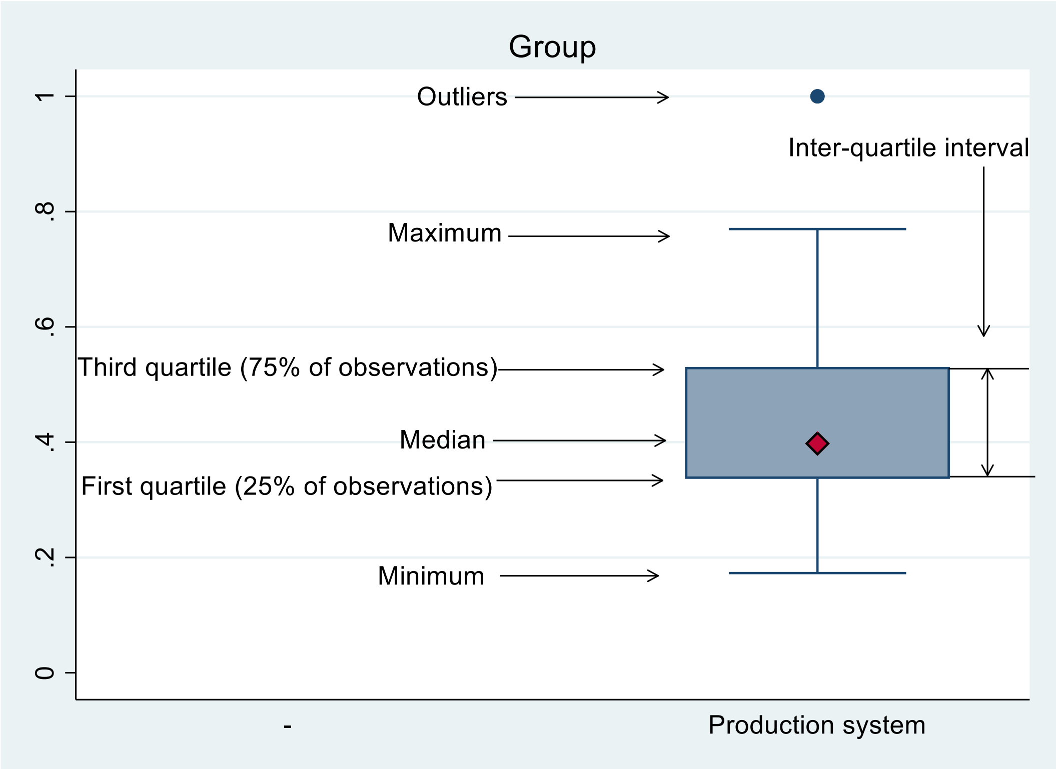
Box and whisker plot

A box and whisker plot—a graphic representation of several distribution parameters for a variable (OECD, 2007, pp. 140–141)—can present useful information when looking at TBI, ESI and HI distributions. In a box plot, the centre of the data scatter is represented by a rectangular box. The whisker extending from both ends of the box represents the spread of the ends. In general, a box and whisker plot

[92] Steel products can be grouped into five categories at the broad level and 16 categories at the medium level. In contrast, they can be divided into around 190 products at the high-level classification. For a detailed classification of steel products, see Appendix Table 1.

display the minimum value, first quartile, median, third quartile and maximum value. Figure 3.3 illustrates how to interpret the box and whisker plot.

Figure 3.3 Explanation of the box-whisker plot



Source: Author based on the OECD (2007, p. 141)

Cluster analysis

Cluster analysis can be broadly divided into hierarchical and non-hierarchical analysis.[93] The researcher determines which analysis to use. In general, non-hierarchical cluster analysis is more suitable for large samples. Since this chapter analyses all non-OECD countries that produce steel with large samples, non-hierarchical cluster analysis is used. In non-hierarchical cluster analysis, the researcher specifies the number of clusters in advance and groups the objects into the specified number of clusters.

[93] This paragraph is based on Ishiguro (2014, p. 165).

Kruskal–Wallis test

The Kruskal–Wallis test is a rank-based nonparametric test to determine whether three or more independent groups are the same or different on some variables (Laerd Statistics, n.d.). It is commonly used to compare the mean rank of three or more different groups (University of Sheffield, n.d.). The statistical technique is used when normality cannot be assumed and many outliers or a small sample size are included. When a significant difference is found across groups, a multiple comparison procedure, such as the Steel–Dwass test, is required since in which group the significant difference is found is unknown (Stats Guild, 2021).

3.3.3 Data

The primary trade data comes from the International Trade Centre's Trade Map (ITC, 2021), an online database of international trade data. Trade data in value terms were used to calculate TBI, ESI and HI. The three indicators were calculated based on HS 6-digit trade data level. The definition of steel products was based on the International Steel Statistics Bureau (ISSB, 2010). Production data were obtained from the World Steel Association (2020b).

3.3.4 List of countries

This chapter focuses on the export performance of the steel industry in all countries with production data by the process available in 2018 to examine the catch-up of the steel industry in non-OECD countries. The chapter also analyses export performance to shed light on the characteristics and degree of catch-up in the steel industry in non-OECD countries. A list of countries is presented in Table 3.1.

An important caveat to bear in mind is that Taiwan can be regarded as an advanced steel-producing country, based on the discussion in Chapter 2. Like the steel industries in Japan and South Korea, Taiwan has similar economic status and production/export structure to advanced countries; thus, the Taiwanese steel industry was excluded from the analyses in this chapter.

Table 3.1 List of countries (2016–2018)

OECD	Non-OECD	Country code (ISO)	Non-OECD	Country code (ISO)
Australia	Algeria	DZA	Morocco	MAR
Austria	Argentina	ARG	Myanmar	MMR
Belgium	Azerbaijan	AZE	Nigeria	NGA
Canada	Bahrain	BHR	Oman	OMN
Chile	Bangladesh	BGD	Pakistan	PAK
Colombia	Belarus	BLR	Paraguay	PRY
Czechia	Bosnia and Herzegovina	BIH	Peru	PER
Finland	Brazil	BRA	Philippines	PHL
France	Bulgaria	BGR	Romania	ROU
Germany	China	CHN	Russia	RUS
Greece	Croatia	HRV	Saudi Arabia	SAU
Hungary	Cuba	CUB	Serbia	SRB
Israel	D.R. Congo	COD	Singapore	SGP
Italy	Ecuador	ECU	South Africa	ZAF
Japan	Egypt	EGY	Sri Lanka	LKA
Luxembourg	El Salvador	SLV	Syria	SYR
Mexico	Ghana	GHA	Thailand	THA
Netherlands	Guatemala	GTM	Tunisia	TUN
New Zealand	India	IND	Uganda	UGA
Norway	Indonesia	IDN	Ukraine	UKR
Poland	Iran	IRN	United Arab Emirates	ARE
Portugal	Jordan	JOR	Uruguay	URY
Slovakia	Kazakhstan	KAZ	Uzbekistan	UZB
Slovenia	Kenya	KEN	Venezuela	VEN
South Korea	Kuwait	KWT	Vietnam	VNM
Spain	Libya	LBY		
Sweden	Macedonia	MKD		
Switzerland	Malaysia	MYS		
Turkey	Moldova	MDA		
United Kingdom	Mongolia	MNG		
United States	Montenegro	MNE		

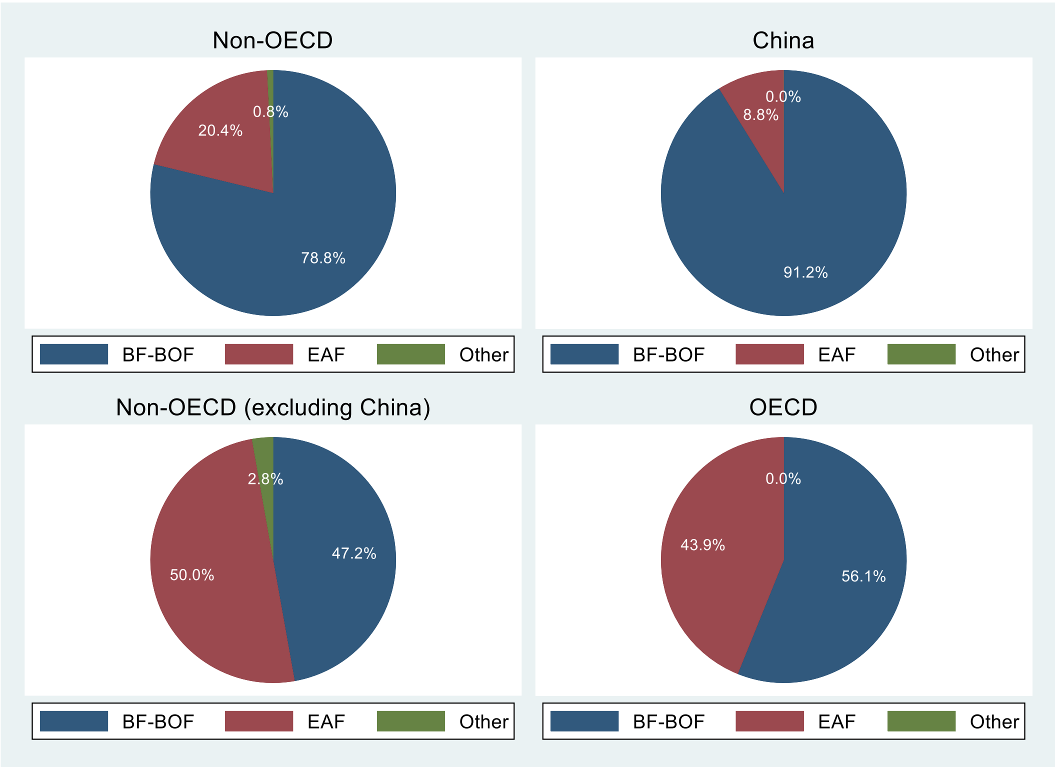
Note: Qatar's 2016–2018 data appears to be inadequate and has been excluded. Mauritania was excluded because it does not produce via BF–BOF or EAF routes.
Source: Author

3.4 Overview of Technology Choice/Production Systems

A key question that arises when analysing steel production is what types of technologies steel firms have selected to form their production systems. It is particularly important to shed light on selected production systems, given that production structures may be linked to export structures. Crude steel output by the process can be used as a proxy for steel firms' technology choices.

Figure 3.4 illustrates the shares of crude steel output by the process in 2016–2018, indicating significant variation across groups. In the steel industry in non-OECD countries, the share of the BF–BOF route is extremely high since the production technology dominates the Chinese steel industry. Conversely, the electric arc furnace (EAF) route has a primary role in the steel industry in non-OECD countries, excluding China. Turning to the steel industry in OECD countries, the BF–BOF route is the predominant steelmaking technology, although the share of the EAF route has grown over decades (Laplace Conseil, 2012, p. 11). Overall, the share of other production technologies, notably the open-hearth furnace route, tends to be exceptionally low since this method has largely been phased out (IEA, 2020, p. 30).

Figure 3.4 The share of crude steel output by process (2016–2018)

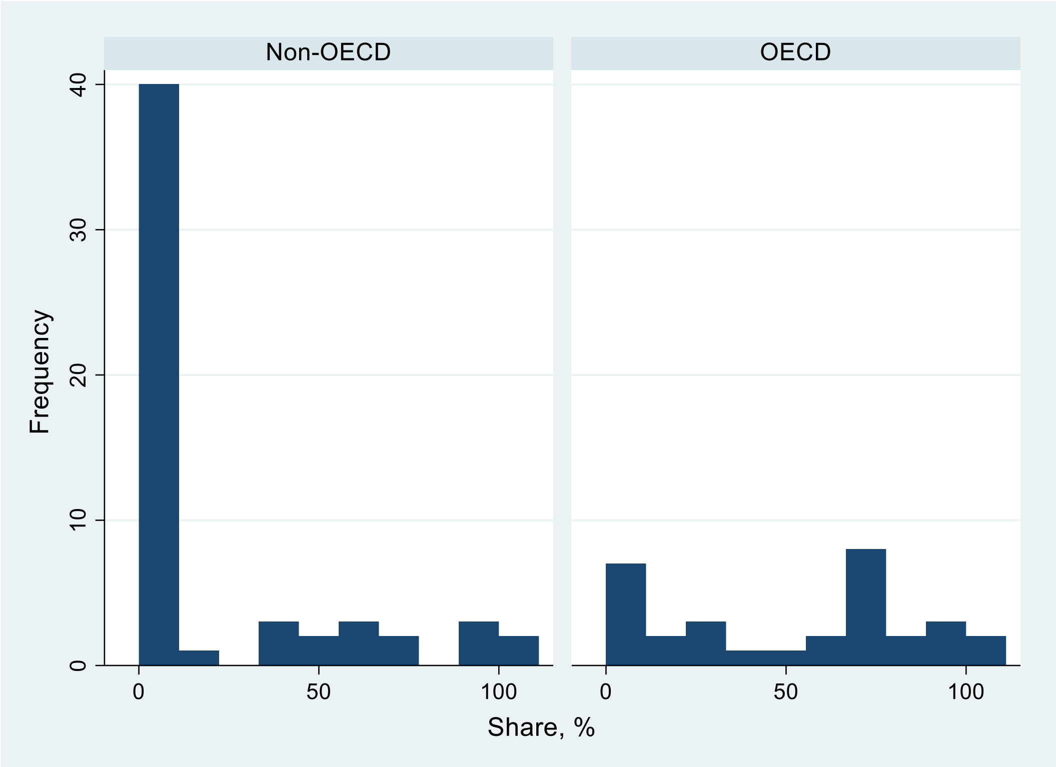


Source: Author’s calculations based on data from the World Steel Association (2020b)

Since the volume of large steel-producing countries may significantly influence production shares, it is also important to focus on the distribution of production shares in each steel industry. Figure 3.5 presents the distribution of the share of the BF–BOF route in crude steel output during 2016–2018 using a histogram, indicating marked differences in the BF–BOF share in the steel industry between non-OECD and OECD countries. The steel industry in non-OECD countries, with a 0% share of BF–BOF, was concentrated in the steel industry in non-OECD countries, showing that nearly 70% of the countries in the group did not produce steel through the BF–BOF route. The production system in the steel industry in OECD countries appears to be more diversified than that of non-OECD countries, and several OECD countries use the BF–BOF route to produce steel.

While Figure 3.5 suggests that most of the steel industry in non-OECD countries used the EAF route, Figure 3.4 indicates that the BF–BOF route was the primary production route due to BF–BOF-intensive technology choice in the Chinese steel industry. Even excluding China's steel industry, there are no significant differences between the BF–BOF and the EAF routes in terms of the shares of crude steel output in non-OECD countries. This suggests that steel industry production systems in non-OECD countries are characterised by steel production using the BF–BOF route in a small number of steel-producing countries, including China, and a considerable number of countries use the EAF route.

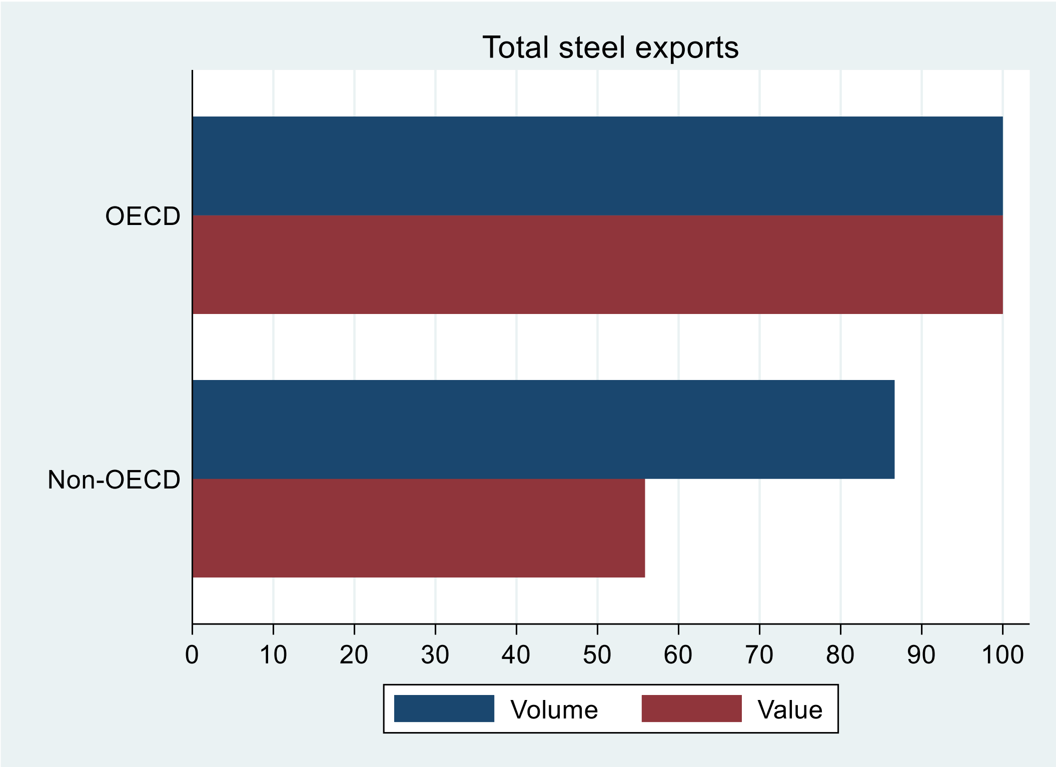
Figure 3.5 Distribution of the share of the BF–BOF route in crude steel output (2016–2018)



Note: N = 56 (non-OECD countries), 31 (OECD countries).
Source: Author's calculations based on data from the World Steel Association (2020b)

The next question is how production activities are reflected in the export structures between the steel industry in non-OECD and OECD countries. It is important to compare the structure of steel exports in non-OECD and OECD countries to assess the level of export sophistication of each group. Figure 3.6 presents the ratio of total steel exports of the steel industry in non-OECD countries to those of OECD countries, revealing a notable difference between them in terms of the value of steel exports. Although the difference in steel exports in terms of volume appears slight, there are clear differences between the two groups in value terms. This suggests a more sophisticated steel industry export structure in OECD countries, which aligns with the argument that OECD countries export high value-added steel products (Laplace Conseil, 2012, p. 7).

Figure 3.6 The ratio of total steel exports (the steel industry in OECD countries = 100) (2016–2018)



Note: The figure above includes a number of non-OECD and OECD countries with unavailable production data by the process.
Source: Author's calculations based on data from the ITC (2021)

3.5 Distributions of Trade Balance, Export Sophistication and Export Diversification

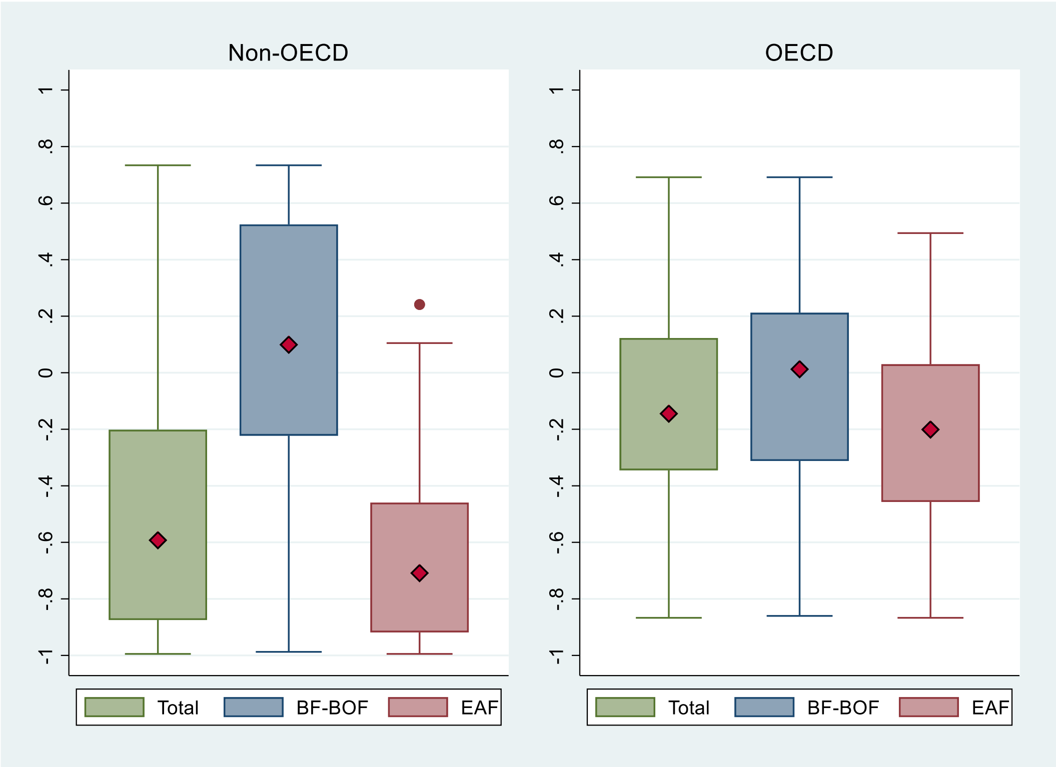
3.5.1 Trade balance

It is essential to distinguish whether each steel industry is a net exporter or a net importer to examine the difference in trade structure between non-OECD and OECD countries' steel industry and levels of international competitiveness. Figure 3.7 illustrates distributions of TBI values for the two groups in 2016–2018 using a box and whisker plot.

The steel industry in non-OECD countries appears to have low TBI values overall when focusing on median values, suggesting that there are many net importers of steel in the group. Technology choice seems to be related to the degree of the trade balance of each steel industry. BF–BOF-based countries are more likely to be net exporters of steel than EAF-based countries in the steel industry of both non-OECD and OECD countries. Regarding BF–BOF technology, non-OECD countries have higher median values than those of OECD countries, but non-OECD countries have lower median values in terms of the EAF route. This suggests that the BF–BOF-based non-OECD countries could be the most competitive group vis-à-vis international competitiveness.

While the BF–BOF-based non-OECD countries have high TBI values, the key questions are how other trade indicators differ between the steel industry in non-OECD and OECD countries and what the difference is between the BF–BOF-based and EAF-based countries.

Figure 3.7 TBI values for total steel products (2016–2018)



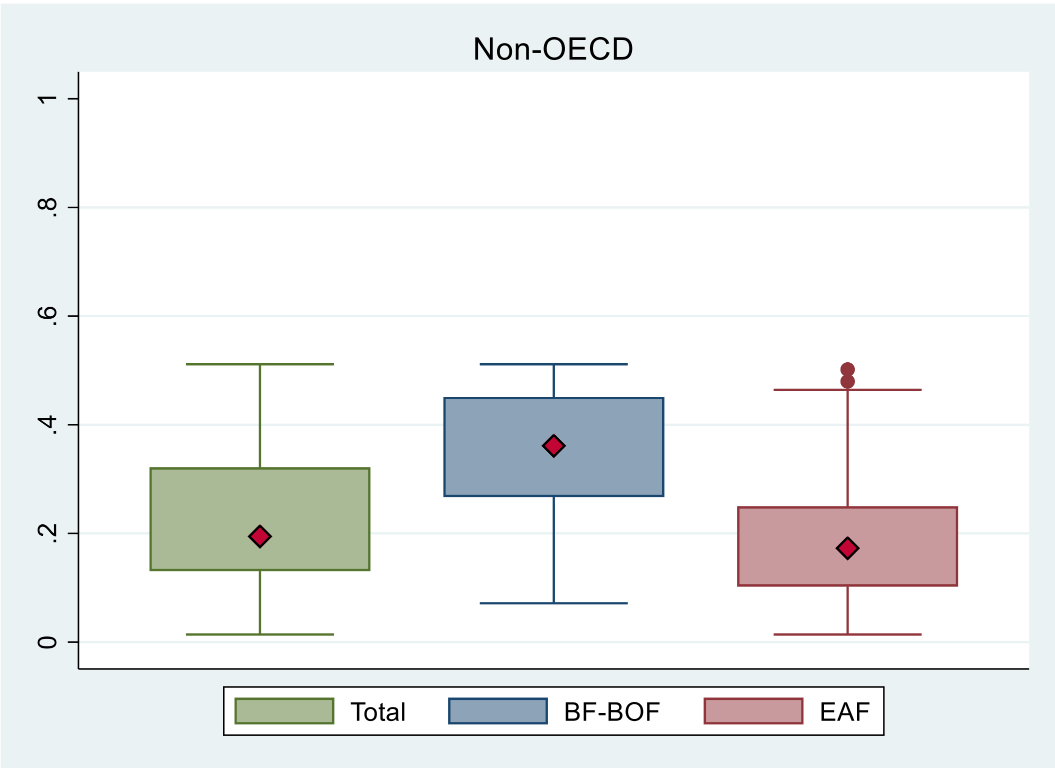
Note: N = 11 (BF–BOF-based non-OECD countries), 45 (EAF-based non-OECD countries), 18 (BF–BOF-based OECD countries), 13 (EAF-based OECD countries).
Source: Author’s calculations based on data from the ITC (2021)

3.5.2 Export sophistication

It is also valuable to shed light on the issue of export sophistication, given that it is closely linked to the discussion regarding the catch-up of emerging/developing countries. Here the similarities in the steel products of countries exported to aggregate OECD countries can be used as a proxy to measure a country's relative export sophistication. This is based on the assumption that the structure of steel exports in the steel industry in OECD countries is more sophisticated than that of non-OECD countries.[94]

Figure 3.8 presents distributions of ESI values for the steel industry in non-OECD countries in 2016–2018. Overall, the steel industry in non-OECD countries has low ESI values, indicating that their export structure differs significantly from the OECD countries. Nevertheless, BF–BOF-based non-OECD countries are more likely to have sophisticated export portfolios and BF–BOF-based countries have much higher ESI values than EAF-based ones. The next inquiry is how does trade diversification differ between BF–BOF-based and EAF-based countries?

Figure 3.8 ESI values for total steel products (2016–2018)



Note: N = 11 (BF–BOF-based non-OECD countries), 45 (EAF-based non-OECD countries).
Source: Author's calculations based on data from the ITC (2021)

[94] Detailed steel export data for the whole OECD steel industry are presented in Appendix Table 2.

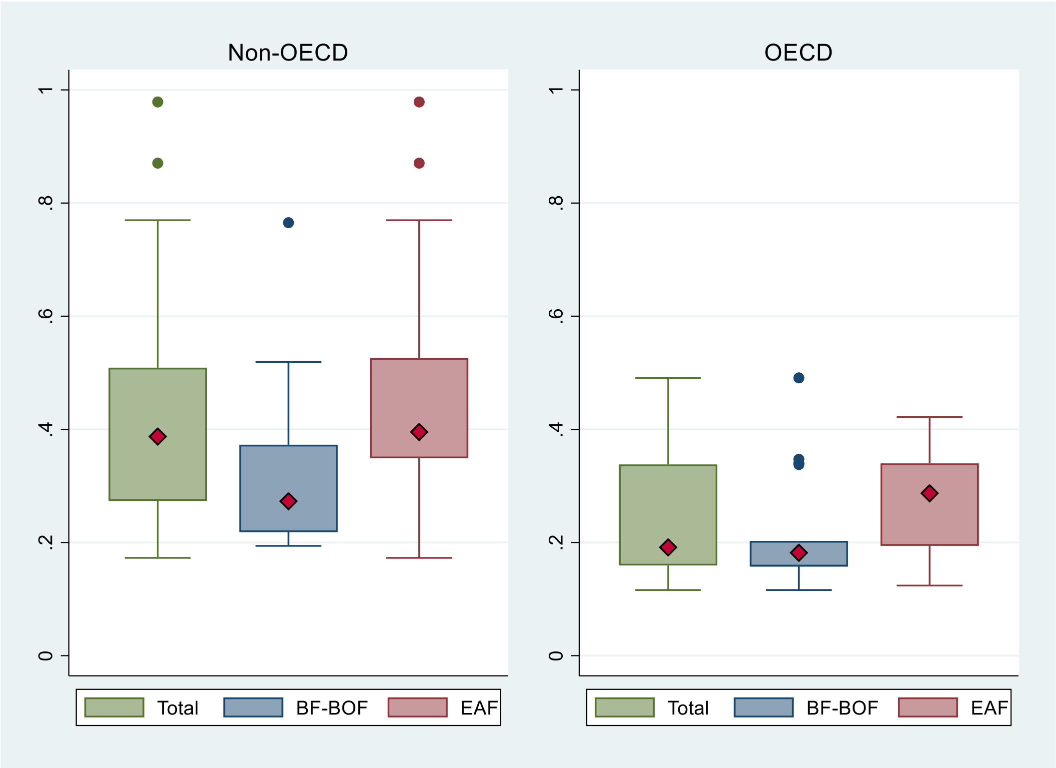
3.5.3 Export diversification

Understanding the degree of export diversification is also critical to assessing the catch-up level of each steel industry, based on the assumption that advanced steel-producing countries can supply a wide variety of steel products rather than concentrate on specific steel products.

Figure 3.9 displays HI values for the steel industry in non-OECD and OECD countries in 2016–2018. In addition to export sophistication, there is a considerable gap in both groups regarding export diversification. The steel industry in non-OECD countries has much higher HI values than those of OECD countries, indicating that the former has a higher concentrated export structure.

Export diversification appears to prevail in BF–BOF-based non-OECD countries more than in EAF-based ones. BF–BOF-based countries appear to be more diverse than EAF-based countries for both non-OECD and OECD countries. This reflects the fact that BF–BOF-based firms can supply a broader range of steel products than EAF-based ones.

Figure 3.9 HI values for total steel products (2016–2018)



Note: N = 11 (BF–BOF-based non-OECD countries), 45 (EAF-based non-OECD countries), 18 (BF–BOF-based OECD countries), 13 (EAF-based OECD countries).
Source: Author’s calculations based on data from the ITC (2021)

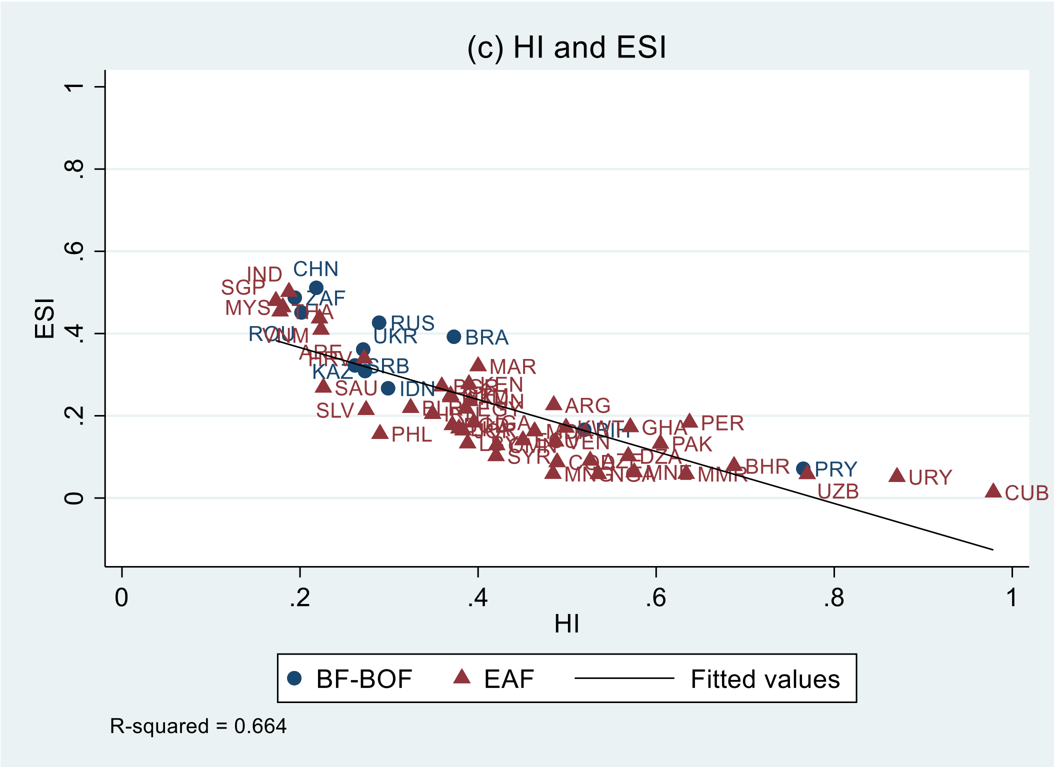
3.5.4 Relationships between TBI, ESI and HI

In the analysis up to this point, the evaluation of the TBI, ESI and HI of the steel industry in non-OECD countries has been undertaken. An important question that arises when analysing this is how these indicators are correlated. To shed light on the associations between these indicators, Figures 3.10a–c display the relationships between TBI, ESI and HI, which indicates that these three indicators appear to be correlated with each other.

First, the TBI value appears to be correlated with the ESI value (Figure 3.10a). This implies that the structure of steel exports in net-exporting status tends to be a more sophisticated export structure in the steel trade. Regarding steel exports by the production system, BF–BOF-based non-OECD countries are concentrated in the upper right-hand corner, while several EAF-based non-OECD countries are scattered on the lower left-hand side. Second, negative correlations between the TBI value and the HI value are apparent, suggesting that net-exporting countries' steel exports are more diversified than other exporting countries (Figure 3.10b). BF–BOF-based non-OECD countries are largely scattered in the lower right-hand corner. Finally, there appears to be negative correlations between the HI value and the ESI value (Figure 3.10c). This suggests that countries with more diversified steel exports have more sophisticated steel export structures. BF–BOF-based non-OECD countries seem to have lower HI values and higher ESI values than EAF-based non-OECD countries.

Overall, the quantity and quality of steel exports in the steel industry in non-OECD countries appear to correlate with one another, suggesting a need to upgrade steel exports in both quantity and quality sides to catch-up.

Figure 3.10 Relationships between TBI and ESI, TBI and HI and HI and ESI in 2016–2018



Note: N = 11 (BF–BOF-based non-OECD countries), 45 (EAF-based OECD countries).
Source: Author's calculations based on data from the ITC (2021) and the World Steel Association (2020b)

3.5.5 Grouping

The next question that arises when analysing steel exports in non-OECD countries is how they can be classified based on production systems and export performance. To group and identify competitive steel industries in non-OECD countries according to production systems and export performance, a non-hierarchical cluster analysis was performed using 2016–2018 data. The analysis used four indicators; i) the ratio of the BF–BOF route in total crude steel output; ii) TBI value; iii) ESI value and iv) HI value. Table 3.2 summarises these variables.

Table 3.2 Indicators used in the cluster analysis (2016–2018)

Indicator	Abbreviation
The ratio of BF–BOF route in total crude steel output	BF–BOF
Trade balance index	TBI
Export similarity index	ESI
Herfindahl index	HI

Source: Author

Table 3.3 and Figure 3.11 present the results of the non-hierarchical analysis using the four variables (i.e. the ratio of BF–BOF route, TBI, ESI and HI). These clusters represent the best results for diversification in terms of possibilities for interpretation.

The steel industry in Cluster 1 consists of BF–BOF-based countries that demonstrate high export performance, although India is an EAF-based country.[95] They have positive TBI values and comprise all net exporters of steel. In addition, the steel industry in non-OECD countries in the cluster appears to have high ESI values and low HI values, suggesting superior export performance to other clusters.

The steel industry in Cluster 2 consists of BF–BOF-based countries that exhibit low export performance.[96] While BF–BOF technology is the major route to producing steel in the cluster, the cluster seems to have extremely low TBI and ESI values and high HI values, indicating a low degree of export orientation.

The steel industry in Cluster 3 comprises of BF–BOF-based countries that show relatively high export performance. This cluster appears to have rather high values for TBI and ESI and low values for HI, although their export performance is much lower than Cluster 1.

The steel industry in Cluster 4 includes EAF-based countries that show somewhat high performance of trade indicators. While the steel industry in the group is net importers of steel, they appear to have relatively high ESI values and low HI values. Apart from steelmaking firms, re-rolling/surface treating steel firms might have important roles in steel exports.

The steel industry in Cluster 5 is constituted of EAF-based countries that indicate low export performance. They appear to have low TBI and ESI values and high HI values. This implies that the steel industry in the group has not focused on the international steel trade.

Based on Figure 3.11, it is reasonable to assert that the steel industry in Cluster 1 is the most competitive group in the steel industry in non-OECD countries.

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[95] Note that the share of crude steel output via the BF–BOF route in the Indian steel industry is high compared to other EAF-based non-OECD countries, accounting for 44.6% of its total crude steel output in 2016–2018. For the detailed characteristics of steel exports in the Indian steel industry, see Chapter 4 of this research.

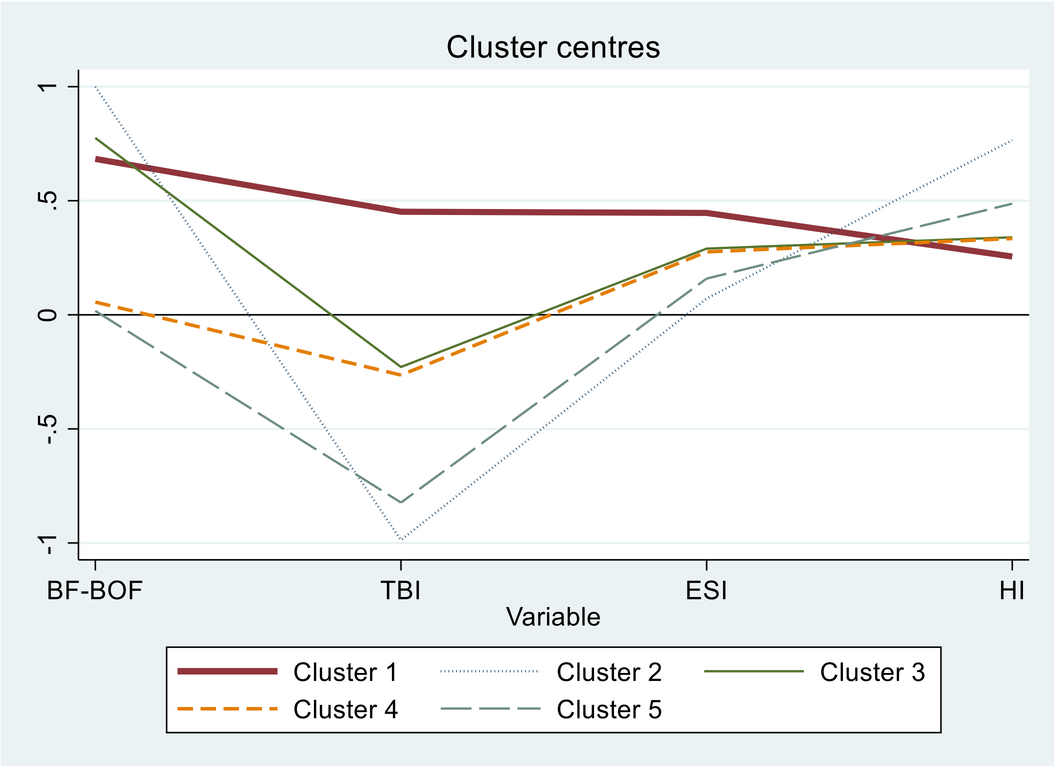
[96] Paraguay is a very small steel-producing country, and only one steel firm—Acepar (Aceros del Paraguay)—has steelmaking facilities. The steel firm has two BF (charcoal) facilities and two BOF facilities, and its total steelmaking capacity is only 0.18 million metric tonnes (mmt) (OECD, 2014b, p. 489).

Table 3.3 List of the steel industry by group based on the cluster analysis results

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Brazil	Paraguay	Argentina	Bahrain	Algeria
China		Bosnia-Herzegovina	Belarus	Azerbaijan
India		Indonesia	Bulgaria	Bangladesh
Russia		Kazakhstan	El Salvador	Croatia
South Africa		Romania	Guatemala	Cuba
Ukraine		Serbia	Iran	D.R. Congo
			Macedonia	Ecuador
			Malaysia	Egypt
			Oman	Ghana
			Singapore	Jordan
			Uganda	Kenya
			United Arab Emirates	Kuwait
			Vietnam	Libya
				Moldova
				Mongolia
				Montenegro
				Morocco
				Myanmar
				Nigeria
				Pakistan
				Peru
				Philippines
				Saudi Arabia
				Sri Lanka
				Syria
				Thailand
				Tunisia
				Uruguay
				Uzbekistan
				Venezuela

Source: Author's calculations based on data from the ITC (2021) and the World Steel Association (2020b)

Figure 3.11 Results of cluster analysis



Note: The y-axis shows the mean values of the respective variables for individual clusters.
Source: Author’s calculations based on data from the ITC (2021) and the World Steel Association (2020b)

While the previous analysis demonstrated diverse patterns of export performance, two questions arise. Why does export performance differ although the steel industry in some countries employs the same production system? Correspondingly, why is the steel industry in Cluster 1 more competitive than others? While the steel industry in Clusters 1, 2 and 3 have formed BF–BOF-based production systems, large gaps remain in terms of export performance. There must be some differences between them.

It is important to highlight the volume of crude steel output, given that it is one of the most critical indicators that can measure the development of the steel industry across countries. In addition, it helps to assess the link of steel supply in terms of quantity and quality.

Table 3.4 presents the crude steel output of five clusters in 2016–2018. Variations in the crude steel output volume of these five clusters were analysed using Kruskal–Wallis and Steel–Dwass tests. The Kruskal–Wallis test demonstrates that crude steel output is significantly different at the 1% level. The

Steel–Dwass test indicates a difference between Cluster 1 and other clusters due to the magnitude of crude steel output (Tables 3.5 and 3.6).[97]

[97] The steel industry in Cluster 2 is not statistically significant. This might be explained by the extremely small sample size.

Table 3.4 Crude steel output of each cluster (2016–2018), mmt

Cluster 1	Crude steel output	Cluster 2	Crude steel output	Cluster 3	Crude steel output	Cluster 4	Crude steel output	Cluster 5	Crude steel output
Brazil	33.9	Paraguay	0.03	Argentina	4.6	Bahrain	0.7	Algeria	1.1
China	868.9			Bosnia-Herzegovina	0.8	Belarus	2.3	Azerbaijan	0.2
India	102.1			Indonesia	5.4	Bulgaria	0.6	Bangladesh	3.6
Russia	71.4			Kazakhstan	4.3	El Salvador	0.1	Croatia	0.05
South Africa	6.3			Romania	3.4	Guatemala	0.3	Cuba	0.2
Ukraine	22.2			Serbia	1.5	Iran	21.2	D.R. Congo	0.03
						Macedonia	0.2	Ecuador	0.6
						Malaysia	3.4	Egypt	6.6
						Oman	2.0	Ghana	0.03
						Singapore	0.6	Jordan	0.3
						Uganda	0.03	Kenya	0.02
						United Arab Emirates	3.2	Kuwait	1.3
						Vietnam	11.6	Libya	0.4
								Moldova	0.4
								Mongolia	0.1
								Montenegro	0.1
								Morocco	0.5
								Myanmar	0.3
								Nigeria	0.1
								Pakistan	4.4
								Peru	1.2
								Philippines	1.3
								Saudi Arabia	6.2
								Sri Lanka	0.03
								Syria	0.01
								Thailand	6.2
								Tunisia	0.1
								Uruguay	0.1
								Uzbekistan	0.7
								Venezuela	0.4

Source: Author’s calculations based on data from the World Steel Association (2020b)

Table 3.5 Results of the Kruskal–Wallis test

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
N	6	1	6	13	30
Average of the ranks	53.00	5.00	39.25	29.50	21.80

Note: Significance: *** p < 0.01.
Source: Author's calculation based on data from the World Steel Association (2020b)

Table 3.6 Results of the Steel–Dwass test

		P-value
Cluster 1	**Cluster 2**	0.4456
Cluster 1	**Cluster 3**	0.0222**
Cluster 1	**Cluster 4**	0.0071***
Cluster 1	**Cluster 5**	0.0010***
Cluster 2	**Cluster 3**	0.4456
Cluster 2	**Cluster 4**	0.4506
Cluster 2	**Cluster 5**	0.5779
Cluster 3	**Cluster 4**	0.3727
Cluster 3	**Cluster 5**	0.0494**
Cluster 4	**Cluster 5**	0.3544

Note: Significance: *** p < 0.01, ** p < 0.05, * p < 0.1
Source: Author's calculation based on data from the World Steel Association (2020b)

3.6 Summary and Implications

This chapter investigated the current export performance of the steel industry in non-OECD countries in terms of export upgrading from both quantity and quality sides, providing important implications for its current level of catch-up in the global steel industry. It also presented insights into the characteristics of the steel industry in non-OECD countries and differences compared to the those in OECD countries.

The chapter formulated the hypothesis that technology choice is reflected in export upgrading in the steel industry in non-OECD countries. The results demonstrated that the current production systems are linked to the present structure of steel exports of non-OECD countries in terms of quantity and quality; thus, steel firms' technology choices in non-OECD countries are closely related to the current export performance.

The evidence in this chapter indicated that the steel industry in some non-OECD countries has gained a comparative advantage, and become internationally competitive in the global steel industry. In addition, the results indicated that the magnitude of steel output is crucial to demonstrate higher export performance, which is linked to the discussion of the catch-up model presented in Chapter 1. This confirms the existence of the model, in which an increase in steel production/productivity results in the improvement of comparative advantage and international competitiveness.

The results from the analyses in this chapter provided important insights into the difference in the steel industry between non-OECD and OECD countries as well as into the differences between the industries in non-OECD countries. First, the structure of steel exports in non-OECD countries appears less sophisticated and diversified than that of OECD countries. Second, the development level of the steel industry in non-OECD countries seems to vary significantly across types of production systems. BF–BOF-based non-OECD countries had higher degrees of international competitiveness than EAF-based ones, suggesting that the former has a high net export ratio in the steel trade.

Overall, a small number of BF–BOF-based non-OECD countries indicated high performance in terms of steel production and both quantity and quality of steel exports, with significant differences from the rest of the non-OECD countries. The EAF route has been the primary steelmaking route of various non-OECD countries, and they demonstrate low export performance in the steel trade.

The evidence in this chapter suggested that selecting the BF–BOF route is a necessary but not sufficient condition for the catch-up of the steel industry in non-OECD countries. The results in this chapter provided important insights into the relationship between technology choice and export performance in the steel industry in non-OECD countries, which is in line with Chapter 2. The evidence in the chapter indicates another necessary condition for the catch-up of the steel industry in non-OECD countries. It may be important for the steel industry in non-OECD countries to upgrade steel exports in both quantity and quality to catch-up, given that international competitiveness, export sophistication and export diversification are interlinked.

Overall, the results from the analyses in Chapters 2 and 3 suggested that BF–BOF-based non-OECD countries have a high degree of international competitiveness and are extremely specialised in specific products compared to OECD countries. Therefore, it is crucial to determine whether major non-

OECD steel-producing countries have experienced a significant shift in export structure towards export upgrading in the 21st century.

By providing a first look at export upgrading in the global steel industry, this chapter raises a number of questions for which further research is warranted. First, the steel industry in some non-OECD countries appears to indicate high export performance based on past technology choices; however, when and how did the steel firms in these countries select production technologies? In addition, while the current level of export performance of the steel industry in non-OECD countries was assessed, it remains unclear how they have developed in the global steel industry. Further work with the steel industry in non-OECD countries would be particularly important to deepen the understanding of specific characteristics and catch-up path based on a time-series perspective. The evidence in this chapter indicates a need to further investigate the catch-up of non-OECD countries in the global steel industry.

Chapter 4. The Evolution of the Steel Industry in Non-OECD Countries in the 21st Century: Developments in Steel Trade and the Role of Technology

4.1 Introduction

The global steel industry experienced a significant increase in steel production in the past two decades, with a growing role of emerging/developing countries exemplified by the steel industry in non-OECD countries. It is a market turnaround from an era of stagnation that spanned from the mid-1970s until the end of the 20th century; global crude steel output growth in 2001–2018 was around 4.6% per annum, compared to 1.1% per annum in 1975–2000. Global crude steel output reached 1,825.5 million metric tonnes (mmt) in 2018, up by as much as 975.5 mmt (or 114.8%) compared to its level of 850.0 mmt in 2000, indicating that the global steel industry has experienced remarkably unprecedented growth in production in the 21st century. Nevertheless, minimal research and economic literature has been produced regarding the comprehensive development of the global steel industry and the catch-up trajectory in non-OECD countries. Therefore, it is particularly important to investigate the growth and current state of the global steel industry from an industry development perspective and how the steel industry in non-OECD countries has evolved during the 20th and 21st centuries to determine the industry's catch-up path.

The empirical results in Chapters 2 and 3 suggested that steel firms' technology choices matter for the steel industry in non-OECD countries. More specifically, those that selected the blast furnace–basic oxygen furnace (BF–BOF) route appear to be more likely to demonstrate high export performance than those using the electric arc furnace (EAF) route. However, these chapters did not focus on when and how non-OECD countries' steel firms made technology choices and lacked the perspective of time-series analyses. Therefore, the research question in this chapter is as follows. *When and how were technology choices that affect comparative advantage and international competitiveness implemented among major steel industries in non-OECD countries?*

To address the research question, this chapter examines the evolution of the global steel industry during the 20th and 21st centuries. Focusing on the relationships between technology choice and export performance could help us better understand how the steel industry in non-OECD countries has evolved in this century and how it has contributed to the development of the global steel industry.

The remainder of this chapter proceeds as follows. Section 4.2 provides a brief literature review. Section 4.3 presents the analytical perspective of this chapter based on the catch-up model presented in Chapter 1 while discussing the role of technology in the steel industry. Section 4.4 provides the global-level analysis of the evolution of the steel industry from the second half of the 20th century to the first two decades of the 21st century, including changes in production capacity, technology choice and export performance in the international steel market. Section 4.5 provides the global-level analysis of the first two decades of the 21st century, highlighting the development of the supply and demand of steel and the relation between its production and export. Section 4.6 presents the country-level analysis from the second half of the 20th century to the first two decades of the 21st century and investigates the technology pathways of major non-OECD steel-producing countries. Section 4.7 provides the country-level analysis of the first two decades of the 21st century and explains the evolution of the comparative advantage and international competitiveness of major non-OECD steel-producing countries. Section 4.8 provides a summary of the findings and some implications.

4.2 Literature Review

The economic literature suggests that industries in latecomer countries can develop trade structures over time to catch-up with those that came before. According to the 'flying-geese' theory of economic development introduced by Akamatsu (1962) and developed by Kojima (2000), import, production and export cycles can be observed in industries' development patterns over time and can transform the export structure through diversification and upgrading export products (Kojima, 2000, p. 376).

Such export structure transformation is closely related to issues of comparative advantage and international competitiveness. Based on the flying-geese model, latecomer countries are expected to strengthen international competitiveness while acquiring comparative advantage for a wide variety of goods as the economy develops (Widodo, 2009). Indeed, comparative advantage can change over time (Kowalski, 2011). Countries can move up the ladder of comparative advantage from resource-intensive products to labour-, capital-, technology- and knowledge-intensive products (Balassa, 1981; Chow, 2012; Meier, 1995), and patterns of trade specialisation vary significantly across countries and industries (Dalum et al., 1998; Laursen, 2015). To summarise, economic literature suggests that economic development can provide opportunities to countries and industries to change the structure of comparative advantage and international competitiveness.

The discussion about the flying-geese model is also related to the development patterns in the steel industries of latecomer countries. The historical patterns suggest that countries' steel industries gradually fill the domestic market. By gaining external competitiveness of its products at the import stage, increasing production through the development of steel-consuming industries and the improvement of technological capabilities, countries gradually reach the stage of enjoying economies of scale while gaining export competitiveness.[98]

The stages of development of the steel industry in latecomer countries include: i) a period of sufficiency through imports; ii) a period of sufficiency through imports and partial domestic production, followed by a period of domestic production of major demand products; iii) a period of expansion of the variety and quantity of products domestically produced while importing; iv) a period of imports of high value-added products and full-scale production of low- and medium-value-added products; and v) a period when all grades of products are produced and the country attains the status of an advanced steel-producing country.[99] During the shift from period ii) to period iii), the steel industry in latecomer countries tends to select either the BF–BOF or EAF steel production routes.

Indeed, flying-geese development patterns can be observed in the steel industries of emerging/developing countries.[100] Considering the evolution of steel supply and demand in the Vietnamese steel industry, production has increased along with demand expansion. In contrast, imports have decreased and exports have begun. These development patterns fit the flying-geese development model.

The principle of comparative advantage is a prevalent construct in trade literature and is also relevant to the international steel trade. de Carvalho and Sekiguchi (2015) highlighted changes in trade specialisation patterns for large steel-exporting countries/regions between 2004 and 2014, suggesting that trade specialisation patterns in the steel industry in some countries have changed over the decade; the steel industries in emerging/developing countries have now moved up the value chain and begun exporting more

[98] This paragraph is based on Toda (1984, p. 169).

[99] This paragraph is based on Toda (1984, pp. 186–187).

[100] This paragraph is based on Kawabata (2016b, pp. 16–17).

sophisticated steel products. While Mattera (2018, pp. 27–30) discussed comparative advantage in the steel industry using de Carvalho and Sekiguchi's (2015) results, he pointed out that 'Since only two years of data are being compared, the results should be interpreted with caution' (p. 27). The implication is that it is important to analyse changes in trade specialisation of major steel-producing countries over a longer period to comprehensively discuss catch-up in the global steel industry.

While these studies analysed comparative advantage in the context of the steel industry, they lacked the perspective of linking technology choice and export performance with time-series variations to discuss the catch-up of the steel industry in emerging/developing countries.

Despite the importance of technology choice in the steel industry, very little is known about when, how or by whom such decisions are made and which production technology was chosen, accelerating the catch-up of the steel industry in non-OECD countries. Given that the steel industry in emerging/developing countries appears to have experienced significant growth in steel output in the 21st century, it is essential to track the evolution of the steel industry in non-OECD countries using time-series analyses.

Economic literature uses the Revealed Symmetric Comparative Advantage (RSCA) index to discuss a country's comparative advantage (Dalum et al., 1998; Laursen, 2015; Widodo, 2009) to examine the country's specialisation in a given product compared to the rest of the world. In contrast, the Trade Balance Index (TBI) enables a discussion on international competitiveness in a country's steel industry (Marukawa, 2018, pp. 252–254; Marukawa & Hattori, 2019, pp. 32–33; Tanaka & Isomura, 2020, pp. 122–127) indicating the development level of its steel industry.

Overall, this chapter assumes that combining the RSCA index and the TBI enables the assessment of the development of the steel industry in non-OECD countries in terms of comparative advantage and international competitiveness. To shed light on how non-OECD countries' steel industries have evolved in the 21st century, the RSCA index and TBI are developed for the whole steel industry and some broad product categories.

4.3 Analytical Perspective

4.3.1 Analytical model

Based on the catch-up model presented in Chapter 1, this chapter investigates the hypothesis of whether the steel industry in non-OECD countries develops in the order of i) market expansion; ii) technology choice and productivity improvement; iii) production expansion and productivity improvement; iv) acquisition of comparative advantage; v) improvement of international competitiveness and vi) sophistication and diversification of the export structure.

Three important perspectives must be considered when analysing non-OECD countries' catch-up in the global steel industry. First, analysing the evolution of the steel industry from a time-series perspective is particularly important to elicit a thorough and accurate understanding of the global steel industry's evolution in the 21st century. While the global steel industry has clearly experienced a significant increase in production in this century, what happened and how major non-OECD steel-producing countries have evolved during the 20th and 21st centuries is less understood. Given the complex nature of the development process, as discussed, it may take some time for the steel industry in non-OECD countries to develop through each step. Given that a time-series perspective is a critical aspect of the concept of this catch-up, this perspective will offer a more comprehensive understanding of the development of the global steel industry.

Second, understanding steel firms' technology choice patterns is critical to the discussion regarding the development of the steel industry in non-OECD countries. As noted in Chapter 1, this research regards a large-scale integrated production system by using the BF–BOF route as state-of-the-art technology, while it does not consider the EAF route as appropriate technology, based on the assumption that 'appropriate' differs depending on the conditions of each steel industry.[101] An important caveat to bear in mind is that not all BF–BOF routes are based on the latest technology. This research assumes that the most advanced production technology is the BF–BOF route equipped with large-scale production facilities, which is suitable for mass production, leading to export competitiveness.

[101] Technologically, a brand-new EAF could be the latest technology, but it does not enable mass production and enhance export competitiveness, which is necessary for the catch-up.

Finally, focusing on the technology pathways when considering the development of the steel industry in non-OECD countries is also necessary. The steel industry in latecomer countries may upgrade to state-of-the-art technology through technology accumulation if they have already formed a BF–BOF-based production system. More specifically, the steel industry in some countries that initially used old or small-scale BF–BOF facilities may upgrade to the BF–BOF route equipped with large-scale production facilities in a later stage to facilitate mass production and the ability to compete in the international market. This research assumes that the sizes of BFs (inner volume/working volume more than 2,000 m^3) are critical to assessing whether it is the latest technology for the BF–BOF route.

To assess the catch-up of the steel industry in non-OECD countries, this chapter uses the model presented in Chapter 1. The explanation of Figure 4.1 is provided below:

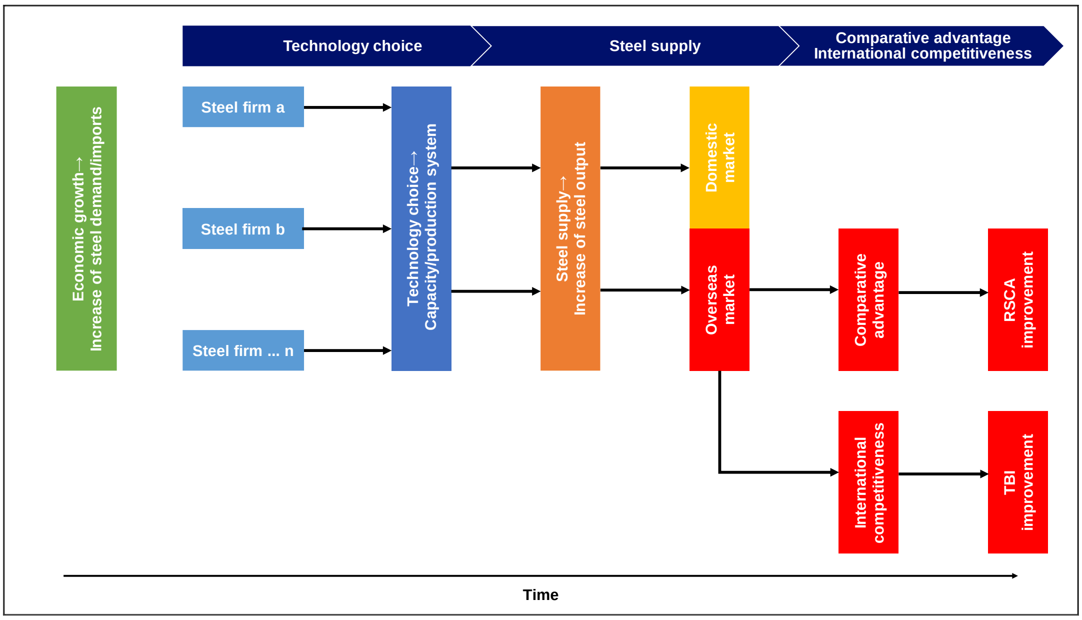
- The catch-up process begins with import substitution, which primarily stems from growing steel demand. High economic growth during industrialisation may lead to an increase in steel demand from domestic steel-using industries (e.g. construction and automobiles), triggering the growth of apparent steel use (ASU) and steel imports. To fill the production/demand gap and supply steel products that meet the level of domestic demand, some steel firms may begin to consider local investment in production facilities and may contemplate the future possibility of export.
- Steel firms' technology choices have a vital influence on accelerating the catch-up process. Once a steel firm decides to invest in production facilities, upstream/downstream facilities are selected and installed, increasing production capacity, forming production systems (i.e. BF–BOF-based or EAF-based countries) and defining the product mix for the entire domestic steel industry.
- In the next phase, the catch-up process shifts to steel supply. Following the installation of production facilities, production begins. Steel firms can improve productivity through capability-building efforts, leading to competitiveness in the market and the ability to supply the domestic market first and the foreign market later.
- Increased steel production helps the domestic steel industry to acquire a comparative advantage and strengthen international competitiveness. If steel firms can further expand steel output, they can enjoy economies of scale and increase proficiency, contributing to productivity enhancement. A virtuous

cycle may occur in which productivity is further improved by the increasing production volume. Steel firms may also have an opportunity to upgrade to large-scale production facilities in line with growing steel output. As the domestic steel industry develops, it can gain comparative advantage over other industries, increasing the RSCA index for the entire steel industry and reflecting productivity enhancement. In addition, imports may be substituted with domestic production, resulting in a rising proportion of exports to imports, leading to TBI improvement for the whole steel industry.

- The development of the domestic steel industry facilitates the upgrade of its steel export structure. As the domestic steel industry further develops, opportunities to upgrade the quality of its steel exports may arise. The domestic steel industry may demonstrate high RSCA and TBI values for high-value-added segments (flat products, pipe and tube products).
- The RSCA index and the TBI in the domestic steel industry may change in parallel, but their development may not necessarily be linked. This is because the RSCA index is calculated based on only export data; thus, the improvement of the RSCA index may precede the TBI index. Since both import and export data are used for the TBI, improvement of the TBI may occur later than the RSCA index. The development of steel demand/imports in the domestic steel industry is likely to significantly affect changes in the TBI. Even if the domestic steel industry's RSCA index improves due to the growing comparative advantage over other industries, steel imports may increase if the demand growth is greater than the change in production. In this case, the TBI of the domestic steel industry may not necessarily improve.

According to Figure 4.1, the interplay of steel production/exportation, which leads to the improvement of comparative advantage and international competitiveness and steel demand/importation, is likely to determine the evolution of the steel industry in non-OECD countries. Steel industries in some non-OECD countries may have already experienced this interplay in the 20th century, while others may experience it in the 21st century. It is important to determine which steel production/exportation or demand/importation have been more significant and whether the evolution occurred in the 20th or 21st centuries for individual non-OECD countries.

Figure 4.1 Hypothetical catch-up model in the steel industry



Source: Author

4.3.2 Flow of analysis

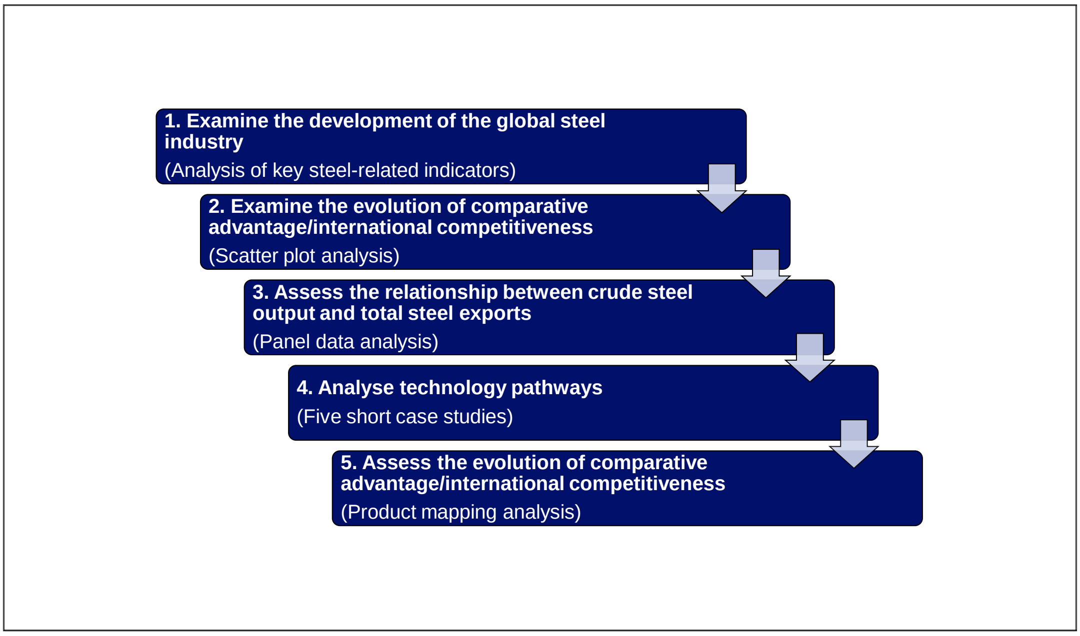
This chapter consists of two parts: global-level analysis that examines the development of the global steel industry and country-level analysis that investigates the catch-up of major non-OECD steel-producing countries. These analyses were conducted in two periods: i) the second half of the 20th century to the first two decades of the 21st century and ii) the first two decades of the 21st century.

The global-level analysis examines i) how steelmaking capacity has developed, ii) how production technologies have evolved, iii) what technology choice patterns were observed in the steel industries in non-OECD and OECD countries from the second half of the 20th century to the first two decades of the 21st century, and iv) how major steel-related indicators have changed since the early 2000s; in addition, the analysis investigates v) how comparative advantage and international competitiveness have evolved in the global steel industry and vi) the relationship between steel production and steel exports in the first two decades of the 21st century. In contrast, the country level analysis examines when and how technology choices that affect comparative advantage and international competitiveness were implemented among major steel industries in non-OECD countries.

Figures 4.2 presents an overview of the flow of analysis and analytical tools used in this chapter.

1. The global-level analysis begins with the analysis on how the steel industry in the world and various countries/regions has increased steelmaking capacity to meet growing steel demand and reduce import dependency. In addition, it focuses on steel production by process to assess how production technologies have evolved and which technologies the steel industry in non-OECD and OECD countries selected from the second half of the 20th century to the first two decades of the 21st century.
2. The global-level analysis sheds light on the development of key steel-related indicators in the first two decades of the 21st century. Then, it examines how comparative advantage and international competitiveness of the steel industry in non-OECD and OECD countries evolved in the same period.
3. Moreover, the global-level analysis also focuses on the relationship between crude steel output and total steel exports in non-OECD countries in the first two decades of the 21st century to examine to what extent steel production is related to steel exports and whether an increase in steel production immediately results in increased steel exports or if there is a time lag between these events.
4. The country-level analysis begins with case study examples for major non-OECD steel-producing countries. The analysis sheds light on countries' technology pathways through five short case studies from the second half of the 20th century to the first two decades of the 21st century.
5. Finally, the country-level analysis investigates the evolution of major non-OECD steel-producing countries in terms of export performance to examine when and how technology choices that affect comparative advantage and international competitiveness were implemented among major steel industries in non-OECD countries in the first two decades of the 21st century.

Figure 4.2 Overview of the flow of analysis and analytical tools



Source: Author

4.3.3 Methodology

This chapter assesses the catch-up of the steel industry in non-OECD countries in the 21st century, using the RSCA index and TBI as proxies for comparative advantage and international competitiveness.

Revealed Symmetric Comparative Advantage index and Trade Balance Index

The RSCA index provides information on a country's specialisation in a given steel product relative to the rest of the world. This chapter uses the RSCA index to discuss a country's comparative advantage in the international steel market. This chapter also uses TBI to indicate a country's international competitiveness in the global steel market.[102]

Product mapping

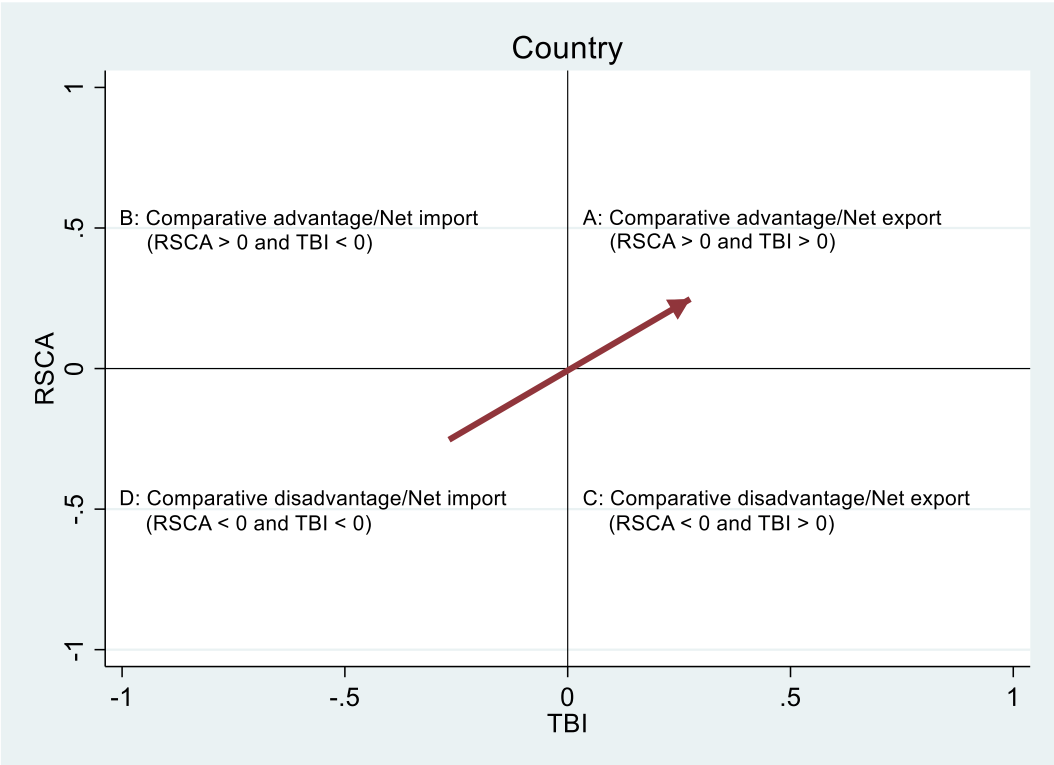
Widodo (2009) introduced an analytical tool called 'product mapping' using the RSCA index and the TBI to analyse exported products. While Chapter 2 used this framework to indicate the current situation of comparative advantage and international competitiveness at the detailed product level, it is

[102] A detailed explanation of RSCA and TBI is available in Chapter 2.

applied to this chapter to better understand the RSCA index and TBI's dynamics for major non-OECD steel-producing countries in the 21st century.

As Widodo (2009) suggested, latecomer countries are expected to acquire comparative advantage for a wide variety of goods while improving international competitiveness as the economy develops. This chapter assumes that the position of each steel industry is expected to shift from D to A if it obtains a comparative advantage and strengthens international competitiveness in the international steel market (Figure 4.3). The analysis was conducted through six periods (2001–2003, 2004–2006, 2007–2009, 2010–2012, 2013–2015 and 2016–2018).

Figure 4.3 Product mapping



Source: Author based on Widodo (2009, p. 67)

4.3.4 Data and list of countries

The primary trade data comes from the International Trade Centre's Trade Map (ITC, 2021), an online database of international trade data unless otherwise indicated. Trade data in value terms were used to calculate the RSCA index and TBI. This dataset contains trade data for the years 2001–2018. The data were based on the steel industry in countries with available production data by process. This chapter's definition of steel products was based on the International Steel Statistics Bureau (ISSB, 2010).

Regarding other key steel-related data, figures for steel production and steel use were taken or calculated from the World Steel Association (various years). Moreover, steelmaking capacity data were based on OECD (2020b) and WV Stahl (various years) data, and the information on large-sized BFs was obtained from CISA (various years) and KOSA (various years) unless otherwise indicated.

Major non-OECD steel-producing countries are defined in this chapter as the top 10 non-OECD steel-producing countries in 2018, based on the crude steel output ranking released by the World Steel Association (2019c). Although Taiwan was ranked the sixth largest steel producer in non-OECD countries in 2018, it was excluded from the analyses in this chapter because it is considered an advanced country (IMF, 2021b) and has a similar structure to the steel industry in advanced countries (see Chapter 2). Instead of Taiwan, this chapter focuses on Indonesia for the case studies, the 11th largest steel-producing non-OECD country, based on the crude steel output ranking released by the World Steel Association (2019c). In 2018, the combined crude steel output of major non-OECD countries was 1,226.5 mmt, accounting for 93.1% of steel production in non-OECD countries.

To underscore the differences in steel industry development in non-OECD countries, this chapter also highlights those in OECD countries. A list of countries is available in Table 4.1.

Table 4.1 List of countries (2001–2018)

OECD	Country code (ISO)	Non-OECD	Country code (ISO)	Non-OECD	Country code (ISO)
Australia	AUS	Algeria	DZA	Montenegro	MNE
Austria	AUT	Argentina	ARG	Morocco	MAR
Belgium	BEL	Azerbaijan	AZE	Myanmar	MMR
Canada	CAN	Bahrain	BHR	Nigeria	NGA
Chile	CHL	Bangladesh	BGD	Oman	OMN
Colombia	COL	Belarus	BLR	Pakistan	PAK
Czechia	CZE	Bosnia and Herzegovina	BIH	Paraguay	PRY
Finland	FIN	Brazil	BRA	Peru	PER
France	FRA	Bulgaria	BGR	Philippines	PHL
Germany	DEU	China	CHN	Qatar	QAT
Greece	GRC	Croatia	HRV	Romania	ROU
Hungary	HUN	Cuba	CUB	Russia	RUS
Israel	ISR	D.R. Congo	COD	Saudi Arabia	SAU
Italy	ITA	Ecuador	ECU	Serbia	SRB
Japan	JPN	Egypt	EGY	Singapore	SGP
Luxembourg	LUX	El Salvador	SLV	South Africa	ZAF
Mexico	MEX	Ghana	GHA	Sri Lanka	LKA
Netherlands	NLD	Guatemala	GTM	Syria	SYR
New Zealand	NZL	India	IND	Thailand	THA
Norway	NOR	Indonesia	IDN	Tunisia	TUN
Poland	POL	Iran	IRN	Uganda	UGA
Portugal	PRT	Jordan	JOR	Ukraine	UKR
Slovakia	SVK	Kazakhstan	KAZ	United Arab Emirates	ARE
Slovenia	SVN	Kenya	KEN	Uruguay	URY
South Korea	KOR	Kuwait	KWT	Uzbekistan	UZB
Spain	ESP	Libya	LBY	Venezuela	VEN
Sweden	SWE	Macedonia	MKD	Vietnam	VNM
Switzerland	CHE	Malaysia	MYS		
Turkey	TUR	Mauritania	MRT		
United Kingdom	GBR	Moldova	MDA		
United States	USA	Mongolia	MNG		

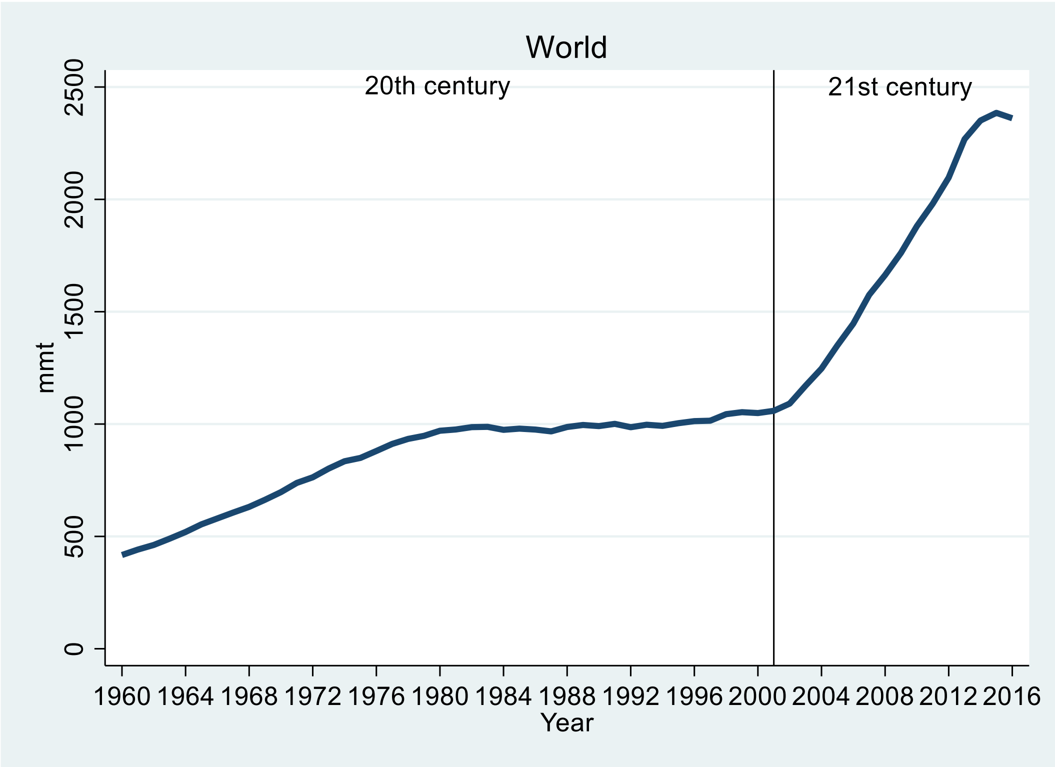
Source: Author

4.4 Global-Level Analysis (From the Second Half of the 20th Century to the First Two Decades of the 21st Century)

4.4.1 The evolution of steelmaking capacity (1960–2016)

Growing markets are likely to attract capacity growth in many steel firms in the global steel industry, contributing to import substitution. Thus, it is essential to determine whether the global steel industry increases steelmaking capacity along with significant growth in steel demand in the 21st century. Figure 4.4 provides the development of world steelmaking capacity during 1960–2016, indicating a steady increase until the early 1980s and then stabilising until the 1990s. While the pace of world steelmaking capacity was moderate in the 1990s, the global steel industry has experienced a significant increase in capacity in the 21st century. The question arises as to whether the steel industries in all countries/regions have expanded steelmaking capacity in this century to meet expanding steel demand, and if not, which countries/regions have expanded their production capacity.

Figure 4.4 Evolution of steelmaking capacity (1960–2016)



Note: Data for steelmaking capacity are available between 1960 and 2016.
Source: WV Stahl (various years)

It is important to identify countries/regions that have expanded capacity during the 20th and 21st centuries. Table 4.2 presents steelmaking capacity in the global steel industry at country and regional levels, indicating divergent trends. The steel industry in some major steel-producing countries exhibited a steady increase in production capacity in the 20th century but has declined in the 21st century. While steelmaking capacity in other countries and regions gradually moved from a low base in the 20th century, it has increased at an unprecedented pace in the 21st century.

Although the steel industry in some OECD countries had a significant role in steel supply in the 20th century, capacity declined in the 21st century. Some major OECD countries' steel industries steadily expanded steelmaking capacity until the 1970s and 1980s, and the global steel industry witnessed the rapid catch-up of the Japanese steel industry in steelmaking capacity in the 20th century. Steelmaking capacity in many OECD countries (e.g. the United States, European countries and Japan) reached its peak in the 20th century and has been declining since. In contrast, steelmaking capacity in some regions, such as Latin America, the Middle East and Asia (excluding China and Japan) have risen significantly in the 21st century. The Chinese steel industry in particular has steadily increased since the 20th century, and development momentum accelerated in the 21st century.

Table 4.2 Evolution of steelmaking capacity of selected countries/regions (1960–2016)

	20th century								21st century			
	1960	1965	1970	1975	1980	1985	1990	1995	2001	2005	2010	2016
	Tonnage, mmt								Tonnage, mmt			
EU	106.6	134.6	126.9	189.5	204.6	171.2	189.5	237.0	228.1	231.0	239.2	217.2
Germany	35.3	45.5	53.1	62.9	69.1	49.0	48.1	51.2	52.1	52.2	52.8	51.9
France	17.9	22.7	25.1	33.6	32.5	28.5	25.4	22.5	23.5	23.5	23.5	19.5
United Kingdom	na	na	na	27.1	28.0	24.0	23.9	20.7	18.9	17.5	17.5	10.9
Belgium	12.2	15.4	20.9	26.5	26.1	20.2	18.9	18.5	19.6	18.5	16.3	10.9
Soviet Union/CIS	72.6	101.1	128.8	159.9	180.0	194.0	196.0	145.4	120.6	126.7	146.6	153.8
United States	138.0	154.0	152.0	138.9	139.4	121.2	105.8	101.7	111.7	112.7	114.8	112.3
Latin America	5.7	10.9	17.0	23.0	36.7	39.0	43.7	43.7	48.6	53.3	65.6	76.2
Middle East	0.3	0.5	0.7	2.1	3.9	6.2	10.1	11.6	15.6	21.0	27.8	72.2
China	15.0	19.0	19.0	33.0	39.5	53.0	71.9	106.3	160.0	423.8	800.3	1,119.0
Japan	25.0	51.4	103.0	151.0	158.8	162.0	136.6	148.5	145.3	121.4	132.4	129.1
Asia (excl. China, Japan)	5.0	11.7	13.9	20.1	45.3	63.6	77.0	111.7	130.7	153.1	223.3	312.0
Oceania	4.3	6.5	8.4	9.6	9.3	8.2	8.7	9.6	8.8	8.8	9.3	9.3
World	417	554	697	849	970	980	991	1,004	1,059	1,350	1,881	2,361

Note: The number of countries in the EU varies from year to year. Steelmaking capacity for Belgium includes Luxembourg's capacity. Since data for 2016 for Asia is not available, data for 2015 were used in the above table.
Source: WV Stahl (various years)

4.4.2 Evolution of steel production by technologies (1970–2018)

While it is evident that the steel industry in some countries/regions rapidly or steadily expanded steelmaking capacity during the 20th and 21st centuries, which technologies the steel industry in OECD and non-OECD countries selected during these centuries remains unclear.

Before discussing technology choice between non-OECD and OECD countries in the steel industry, it is important to focus on how major production technologies in the global steel industry evolved between the 20th and 21st centuries. Figure 4.5 presents the evolution of world crude steel output by the process in the period 1970–2018. Although the OHF/Other route was the major production technology until the middle of the 20th century (Metinvest, 2020; World Steel Association, 2012, p. 24), it significantly declined in the wake of the technological advances of BOF and EAF.[103] Global steel production via the BF–BOF and EAF routes has consistently increased; crude steel output through the BF–BOF route had considerable growth since the early 2000s.

Figure 4.6 displays changes in the crude steel output volume by technology and group from 1970–2000 to 2001–2018. Regarding technology choice in the 20th and 21st centuries, both BF–BOF and EAF routes have increased in the 21st century; however, the patterns and scales in technology choice in non-OECD and OECD countries significantly varied. Technology choice patterns were relatively diverse for steel industries in non-OECD and OECD countries in the 20th century. The global steel industry witnessed the rapid expansion of steel production via the BF–BOF route in the Chinese steel industry during the first two decades of the 21st century. Steel output via the EAF route in the steel industry in non-OECD countries, excluding China, also contributed to an increase in total crude steel output during the same period. Only EAF steel production has increased in steel industries in OECD countries in this century.[104]

[103] The OHF route was replaced by BF–BOF and EAF routes due to issues, including long smelting times, the need for continuous external furnace heating, rising natural gas prices and unsustainable methods (Metinvest, 2020).

[104] Between 2001 and 2018, BF–BOF output in the steel industry in OECD countries slightly decreased from 283.2 mmt to 280.1 mmt.

Figure 4.5. Development of world crude steel output by process (1970–2018)

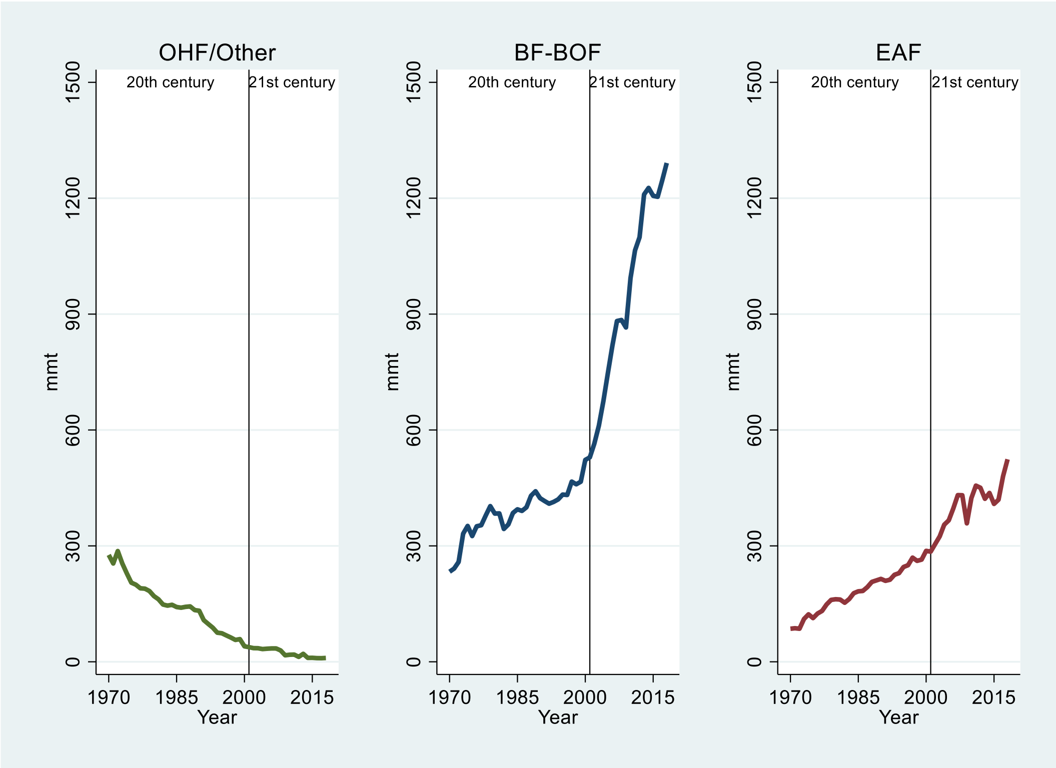
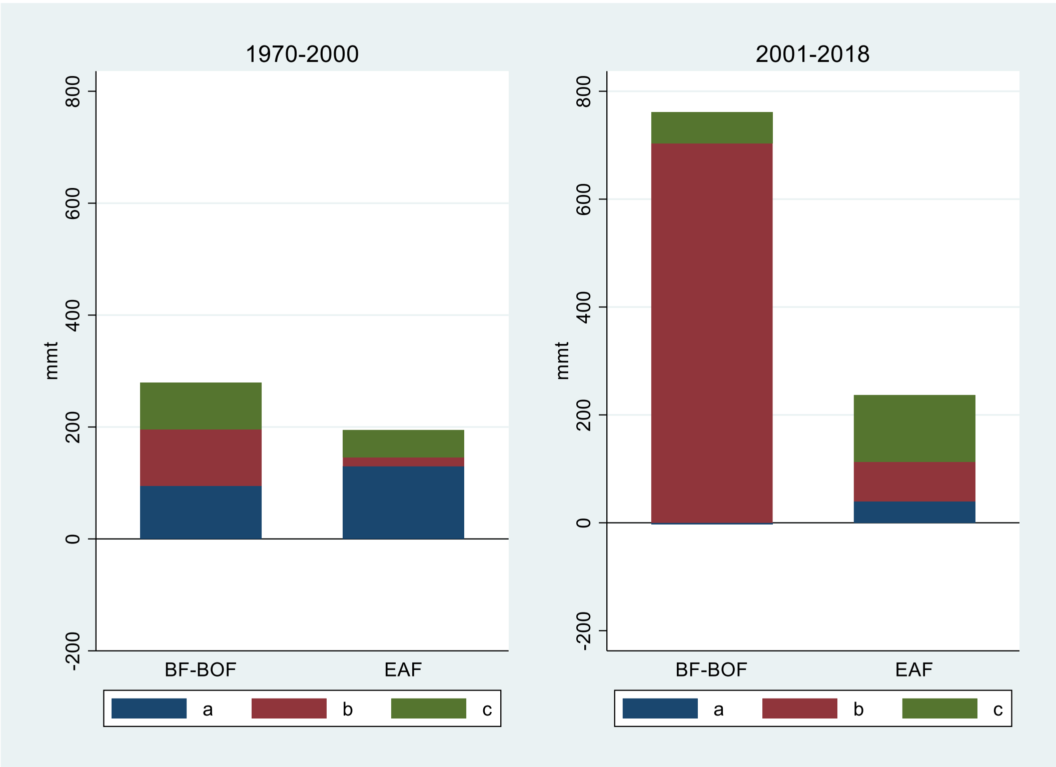


Figure 4.6. Changes in crude steel output (1970–2018)



Note: a denotes the OECD countries, b denotes China and c denotes non-OECD countries, excluding China.
Source: Author's calculations based on data from the World Steel Association (various years)

4.5 Global-Level Analysis (The First Two Decades of the 21st Century)

4.5.1 The development of the steel supply and demand (2001–2018)

The previous section examined the evolution of the global steel industry from the second half of the 20th century to the first two decades of the 21st century. To more comprehensively investigate the development of the steel industry in non-OECD countries in the first two decades of the 21st century, it is critical to assess trade performance through a comparison of OECD countries and other steel-related indicators. Table 4.3 presents key steel-related indicators for 2001, 2007 and 2018.

Steel imports in non-OECD countries have grown at a rapid pace since 2001, in line with increasing steel demand. To proceed with import substitution, steelmaking capacity and crude steel output in the steel industry in non-OECD countries increased at an unprecedented pace in the 21st century, surpassing OECD countries' steelmaking capacity and crude steel output, and steel exports increased steadily, supported by the tremendous growth of the Chinese steel industry. Although the steel industry in non-OECD countries, excluding China, increased steel production and exports in the 21st century, non-OECD countries have continued to exhibit considerable trade deficits.

Turning to the steel industry in OECD countries, ASU grew steadily from 2001 to 2007, and its crude steel output reached its peak in 2007 to meet the steel demand; however, it experienced a marked decline based on the global financial crisis in 2008 and has not fully recovered since that time.

The analyses so far have focused on the development of market expansion, technology choice and production increase in non-OECD countries' steel industries. It remains essential to investigate the evolution of comparative advantage and international competitiveness in the 21st century.

Table 4.3 Summary of key steel-related indicators, 2001, 2007 and 2018

	2001				2007				2018			
	Unit: mmt											
	Non-OECD	China	Non-OECD excl. China	OECD	Non-OECD	China	Non-OECD excl. China	OECD	Non-OECD	China	Non-OECD excl. China	OECD
Apparent steel use	366.6	170.6	195.9	470.9	744.3	435.9	308.4	567.9	1,297.5	870.9	426.6	516.9
Steel imports	79.9	25.6	54.2	181.8	155.0	17.2	137.8	263.8	178.4	14.4	164.1	258.1
Steelmaking capacity	536.9	253.0	283.8	607.9	1,163.5	806.8	356.7	631.6	1,654.4	1,128.0	526.5	644.6
Crude steel output	362.3	151.6	210.7	472.4	782.5	489.7	292.8	544.8	1,294.0	928.3	365.8	508.2
Steel exports	95.0	7.3	87.8	191.9	184.5	66.4	118.1	251.3	192.7	68.8	123.9	252.7
Trade balance	15.2	-18.3	33.5	10.1	29.5	49.2	-19.7	-12.5	14.2	54.4	-40.2	-5.4

Note: The table above uses the same definition of the OECD from 2001 to 2018 and includes a number of non-OECD and OECD countries with unavailable production data by the process.
Source: Author's calculations based on data from the OECD (2020b) and the World Steel Association (various years)

It is evident that the steel industry in non-OECD countries has experienced a significant or steady increase in steel production in the 21st century, supported by robust steel market expansion. A key question is how these developments led to the evolution of international steel trade dynamics through examining comparative advantage and international competitiveness. To do so, Figure 4.7 illustrates the RSCA and TBI values of total steel products in non-OECD and OECD countries between 2001–2003 and 2016–2018.

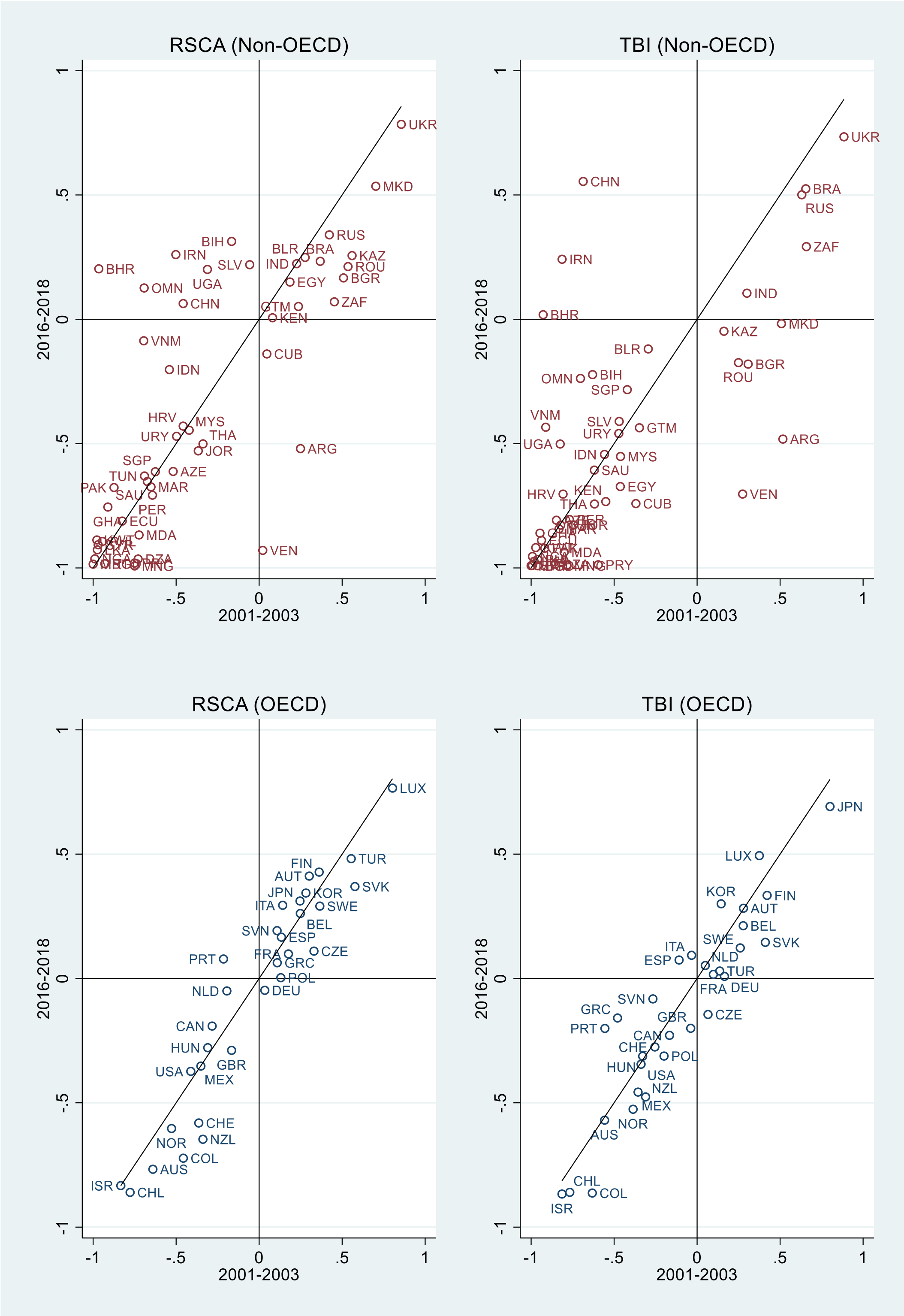
The steel industry in some non-OECD countries (mostly in quadrant 2) appears to have increased RSCA values between 2001–2003 and 2016–2018, suggesting that some appear to have gradually gained comparative advantage in the steel industry, albeit marginally. In addition, the steel industry in some countries in quadrant 1 has maintained positive RSCA values in the same period, indicating the important role of steel products in international trade in goods. While the steel industry in many countries is still concentrated in the lower left-hand corner (quadrant 3), a few countries appear to be heading to quadrant 2, suggesting improvements in the RSCA index.

Only a few non-OECD countries' steel industries have improved TBI values (quadrant 2), indicating that a limited number of countries have improved international competitiveness. While major exporters have maintained their net exporters' positions (quadrant 1), the industry in some non-OECD countries (mostly in quadrant 4) has decreased TBI values, becoming net steel importers.

The steel industry in OECD countries has a relatively stable structure in terms of RSCA and TBI values, suggesting that the comparative advantage and international competitiveness in the group has not changed much since the beginning of the 21st century.

Table 4.3 and Figure 4.7 demonstrate how the export performance of the steel industry in non-OECD countries has evolved in the 21st century. These results provide at least two important insights into non-OECD countries’ export performance. First, overall export structure has not yet reached a trade surplus, excluding the Chinese steel industry, although a steady increase in steel production is evident in this century. Second, only a limited number of the steel industries in non-OECD countries have improved TBI values in the last 20 years, although some seem to have marginally improved RSCA values. This is likely due to the time it takes for steel industries to improve RSCA values from the expansion of crude steel output and TBI values from the development of RSCA values.

Figure 4.7. Evolution of RSCA and TBI values (2001–2003 and 2016–2018)



Note: N = 50 (non-OECD countries) and 31 (OECD countries). Countries for which trade data were not available between 2001–2003 and 2016–2018 were excluded.
Source: Author’s calculations based on data from the ITC (2021)

4.5.2 Links between steel production and steel exports (2001–2018)

A key question that arises when analysing the steel trade is how steel production and steel exports are related. To assess the extent that production is related to exportation, two simple econometric analyses, analysing the relationship between crude steel output and total steel exports were performed. The following fixed effects model was employed to evaluate the heterogeneous link between crude steel output and total steel exports.

$$ln\ EXP_{it} = \alpha_0 + \alpha_1 ln\ CSO_{it} + x_i + y_t + \epsilon_{it}$$

where $ln\ EXP_{it}$ is the log total steel exports in volume terms for country i in year t, and $ln\ CSO_{it}$ is the log crude steel output for country i in year t. The model includes country and year fixed effects specified by x_i and y_t, respectively. ϵ_{it} is the error term for country i in year t.

Table 4.4 presents the results of the relationship between crude steel output and total steel exports for the steel industry in all countries and in non-OECD countries from 2001 to 2018. Overall, the results suggest a close relationship between crude steel output and total steel exports, as expected. It demonstrates that greater volumes of crude steel output are significantly associated with higher total steel exports, with significance at the 1% level. For instance, a 10% increase in crude steel output is estimated to lead to a 5.0% increase in total steel exports for the industry in non-OECD countries.

In summary, the results suggest a close relationship between crude steel output and total steel exports in non-OECD countries. The following important question that arises when analysing the steel trade is: How does the relationship between crude steel output and total steel exports change over time?

Table 4.4. Relationship between crude steel output and total steel exports (2001–2018)

Variable	All countries	Non-OECD countries
	Dependent variable	
	ln total steel exports	
ln crude steel output	0.478*** (0.08)	0.495*** (0.09)
Fixed effects		
Year	✓	✓
Country	✓	✓
Observations	1,435	880
R-squared	0.920	0.884

Note: All regressions include country and year fixed effects. Robust standard errors clustered at the country year level in parentheses. Significance: *** p < 0.01, ** p < 0.05, * p < 0.1.
Source: Author's calculations based on data from the ITC (2021) and the World Steel Association (various years)

The analysis above confirms the causal relationship between production and exports in the steel industry, while it is still not evident whether an increase in crude steel output leads to growing total steel exports immediately or a time lag exists in non-OECD countries. To gauge this potential time lag between the increase in steel production and growth in steel exports, an additional analysis was performed.

The empirical model assesses the relationship between log growth total exports ΔEXP_{it} and ΔCSO_{it} from 1- to 5-year periods. Note that log growth in total steel exports is calculated as the change in log exports between time *t* and *t*-1, *t*-2, *t*-3, *t*-4 and *t*-5, respectively. This analysis endeavours to explore the extent to which changes to steel output impact total steel exports over short and medium time periods. The following model is employed:

$$\Delta EXP_{it} = \alpha_0 + \alpha_1 \Delta CSO_{it} + x_i + \epsilon_{it}$$

where ΔEXP_{it} is the log growth of total steel exports in volume terms for country *i* in year *t*, and ΔCSO_{it} is the log growth of crude steel output for country *i* in year *t*. The model also includes country fixed effects signified by x_i, and ϵ_{it} is the error term for country *i* in year *t*.

Table 4.5 examines the causal relationship between changes in crude steel output to those in total steel exports for the steel industry in non-OECD countries. The results suggest that steel output is associated with higher export levels and changes over time. A 10% increase in crude steel output leads to an approximate 4.0% increase in total steel exports over the 5-year period, compared to 2.3% over a 1-year period.

Regarding the steel industry in non-OECD countries, the results suggest that changes in crude steel output are more likely to be revealed over longer periods, indicating that the size of coefficients of the steel industry in non-OECD countries increases with each incremental year increase in the period regressions. This suggests gradual shifts in steel supply in the steel industry in non-OECD countries from the domestic market to the overseas market. For the steel industries in such countries, it is possible that an increase in crude steel output leads to growing total steel exports, particularly after some time. The results suggest that crude steel output is closely related to total steel exports, but there appears to be a definite time lag for non-OECD countries to transition from the development and expansion process in steel production to increasing steel exports.

Table 4.5. Changes in crude steel output and total steel exports for non-OECD countries (2001–2018)

Variable	(1)	(2)	(3)	(4)	(5)
	Dependent variable				
	Δln total steel exports, t-1 to t	Δln total steel exports, t-2 to t	Δln total steel exports, t-3 to t	Δln total steel exports, t-4 to t	Δln total steel exports, t-5 to t
Δln crude steel output, t-1 to t	0.230***				
	(0.05)				
Δln crude steel output, t-2 to t		0.244***			
		(0.05)			
Δln crude steel output, t-3 to t			0.268***		
			(0.06)		
Δln crude steel output, t-4 to t				0.326***	
				(0.08)	
Δln crude steel output, t-5 to t					0.402***
					(0.09)
Fixed effects					
Year					
Country	✓	✓	✓	✓	✓
Observations	810	756	699	648	596
R-squared	-0.023	0.015	0.063	0.113	0.206

Note: All regressions include country fixed effects. Year fixed effects are excluded from these regressions since variables are calculated as changes. Robust standard errors clustered at the country year level are in parentheses. Significance: *** p < 0.01, ** p < 0.05, * p < 0.1. Note that in columns 1 and 2, the R-squared is very small, given that changes in steel production are likely to reveal themselves over longer periods, potentially due to technology catch-up. Thus, the results suggest that it is more appropriate to assess the relationship over a longer time period.
Source: Author's calculations based on data from the ITC (2021) and the World Steel Association (various years)

4.6 Country-Level Analysis (From the Second Half of the 20th Century to the First Two Decades of the 21st Century)

4.6.1 Case study examples of technology choice in major non-OECD steel-producing countries

While this research has presented various quantitative analyses, a qualitative analysis could offer important insights into the dynamics of the technology pathways, which is essential to gaining a more comprehensive understanding of the catch-up dynamics in major non-OECD steel-producing countries during the 20th and 21st centuries. More specifically, case study analysis is crucial for analysing i) when steel firms in major non-OECD steel-producing countries made technology choices, and ii) how and in what situations steel firms in non-OECD countries made such technology choices.

The next analysis presents five short case studies (Table 4.6). The first case study examines the Chinese steel industry which executed BF–BOF-intensive technology choice in the 20th century, resulting in a significant increase in steel production in the 21st century. The second case study focuses on the steel industries in countries that primarily selected the BF–BOF route in the 20th century, leading to the 21st century production system. The first set of cases include steel industries in Russia, Ukraine, Brazil and South Africa. The next case study examines the Indian steel industry which selected a combination of EAF/IF (induction furnace) and BF–BOF routes in the 20th century, resulting in a rapid increase in production in the 21st century. The subsequent case study discusses the steel industries in Iran and Egypt that developed rapidly in the 21st century, based on the EAF technology choice equipped with DRIs in the 20th century. The final case study details the steel industries in Vietnam and Indonesia which developed in the 21st century through EAF choice in the 20th century and BF–BOF choice in the 21st century.

Table 4.6. List of case studies

No	Country
1	China
2	Russia
	Ukraine
	Brazil
	South Africa
3	India
4	Iran
	Egypt
5	Vietnam
	Indonesia

Source: Author

Case study 1: BF–BOF-intensive technology choice in the 20th century, followed by a significant increase in steel output in the 21st century

The first case study examines the evolution of the Chinese steel industry. The Chinese steel industry executed BF–BOF-intensive technology choice in the 20th century, resulting in a significant increase in steel production in the 21st century. The substantial economic growth and development of steel-using industries in China in this century generated demand for high value-added steel products, triggering the construction of coastal steelworks equipped with large-scale BF–BOFs.

While China has ancient roots in steelmaking, the Chinese steel industry was underdeveloped until the second half of the 20th century (World Steel Association, 2012, p. 41).[105] When the People's Republic of China was established in 1949, its steel production was very low at 0.158 mmt and concentrated in the northeast region, where Japan developed the industry during its occupation of Manchuria.[106] In the 1950s, the Chinese government began constructing steel mills with assistance from the former Soviet Union. The First Five-Year Plan commenced in 1953 and promoted the expansion of existing steelworks (e.g. Anshan) and the construction of new integrated steelworks (e.g. Baotou and Wuhan).[107] During the Great Leap Forward from 1958 to 1960, increasing steel production activities were carried out, and numerous very small BFs were constructed in many parts of the country. While Shijingshan Iron and Steel Company put into operation the first 30-tonne oxygen top blowing converter in China in 1964 (Shougang, 2019), the full-scale introduction of BOFs in China was in the mid-1970s (Gang, 2000, p. 81).

While the Chinese economy and steel production stagnated during the Cultural Revolution in 1966–1976 (Tang, 2010, p. 2), the Chinese steel industry expanded impressively with the economic reforms of the 1980s, triggering high economic growth and expansion of steel demand and supply in the Chinese steel industry (World Steel Association, 2012, p. 41). Indeed, China's ASU increased from 30.2

[105] The practice of steelmaking is not new, as master artisans in ancient China and India were skilled in steel production (World Steel Association, 2012, p. 7).

[106] This paragraph is based on Tang (2010, p. 2) and Sugimoto (1993, pp. 268–269).

[107] The steel industry has historically been regarded as a key industry in China since the First Five-Year Plan period (METI, 2018, p. 344).

mmt in 1970–1979 to 58.7 mmt in 1980–1989, expanding further to 108.9 mmt in 1990–2000, resulting in Chinese steel firms' BF–BOF-intensive technology choices in the 20th century.

Chinese steel firms started adopting more advanced technology from foreign steel firms and began to accept foreign investment and raw material imports (Tang, 2010, p. 2). Baoshan Iron and Steel (now known as China Baowu Steel Group) constructed a brand-new steel plant at Baoshan near the port of Shanghai in 1978 (World Steel Association, 2012, p. 41). The steel firm established the first large-sized BF (with inner volumes of 4,063 m^3) in collaboration with Japan's Nippon Steel in 1985 in China (Liu et al., 2015 p. 1,147), and its second BF (4,063 m^3) and third BF (4,350 m^3) were put into operation between 1991 and 1994, respectively. BF–BOF-intensive technology choice in the 20th century enabled crude steel output in the Chinese steel industry to double, from 47.0 mmt in 1980–1989 to 97.5 mmt in 1990–2000, leading to China's position as the world's largest steel-producing country since 1996.

In the 21st century, steel demand in the Chinese market has been supported by high economic growth; more specifically, strong demand from steel-using industries.[108] China's steel imports have also seen a rapid increase in line with the growing steel market.[109] China is a vast nation, and there has been a massive demand for steel to develop transportation networks and urban infrastructure, coupled with the need to construct homes and workplaces for the new urban inflow, resulting in a boom in construction. China has become the world's factory, and requires large volumes of steel inputs due to the development of the manufacturing industry. Moreover, the Chinese government implemented a 4 trillion-yuan economic package to support domestic steel demand (METI, 2018, p. 347).

As a result of these strong demands, China's ASU increased from 350.4 mmt in 2001–2009 to 729.7 mmt in 2010–2018, generating further investment in the BF–BOF route, including some coastal steelworks equipped with large-scale production facilities, accelerating industrialisation and urbanisation.[110] While the construction industry has been the largest driver of steel demand, the ratio of the manufacturing industry has been steadily rising (MPI, 2014, p. 3).

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[108] This paragraph is based on Sugimoto (2008, p. 139).

[109] The Chinese automobile industry increased automobile production from 2.1 million units in 2000 to 27.8 million units in 2018 (OICA, 2021a, 2021b). In 2003, steel imports in China reached 43.0 mmt, and China was the world's largest steel importer.

[110] The Chinese steel industry has achieved rapid development since its accession into the World Trade Organisation in 2001 (METI, 2018, p. 344).

Several Chinese steel firms have constructed coastal steelworks equipped with large-scale BF–BOF facilities to meet the growing demand for high value-added products.[111] Therefore, the location of steelworks in the Chinese steel industry has shifted from the tradition of building mills in resource-rich inland regions to coastal areas, where it is more convenient to import raw materials in the 21st century.[112]

Some important coastal steelworks projects were constructed by large Chinese state-owned enterprises (SOEs).[113] For instance, Anshan Iron and Steel Group completed its Yingkou Bayuquan steel plant with two BFs (4,038 m^3) along with three BOFs, slab casters, a plate mill and a hot strip mill in Yingkou City, Liaoning Province in 2009 (OECD, 2011, p. 149). In addition, Shougang Group's Jingtang United Iron & Steel constructed two BFs (5,500 m^3) with three BOFs, three slab casters and facilities for flat products in Tangshan City in Hebei Province in 2009–2010 to produce hot-rolled/cold-rolled coils and galvanised sheets for the manufacturing industry (e.g. automobile and home appliances) (OECD, 2011, p. 213, 2014b, p. 206; Shougang, 2017).[114] Moreover, Baosteel Group's Baosteel Zhanjiang Iron and Steel began operating steelworks with two BFs (5,050 m^3), two BOFs, three slab casters and downstream facilities, including a plate mill, a hot strip mill and cold strip mills at Zhanjiang steelworks in Guangdong Province in 2015–2016 (Baosteel, 2015a, p. 17, 2015b, p. 41, 2016a, p. 11, 2016b, p. 81; OECD, 2014b, p. 161).[115] The steelworks aimed to supply steel products to automobile and home appliance industries in southern China and to export to other regions, such as Southeast Asia (Baosteel, 2015a, p. 20; OECD, 2014b, p. 161).

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[111] Most coastal steelworks are equipped with facilities for flat products and designed to produce high value-added steel products (Sekiguchi et al., 2016, pp. 21–22).

[112] The World Steel Association (2018) noted that 'Gravity of China's steel production has been moving from inland regions to east and coastal areas' (p. 20).

[113] Large Chinese steel firms have the advantages of shipping cheaper seaborne iron ore directly to coastal steelworks, selling to customers nearby or shipping steel overseas (Reuters, 2015).

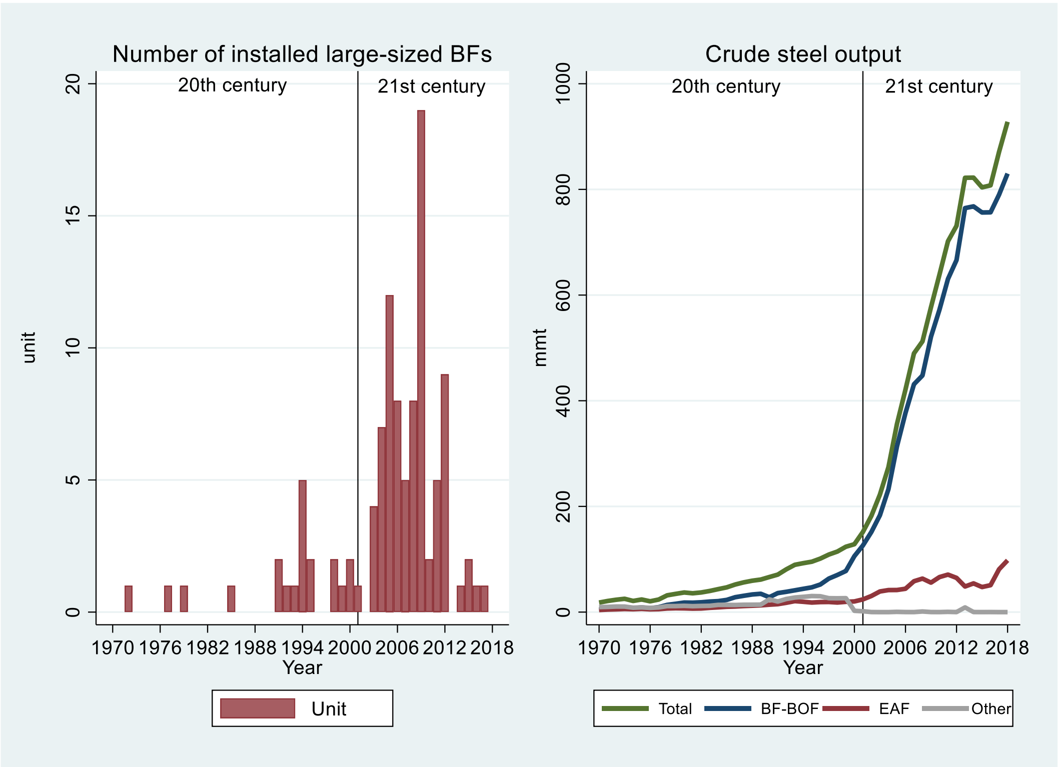
[114] Shougang (2017) summarises some characteristics of coastal steelworks noting that 'The overall technology and equipment of Shougang Jingtang Company reached the world's top level in the 21st century, becoming an internationally-advanced plate production base, a model plant for independent innovation and a symbolic energy-saving and emission-reducing factory for the development of circular economy. With features and advantages of being adjacent to the sea and close to the port, raw materials and products can be transported by sea, which significantly reduces the transport costs. What's more, it also has the shining points of boasting compact process, large-scale equipment, advanced technology, high-end products, recycling economy, clean environment and high-efficiency management; it fully reflects the construction objectives' (para, 5).

[115] China Baowu Steel Group was established through the consolidation and restructuring of Baosteel Group and Wuhan Iron & Steel (Group) in 2016 (China BaoWu Steel Group Corporation, n.d.).

The case of the Chinese steel industry indicates that domestic steel firms made BF–BOF-intensive technology choices in the 20th century, along with steady growth in demand, leading to a rapid increase in steel production in the 21st century. China has experienced a significant increase in steel demand, and this development has also led to growth in ASU and steel imports. In addition to the growth in volume of steel consumption, the industrial structure of the domestic steel market has become more sophisticated, generating the need for coastal steelworks that produce high value-added products.

While the Chinese steel industry initially produced steel with small-scale BF–BOFs, it has upgraded to state-of-the-art technology based on existing technology accumulation. Indeed, the Chinese steel industry has established numerous large-sized BFs (with inner volumes of more than 2,000 m^3) in the 21st century (Figure 4.8, left), contributing to a significant increase in steel production via the BF-BOF route (Figure 4.8, right). A notable issue to bear in mind is that the Chinese steel industry has steadily improved its labour productivity in the 21st century (OECD, 2013a, p. 4).

Figure 4.8 Number of installed large-sized BFs and crude steel output in the steel industry in China (1970–2018)



Source: Author's calculations based on data from CISA (various years) and the World Steel Association (various years)

Case study 2: BF–BOF-intensive technology choice in the 20th century, forming the production system in the 21st century

The second case study focuses on the steel industry in countries that primarily selected the BF–BOF route in the 20th century, leading to the 21st century production system. These include the steel industries of Russia, Ukraine, Brazil and South Africa. Robust steel demand after World War II brought about the construction of large-sized BFs, accelerating industrialisation in these countries.

The steel industry in the Soviet Union (USSR) developed rapidly following World War II, during industrialisation based on the principle of Soviet central planning. Rapid growth in steel demand resulted in technology choice using the BF–OHF route in the initial stage, leading to the BF–BOF route in a later stage of the 20th century. Crude steel output in the Soviet steel industry increased from 12.3 mmt in 1945 to 102.2 mmt in 1967, peaking at 163.0 mmt in 1988 (WV Stahl, various years). As a result, the USSR was the world's largest steel-producing country until its dissolution in 1991.

The Russian steel industry inherited large steelmaking capacities from the Soviet Union. Along with steady growth in steel demand, Soviet steel firms made BF–OHF/BF–BOF-intensive technology choices in the 20th century. Indeed, a number of new integrated steelworks were established in the Soviet steel industry during 1920–1940. For instance, Magnitogorsk Iron and Steelworks began production with its first BF in 1932 and installed two large-sized BFs (2,014 m^3) in 1964–1966. Novolipetsk Steel (NLMK), located in Lipetsk, launched its first BF in 1934, which aided the development of heavy engineering and industrialisation in the central USSR.[116] The steel firm began steel production with BOF in 1966 and installed two large-sized BFs (3,200 m^3) in the 1970s, the largest BFs in the USSR at that time. Downstream technologies were also developed, supported by the 'white goods boom' of the 1980s. Severstal fired up its first BF in 1955 and two large-sized BFs (2,000 m^3, 2,700 m^3) in 1962–1969 using OHF technology and began production with the BOF technology in 1980 (Severstal, 2021). The steel firm installed a large-sized BF (5,580 m^3) at its Cherepovets steelworks in 1986, which was the world's biggest BF at that time (Toda, 1984, p. 5).

The Ukrainian steel industry developed during the economic recovery after World War II. Illich Iron and Steel Works constructed two large-sized BFs (2,002 m^3, 2,300 m^3) in 1962–1973. In addition,

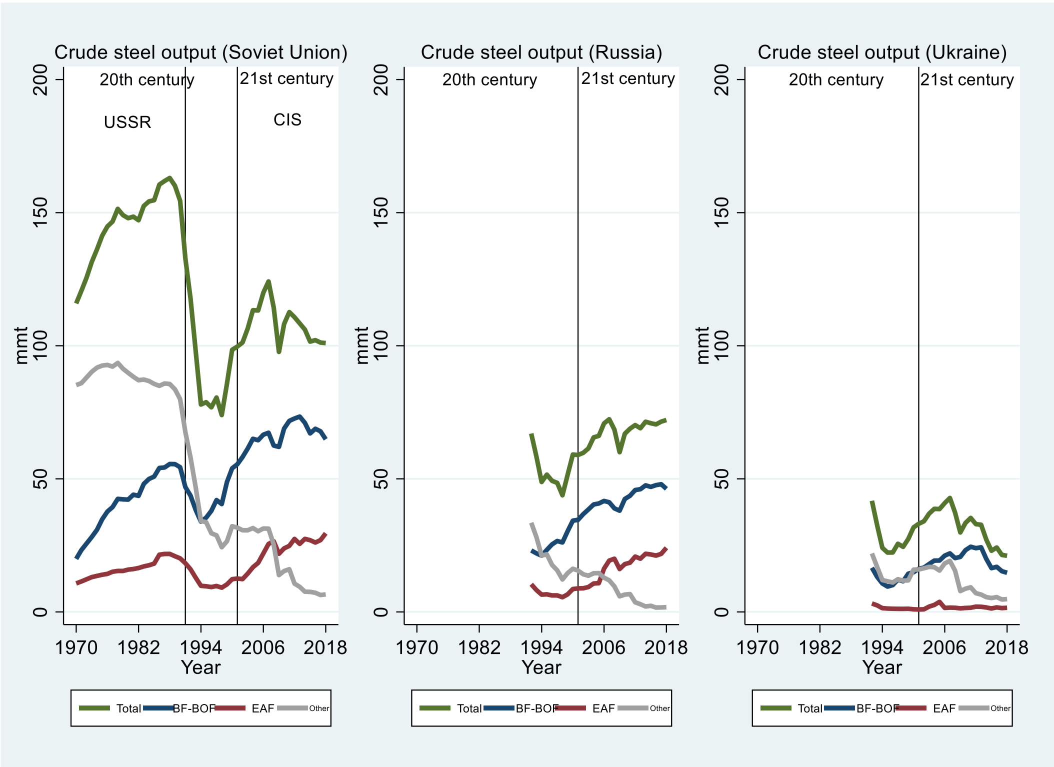
[116] The information on NLMK is based on NLMK (2009).

Kryvorizhstal (now known as ArcelorMittal Kryvyi Rih), located in Kryvyi Rih in the Dnepropetrovsk, began steel production with the first BF in 1934 and installed large-sized BFs (e.g. 2,000 m^3, 2,000 m^3, 2,700 m^3) in the 1960s with BOF and OHF (ArcelorMittal, n.d.-d). In 1974, the steel firm commissioned its large-sized BF (5,000 m^3), which was the world's biggest BF at that time (Toda, 1984, p. 4).

Following the dissolution of the USSR in 1991, the Soviet steel market experienced a significant drop, and steel demand fell more than crude steel output, resulting in a large production and demand gap.[117] Following the collapse of the USSR, integrated steelworks in Russia and Ukraine were privatised, including modernisation of outdated facilities (World Steel Association, 2012, p. 35).

Overall, expansion in the Soviet steel market led to technology choice of the BF–OHF/BF–BOF route in the 20th century (Figure 4.9, left). The BF–BOF route has continued to have a significant role in the steel industries of Russia and Ukraine in the 21st century (Figure 4.9, middle and right).

Figure 4.9 Crude steel output in the steel industries of the Soviet Union, Russia and Ukraine (1970–2018)



Source: Author's calculation based on data from the World Steel Association (various years)

[117] Between 1992 and 1998, crude steel output in the CIS region decreased by 37.2%, while its ASU dropped by 71.5% during the same period.

The Brazilian steel industry developed under the government's policy of heavy industrialisation and import substitution in the wake of World War II (Associação Central Nipo Brasileira, 2011). The modest increase in steel demand along with the government-led industrialisation policy in the Brazilian steel industry resulted in the choice of BF–BOF-intensive technology in the 20th century.

A number of large-scale, state-owned steelworks were established in Brazil between 1945 and 1990 (de Paula, 2021, p. 2). For instance, Companhia Siderúrgica Nacional (CSN) was constructed in 1946 with the first BF, representing an important milestone in the Brazilian steel industry (CSN, 2020; Instituto Aço Brasil, n.d.). In 1976, CSN commissioned a large-sized BF (3,815 m^3) at its Volta Redonda in Rio de Janeiro, which was the largest BF in the domestic steel industry (Toda, 1984, p. 4). Usiminas was constructed in 1958 with technical cooperation from Nippon Steel and other Japanese firms (Nippon Steel Corporation, 2012). The steel firm put a large-sized BF (2,700 m^3) into operation at its Ipatinga steelworks in Minas Gerais in 1974, which was the biggest BF prior to the one commissioned by CSN in 1976 (Toda, 1984, p. 4). Steel demand from the automobile industry had a vital influence on the development of the domestic steel industry due to a high linkage effect, with CSN and Usiminas (including Cosipa) supplying flat products, which contributed to import substitution in the domestic steel industry (Hasegawa, 1993). In the 1970s, Companhia Siderúrgica de Tubarão (CST) (now ArcelorMittal Tubarão) was established in 1976 in Serra in Espirito Santo as a state-controlled joint venture with Kawasaki Steel (now JFE Steel) and Finsider (ArcelorMittal, n.d.-a). The firm was formed as an export-oriented slab-based steelworks (Hasegawa, 1994). The steel firm inaugurated its first BF (3,707 m^3) in 1983 (AIST, 2017, p. 45), which was the largest BF in the domestic steel industry at that time (Toda, 1984, p. 4).

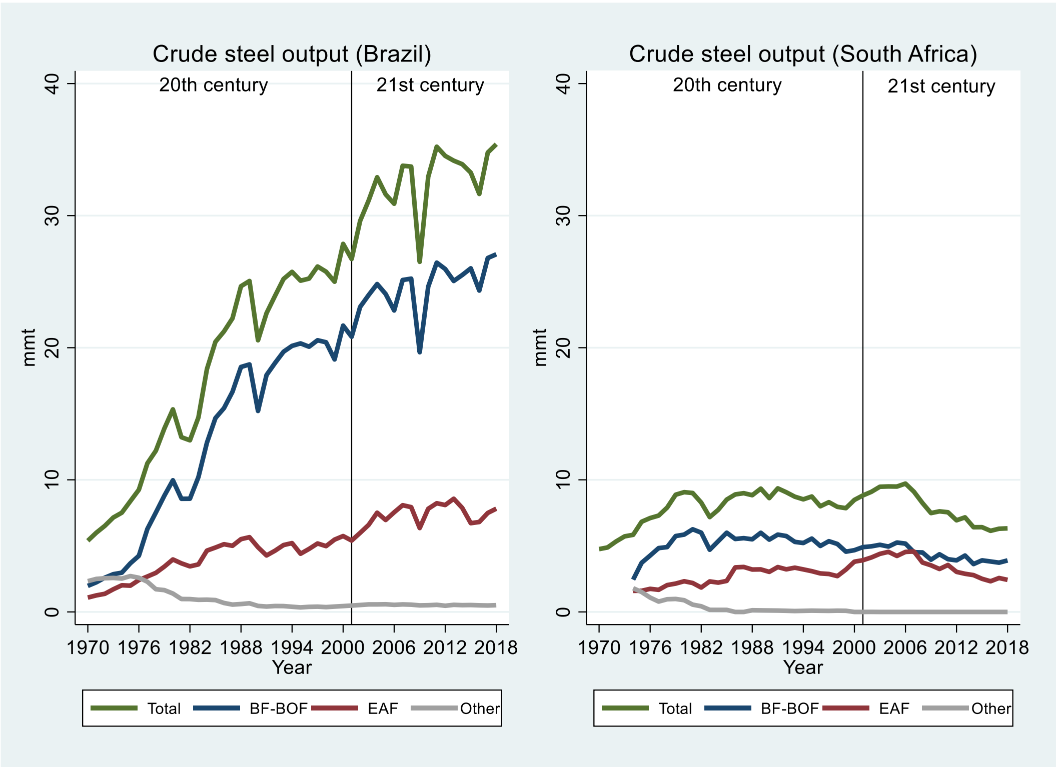
The steel industry has significantly contributed to the economic development and industrialisation of South Africa (Mineral Resources of Republic of South Africa, 2011, p. 1). As with the previous cases, the South African steel industry primarily developed after World War II, leading to BF–BOF technology choice in the 20th century. Iscor (now known as ArcelorMittal South Africa) was established as a SOE to produce steel and steel production began at the Pretoria Works in 1934 with OHF technology (ArcelorMittal, n.d.-e).[118] After World War II, the steel firm constructed an integrated

[118] Iscor was privatised in 1989 (ArcelorMittal, n.d.-e).

steelworks at Vanderbijlpark in Gauteng Province in 1947 in line with growing steel demand and implemented considerable expansion of BOFs in the 1970s to meet the demand for flat products (ArcelorMittal, n.d.-e). Moreover, the company constructed integrated steelworks at Newcastle steelworks in Kwazulu Natal Province in 1974 (ArcelorMittal, n.d.-c). In the 20th century, the steel firm fired up two large-sized BFs at Vanderbijlpark steelworks (2,007 m^3) and Newcastle steelworks (2,017 m^3). ArcelorMittal South Africa has become one of the largest steel firms on the African continent, supplying more than 60% of the steel used in South Africa and exporting the rest to sub-Saharan Africa and elsewhere (ArcelorMittal, n.d.-b).[119]

Overall, the market expansion in Brazil and South Africa led to technology choice in the BF–BOF route in the 20th century, leading to the production systems of the 21st century, although steel production in South Africa appears to have stagnated in this century (Figure 4.10).

Figure 4.10 Crude steel output in the steel industries of Brazil and South Africa (1970–2018)



Source: Author's calculation based on data from the World Steel Association (various years)

[119] ArcelorMittal South Africa produces steel, from long to flat products. It operates similarly to steel firms in advanced countries, with a flat products ratio of 60%–70% (Hori, 2013, p. 160).

Case study 3: Technology choice using a combination of EAF and BF–BOF routes in the 20th century

The third case study focuses on the Indian steel industry. The Indian steel industry selected a combination of EAF/IF and BF–BOF routes in the 20th century, leading to a rapid increase in steel production in the 21st century. Robust steel demand from steel-using industries—owing to high economic growth—has led to capacity growth in many domestic steel firms.

While India, like China, also has ancient roots in steelmaking (World Steel Association, 2012, p. 41), its history in the modern steel industry can be traced back to the establishment of the Tata Iron and Steel company (now known as Tata Steel) in 1907 (Tata Steel, 2011). Following independence in 1947, the Indian government developed the domestic steel industry under the state's initiative, while promoting an import substitution industrialisation policy and allowing large-scale investments limited to only SOEs (Ministry of Steel of India, 2021, p. 10).

The development of the Indian steel industry accelerated after the economic liberalisation of 1991, which induced high economic growth and expansion of steel demand (Ministry of Steel of India, 2021, pp. 10–11). India's ASU expanded from 8.6 mmt in 1970–1979 and 15.1 mmt in 1980–1989 to 24.5 mmt in 1990–2000, stimulating Indian steel firms' EAF/IF and BF–BOF choices in the 20th century.

In the 1980s, the state-owned Steel Authority of India Limited (SAIL) installed four large-sized BFs (2,000 m^3) at Bokaro steelworks and a large-sized BF (2,000 m^3) at Bhilai steelworks, and another SOE, Rashtriya Ispat Nigam Limited (RINL), also known as Vizag Steel, commissioned two large-sized BFs (3,200 m^3) at Visakhapatnam steelworks in the 1990s. With the opening of the economy, the government permitted investment from foreign firms, abolishing limitations of large investment to SOEs, encouraging private firms to enter the market (Ministry of Steel of India, 2021, pp. 10–11).

While the BF–OHF route was the primary production route in the Indian steel industry until the mid-1980s, BF–BOF and the EAF routes have grown faster since that time. With steady growth in BF–BOF and the EAF routes, crude steel output in the domestic steel industry increased from 11.8 mmt in 1980–1989 to 21.1 mmt in 1990–2000.

The Indian steel market has experienced a significant increase in steel demand in the 21st century, supported by high economic growth and strong demand from steel-using industries, especially construction and infrastructure, major drivers of its steel consumption (Steel Recycling Research, 2014, p. 8). India's ASU expanded further from 45.2 mmt in 2001–2009 to 86.6 mmt in 2010–2018, triggering a massive steelmaking expansion in the EAF/IF and BF–BOF routes in the 21st century.

Along with significant growth in demand, several private steel firms have invested in the EAF route equipped with DRIs, forming a DRI-based integrated production system. For instance, Essar Steel (now known as AM/NS India) commissioned DRIs by coal and gas, a BF, EAFs, thin slab casters and hot strip mills at Hazira steelworks in Gujarat in the 21st century (Nippon Steel Corporation, 2019, p. 6). In addition, Jindal Steel and Power Limited (JSPL) inaugurated two 100-tonne EAFs at the Raigarh plant in Chhattisgarh in 2005 and a 250-tonne EAF (India's largest EAF) at the Angul plant in Odisha in 2013 (JSPL, 2015, p. 5; SMS Group, 2013) and a DRI plant in 2015 (Midrex, 2019, p. 13).

There have also been numerous entries in IF steel firms in the 21st century.[120] IFs are very small-scale EAFs that have been developed in the Indian steel industry since the 1980s (Sato, 2014, p. 31). The IF route has played a key role in meeting the local demand for construction steel due to low cost, flexibility and expedient small-lot response (Steel Recycling Research, 2015, pp. 3–4).[121]

Apart from the EAF/IF route, significant increases in production capacity have emerged in the BF–BOF route, in line with the National Steel Policy launched in 2005 and 2017 (Ministry of Steel of India, 2005, 2017).[122] For instance, SAIL inaugurated a number of large-sized BFs at Rourkela Steel Plant (4,060 m^3) in Odisha in 2013, IISCO Steel Plant (4,160 m^3) in West Bengal in 2014 and Bhilai Steel Plant (4,060 m^3) in Chhattisgarh in 2018 (SAIL, 2013, 2014, 2018). In addition, RINL fired up a new BF (3,800 m^3) at Visakhapatnam steelworks in 2012 (RINL, 2012).

Private steel firms have also heavily invested in the BF–BOF route to meet growing steel demand. Tata Steel acquired Anglo-Dutch steel firm Corus in 2007 (Tata Steel, 2007) and is now the

[120] The Ministry of Steel of India (2002, p. 4) estimated that 657 IF units were in operation in 2000–2001, and this number had risen to 1,128 units as of March 2016 (Ministry of Steel of India, 2017, p. 20).

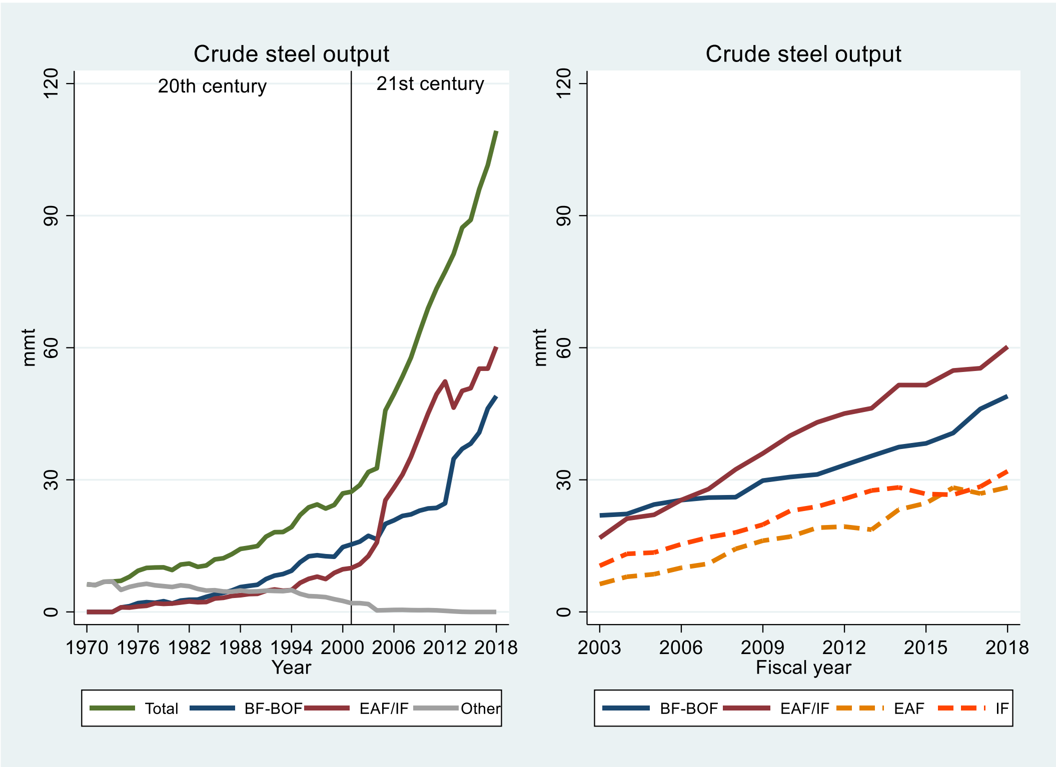
[121] It is important to note that IF-based firms in the Indian steel industry rarely export. Generally, traditional integrated steel firms and new integrated steel firms export steel products (Sato, 2006, p. 237). Therefore, it is reasonable to assume that a division of labour has been established between integrated firms and IF/EAF-based firms; the former produces steel that meets international standards, whereas the latter supplies steel products to meet construction demand in the domestic market.

[122] The Indian steel industry aims to expand its steelmaking capacity from 122 mmt in 2015–2016 to 300 mmt by 2030–2031, based on the assumption that India's steel demand will grow threefold, reaching 230 mmt by 2030–2031 (Ministry of Steel of India, 2017, p. 23).

largest steel firm in India. The firm commissioned two large-sized BFs (3,814 m^3) at its Jamshedpur steelworks in Jharkhand in 2008–2011 (Paul Wurth, 2012, p. 2; Tata Steel, 2008).[123] Tata Steel also constructed Kalinganagar steelworks in Odissa with a BF (4,330 m^3), two BOFs, a slab caster and a hot strip mill in 2015–2016 (Tata Steel, 2016, 2017, p. 5). JSW Steel installed two large-sized BFs (4,019 m^3) at its Vijayanagar Works in Karnataka between 2009 and 2011, which were the largest BFs in the Indian steel industry at that time (JSW Steel, 2010, p. 2, 2012, p. 44; Primetals Technologies, 2020b, p. 2; Siemens VAI, 2010, p. 35).

Overall, technology choice in a combination of the EAF/IF and BF–BOF routes in the 20th century has led to significant increases in production in the 21st century. While the BF–BOF route was the primary production route in the 20th century, steel output via the EAF route has accelerated in the 21st century (Figure 4.11, left) with a steady increase in vital domestic IF steel output (Figure 4.11, right).

Figure 4.11 Crude steel output in the steel industry in India (1970–2018)



Source: Author's calculation based on data from World Steel Association (various years) and the Ministry of Steel of India (various years)

[123] While Tata Steel constructed its first BF in India in 1911 and commissioned six BFs between 1912 and 1992 (Tata Steel, 2011), they were not large-sized BFs.

Case study 4: EAF-intensive technology choice in the 20th century

The fourth case study focuses on the steel industries of Iran and Egypt which developed rapidly in the 21st century, based on the EAF technology choice equipped with DRIs in the 20th century.

The development of the Iranian steel industry dates back to the mid-1960s (JETRO, 2018, p. 45), when the first private steel firm, Iran National Steel Industries Group, was established (MEsteel.com, n.d.). Esfahan Steel, the first large state-owned BF–BOF-based firm, was commissioned in 1971 (Esfahan Steel, 2021), followed by two EAF-based state-owned firms, established in the 1990s, Khouzestan Steel Company, which was formed based on Ahvaz Steel Complex and Kavian Heavy Plate Mill, and Mobarakeh Steel Company, another SOE, was formed to meet the domestic steel demand (IMIDRO, 2016, p. 38; MEsteel.com, n.d.). As a result, steel production via the EAF route had grown much faster than the BF–BOF route since the mid-1990s.

Iran's steel market has further developed in line with growing steel demand in the 21st century, which has led to significant investment in the EAF route. Iran's ASU expanded from 6.6 mmt in 1990–2000 to 14.9 mmt in 2001–2009, further increasing to 22.0 mmt in 2010–2018.

To fill the gap between steel production and demand, numerous EAF projects equipped with DRIs have been announced in the Iranian steel industry based on the availability of natural gas and iron ore (OECD, 2015a, p. 14; Steel Recycling Research, 2021, p. 6).[124] Mobarakeh Steel Company, located in Isfahan, is now one of the largest steel firms in the Middle East and Northern Africa (IMIDRO, 2016, p. 38). The firm increased production capacity in 2009–2011 through expansion projects involving Saba and Hormozgan Steel Complexes, equipped with DRIs and EAFs (OECD, 2011, pp. 566–581). As a result of investment in the EAF route, crude steel output in the Iranian steel industry increased from 9.0 mmt in 2001–2009 to 16.8 mmt in 2010–2018.

The landmark in the Egyptian steel industry can be traced back to the establishment of the state-owned Egyptian Iron and Steel Company (known as EISCO or Hadisolb) in 1957 (Egyptian Iron and Steel Company, n.d., p. 8). Between the 1970s and 1980s, high economic growth resulted in the expansion of steel demand in the Egyptian market, leading to the establishment of DRI–EAF-based

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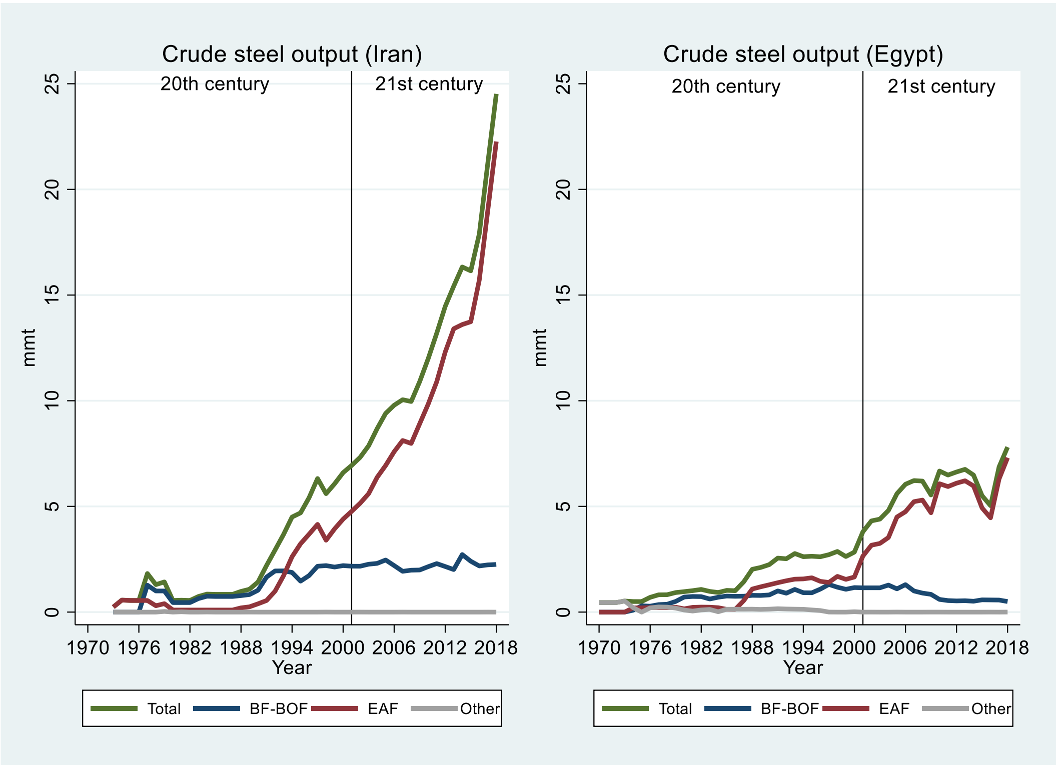
[124] The Iranian government aims to increase steelmaking capacity in the Iranian steel industry to 55 mmt by 2025 (IMIDRO, 2016, p. 30; OECD, 2015a, p. 14) and to become a net steel exporter after achieving self-sufficiency (Sekiguchi et al., 2016, p. 20).

Alexandria National Iron and Steel Company (now known as Ezz Steel) in the 1980s (Ezz Steel, 2021a; JICA, 1988, pp. 1–2).

Egypt's steel market has developed in the 21st century, triggering expansion in EAF steelmaking capacity. The country's ASU increased from 6.0 mmt in 2001–2009 to 10.6 mmt in 2010–2018, raising its steel output in this century. Ezz Steel, located in Cairo, is the largest Egyptian steel firm. Between 1998 and 2003, Ezz Steel commissioned three plants based on the EAF route: Sadat City plant, Suez plant and EZDK flat steel plant (Ezz Steel, 2021b). Egypt's second-largest producer, Beshay steel, has also recently installed two EAFs and a DRI at its Egyptian Sponge Iron and Steel plant (Beshay Steel, 2021; Midrex, 2016, p. 4). As a result, crude steel output in the Egyptian steel industry rose from 2.6 mmt in 1990–2000 to 6.5 mmt in 2010–2018.

Overall, technology choice in the EAF route in the 20th century has contributed to increasing crude steel output in the steel industries of Iran and Egypt in the 21st century, although Iran's steel industry has evolved much faster than Egypt's (Figure 4.12).

Figure 4.12 Crude steel output in the steel industries of Iran and Egypt (1970–2018)



Source: Author's calculation based on data from the World Steel Association (various years)

Case study 5: EAF-intensive technology choice in the 20th century and the growing role of the BF–BOF route in the 21st century

The fifth and final case study examines the steel industries of Vietnam and Indonesia that have developed in the 21st century. While each country selected the EAF route in the 20th century, the BF–BOF route has had an increasingly significant position in steel production in the 21st century.

The development of the Vietnamese steel industry dates back to the construction of the Thai Nguyen Iron and Steel Corporation (TISCO) in northern Vietnam with small-scale BFs that was commissioned in the 1960s.[125] Since the 1960s, international affairs and delays in technology development in the domestic steel industry led to a downturn in TISCO's production activities. In southern Vietnam, several EAFs had been constructed since the late 1960s; thus, the south had a larger production capacity than the north. Domestic production was extremely small until a few years following the introduction of the Doi Moi policy in 1986.

In the 21st century, the Vietnamese steel market has experienced a significant expansion in steel demand; Vietnam's ASU increased from 1.3 mmt in 1990–2000 to 7.4 mmt in 2001–2009 and further expanded to 17.9 mmt in 2010–2018, signalling massive capacity expansion.

The Vietnamese steel industry has relied on imported billets, thus many EAF projects have been announced (Kawabata, 2007, p. 177). Southern Steel Corp, a subsidiary of state-owned VNSteel, commissioned an EAF in Ba Ria-Vung Tau Province in 2006 (OECD, 2011, p. 408). The role of private steel firms has expanded, and large-scale projects funded by foreign capital have been announced (Kawabata, 2007, pp. 186–193). Formosa Ha Tinh Steel Corporation (FHS), a joint venture between Formosa Plastic Group (Taiwan), China Steel Corporation (Taiwan) and JFE Steel Corporation (Japan), fired up two BFs (4,350 m^3) with three BOFs, a billet caster, a bloom caster, two slab casters, a wire rod mill and a hot strip mill in Ha Tinh Province in 2017–2018 (CISDI USA, 2017, p. 3, 2018, p. 3; FHS, n.d.-a, n.d.-b; Primetals Technologies, 2016, 2017; Steel Plantech, 2017). As a result, crude steel output in the Vietnamese steel industry increased steadily, from 1.3 mmt in 2001–2009 to 7.4 mmt in 2010–2018.

The establishment of state-owned Krakatau steel in 1970 was an important milestone in the Indonesian steel industry (Krakatau Steel, 2017, p. 6). The firm established an integrated production

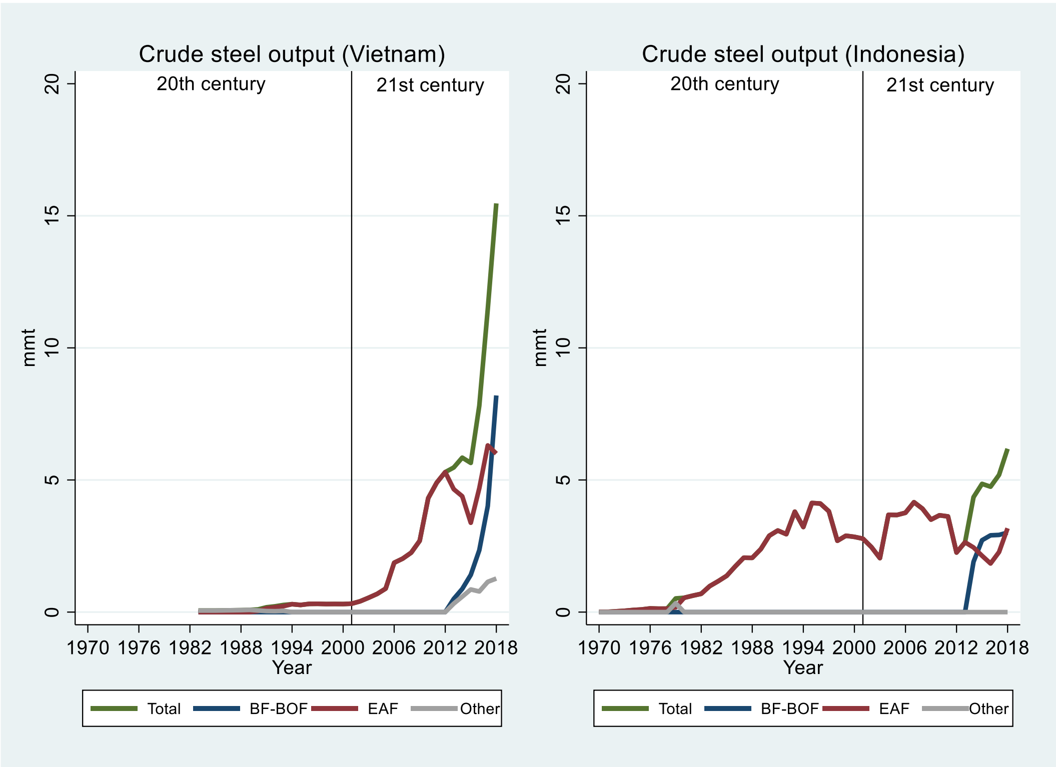
[125] This paragraph is based on Kawabata (2003b, pp. 176–178).

system using the DRI–EAF route to produce flat steel products (Krakatau Steel, 2017, pp. 8–9). The Indonesian steel market has experienced rapid growth in steel demand in the 21st century (OECD, 2013c, p. 2). The nation's ASU increased from 7.5 mmt in 2001–2009 to 14.8 mmt in 2010–2018; however, growing imports have stagnated domestic production (Sato Yuri, 2008, pp. 232–233).

The number of investments in the Indonesian steel industry since 2000 seems to be lower than that of Vietnam. Regarding the BF–BOF route, Krakatau POSCO, a joint venture between South Korea's largest steel firm POSCO and Indonesia's SOE Krakatau Steel, constructed its first BF (3,800 m^3), a BOF, a slab caster and a plate mill at the Cilegon steelworks in Banten Province in 2013 (Krakatau POSCO, 2019; POSCO, 2013, p. 5). It was the first large-scale integrated steelworks in the ASEAN steel industry (OECD, 2013c, p. 7; Sekiguchi et al., 2016, p. 24).

Technology choice of the EAF route in the 20th century formed the development pathways of the steel industries in Vietnam and Indonesia (Figure 4.13), and BF–BOF technology choice in the 21st century has contributed to the further steel industry development in both nations.

Figure 4.13 Crude steel output in the steel industries of Vietnam and Indonesia (1970–2018)



Source: Author's calculation based on data from the World Steel Association (various years)

4.6.2 Summary of case study examples of technology choices in major non-OECD steel-producing countries

The above case studies provided detail on the technology pathways in major non-OECD steel-producing countries, and Table 4.7 summarises the steel supply and demand evolution for major non-OECD countries during the 20th and 21st centuries. The key inquiries are i) whether steel production grew in the 20th or 21st centuries, ii) whether BF–BOF or EAF routes contributed to that growth and iii) how the gap between demand and production evolved.

Some major non-OECD steel-producing countries experienced significant increases in steel production in the 21st century, with huge differences emerging between China and all other major non-OECD steel-producing countries. Technology choice patterns were also found to be far from homogeneous across major non-OECD steel-producing countries.

The BF–BOF route has played a vital role in some major non-OECD steel-producing countries. Crude steel output in the Chinese steel industry increased at an unprecedented pace and experienced significant growth in the 21st century due to BF–BOF-intensive technology choice in the 20th century, resulting in a significant increase in its crude steel output in this century.

Technology choice of the BF–BOF route also contributed to developing the steel industries of a number of countries, including Russia, Ukraine, Brazil and South Africa in the 20th century. It is reasonable to assume that the steel industries in Russia and Ukraine experienced rapid development in steel production in the 20th century, given that the USSR was the world's largest steel-producing country until its dissolution in 1991. The steel industries of Brazil and South Africa also chose the BF–BOF route in the 20th century, and this technology has continued to have an important role in the 21st century.

Meanwhile, other major non-OECD steel-producing countries made EAF-intensive technology choices. The Indian steel industry has also demonstrated a considerable increase in steel production in the 21st century. While the BF–OHF route had been the primary production route until the mid-1980s, EAF/IF and the BF–BOF routes have grown more rapidly than the production route since then. In the 21st century, the EAF/IF route has become increasingly significant; thus, India has become an EAF-based country.

The EAF route has also been important to other major non-OECD steel-producing countries. The steel industries in Iran and Egypt have both experienced steady increases in crude steel output, supported by technology choice of the DRI–EAF route in the 20th century and the continuation of the process in the 21st century, although the former has grown much faster than the latter. While the steel industries of Vietnam and Indonesia chose the EAF route in the previous century, BF–BOF technology choice in this century has helped to increase steel production.

Some major non-OECD steel-producing countries have narrowed the gap between crude steel output and ASU (i.e. domestic demand), which is closely related to export capacity. For instance, steel production in the Chinese steel industry increased at a much higher pace than its domestic demand in the 21st century, which is assumed to have contributed to increasing the capacity for exports.

The production/demand gap has been large in the steel industry in some major non-OECD countries (e.g. Russia, Ukraine, Brazil and South Africa) since the 20th century. This gap has widened in the steel industries of Russia and Ukraine, caused by the steel market collapse following the dissolution of the Soviet Union in 1991. The production/demand gap remained considerable for the steel industries in Brazil and South Africa since the 20th century.

While ASU had exceeded crude steel output in the Indian steel industry, the latter has surpassed the former in recent years. In contrast, some other major non-OECD steel-producing countries (e.g. Iran, Egypt, Vietnam and Indonesia) has been unable to keep up with domestic demand in the 21st century.[126]

Overall, these case study examples suggest a development pattern from market expansion and technology choice to production expansion; thus, it is important to assess whether production expansion leads to improvement in comparative advantage and international competitiveness.

[126] Nevertheless, crude steel output in the Iranian steel industry surpassed its ASU in 2018.

Table 4.7. Summary of the supply and demand for major non-OECD steel-producing countries

		1970–1979 (mmt)			A				
		ASU	Production	Gap (pro-asu)	BF–BOF	EAF	Other	BF–BOF	EAF
20th century	China	30.2	24.3	-5.9	9.0	5.6	9.7	-	-
	Soviet Union	135.4	137.5	2.1	33.2	13.7	90.6	-	-
	Russia	-	-	-	-	-	-	-	-
	Ukraine	-	-	-	-	-	-	-	-
	Brazil	10.2	8.8	-1.4	4.3	2.1	2.3	-	-
	South Africa	5.8	7.3	1.6	4.3	1.8	1.2	-	-
	India	8.6	9.1	0.5	1.9	1.4	5.9	-	-
	Iran	3.9	0.9	-3.0	0.5	0.5	0.0	-	-
	Egypt	1.2	0.7	-0.5	0.3	0.2	0.2	-	-
	Vietnam	-	-	-	-	-	-	-	-
	Indonesia	1.3	0.1	-1.2	0.0	0.1	0.0	-	-
		1980–1989 (mmt)			B			B - A	
		ASU	Production	Gap (pro-asu)	BF–BOF	EAF	Other	BF–BOF	EAF
	China	58.7	47.0	-11.7	24.5	9.5	13.0	**15.6**	**3.8**
	Soviet Union	157.7	155.1	-2.7	49.8	18.7	86.5	**16.6**	**5.1**
	Russia	-	-	-	-	-	-	-	-
	Ukraine	-	-	-	-	-	-	-	-
	Brazil	12.5	18.8	6.3	13.4	4.6	0.9	**9.1**	**2.5**
	South Africa	5.8	8.6	2.7	5.7	2.6	0.3	**1.4**	**0.8**
	India	15.1	11.8	-3.2	3.8	2.9	5.1	**2.0**	**1.5**
	Iran	4.5	0.8	-3.8	0.7	0.1	0.0	**0.2**	**-0.3**
	Egypt	2.8	1.3	-1.5	0.7	0.4	0.1	**0.4**	**0.2**
	Vietnam	0.2	0.1	-0.1	0.0	0.0	0.1	-	-
	Indonesia	2.8	1.4	-1.5	0.0	1.4	0.0	**0.0**	**1.3**
		1990–2000 (mmt)			C			C - B	
		ASU	Production	Gap (pro-asu)	BF–BOF	EAF	Other	BF–BOF	EAF
	China	108.9	97.5	-11.4	55.0	18.3	24.3	**30.4**	**8.8**
	Russia	27.7	53.1	25.4	25.8	7.2	20.1	-	-
	Ukraine	11.3	28.0	16.8	12.6	1.6	13.9	-	-
	Brazil	14.2	24.8	10.6	19.5	5.0	0.4	**6.0**	**0.4**
	South Africa	4.7	8.5	3.8	5.3	3.2	0.1	**-0.4**	**0.5**
	India	24.5	21.1	-3.3	10.6	6.5	4.0	**6.8**	**3.7**
	Iran	6.6	4.5	-2.1	1.9	2.6	0.0	**1.2**	**2.5**
	Egypt	4.2	2.6	-1.6	1.0	1.5	0.1	**0.3**	**1.1**
	Vietnam	1.3	0.3	-1.0	0.0	0.2	0.0	**0.0**	**0.2**
	Indonesia	5.2	3.3	-1.9	0.0	3.3	0.0	**0.0**	**2.0**
21st century		2001–2009 (mmt)			D			D - C	
		ASU	Production	Gap (pro-asu)	BF–BOF	EAF	Other	BF–BOF	EAF
	China	350.4	354.1	3.7	309.3	44.3	0.4	**254.4**	**26.0**
	Russia	35.0	64.9	29.9	39.0	13.4	12.5	**13.2**	**6.1**
	Ukraine	6.9	36.9	30.0	19.3	1.8	15.8	**6.7**	**0.3**
	Brazil	20.8	30.8	9.9	23.3	6.9	0.5	**3.8**	**2.0**
	South Africa	5.6	9.0	3.4	4.8	4.2	0.0	**-0.4**	**1.0**
	India	45.2	43.4	-1.8	19.2	23.3	0.9	**8.6**	**16.7**
	Iran	14.9	9.0	-5.9	2.2	6.8	0.0	**0.3**	**4.2**
	Egypt	6.0	5.2	-0.8	1.1	4.1	0.0	**0.1**	**2.6**
	Vietnam	7.4	1.3	-6.1	0.0	1.3	0.0	**0.0**	**1.1**
	Indonesia	7.5	3.3	-4.1	0.0	3.3	0.0	**0.0**	**0.0**
		2010–2018 (mmt)			E			E - D	
		ASU	Production	Gap (pro-asu)	BF–BOF	EAF	Other	BF–BOF	EAF
	China	729.7	791.8	62.2	726.1	64.7	1.1	**416.7**	**20.4**
	Russia	46.1	70.2	24.0	46.0	20.9	3.2	**7.1**	**7.5**
	Ukraine	5.7	27.9	22.3	19.9	1.6	6.4	**0.6**	**-0.2**
	Brazil	26.3	34.0	7.7	25.8	7.7	0.5	**2.5**	**0.8**
	South Africa	5.7	6.8	1.1	3.9	2.8	0.0	**-0.9**	**-1.4**
	India	86.6	87.1	0.5	35.3	51.7	0.1	**16.1**	**28.4**
	Iran	22.0	16.8	-5.2	2.3	14.5	0.0	**0.1**	**7.7**
	Egypt	10.6	6.5	-4.1	0.6	5.9	0.0	**-0.5**	**1.8**
	Vietnam	17.9	7.4	-10.6	1.9	4.9	0.6	**1.9**	**3.6**
	Indonesia	14.8	4.2	-10.6	1.5	2.7	0.0	**1.5**	**-0.7**

Source: Author's calculation based on data from the World Steel Association (various years)

4.7 Country-Level Analysis (The First Two Decades of the 21st Century)

4.7.1 Characteristics of each steel industry by groups based on case studies

The previous section investigated technology pathways in major non-OECD steel-producing countries from the second half of the 20th century to the first two decades of the 21st century. This section examines their evolution of comparative advantage and international competitiveness in the first two decades of the 21st century.

Before conducting an analysis of product mapping, it is crucial to classify major non-OECD steel-producing countries based on the case study results since the classification could provide a more comprehensive understanding of the links between technology choice and export performance, such as comparative advantage and international competitiveness in the steel industry. Major non-OECD steel-producing countries can be divided into two groups: (I) BF–BOF-based countries and (II) EAF-based countries. Furthermore, the two groups can be further categorised into five groups. Table 4.8 summarises the characteristics of each steel industry by groups based on the case studies presented.

First, the steel industry in Group I-1, the Chinese steel industry, made BF–BOF-intensive technology choice in the 20th century and experienced a significant increase in steel output in the 21st century. Second, the steel industry in Group I-2 includes Russia, Ukraine, Brazil and South Africa. The key characteristic of the steel industries in these countries is BF–BOF-intensive technology choice in the 20th century, forming the current production system. Third, the steel industry in Group II-1 is the Indian steel industry, which selected combinations of EAF/IF and BF–BOF routes in the 20th century and rapidly increased steel production in the 21st century. Fourth, Group II-2's steel industry selected the EAF route in the 20th century and steadily increased steel output in the 21st century, including the Iranian and Egyptian steel industries. Finally, the steel industry in Group II-3 primarily selected the EAF route in the 20th century, but the BF–BOF route had an increasingly important role in the 21st century, and included the steel industries of Vietnam and Indonesia.

Table 4.8. Characteristics of each steel industry by groups based on case studies

Group		Country	Characteristics
Broad	Medium		
I (BF–BOF-based)	I-1	China	• BF–BOF-intensive technology choice in the 20th century, followed by a significant increase in steel production in the 21st century
	I-2	Russia	• BF–BOF-intensive technology choice in the 20th century
		Ukraine	
		Brazil	
		South Africa	
II (EAF-based)	II-1	India	• Combination of EAF/IF and BF–BOF routes in the 20th century and rapid growth in steel output in the 21st century
	II-2	Iran	• EAF-intensive technology choice in the 20th century and steady increase in steel output in the 21st century
		Egypt	
	II-3	Vietnam	• EAF-intensive technology choice in the 20th century and the growing role of the BF–BOF route in the 21st century
		Indonesia	

Source: Author

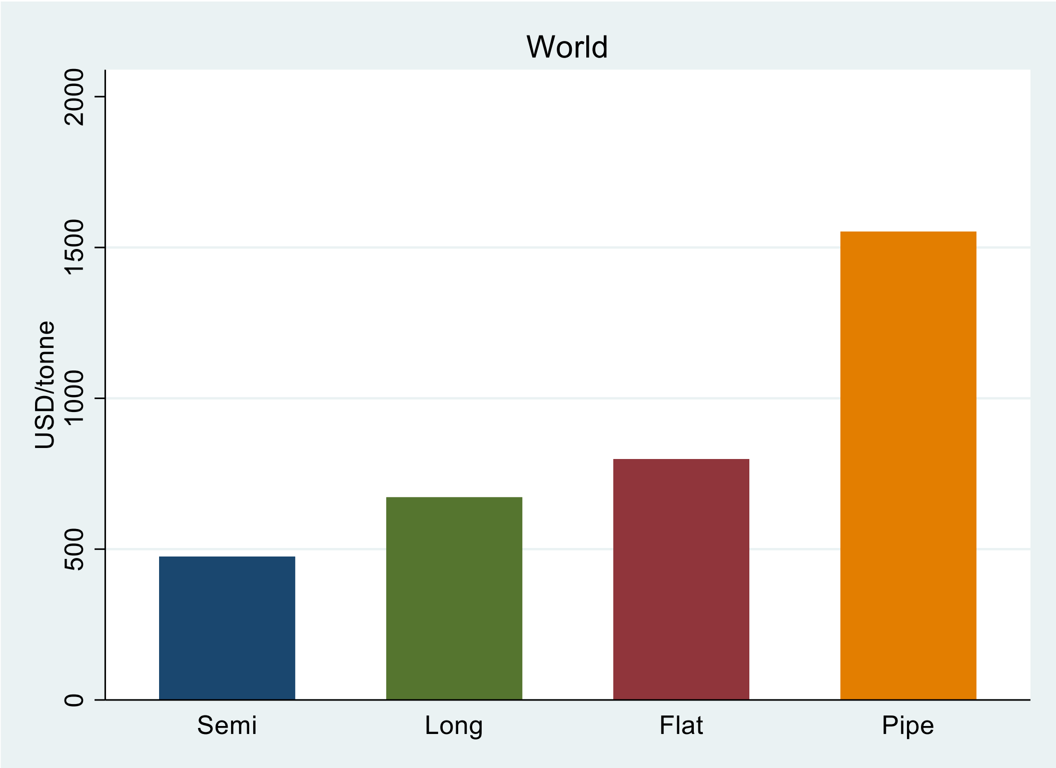
4.7.2 The values of steel products at a broad level

It is also critical to illustrate the values of steel products at a broad level to expand the understanding of the development of comparative advantage and international competitiveness in major non-OECD steel-producing countries in the 21st century at the product level. Examining the unit value of steel exports (nominal sales divided by tonnes of steel exported) could provide useful information to determine values across steel products in the global steel industry.

Figure 4.14 depicts world export unit values in 2001–2018, indicating that steel prices differ widely across types of steel products. Export unit values increase in the order of ingots/semi-finished products, long products, flat products and pipe and tube products. In this chapter, ingots/semi-finished steel products and long products are used as a proxy for low value-added segments, whereas flat products and pipe and tube products are proxied for high value-added segments.

The differences in the unit values of each steel product category will offer a clearer understanding of the development of the product mapping of major non-OECD steel-producing countries at the product level.

Figure 4.14 Export unit values (2001–2018)



Source: Author's calculations based on data from the ITC (2021)

4.7.3 Product mapping analysis (2001–2018)

It is crucial to assess the development of the steel industry in non-OECD countries using the results of analyses in this chapter thus far and the analysis of product mapping to analyse whether they developed in the proposed order of i) market expansion, ii) technology choice and productivity improvement, iii) production expansion and productivity improvement, iv) acquisition of comparative advantage, v) improvement of international competitiveness and vi) sophistication and diversification of the export structure.

The critical question when analysing product mapping in the steel industry is whether major non-OECD steel-producing countries have strengthened international competitiveness while acquiring comparative advantage for total steel products (i.e. the whole steel industry). Figure 4.15 presents a product mapping of total steel products from 2001–2003 to 2016–2018, suggesting that countries in Group I have higher RSCA and TBI values than Group II. This indicates that BF–BOF-intensive technology choice is more likely to lead to a higher degree of comparative advantage and international competitiveness than EAF-intensive choice.

Among the steel industries in Group I, China (Group I-1) has been the world's largest steel-producing country since 1996; however, its position in product mapping was D (comparative disadvantage/net import) in 2001–2003. The Chinese steel industry has improved RSCA and TBI values since 2004–2006, and its position has now advanced to A (comparative advantage/net export) since 2013–2015. This suggests that the Chinese steel industry has acquired a comparative advantage and strengthened international competitiveness within the whole steel industry in the 21st century, supported by strong capacity expansion in the BF–BOF route. This tendency also suggests that the acquisition of comparative advantage and international competitiveness can take time, given that China was already the world's largest steel-producing country in 2001–2003, but its position was ranked as D.

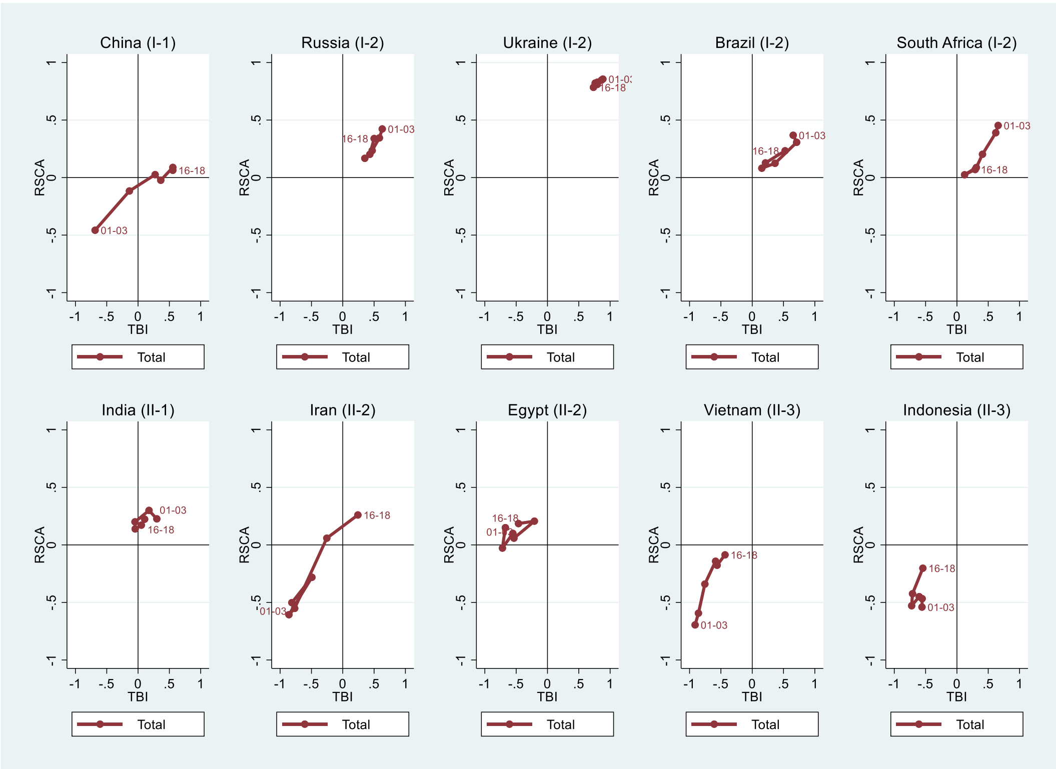
The positions of the steel industries in Group I-2 (Russia, Brazil, Ukraine and South Africa) have remained stable (A) since 2001–2003, suggesting that they have maintained a comparative advantage and international competitiveness within the whole steel industry in this century.

Turning to Group II, the Indian steel industry (Group II-1) witnessed only slight changes in RSCA and TBI values from 2001–2003 to 2016–2018. Nevertheless, its steel industry appears to have gained a comparative advantage and international competitiveness within the whole steel industry in recent years, albeit marginally.

Within Group II-2, the Iranian steel industry has seen a rapid increase in RSCA and TBI values since 2013–2015 and ranked in an A position in 2016–2018, reflecting heavy investments of Iranian steel firms in the EAF route. This indicates that the Iranian steel industry has gained a comparative advantage and improved international competitiveness within the whole steel industry in recent years. In contrast, the Egyptian steel industry has remained at a B (comparative advantage/net import), suggesting that steel products have an important role in the country's trade, but the development of steel demand/imports may have affected the evolution of its TBI values.

Although the positions of the Vietnamese and Indonesian steel industries (Group II-3) have remained D since the early 2000s, their RSCA and TBI values are heading to B. This indicates that the steel industries in these countries are beginning to improve comparative advantage, and the technology choice of the BF–BOF route in the 21st century may have impacted this development. Both nations still lack international competitiveness, and their comparative advantage is inadequate; thus, it may take time for the steel industries in these latecomer countries to improve export performance.

Figure 4.15. Product mapping of total steel products (the whole steel industry)



Source: Author's calculations based on data from the ITC (2021)

While the previous analyses suggest that some major non-OECD steel-producing countries have acquired comparative advantage and international competitiveness, it is not apparent that export performance has improved at the broad product category level. The steel industry in some countries may have experienced a significant shift in export structure towards higher value-added segments, as in the catch-up model presented in this chapter. In contrast, the industries in other countries may have improved or maintained high export performance in low value-added segments. Thus, the next important question is whether major non-OECD steel-producing countries have improved RSCA and TBI values in the 21st century at the product level.

Figures 4.16–4.19 illustrate product mapping of four broad categories of steel products (ingots/semi-finished products, long products, flat products, pipe and tube products) from 2001–2003 to 2016–2018 assessing RSCA and TBI values. The results reveal notable variations in degrees of comparative advantage and international competitiveness across each of the steel industries. The technology choice of each group appears to be associated with the evolution of product mapping at the broad product level.

The steel industry in Group I tends to have higher RSCA/TBI values than Group II, suggesting that BF–BOF-intensive technology choice has helped a number of major non-OECD steel-producing countries to gain comparative advantage and improve international competitiveness for some product categories in the 21st century.

The Chinese steel industry (Group I-1) has increased RSCA and TBI values for most product categories since 2004–2006. Between 2001–2003 and 2016–2018, the position of the Chinese steel industry in product mapping for ingots/semi-finished products shifted to D, while its position for long products advanced to A during the same period.[127] In addition, the Chinese steel industry has seen a steady increase in RSCA and TBI values for high value-added segments (i.e. flat products, pipe and tube products) since 2010–2012, suggesting that its export structure has become more sophisticated and complex than previously.

Regarding the steel industry in Group I-2, Russia, Brazil and Ukraine have maintained positive RSCA and TBI values for flat products since 2001–2003, although the Brazilian steel industry has lost its comparative advantage/international competitiveness for the product category. Other than the South African steel industry, the steel industries in Group I-2 have been extremely specialised in ingots/semi-finished products since the early 2000s. Given that the positions of ingots/semi-finished products in the steel industry in Group I-2 have remained A since 2001–2003, they clearly have a strong comparative advantage and international competitiveness in this product category.

With respect to the steel industry in Group II, the Indian steel industry (Group II-1) has not shown high RSCA and TBI values compared to Group I; however, the Indian steel industry has gained a comparative advantage and international competitiveness for low value-added segments (i.e. ingots/semi-finished products, long products) since 2013–2015, reflecting a steady expansion in capacity by Indian steel firms in upstream facilities. While its position for pipe and tube products has remained A since 2001–2003, flat products have turned to B since 2007–2009.

[127] See Chapter 2 for the background of the decline of RSCA and TBI values for ingots/semi-finished products in the Chinese steel industry.

Within Group II-2, the Iranian steel industry has shown a rapid increase in RSCA and TBI values for ingots/semi-finished products and long products in recent years, indicating that it has gained a comparative advantage and improved international competitiveness for low value-added segments, reflecting capacity developments for steelmaking and long products. In contrast, the product mapping position of the Egyptian steel industry went from A to B for long products and flat products between 2004–2006 and 2016–2018, suggesting that demand for steel in the Egyptian industry has grown faster than its steel production and steel imports have increased, thus it became a net importer.

The steel industry in Group II-3 lacks comparative advantage and international competitiveness for all product categories. Nevertheless, in the Vietnamese steel industry, the RSCA and TBI values for some product categories, such as long products and flat products, have been heading to a B position, suggesting that it is starting to improve the comparative advantage for these product categories. The Indonesian steel industry has gained a comparative advantage for ingots/semi-finished products, which might reflect recent additions of capacity in the BF–BOF route. The cases of the steel industries in Vietnam and Indonesia suggest that improvement in the RSCA index had preceded TBI.

Figure 4.16. Product mapping of ingots/semi-finished products

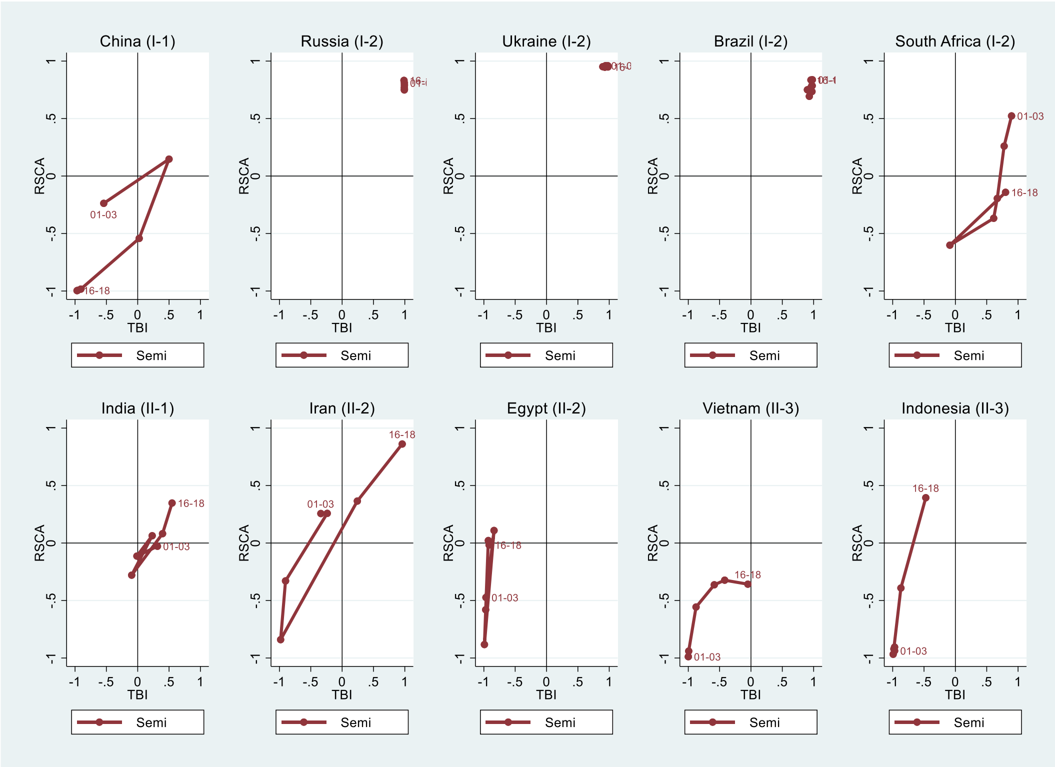


Figure 4.17. Product mapping of long products

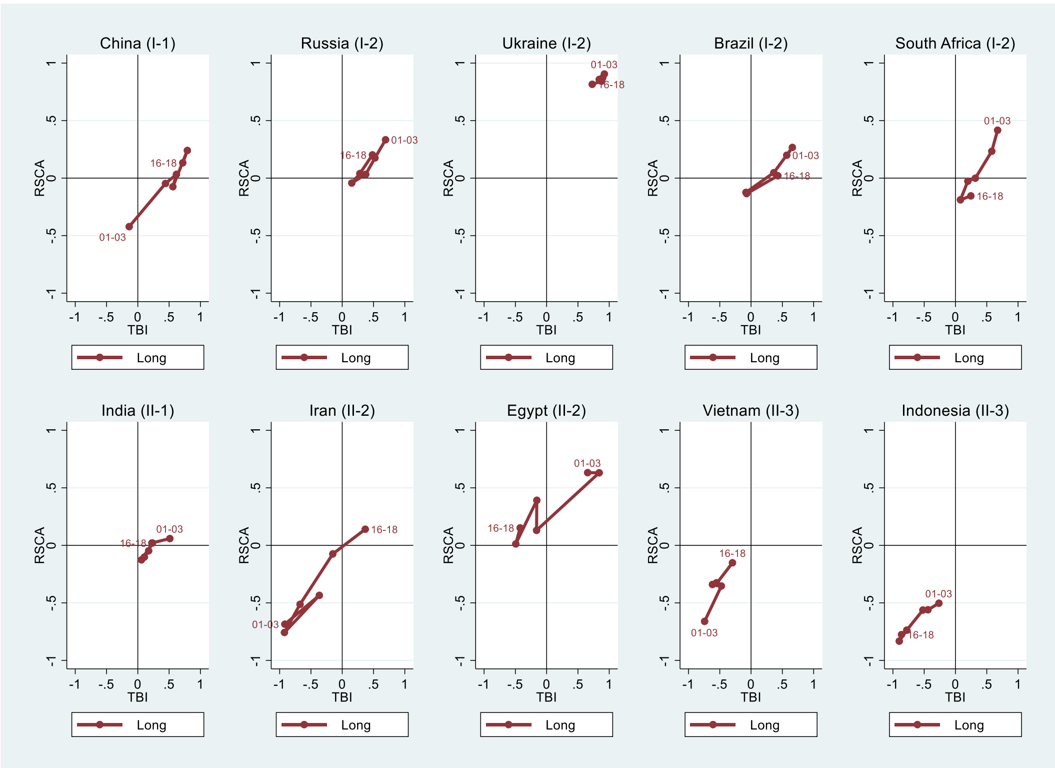


Figure 4.18. Product mapping of flat products

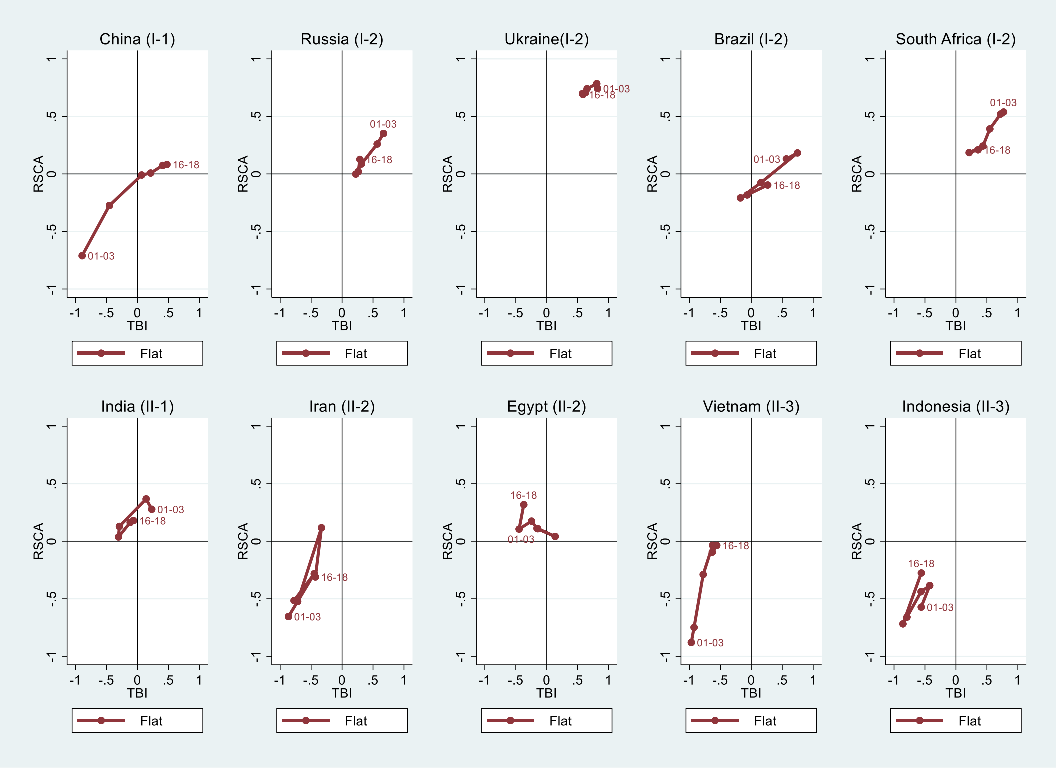
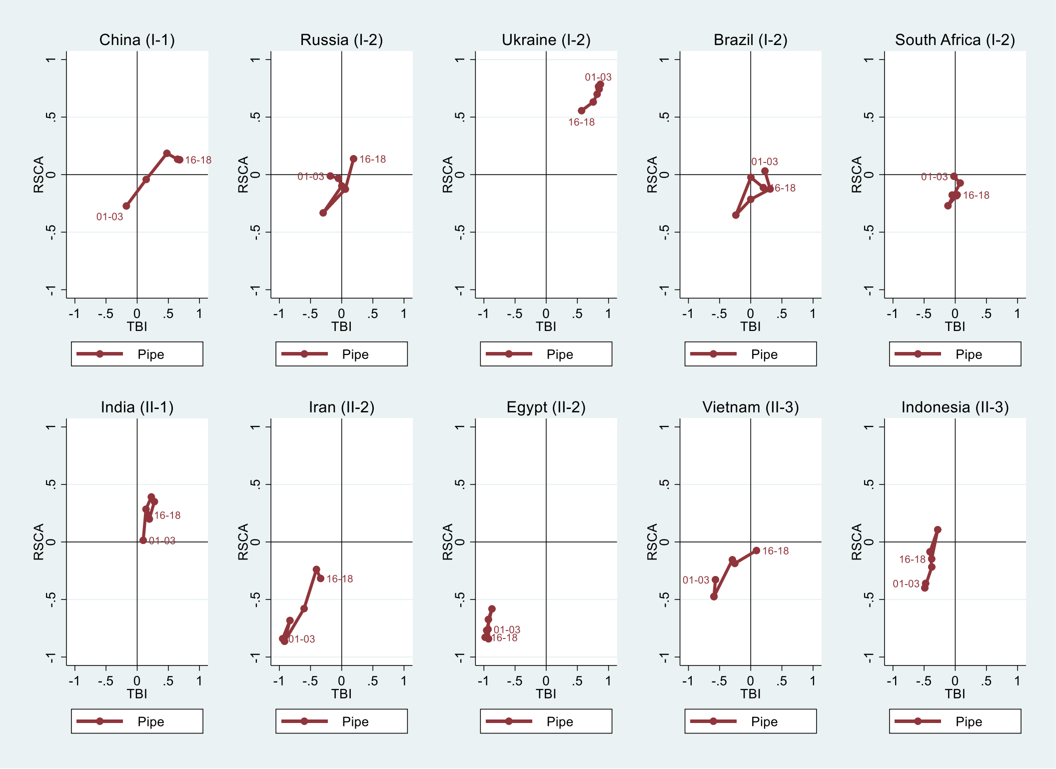


Figure 4.19. Product mapping of pipe and tube products



Source: Author's calculations based on data from the ITC (2021)

Table 4.9 summarises the results of product mapping analysis for major non-OECD steel-producing countries from 2001–2003 to 2016–2018. The steel industry in Group I (BF–BOF-based countries) appears to demonstrate higher RSCA/TBI values than Group II (EAF-based countries), suggesting that BF–BOF-intensive technology choice was particularly relevant for comparative advantage and international competitiveness within the whole steel industry and some product categories in the 21st century.

Among Group I, the Chinese steel industry (Group I-1) has experienced a remarkable change in its export performance, given that it has acquired comparative advantage and strengthened international competitiveness within the whole steel industry and low/high value-added segments. Given the case study results, it may be reasonable to assume that the development of several coastal steelworks has helped the Chinese steel industry to experience a significant shift in its export structure towards higher value-added products. Its export structure appears to have become more sophisticated and diversified than previously.

The steel industries in Group I-2 have maintained A positions within the whole steel industry and some product categories since the early 2000s, which may be the result of large-sized BFs commissioned in the 20th century.[128] The steel industries in these countries have maintained comparative advantage and international competitiveness in the 21st century based on BF–BOF-intensive technology choice in the 20th century. At the product level, they have been extremely specialised in low value-added segments since the early 2000s.

Turning to the steel industries in Group II, the speed of the export performance improvement seems moderate in the Indian steel industry (Group II-1) compared to the Chinese steel industry. In addition to the effect of technology choice using a combination of EAF/IF and BF–BOF routes, robust domestic demand may have absorbed a substantial portion of its growing steel production. Nevertheless, the Indian steel industry seems to have gradually gained a comparative advantage and improved international competitiveness within the whole steel industry and some low value-added segments. Along

[128] The product mapping for the Ukrainian steel industry shows it has been A for all categories since 2001–2003, although it has lacked comparative advantage and international competitiveness for some products at the detailed product level (see Chapter 2). The dominant role of steel products in Ukrainian export goods and the high export ratio (total steel exports/crude steel output) and low import ratio (total steel imports/ASU) might explain its high RSCA and TBI values. Steel products have been the largest export item from Ukraine, accounting for about 30% of its export in goods in 2001–2018. The Ukrainian steel industry has produced steel primarily to meet demand in export markets. Indeed, the Ukrainian steel industry is highly export-oriented, and the export ratio (total steel exports/crude steel output) in 2001–2018 was extremely high at 74.1%.

with significant growth in steel demand over the past decade, EAF/IF-based steel firms in India may have contributed to supplying steel to meet construction/infrastructure demand in the domestic market, while its BF–BOF-based steel firms may have helped to improve comparative advantage and international competitiveness in the foreign market.

Among the steel industries in Group II-2, the Iranian steel industry has witnessed steady improvement in RSCA and TBI values, and its position within the whole steel industry and some low value-added segments has become A in recent years. Significant investments in the EAF route may have enabled the Iranian steel industry to gain a comparative advantage and international competitiveness in the 21st century, although its position of high value-added segments has remained D since 2001–2003. While the Egyptian steel industry increased its steel production in the 21st century, its positions within the whole steel industry and some product categories have decreased to B. This suggests that demand/imports in the Egyptian steel industry have grown faster than its steel production; thus, international competitiveness has not improved since the early 2000s. Possible explanations of the difference in export performance between the Iranian and Egyptian steel industries may be the development speed of steel production and the balance of production/exports and demand/imports.

The positions of the steel industry in Group II-3 have remained in D within the whole steel industry and most product categories, suggesting that the steel industries in Vietnam and Indonesia continue to lack comparative advantage and international competitiveness. Nonetheless, the group may show some signs of gradual improvement of comparative advantage. If the BF–BOF route is suitable for mass production, leading to export competitiveness, the choice of BF–BOF-technology in the 21st century could impact export performance.[129]

[129] The share of EAF in the steel industry in ASEAN-6 countries has gradually declined from 100.0% in 2000 to 61.1% in 2018. Apart from the steel industry in Vietnam and Indonesia, Alliance Steel, a China-invested greenfield integrated steel project in Malaysia, fired up two BFs (1,080 m^3) in 2018 (Alliance Steel, 2019). In recent years, Chinese firms have announced numerous integrated steel mill projects in the ASEAN region (SEAISI, 2020, pp. 31-33).

Table 4.9. Summary of product mapping analysis in major non-OECD steel-producing countries

Group	Country	Total steel products						Ingots/semi-finished products						Long products					
		01–03	04–06	07–09	10–12	13–15	16–18	01–03	04–06	07–09	10–12	13–15	16–18	01–03	04–06	07–09	10–12	13–15	16–18
I-1	China	D	D	**A**	C	**A**	**A**	D	**A**	C	D	D	D	D	C	**A**	C	**A**	**A**
I-2	Russia	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	C	**A**	**A**
	Ukraine	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**
	Brazil	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	D	D	**A**
	South Africa	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	C	C	D	C	**A**	**A**	C	C	C	C
II-1	India	**A**	**A**	B	B	**A**	**A**	C	D	**A**	D	**A**	**A**	**A**	**A**	C	C	C	**A**
II-2	Iran	D	D	D	D	B	**A**	B	B	D	D	**A**	**A**	D	D	D	D	D	**A**
	Egypt	B	B	B	B	D	B	D	B	D	D	B	D	**A**	**A**	B	B	B	B
II-3	Vietnam	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
	Indonesia	D	D	D	D	D	D	D	D	D	D	D	B	D	D	D	D	D	D

Group	Country	Flat products						Pipe and tube products					
		01–03	04–06	07–09	10–12	13–15	16–18	01–03	04–06	07–09	10–12	13–15	16–18
I-1	China	D	D	C	**A**	**A**	**A**	D	C	**A**	**A**	**A**	**A**
I-2	Russia	**A**	**A**	**A**	C	**A**	**A**	D	D	C	D	C	**A**
	Ukraine	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**	**A**
	Brazil	**A**	**A**	C	D	D	C	**A**	C	D	D	C	C
	South Africa	**A**	**A**	**A**	**A**	**A**	**A**	D	C	D	C	D	C
II-1	India	**A**	**A**	B	B	B	B	**A**	**A**	**A**	**A**	**A**	**A**
II-2	Iran	D	D	D	D	B	D	D	D	D	D	D	D
	Egypt	B	**A**	B	B	B	B	D	D	D	D	D	D
II-3	Vietnam	D	D	D	D	D	D	D	D	D	D	D	C
	Indonesia	D	D	D	D	D	D	D	D	D	D	B	D

Note: Position A is highlighted in bold.
Source: Author’s calculations based on data from the ITC (2021)

4.8 Summary and Implications

This chapter examined the development of the global steel industry during the 20th and the 21st centuries, with a particular focus on the evolution of the steel industry in non-OECD countries through the global-level analysis and the country-level analysis, providing important insights into their catch-up dynamics in the 21st century. To shed light on when and how technology choices that affect comparative advantage and international competitiveness were executed among major steel industries in non-OECD countries, the chapter analysed the technology pathways and trade dynamics for major non-OECD steel-producing countries.

The results of the analyses in this chapter demonstrated that the steel industry in non-OECD countries developed the order of i) market expansion; ii) technology choice and productivity improvement; iii) production expansion and productivity improvement; iv) acquisition of comparative advantage; v) improvement of international competitiveness and vi) sophistication and diversification of the export structure. The results suggest that major non-OECD steel-producing countries that led the catch-up of the entire steel industry in non-OECD countries in the first two decades of the 21st century took a long time to develop their steel industries, and acquisition of state-of-the-art technology through technology accumulation contributed to their evolution in the global steel industry.

The global-level analysis indicated that the global steel industry experienced a significant increase in capacity and production in the last two decades, with the rapid development of non-OECD countries in the 21st century. Nevertheless, only a limited number of countries have been the drivers of this evolution in the steel industry in non-OECD countries, impacting the development of the global steel industry during the 20th and 21st centuries. While the steel industry in non-OECD countries has certainly expanded steel production in this century, very few countries improved competitiveness in the international steel market, although some seem to have marginally gained a comparative advantage.

The country-level analysis indicates that major non-OECD steel-producing countries have an increasingly significant role in the global steel industry in the 21st century in terms of steel supply and demand. Notable variations were observed in the timing and patterns of technology choice and pace of progress across each steel industry.

Several major non-OECD steel-producing countries made technology choices in the BF–BOF route and/or EAF route in the 20th century, resulting in steady development in steel production in the 21st century. Results from the analyses suggested that technology choice, particularly that of the BF–BOF route, equipped with large-scale production facilities based on state-of-the-art technology, was particularly relevant to export performance, comparative advantage and international competitiveness, accelerating non-OECD countries' steel industry catch-up. For instance, the Chinese steel industry chose BF–BOF-intensive technology in the 20th century, resulting in a significant increase in steel production in the 21st century. This development has helped the industry acquire comparative advantage, strengthening international competitiveness within the whole steel industry and low/high value-added product segments. In addition, other major non-OECD steel-producing countries, such as Russia, Ukraine and Brazil have maintained comparative advantage and international competitiveness in the 21st century based on BF–BOF-intensive technology choices in the 20th century.

While some major non-OECD steel-producing countries initially produced steel via small-scale BF–BOFs, they have now upgraded to the BF–BOF route equipped with large-scale production facilities (i.e. state-of-the-art technology) through technology accumulation, contributing to increasing steel production and strengthening export competitiveness, thus expediting their catch-up in the global steel industry.

Chapter 5. Conclusion

This research examined the catch-up of emerging/developing countries, exemplified by non-OECD countries in the 21st century in the context of the steel industry, focusing on the development of the steel trade and the role of technology. Several analyses were performed using an international steel trade dataset, providing important insights into the characteristics of the steel industry in non-OECD countries and catch-up dynamics. The key enquiries and findings of this research are presented below.

5.1 How are Technology Choice and the Level of Economic Development Associated With Advantages in Specific Types of Steel Products, Forming Current Global Steel Trade Patterns?

To shed light on current global steel trade patterns, Chapter 2 investigated the associations between technology choice (BF–BOF and EAF routes), the level of economic development (advanced and emerging/developing economies) and export performance (comparative advantage and international competitiveness), examining the case of the world's 15 largest steel-producing countries. The results demonstrated that technology choice and the level of economic development are associated with advantages in specific types of steel products in the international steel market.

A number of large steel-producing countries have high degrees of comparative advantage and international competitiveness for the entire steel industry and a wide range of steel products. In particular, BF–BOF-based countries are more likely to retain a specific comparative advantage and maintain international competitiveness for a variety of steel products. Nonetheless, there is wide differentiation according to levels of economic development. BF–BOF-based emerging/developing economies are likely to be associated with higher degrees of comparative advantage and international competitiveness for low value-added products compared to BF–BOF-based advanced economies. In contrast, BF–BOF-based advanced economies are associated with higher degrees of comparative advantage and international competitiveness for both low and high value-added products than those in emerging/developing economies. Although some EAF-based countries tend to be extremely specialised in low value-added products, EAF-based production systems appear to be less linked to steel export patterns compared to BF–BOF-based production systems. Therefore, integrated production systems using the BF–BOF route appear to be more likely to determine the development patterns of each steel industry than those employing the EAF route.

5.2 To What Extent has the Steel Industry in Non-OECD Countries Caught up in Terms of Upgrading Exports, in Reference to Export Sophistication and Diversification?

To provide relevant information on the present level of catch-up in the global steel industry, Chapter 3 assessed the current progress of export upgrades in the steel industry in non-OECD countries in terms of export upgrading from both quantity and quality perspectives. More specifically, this chapter investigated two aspects non-OECD countries' export upgrading, primarily examining the quality (export sophistication and export diversification) and the quantity of steel exports, in reference to the extent of trade balance. The chapter also presented insights into the characteristics of the steel industry in non-OECD countries and differences in comparison to those in OECD countries.

The results demonstrated that the current production systems are linked to the present structure of steel exports of non-OECD countries in terms of quantity and quality; thus, steel firms' technology choices in non-OECD countries are closely related to the current export performance. The evidence suggested that the steel industries of some non-OECD countries have gained a comparative advantage and become internationally competitive. The quantity and quality of steel exports of non-OECD countries appeared to correlate with one another, suggesting a need to upgrade both the quantity and quality of steel exports to catch-up. In addition, the results indicated that the magnitude of steel output is crucial to demonstrate higher export performance.

This chapter offered important insights into the differences of the steel industries in non-OECD and OECD countries, as well as variances of the industries in non-OECD countries. The structure of steel exports in non-OECD countries appears to be less sophisticated and diversified than that of OECD countries. In addition, development levels of the steel industry in non-OECD countries seem to vary significantly across types of production systems.

Overall, a small number of BF–BOF-based non-OECD countries demonstrated high performance in steel production and both quantity and quality of steel exports, with significant differences from the rest of the non-OECD countries. As the EAF route has been the primary steelmaking route of various non-OECD countries, they demonstrated low export performance in the steel trade.

5.3 When and how Were Technology Choices That Affect Comparative Advantage and International Competitiveness Implemented Among Major Steel Industries in Non-OECD Countries?

Chapter 4 analysed the technology pathways and trade dynamics of major non-OECD steel-producing countries to illuminate when and how technology choices that affect comparative advantage and international competitiveness were implemented by these countries. The chapter also provided vital insights into how the steel industry in non-OECD countries has evolved during the 20th and 21st centuries and how it has contributed to the development of the global steel industry in this century.

The results demonstrated that some non-OECD countries' steel industries developed in the order of i) market expansion, ii) technology choice and productivity improvement, iii) production expansion and productivity improvement, iv) acquisition of comparative advantage, v) improvement of international competitiveness and vi) sophistication and diversification of export structure. The results suggest that major non-OECD steel-producing countries that led the catch-up of the entire steel industry in non-OECD countries in the first two decades of the 21st century took a long time to develop their steel industries, and acquisition of state-of-the-art technology through technology accumulation contributed to their evolution in the global steel industry.

Major non-OECD steel-producing countries have had an increasingly important influence in the global steel industry in the 21st century in terms of steel supply. Nonetheless, notable variations were observed in the timing and patterns of technology choice and pace of progress across each steel industry. Several major non-OECD steel-producing countries implemented technology choices in the BF–BOF route in the 20th century, resulting in rapid or steady development in steel production in the 21st century. For instance, the Chinese steel industry executed BF–BOF-intensive technology choice in the 20th century, resulting in a significant increase in steel production in the 21st century. This development has helped the industry acquire comparative advantage, strengthening international competitiveness within the whole steel industry and low/high value-added product segments. Apart from the Chinese steel industry, other major non-OECD steel-producing countries, such as Russia, Ukraine and Brazil, have maintained comparative advantage and international competitiveness in the 21st century based on BF–BOF-intensive technology choices in the 20th century.

5.4 How has Technology Choice Contributed to the Catch-up of the Steel Industry in Non-OECD Countries in the 21st Century as Demonstrated Through Export Performance?

The evidence in this research supports the hypothesis presented in Chapter 1. Apart from steel firms' capability-building for productivity improvement to advance exportation, technology choice followed by upgrading to state-of-the-art technology through accumulation was a necessary condition for the catch-up of the steel industry in non-OECD countries from the second half of the 20th century to the first two decades of the 21st century.

Choice of the BF–BOF route was demonstrated to be particularly relevant for export performance compared to the EAF route, as it helped some major non-OECD steel-producing countries exhibit high export performance. First, technology choice, notably the BF–BOF route, was associated with advantages in specific types of steel products in the international steel market, although some notable differences were also found to depend on levels of economic development. Second, selecting the BF–BOF route contributed to upgrading steel exports in non-OECD countries, leading to high performance of trade balance, sophistication and diversification. This indicates that the technology helped both quantity and quality of steel exports to catch-up. Finally, the BF–BOF route contributed to some major non-OECD countries' acquisition of comparative advantage and strengthened international competitiveness within the whole steel industry and some product categories. While some major non-OECD steel-producing countries initially produced steel using small-scale BF–BOFs, they have now upgraded to large-scale production facilities using the BF–BOF route, contributing to increased steel production and export competitiveness. Therefore, it seems reasonable to conclude that a large-scale integrated production system using the BF–BOF route was particularly important for non-OECD countries to demonstrate high export performance; thus, expediting their catch-up in the global steel industry.

Overall, the results of the analyses indicated that the evolution of the global steel industry in the 21st century is characterised by rapid development in a limited number of non-OECD countries. At first glance, non-OECD countries' steel industry catch-up appeared to be progressing, as illustrated in Figure 1.1 in Chapter 1. Despite this, the evidence in this research suggested that this progress has only been made by a small number of countries; for example, the Chinese steel industry rapidly evolved in the 21st century, and some other major large steel-producing countries (e.g. Russia and Brazil) have developed since the

20th century. Due to the large magnitude of steel production in a small number of countries, the steel industry in non-OECD countries appeared to have grown as a whole in the 21st century.

5.5 Summary of Findings

Based on the analyses in this research, players in the global steel industry can be divided into four groups: i) China; ii) BF–BOF-based major non-OECD steel-producing countries; iii) the rest of the non-OECD countries; and iv) OECD countries. Table 5.1 summarises the findings of this research.

In the 21st century, China has experienced one of the world's fastest economic growth rates and, consequently, expansion in steel demand. Along with this significant growth in demand, the Chinese steel industry selected BF–BOF intensive technology in the 20th century, leading to a significant increase in its steelmaking capacity and steel output in the 21st century. In this century, China's high economic growth and expansion of steel-using industries triggered the construction of coastal steelworks equipped with large-scale BF–BOFs to meet the demand for high value-added steel products. The Chinese steel industry has seen a radical transformation in export performance in the 21st century and has acquired a comparative advantage and strengthened international competitiveness for the entire steel industry, including low/high value-added segments. In addition, its export structure has become more sophisticated and complex than it ever was in the past.

Apart from the Chinese steel industry, the steel industries of non-OECD countries have experienced a moderate or steady increases in steel demand due to robust economic growth in this century, generating expansion in steelmaking capacity. Nonetheless, heterogeneous patterns of technology choice and subsequent development were observed.

Major non-OECD steel-producing countries (Russia, Ukraine, Brazil and South Africa) primarily selected the BF–BOF route in the 20th century, leading to existing 21st century production systems. Robust steel demand following World War II generated the construction of large-sized BFs in these steel-producing countries; thus, choice of the BF–BOF route has had a significant role in steel production. This technology choice has helped these steel industries maintain comparative advantage and international competitiveness in the entire steel industry since the early 2000s. At the product level, these steel industries (excluding South Africa) have been extremely specialised in specific steel products.

Turning to the other steel industries in non-OECD countries, the EAF route has been the major steelmaking method, and such countries have demonstrated low export performance; for instance, they have lacked comparative advantage and international competitiveness for the whole steel industry, and their trade structures have remained unsophisticated and diversified.

Although the EAF route has had an important place in major non-OECD steel-producing countries, multiple technology choice patterns were observed in these countries. They include i) technology choice using a combination of EAF/IF and BF–BOF routes in the 20th century (India), ii) EAF-intensive technology choice in the 20th century (Iran and Egypt) and iii) EAF-intensive technology choice in the 20th century and the growing prominence of the BF–BOF route in the 21st century (Vietnam and Indonesia).

The Indian steel industry selected a combination of EAF/IF and BF–BOF routes in the 20th century, leading to a rapid increase in steel production in the 21st century. Although the Indian steel industry has developed much more slowly than the Chinese steel industry, India has gradually gained a comparative advantage and improved international competitiveness for the whole steel industry, supported by steady capacity additions in the domestic steel industry.

The Iranian steel industry has developed rapidly in the 21st century, based on EAF-intensive technology choice in the 20th century. Significant investments in the EAF route may have helped the Iranian steel industry to gain a comparative advantage and improve international competitiveness in the 21st century, although this development has occurred only in low value-added segments. Although the Egyptian steel industry also made EAF-intensive technology choice, the industry has not demonstrated the same steady improvement of comparative advantage and international competitiveness as the Iranian steel industry.

While the steel industry in other major non-OECD countries (Vietnam and Indonesia) has produced steel via the EAF route since the 20th century, the BF–BOF route is increasingly prominent in their steel production in the 21st century. Although they still lack comparative advantage and international competitiveness, these steel industries appear to have shown some signs of gradual improvement in comparative advantage.

With respect to the steel industry in OECD countries, steelmaking capacity in major OECD steel-producing countries reached its peak in the 20th century and has been declining since. In the steel industry in OECD countries, the BF–BOF route is the predominant steelmaking technology, although the EAF route has had a growing role over decades. Among the steel industries in OECD countries, some BF–BOF-based countries demonstrated higher degrees of comparative advantage and international competitiveness for both low and high value-added products (e.g. Japan, South Korea and France). Nonetheless, the steel industries in some countries (notably the US steel industry) do not elicit a comparative advantage or international competitiveness, although it is a major steel-producing country.

Overall, the findings in this research seem to fit the maturity hypothesis and the advantage of the backwardness hypothesis (Kawabata, 2000) when focusing on the relationship of the steel industry between non-OECD and OECD countries.

Table. 5.1 Summary of findings

	Non-OECD (China)	**Non-OECD (BF–BOF-based major steel-producing countries) (Russia, Ukraine, Brazil and South Africa)**	**Non-OECD (remaining countries)**	**OECD**
Technology choice patterns/ steel supply development	• BF–BOF-intensive technology choice in the 20th century, followed by a significant increase in steelmaking capacity and steel output in the 21st century • Construction of coastal steelworks equipped with large-scale BF–BOFs to meet the demand for high value-added products • Dominant role of the BF–BOF route in steel production	• Moderate or steady increase in steelmaking capacity/steel output in response to growing steel demand		• Peak of steelmaking capacity expansion in the 20th century (major steel-producing countries)
		• BF–BOF-intensive technology choice in the 20th century, forming the production system in the 21st century • Significant role of the BF–BOF route in steel production	• Dominant role of the EAF route in steel production (majority of non-OECD steel-producing countries) • Major steel-producing countries **i)** Combination of EAF/IF and BF–BOF choices in the 20th century (India) **ii)** EAF-intensive technology choice in the 20th century (Iran and Egypt) **iii)** EAF-based technology choice in the 20th century/the BF–BOF choice in the 21st century (Vietnam and Indonesia)	• Predominant steelmaking technology in the BF–BOF route, with expansion of the EAF route over decades
Export performance	• Acquisition of comparative advantage and improvement of international competitiveness for the whole steel industry and low/high value-added segments • More sophisticated and diversified export structure than it ever was in the past • Specialise in various types of steel products while demonstrating international competitiveness	• Maintenance of comparative advantage /improvement of international competitiveness for the whole steel industry • Strong specialisation in some specific steel products (excluding South Africa)	• Lack of a comparative advantage/international competitiveness, and unsophisticated/ undiversified export structures (majority of non-OECD countries) • Major steel-producing countries **i)** Gradual improvement of comparative advantage/international competitiveness (India) **ii)** Steady improvement of comparative advantage/international competitiveness (Iran) **iii)** Inadequate degree of comparative advantage/international competitiveness (Egypt, Vietnam and Indonesia)	• Demonstration of high degrees of comparative advantage/international competitiveness for both low value-added/high value-added products (e.g. Japan, Korea and France) • Low degree of comparative advantage/international competitiveness (e.g. the United States)

Source: Author

5.6 Implications

5.6.1 Catch-up patterns of latecomer countries in the global steel industry

Results from the analyses in this research suggested that some non-OECD steel-producing countries may have developed in the order: i) market expansion, ii) technology choice and productivity improvement, iii) production expansion and productivity improvement, iv) acquisition of comparative advantage, v) improvement of international competitiveness and vi) sophistication and diversification of the export structure. In the case of major non-OECD steel-producing countries (e.g. China, Russia and Brazil), it appears to have taken a long time to develop through each of these steps, although discrepancies in the scale of development are apparent across each steel industry. Each nation appears to have selected the BF–BOF route in the initial stage of development in response to growing steel demand and have increased proficiency and updated production facilities in a later stage, thus obtaining state-of-the-art technology. Given the discussion regarding path dependence, once steel firms have selected production technologies, it might not be easy to switch their production route. This implies that the BF–BOF route is an important strategic choice in an initial stage for catching up, provided that steel demand is adequate.

The cases of major non-OECD steel-producing countries also suggest that these development patterns could differ from the catch-up patterns observed in the steel industry in some latecomer countries, such as South Korea and Taiwan, which experienced rapid development of the industry by introducing the latest technology from the initial development stage. Although more in-depth analyses are needed to verify this proposition, this research implies that at least two types of catch-up patterns may be present in the global steel industry—a rapid catch-up model or an incremental catch-up model. The former pattern may correspond to steel-producing countries such as South Korea and Taiwan, whereas the latter may be applicable to major non-OECD steel-producing countries (e.g. China and Russia). It is uncertain whether currently underdeveloped non-OECD steel-producing countries will take an incremental catch-up model to develop steel industries, given that major non-OECD steel-producing countries appear to have adopted the latter model. Thus, it is important to keep track of the development of underdeveloped non-OECD steel-producing countries, which will provide important insights into the catch-up model in latecomer countries.

5.6.2 Technology choice with or without foreign capital

Recent investment in steelmaking projects could have notable implications for the future catch-up patterns of underdeveloped non-OECD steel-producing countries. Traditionally, steel firms headquartered in emerging/developing countries have been responsible for the development of the steel industry in those countries, whereas some of the key projects in recent years have involved partnerships between large foreign firms and local firms, which could represent a new trend in the global steel industry.

Although the steel industries in Vietnam and Indonesia have not selected the BF–BOF route in the initial stage, nor accumulated the production route as observed in major non-OECD steel-producing countries, they have obtained state-of-the-art technology over the past few years to facilitate industrialisation. The countries may be aiming to save time and capital by adopting the necessary technology and knowledge from large foreign steel firms to accelerate catch-up, which could correspond to the rapid catch-up model. Multiple greenfield integrated steel plant projects with foreign capital (mostly Chinese investors) have been announced in the Association of Southeast Asian Nations (SEAISI, 2020, pp. 31–33), close attention should be paid to the future catch-up trajectory of the region. It is important to monitor whether underdeveloped non-OECD steel-producing countries develop independently or obtain support from foreign capital to expedite catch-up in the global steel industry.

5.6.3 Technology choice under the circumstances of global warming

The BF–BOF route appears to have been advantageous for accelerating the catch-up of the steel industry in non-OECD countries from the second half of the 20th century to the first two decades of the 21st century. Nevertheless, looking ahead, it is uncertain whether this tendency is sustainable for the industry due to the complexity of the environmental and energy challenges faced today, given that the BF–BOF route represents the majority of energy consumption and CO_2 emissions in the steel industry (Laplace Conseil, 2013, p. 3).[130]

Environmental and energy issues are receiving increasing attention from governments and industry alike, due to the Paris Agreement, a new international framework on climate change, adopted on

[130] The steel industry is CO_2 and energy-intensive (World Steel Association, 2021c, p. 2). The industry is highly emissions-intensive due to its reliance on coal for the BF–BOF route (IEA, 2020, p. 38), and the majority of coal is consumed in the BF to transform coal to coke in the coke oven (IEA, 2020, p. 70).

12 December 2015 (UNFCCC, 2015).[131] In October 2020, the International Energy Agency (IEA) released its 'Iron and Steel Technology Roadmap', which analyses the impacts and trade-offs of different technology choices and policy targets for the industry in line with the goals of the Paris Agreement. The IEA (2020) considers the future development of the steel industry in two scenarios: the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario (SDS).[132] While the IEA envisions gradual changes to steel production by 2050 in STEPS, global steel production could be dramatically diversified through various steel production technologies in SDS.[133] Under the IEA's SDS, the steel industry should reduce its direct CO_2 emissions by more than 50% by 2050 relative to 2019 to meet the goals of the Paris Agreement.[134] The emissions intensity of crude steel output must fall by 58% over the period to achieve these goals. The World Steel Association (2021b) argued,

> To transition an industry of this scale to net-zero by 2050, or 2070 (aligned with the original Paris Agreement) will entirely transform our industry … Steel plants have had the same basic structure for 50 years–coke ovens, agglomeration plant, blast furnace, BOF, or possibly an EAF followed by casting and finishing. The future steel plant will look entirely different and will deploy an entirely different set of technologies and skills (paras, 9–10).

Given the critical urgency of the global warming issue in the steel industry, there might be limited time to develop the steel industry in non-OECD countries via the current commercial BF–BOF route.[135] It

[131] This paragraph is based on the IEA (2020) and the World Steel Association (2021c).

[132] The IEA establishes an ambitious pathway to net-zero emissions for the energy system by 2070 in SDS (IEA, 2020, p. 12). STEPS is based on the current trajectory, shaped by existing and announced policies. In contrast, SDS presents a more sustainable endpoint and examining the pathway might be possible (IEA, 2020, p. 54).

[133] In addition to commercial BF–BOF, scrap-based EAF and commercial DRI–EAF routes, various novel production routes are expected to emerge in global steel production, including innovative BF–BOF with carbon capture, use and storage (CCUS), innovative commercial smelting reduction (SR)–BOF, innovative SR–BOF with CCUS, commercial DRI–EAF with CCUS and 100% H_2 DRI–EAF (IEA, 2020, p. 103).

[134] The steel industry accounts for about 20% of industrial final energy consumption and about 8% of global final energy consumption. It is responsible for around a quarter of industrial CO_2 emissions and 7% of global CO_2 emissions due to its significant dependence on coal and coke as fuels and reduction agents (IEA, 2020, pp. 17–18).

[135] Swalec and Shearer (2021, p. 11) emphasised that the steel industry may face the risk of stranded assets in the carbon-intensive BF–BOF-based steel plants currently under development if innovative low-emission technologies reach commercial scale at the projected pace.

is important to follow future technology choices and its impacts on steel production and export performance in the context of the catch-up.

5.7 The Remaining Issues and Future Research

This research provided important insights into the catch-up of the steel industry in non-OECD countries, contributing to deepening the knowledge and understanding of steel industry development in emerging/developing countries in the 21st century. Nonetheless, a number of research limitations offer several avenues for further research.

First, BF–BOF technology choice appears to have been instrumental in expediting the catch-up in a limited number of non-OECD-countries steel industries, whereas the EAF route has been the primary steelmaking route in most non-OECD steel-producing countries. Two important questions that arise are: i) why did only a few non-OECD steel-producing countries that selected the BF–BOF route achieve catch-up? and ii) why do most non-OECD steel-producing countries implement technology choice in the EAF route to produce steel if the choice of the BF–BOF route was a necessary condition for catch-up? Therefore, more research is needed to explore the conditions of successful catch-up of the steel industry in non-OECD countries and the background of EAF-intensive technology choice pattern.

Second, this research endeavoured to provide insights into associations between technology choice and export performance, examining comparative advantage and international competitiveness. Still, the research did not consider other variables that may impact export performance in international steel trade (e.g. exchange rates and trade agreements), which have important implications for more comprehensively understanding the mechanisms of trade and dynamics of the industry. Additional factors that improve export performance in the steel industry remain to be seen, necessitating further analyses of other possible determinants that impact export performance and the catch-up in the global steel industry.

Third, as this research sought to discuss the steel industries' catch-up in non-OECD countries, it did not focus much on domestic markets. Generally, many steel products are used locally and steel firms in countries are likely to prioritise domestic markets prior to commencing exports. Given the importance of the flying-geese model of industrial development (Akamatsu, 1962; Kojima, 2000), it would also be beneficial to focus on the structural linkages between steel demand, steel imports, domestic steel production and steel exports in non-OECD countries, which could contribute to constructing a more sophisticated catch-up model.

Finally, this research indicated that technology choice impacted the catch-up of the steel industry in non-OECD countries in the 21st century. While the research also suggested that the Chinese steel industry is the frontrunner in terms of catch-up in export competitiveness, further investigations into the characteristics of the Chinese steel industry and its unique conditions are needed to understand the characteristics of this phenomenon. Whether the steel industry in other non-OECD countries can accelerate their catch-up by selecting the BF–BOF route in the future could depend on whether they share similar conditions and characteristics to the Chinese industry. It is important to understand the intricacies of the Chinese steel industry more comprehensively for comparison to other non-OECD steel-producing countries.

Despite these limitations, this research provided important insights into the characteristics of the steel industry in non-OECD countries and their evolution within the global steel industry in the 21st century. Analysing the catch-up dynamics in the global steel industry is an important matter with a wide reach, which could provide insights for understanding the development of emerging/developing countries in the world economy. Steel is widely used in numerous industries that are closely tied to overall economic activity; thus, the steel industry is both a reflection of and contributor to global economic growth (IEA, 2020, p. 22). In summary, the development of the global steel industry is directly associated with overall macroeconomic conditions and activities in downstream steel-consuming industries, and such an investigation provides vital insights into the world economy.

References

Abe, M. (2008). Kankoku Tekkogyo no Sangyo Saihen: Sangyo Seisaku no Tenkan to sono Kiketsu (Industrial Reorganisation of the South Korean Steel Industry: Consequences of the Transformation of Industrial Policy). In H. Sato (Ed.), *Ajia Shokoku no Tekkogyo: Hatten to Henyo (The Steel Industry in Asia: Development and Restructuring)* (pp. 47–82). Institute of Developing Economies Japan External Trade Organisation (JETRO). https://doi.org/10.20561/00042525

Agosin, M. R., Alvarez, R., & Bravo-Ortega, C. (2011). Determinants of Export Diversification around the World: 1962–2000. *The World Economy*, 35(3), 295–315. https://doi.org/10.1111/j.1467-9701.2011.01395.x

AISI. (2018). *The Economic Impact of the American Iron and Steel Industry*. American Iron and Steel Institute (AISI). https://www.steel.org/wp-content/uploads/2020/10/Econ-Impact-Study-Executive-Summary.pdf

AIST. (2017). *Blast Furnace Above-Burden Infrared Camera*. Association for Iron & Steel Technology (AIST). https://www.aist.org/AIST/aist/AIST/Social_Media/17_mar_blast_furnace_camera.pdf

Akamatsu, K. (1962). A Historical Pattern of Economic Growth in Developing Countries. *The Developing Economies*, 1, 3–25. https://doi.org/10.1111/j.1746-1049.1962.tb01020.x

Alliance Steel. (2019). *Construction Mobilisation Meeting of MCKIP 3.5 Million Tons Integrated Steel Project and Commencement Ceremony of 2×1080m³ Blast Furnace Project*. http://alliancesteel.com.my/article_34.html?lang=en

Amsalem, M. A. (2003). *Technology Choice in Developing Countries: The Textile and Pulp and Paper Industries*. The MIT Press.

Amsden, A. H. (1992). *Asia's Next Giant: South Korea and Late Industrialisation*. Oxford University Press.

Araujo, L., & Harrison, D. (2000). Technological Trajectories and Path Dependence. *16th Annual IMP Conference*, 1–16.

https://www.researchgate.net/publication/228792822_Technological_Trajectories_and_Path_Dependence

ArcelorMittal. (n.d.-a). *Catalogo Tecnico Para Impressao (Technical Catalogue)*. https://brasil.arcelormittal.com/produtos-solucoes/exportacao/placas?asCatalogo=pdf

ArcelorMittal. (n.d.-b). *Company Overview*. https://www.arcelormittalsa.com/whoweare/ourcompany.aspx

ArcelorMittal. (n.d.-c). *Introduction to ArcelorMittal South Africa Newcastle Works*. https://www.arcelormittalsa.com/Portals/0/Newcastle%20Works.pdf

ArcelorMittal. (n.d.-d). *Our History*. https://ukraine.arcelormittal.com/index.php?id=63

ArcelorMittal. (n.d.-e). *The History of ArcelorMittal South Africa*. https://www.arcelormittalsa.com/Portals/0/The-History-of-ArcelorMittal-South-Africa.pdf

Associação Central Nipo Brasileira. (2011). *Burajiru Tekkogyo no Gaikyo to Kongo no Tembo (Overview of the Brazilian Steel Industry and Future Prospects)*. https://nipo-brasil.org/archives/2120/

Balassa, B. (1965). Trade Liberalisation and 'Revealed' Comparative Advantage. *The Manchester School*, 33(2), 99–123. https://doi.org/10.1111/j.1467-9957.1965.tb00050.x

Balassa, B. (1981). *The Newly Industrialising Countries in the World Economy*. Pergamon Press.

Bannock, G., & Baxter, R. (2011). *The Penguin Dictionary of Economics: Eighth Edition*. Penguin UK.

Baosteel. (2015a). *2015 Annual Report*. http://tv.baosteel.com/ir/pdf/report/600019_2015_e.pdf

Baosteel. (2015b). *2015 Baosteel Guidebook*. http://tv.baosteel.com/web/plc/pic/bg2015en.pdf

Baosteel. (2016a). *2016 Annual Report*. http://tv.baosteel.com/ir/pdf/report/600019_2016_e.pdf

Baosteel. (2016b). 2016 *Baosteel Guidebook*. http://tv.baosteel.com/web/plc/pic/bg2016en.pdf

Beshay Steel. (2021). *History*. https://www.beshaysteel.com/history/

Black, J., Hashimzade, N., & Myles, G. (2017). *A Dictionary of Economics (Oxford Quick Reference)* (5th ed.). Oxford University Press.

BlueScope Steel. (2010). *The Global Steel Industry: An Australian Perspective*. http://www.bluescopesteel.com.au/files/dmfile/globalsteelindustryoct2010pdf1.pdf

Boyd, G. A., & Karlson, S. H. (1993). The Impact of Energy Prices on Technology Choice in the United States Steel Industry. *The Energy Journal*, 14(2), 47–56. https://doi.org/10.5547/issn0195-6574-ej-vol14-no2-3

Cadot, O., Carrère, C., & Strauss-Kahn, V. (2011). Export Diversification: What's Behind the Hump? *Review of Economics and Statistics*, 93(2), 590–605. https://doi.org/10.1162/rest_a_00078

Chandra, V., Boccardo, J., & Osorio, I. (2007). Export Diversification and Competitiveness in Developing Countries. *Working Draft*, 1–18. https://edc.gov.bz/wp-content/uploads/2016/11/ED-2.pdf

China Baowu Steel Group Corporation. (n.d.). *Company Profile*. http://www.baowugroup.com/en/#/aboutus/285

Chow, P. C. Y. (2012). *Trade and Industrial Development in East Asia: Catching Up or Falling Behind*. Edward Elgar Publishing.

Christensen, C. M. (2016). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Harvard Business Review Press.

CISA. (various years). *A Handbook of Iron and Steel Statistics*. China Iron and Steel Association (CISA).

CISDI USA. (2017). *CISDI Newsletter Vol. 5*. https://www.cisdiusa.com/Newsletter/2017/2017_05_CISDI_Newsletter.pdf

CISDI USA. (2018). *CISDI Newsletter Vol. 6*. https://www.cisdiusa.com/Newsletter/2018/2018_06_CISDI_Newsletter.pdf

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, 35(1), 128–152. https://doi.org/10.2307/2393553

CRU. (2016). *China's Investigation on Square Bar Exports*. http://www.crugroup.com/about-cru/cruinsight/Chinas_investigation_on_square_bar_exports Accessed 21 September 2016

Csereklyei, Z., & Stern, D. I. (2018). Technology Choices in the U.S. Electricity Industry before and after Market Restructuring. *The Energy Journal*, 39(01), 157–182. https://doi.org/10.5547/01956574.39.5.zcse

CSN. (2020). *History*. Companhia Siderúrgica Nacional (CSN). https://www.csn.com.br/en/about-us/history/

da Silva, O. M., Drumond, R. R., & de Almeida, F. M. (2011). Similarity and Income Content at the International Trade: The Case of BRICS During the Period 2000/09. *Paper Presented at the IAMO's Forum 2011*, 1–19. https://www.researchgate.net/publication/254459746_Similarity_and_income_content_at_the_international_trade_The_case_of_BRICS_during_the_period_200009

Dahlman, C., & Wermelinger, M. (2015). *How to Continue the Shifting Wealth Momentum*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/fr/dev/development-posts-shifting-wealth.htm

Dalum, B., Laursen, K., & Villumsen, G. (1998). Structural Change in OECD Export Specialisation Patterns: De-specialisation and 'Stickiness'. *International Review of Applied Economics*, 12(3), 423–443. https://doi.org/10.1080/02692179800000017

David, P. A. (2007). Path Dependence: A Foundational Concept for Historical Social Science. *Cliometrica*, 1(2), 91–114. https://doi.org/10.1007/s11698-006-0005-x

D'Costa, A. (1999). *The Global Restructuring of the Steel Industry: Innovations, Institutions and Industrial Change*. Routledge.

de Carvalho, A., & Sekiguchi, N. (2015). The Structure of Steel Exports: Changes in Specialisation and the Role of Innovation. *OECD Science, Technology and Industry Working Papers*, 2015/07, 2–39. https://doi.org/10.1787/5jrxfmstf0xt-en de Paula, G. M. (2021). *Lessons Learned from the Brazilian Privatisation Experience*. Global Forum on Steel Excess Capacity (GFSEC). https://www.steelforum.org/stakeholders/gfsec-april-2021-uberlandia.pdf

Deardorff, A. V. (2011). Comparative Advantage: The Theory Behind Measurement. In *Globalisation, Comparative Advantage and the Changing Dynamics of Trade* (pp. 27–39). OECD Publishing.

Egyptian Iron and Steel Company. (n.d.). *Egyptian Iron and Steel Company*. http://www.hadisolb.com/pdf/Egyption_Iron_&_Steel_Company_DOC/Egyption_Iron_&_Steel_Company_EN.pdf

ESCAP. (2009). *Trade Statistics in Policymaking - A Handbook of Commonly Used Trade Indices and Indicators*. The Economic and Social Commission for Asia and the Pacific (ESCAP). https://artnet.unescap.org/publications/books-reports/trade-statistics-policymaking-handbook

Esfahan Steel. (2021). *Profile*. https://www.esfahansteel.ir/page-English/en/0/form/pId303

EUROFER. (2018). *The Impact of the European Steel Industry on the EU Economy*. European Steel Association (EUROFER). https://www.eurofer.eu/assets/Uploads/20190530-OE-report-for-Eurofer-1-v2.pdf

EUROFER. (2020). *What is Steel and How is Steel Made?* European Steel Association (EUROFER). https://www.eurofer.eu/about-steel/learn-about-steel/what-is-steel-and-how-is-steel-made/

Ezz Steel. (2021a). *EZDK at a Glance*. https://www.ezzsteel.com/investor-relations/al-ezz-dekheila-steel-co-alexandria-s-a-e-ezdk

Ezz Steel. (2021b). *Growth History*. https://www.ezzsteel.com/about-ezz-steel/growth-history

Ferrarini, B., & Scaramozzino, P. (2011). Indicators and Patterns of Specialisation in International Trade. *NCCR Trade Regulation Working Paper*, 2011/10, 1–43. https://www.wti.org/media/filer_public/3c/45/3c450e2f-21a9-4ce0-846b-f33acb38b7b5/indicators_and_patterns_of_specialization.pdf

FHS. (n.d.-a). *Company*. Formosa Ha Tinh Steel Corporation (FHS). https://www.fhs.com.vn/Portal/about

FHS. (n.d.-b). *Technology*. Formosa Ha Tinh Steel Corporation (FHS). https://www.fhs.com.vn/Portal/product

Finger, J. M., & Kreinin, M. E. (1979). A Measure of `Export Similarity' and its Possible Uses. *The Economic Journal*, 89(356), 905. https://doi.org/10.2307/2231506

Fujimoto, T. (2007). *Competing to Be Really, Really Good: The Behind-the-Scenes Drama of Capability-Building Competition in the Automobile Industry*. International House of Japan.

Fujimoto, T. (2013). Posuto Reisenki no Owari to Kokunai Gemba no Saihyoka: Gurobaru Keiei he no Gani (End of 'Post-cold War' and Re-Evaluation of Domestic Sites: Implications for Global Management). *Transactions of the Academic Association for Organisational Science*, 2(2), 1–9. https://doi.org/10.11207/taaos.2.2_1

Fujimoto, T. (2018). A Design-Information-Flow View of Industries, Firms, and Sites. In T. Fujimoto & F. Ikuine (Eds.), *Industrial Competitiveness and Design Evolution (Evolutionary Economics and Social Complexity Science, 12)* (pp. 5–41). Springer. https://doi.org/10.1007/978-4-431-55145-4_1

Fujimoto, T., & Ikuine, F. (2018). Preface. In T. Fujimoto & F. Ikuine (Eds.), *Industrial Competitiveness and Design Evolution (Evolutionary Economics and Social Complexity Science*, 12) (pp. v–xiii). Springer.

Fujimoto, T., Maekawa, R., & Iwao, S. (2019). Sangyo Kyosoryoku to Yuruyakana Tota: Kihon Gainen to Suri Moderu o Mochiita Shimyureshon Bunseki (Industrial Competitiveness and "Mild Selection": Basic Concept and Mathematical Simulation). *Akamon Management Review*, 18(1), 5–40. https://doi.org/10.14955/amr.0180315a

Fujimoto, T., & Shiozawa, Y. (2012). Inter and Intra Company Competition in the Age of Global Competition: A Micro and Macro Interpretation of Ricardian Trade Theory. *Evolutionary and Institutional Economics Review*, 8(2), 193–231. https://doi.org/10.14441/eier.8.193

Gang, Y. (2000). *Chugoku Tekkogyo Hatten no Kozo Hendo (The Growth of Iron & Steel Industry in China)*. Yotsuya Round Publishers.

Gemma, M., & Yoshino, H. (2012). *Gijutsu Sentaku to Keizai Hatten (Technology Choice and Economic Development)*. Institute of Developing Economies Japan External Trade Organisation (JETRO). https://www.ide.go.jp/library/Japanese/Publish/Reports/InterimReport/2011/pdf/420_jo.pdf

Gerschenkron, A. (1962). *Economic Backwardness in Historical Perspective*. Praeger.

Gill, I., & Kharas, H. (2007). *An East Asian Renaissance: Ideas for Economic Growth*. World Bank. http://hdl.handle.net/10986/6798

Girik Allo, A., Sukartini, N. M., & Widodo, T. (2017). Dynamic Changes in Comparative Advantage of Indonesian Agricultural Products. *MPRA Paper*, 80028, 1–31. https://mpra.ub.uni-muenchen.de/80028/1/MPRA_paper_80028.pdf

Giuliani, E., Morrison, A., & Rabellotti, R. (2012). Innovation and Technological Catch-Up in the Wine Industry: An Introduction. In E. Giuliani, A. Morrison, & R. Rabellotti (Eds.), *Innovation and Technological Catch-Up: The Changing Geography of Wine Production* (pp. 1–14). Edward Elgar Publishing.

Hamaguchi, N. (2004). Gijutsu Shimpo to Reonteiefu Gyakusetsu (Technological Progress and the Leontief Paradox). *Waseda Shakai Kagaku Sogo Kenkyu (Waseda Studies in Social Sciences)*, 5(1), 131–142.

Hart, S. L., & Christensen, C. M. (2002). The Great Leap: Driving Innovation from the Base of Pyramid. *MIT Sloan Management Review*, 44(1), 51–56.

Hasegawa, S. (1993). Seifukei Sandai Seitetsujo Taisei to Burajiru Moderu (The ‘Big 3’ of Public Steel and the Brazilian Model). *Kenkyu Nempo Keizaigaku (Annual Report of the Economic Society, Tohoku University)*, 55(1), 93–109. http://www2.itc.kansai-u.ac.jp/~shin/paper/hasegawa1993brsid.html#chap2

Hasegawa, S. (1994). Seifukei Tekko Kigyo no Keiei Kiki to Yushutsu Shiko Sengo Burajiru Kogyoka ni okeru Tekkogyo (Financial Crisis and Export Incentives of the Public Steel Companies in Brazil).

Annual Report of the Economic Society, Tohoku University, 56(2), 65–82. http://www2.itc.kansai-u.ac.jp/~shin/paper/hasegawa1994brsid.html

Hausmann, R., Hwang, J., & Rodrik, D. (2006). What You Export Matters. *Journal of Economic Growth*, 12(1), 1–25. https://doi.org/10.1007/s10887-006-9009-4

Hesse, H. (2008). Export Diversification and Economic Growth. *Working Paper (World Bank)*, 21, 1–23. http://hdl.handle.net/10986/28040

Hori, I. (2013). Arusero-ru Mittaru Sha no Gurobaru Bijinesu Moderu 2 (The Global Business Model of ArcelorMittal Steel 2). *Aichi Kenritsu Daigaku Daigakuin Kokusai Bunka Kenkyuka Ronshu (Bulletin of the Graduate School of International Cultural Studies)*, Aichi Prefectural University, 14, 157–174. https://doi.org/10.15088/00001589

Howell, T. R., Noellert, W. A., Kreier, J. G., & Wolff, A. W. (1988). *Steel and the State: Government Intervention and Steel's Structural Crisis*. Routledge.

IEA. (2020). *Iron and Steel Technology Roadmap: Towards More Sustainable Steelmaking*. OECD Publishing. https://doi.org/10.1787/3dcc2a1b-en

IMF. (2021a). *Frequently Asked Questions World Economic Outlook (WEO)*. International Monetary Fund (IMF). https://www.imf.org/external/pubs/ft/weo/faq.htm#q4b

IMF. (2021b). *World Economic Outlook Database*. International Monetary Fund (IMF). https://www.imf.org/en/Publications/WEO/weo-database/2021/April/select-aggr-data

IMIDRO. (2016). *An Outlook to Iran Pelletising and Steel Industries: Plants, Projects, Technology Selection, Technologies*. Iranian Mines and Mining Industries Development and Renovation (IMIDRO). https://imidro.gov.ir//parameters/imidro/modules/cdk/upload/content/general_content/37/1466411643217j0pv3psuj67s587k0nutanabc2.pdf

Instituto Aço Brasil. (n.d.). *Steel History*. https://acobrasil.org.br/site/en/steel-history/

Ishiguro, I. (Ed.). (2014). *Stata ni yoru Shakai Chosa Deta no Bunseki: Nyumon Kara Oyo Made (Analysing Social Survey Data with Stata: From Introduction to Application)*. Kitaohji syobo.

ISSB. (2010). *ISSB Product Guide*. International Steel Statistics Bureau (ISSB). http://www.issb.co.uk/resources/Pdf/ISSB_TES_Product_Guide_(June_2010).pdf. Accessed 22 September 2016

ITA. (2016). *Global Steel Report*. International Trade Administration U.S. Department of Commerce (ITA). https://legacy.trade.gov/steel/pdfs/07192016global-monitor-report.pdf

ITC. (2021). *Trade Map*. International Trade Centre (ITC). https://www.intracen.org/itc/market-info-tools/trade-statistics/

Jeon, K. (2018). Global Value Chains: A Framework for Analysing the Steel Industry. *Asian Steel Watch*, 6, 14–23. https://www.posri.re.kr/files/file_pdf/59/346/6993/59_346_6993_file_pdf_1546220731.pdf

JETRO. (2018). *Iran Sangyo Gaidobukku (Iranian Industries Guidebook)*. Japan External Trade Organisation (JETRO). https://www.jetro.go.jp/ext_images/_Reports/01/5d3698a309dab63b/20170115.pdf

JICA. (1988). *Ejiputo Koku Deikera Seitetsujo Kakucho Keikaku Chosa Hokokusho (Study Report on the Expansion Project of Dhekelah Steel Plant, Egypt)*. Japan International Cooperation Agency (JICA). https://openjicareport.jica.go.jp/pdf/10650208.pdf

JSPL. (2015). *Annual Report 2014–2015*. Jindal Steel & Power Ltd (JSPL). https://d2lptvt2jijg6f.cloudfront.net/jindalsteelpower/custom/1610710307_JSPL_Annual_Report_2014_15.pdf

JSW Steel. (2010). *Annual Report 2009–2010*. https://www.jsw.in/sites/default/files/assets/industry/steel/IR/Financial%20Performance/Annual%20Reports%20_%20STEEL/1373287322JSW%20Steel%202009-2010.pdf

JSW Steel. (2012). *Annual Report 2011–2012*. https://www.jsw.in/sites/default/files/assets/industry/steel/IR/Financial%20Performance/Annual%20Reports%20_%20STEEL/1373285587JSW%20Steel%202011-2012.pdf

Kaldor, N. (1961). Capital Accumulation and Economic Growth. In D. C. Hague (Ed.), *The Theory of Capital* (pp. 177–222). Palgrave Macmillan. https://doi.org/10.1007/978-1-349-08452-4_10

Kaldor, N. (1966). *Causes of the Slow Rate of Economic Growth of the United Kingdom*. Cambridge University Press.

Kaldor, N. (1970). The Case for Regional Policies. *Scottish Journal of Political Economy*, 17(3), 337–348. https://doi.org/10.1111/j.1467-9485.1970.tb00712.x

Kawabata, N. (2000). Seijuku Kyatchiappu Seidoteki Chosei (Maturation, Catch-Up, and Institutional Coordination). In K. Morisawa & H. Ueda (Eds.), *Gurobaru Kyoso to Rokaraizeshon (Global Competition and Localisation)* (pp. 131–160). University of Tokyo press.

Kawabata, N. (2003a). Competitive Strategy of the Japanese Integrated Steel Firms in Mature Stage. *MPRA Paper*, 42097, 1–33. https://ideas.repec.org/p/pra/mprapa/42097.html

Kawabata, N. (2003b). Tekkogyo: Yunyu Daitai Sangyo no Genjitsuteki Opushon (The Steel Industry: A Realistic Option for Import Substitution Industry). In K. Ohno & N. Kawabata (Eds.), *Betonamu no Kogyoka Senryaku: Gurobaruka Jidai no Tojokoku Sangyo Shien (Industrialisation Strategy for Vietnam: Industrial Promotion of Developing Countries in the Age of Globalisation)* (pp. 173–217). Nippon Hyoron-Sha.

Kawabata, N. (2005). *Higashi Ajia Tekkogyo no Kozo to Dainamizumu (Structure and Dynamism of the Iron and Steel Industry in East Asia)*. Minerva Publishing.

Kawabata, N. (2007). Betonamu no Tekkogyo: Shin Kyokumen to Seisaku Tenkan (Vietnam's Steel Industry: New Phase and Policy Shift). *Chosa Kenkyu Hokoku Sho (Research Reports)*, 173–207. https://www.ide.go.jp/library/Japanese/Publish/Reports/InterimReport/pdf/2006_04_23_06.pdf

Kawabata, N. (2016a). Betonamu Tekkogyo ni okeru Minkan Kigyo no Bokko: Hoa Fuatto Gurupu to Hoa Sen Gurupu no Jirei Kenkyu (Emergence of the Private Companies in the Vietnamese Iron and Steel Industry). *Journal of Asian Management Studies*, 22, 77–92. https://doi.org/10.20784/jamsjsaam.22.0_79

Kawabata, N. (2016b). The Vietnamese Iron and Steel Industry in Transition to a Market Economy: Attainments and Challenges. *TERG Discussion Papers*, 349, 1–45. http://hdl.handle.net/10097/63820

Kawabata, N. (2017). Where is the Excess Capacity in the World Iron and Steel Industry? A Focus on East Asia and China. *RIETI Discussion Paper Series*, 17-E-023, 1–36. https://www.rieti.go.jp/jp/publications/dp/17e026.pdf

Kawabata, N. (2020a). Nihon Tekkogyo no Genjo to Kadai: Koro Meka Denro Meka no Kyoso Senryaku to Sangyo no Sasutenabiritei (Current Status and Issues in the Japanese Steel Industry: Competitive Strategies of Blast Furnace and Electric Arc Furnace Firms and Sustainability of the Industry). *Funtai Gizyutu (Powder Process Engineering)*, 12(10), 15–19. http://www2.econ.tohoku.ac.jp/~kawabata/paper/funtai202010.pdf

Kawabata, N. (2020b). Development of the Vietnamese Iron and Steel Industry Under International Economic Integration. In H. Shioji, D. R. Adhikari, F. Yoshino, & T. Hayashi (Eds.), *Management for Sustainable and Inclusive Development in a Transforming Asia* (pp. 255–271). Springer. https://doi.org/10.1007/978-981-15-8195-3_15

Kawabata, N., & Yin, D. (2020). Gendai Chugoku Tekkogyo ni okeru Seisan Shisutemu no Tayosei: Gijutsu Sentaku to Shijo Tekio (Diversity of the Production Systems of Contemporary Chinese Iron and Steel Industry). *TERG Discussion Paper*, 425, 1–41. http://hdl.handle.net/10097/00128146

Kim, L., & Nelson, R. R. (2000). *Technology, Learning, and Innovation: Experiences of Newly Industrialising Economies*. Cambridge University Press.

Kojima, K. (2000). The "Flying Geese" Model of Asian Economic Development: Origin, Theoretical Extensions, and Regional Policy Implications. *Journal of Asian Economics*, 11(4), 375–401. https://doi.org/10.1016/s1049-0078(00)00067-1

KOSA. (various years). *Steel Statistical Yearbook*. Korea Iron and Steel Association (KOSA).

Kowalski, P. (2011). Comparative Advantage and Trade Performance: Policy Implications. *OECD Trade Policy Papers*, 121, 2–53. https://doi.org/10.1787/5kg3vwb8g0hl-en

Kowalski, P., & Stone, S. F. (2011). Breaking Through on Trade: How a Changing World Dynamic Affects Policy. In *Globalisation, Comparative Advantage and the Changing Dynamics of Trade* (pp. 9–23). OECD Publishing.

Krakatau POSCO. (2019). *About Us*. https://www.krakatauposco.co.id/about

Krakatau Steel. (2017). *Company Profile*. https://www.krakatausteel.com/viewcontent/168

Kumagai, S. (2014). The Middle-Income Trap from the Viewpoint of Trade Structures. *IDE Discussion Paper*, 482, 1–28. http://hdl.handle.net/2344/1389

Kumagai, S., & Kuroiwa, I. (2020). Higashi Ajia ni okeru Yushutsu Kozo no Kodoka: Chushin Shotoku no Wana he no Impurikeshon (Export Upgrading in East Asia: Implications for the Middle-Income Trap). *Ajia Keizai (Quarterly Journal of Institute of Developing Economies)*, 61(2), 2–35. https://doi.org/10.24765/ajiakeizai.61.2_2

Kuwamori, H., Uchida, Y., & Tamamura, C. (2014). *Boeki Shisu Detabesu no Sakusei to Gaiyo (Compilation and Overview of Trade Indices in East Asia)*. Institute of Developing Economies Japan External Trade Organisation (JETRO). https://www.ide.go.jp/library/Japanese/Publish/Reports/InterimReport/2013/pdf/C26_ch0.pdf

Laerd Statistics. (n.d.). *Kruskal-Wallis H Test Using Stata*. https://statistics.laerd.com/stata-tutorials/kruskal-wallis-h-test-using-stata.php

Lafay, G. (1992). The Measurement of Revealed Comparative Advantages. In M. G. Dagenais & P. G. Muet (Eds.), *International Trade Modelling* (pp. 209–234). Chapman & Hill.

Lall, S. (2000a). The Technological Structure and Performance of Developing Country Manufactured Exports, 1985–98. *Oxford Development Studies*, 28(3), 337–369. https://doi.org/10.1080/713688318

Lall, S. (2000b). Technological Change and Industrialisation in the Asian Newly Industrialising Economies: Achievements and Challenges. In L. Kim & R. R. Nelson (Eds.), *Technology, Learning, and Innovation: Experiences of Newly Industrialising Economies* (pp. 13–68). Cambridge University Press.

Lall, S., Weiss, J., & Zhang, J. (2006). The "Sophistication" of Exports: A New Trade Measure. *World Development*, 34(2), 222–237. https://doi.org/10.1016/j.worlddev.2005.09.002

Laplace Conseil. (2012). *The Future of Steel: How will the Industry Evolve?* Laplace Conseil. https://www.oecd.org/sti/ind/Future%20of%20Steel%20-%20LAPLACE%20Conseil.pdf

Laplace Conseil. (2013). *Impacts of Energy Market Developments on the Steel Industry*. Laplace Conseil. https://www.oecd.org/sti/ind/Item%209.%20Laplace%20-%20Steel%20Energy.pdf

Laursen, K. (2015). Revealed Comparative Advantage and the Alternatives as Measures of International Specialisation. *Eurasian Business Review*, 5(1), 99–115. https://doi.org/10.1007/s40821-015-0017-1

Lee, K., & Ki, J. H. (2017). Rise of Latecomers and Catch-Up Cycles in the World Steel Industry. *Research Policy*, 46(2), 365–375. https://doi.org/10.1016/j.respol.2016.09.010

Liebowitz, S. J., & Margolis, S. E. (1995). Path Dependence, Lock-In, and History. *The Journal of Law, Economics, and Organisation*, 11(1), 205–226. https://doi.org/10.1093/oxfordjournals.jleo.a036867

Liu, Z. J., Zhang, J. L., & Yang, T. J. (2015). Low Carbon Operation of Super-Large Blast Furnaces in China. *ISIJ International*, 55(6), 1146–1156. https://doi.org/10.2355/isijinternational.55.1146

Marukawa, T. (2016). ‘Catch-Down’ Innovation in Developing Countries. In *Varieties and Alternatives of Catching-Up: Asian Development in the Context of the 21st Century* (pp. 183–210). Palgrave MacMillan.

Marukawa, T. (2018). Chugoku no Tekko Chotaikokuka to Yushutsu Kyosoryoku no Gensen (China’s Steel Superpower and Source of Export Competitiveness). In A. Suehiro, T. Tajima, & T. Marukawa (Eds.), *Chugoku Shinkokoku Nekusasu Aratana Sekai Keizai Junkan (China-Emerging Countries Nexus: A New Global Economic Cycle)* (pp. 245–279). University of Tokyo Press.

Marukawa, T., & Hattori, M. (2019). Chugoku Roshia no Tekkogyo: Kyosoryoku no Gensen ha Nanika (The Steel Industry in China and Russia: What are the Sources of Competitiveness?). *Japanese Journal of Comparative Economics*, 56(1), 31–47. https://doi.org/10.5760/jjce.56.1_31

Mattera, G. (2018). Steel Global Value Chains and Sub-Sectorial Comparative Advantage. *Asian Steel Watch*, 6, 24–33. https://posri.re.kr/files/file_pdf/59/346/6994/59_346_6994_file_pdf_1546220983.pdf

Mattera, G., & Silva, F. (2018). State Enterprises in the Steel Sector. *OECD Science, Technology and Industry Policy Papers*, 53, 1–47. https://doi.org/10.1787/2a8ad9cd-en

Meier, G. (1995). *Leading Issues in Economic Development*. Oxford University Press.

MEsteel.com. (n.d.). *Iran: Steel Industry Overview*. https://www.mesteel.com/cgi-bin/w3-msql/goto.htm?url=https://www.mesteel.com/countries/iran/overview.htm

METI. (2018). Rise of Emerging and Developing Economies. In *White Paper on International Economy and Trade 2018* (pp. 344–367). Ministry of Economy, Trade and Industry (METI). https://www.meti.go.jp/english/report/data/wp2018/pdf/2-2-2.pdf

Metinvest. (2020). *Steelmaking: History and the Modern Age*. https://metinvestholding.com/en/media/article/viplavka-stali-istoriya-i-sovremennostj

Midrex. (2016). *2015 World Direct Reduction Statistics*. https://www.me-metals.com/Panel/Attachments/636034999812317158.pdf

Midrex. (2018). *DRI Products & Applications*. http://www.midrex.com/wp-content/uploads/MIdrexDRI_ProductsBrochure_4-12-18.pdf

Midrex. (2019). *2018 World Direct Reduction Statistics*. https://www.midrex.com/wp-content/uploads/Midrex_STATSbookprint_2018Final-1.pdf

Mineral Resources of Republic of South Africa. (2011). *South African Steel Producers Handbook*. https://www.dmr.gov.za/LinkClick.aspx?fileticket=XcYm78qEVRc%3D&portalid=0

Ministry of Steel of India. (2002). *Year at a Glance*. https://steel.gov.in/sites/default/files/Chapter%20I%20%281%29.pdf

Ministry of Steel of India. (2005). *National Steel Policy 2005*. https://steel.gov.in/sites/default/files/nspolicy2005_0.pdf

Ministry of Steel of India. (2017). *National Steel Policy 2017*. https://steel.gov.in/sites/default/files/NATIONAL_STEEL_POLICY_2017_0.pdf

Ministry of Steel of India. (2021). *Annual Report 2020–21*. https://steel.gov.in/sites/default/files/Annual%20Report-Ministry%20of%20Steel%202020-21.pdf

Ministry of Steel of India. (various years). *Annual Report*. https://steel.gov.in/annual-reports

MPI. (2014). *Consumption and Development of China's Steel Market*. China Metallurgical Industry Planning and Research Institute (MPI). https://www.oecd.org/sti/ind/Item%205.%20MPI-CISA.pdf

Nakaya, N. (2008). Tekkogyo no Kodoka: Sono Hiyakuteki Seicho to Sangyo Saihen (The Upgrading of the Steel Industry: Its Rapid Growth and Industrial Restructuring). In K. Imai & K. Ding (Eds.), *Chugoku Sangyo Kodoka no Choryu (Trends in Chinese Industrial Upgrading)* (pp. 77–116). Institute of Developing Economies Japan External Trade Organisation (JETRO). https://doi.org/10.20561/00031972

Nelson, R. R., & Winter, S. G. (1985). *An Evolutionary Theory of Economic Change*. Harvard University Press.

Nippon Steel Corporation. (2012). *Usiminas Celebrated the 50th Anniversary of Its Commencement of Operation*. Nippon Steel. https://www.nipponsteel.com/en/news/20121029_100.html

Nippon Steel Corporation. (2019). *Joint Acquisition of Essar Steel*. https://www.nipponsteel.com/common/secure/en/ir/library/pdf/20191216_500.pdf

NLMK. (2009). *Annual Report 2009*. Novolipetsk Steel (NLMK). https://nlmk.com/upload/iblock/765/ar_2009_1_.pdf

OECD. (2007). *International Migration Outlook 2007*. OECD Publishing. https://doi.org/10.1787/migr_outlook-2007-en

OECD. (2011). *Developments in Steelmaking Capacity of Non-OECD Economies 2010*. OECD Publishing. https://doi.org/10.1787/steel_non-oecd-2010-en-fr

OECD. (2012). *The Future of the Steel Industry: Selected Trends and Policy Issues*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/sti/ind/Steel%20Dec%202012%20Future%20of%20Steel%20%20OECD.pdf

OECD. (2013a). *Evaluating the Current State of the Steel Industry: Work in Progress*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/sti/ind/Item%204.1%20OECD.pdf

OECD. (2013b). *Overview of the ASEAN Steel Market*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/sti/ind/Item%206.%20OECD%20Steel%20Secretariat%20-%20Mr.%20Naoki%20Sekiguchi%20-%20July%202013.pdf

OECD. (2013c). *The Structure and Prospects of the Indonesian Steel Industry*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/sti/ind/Item%205%203%20OECD%20Naoki%20-%20Copy.pdf

OECD. (2013d). *The Viability of the Steel Industry: An Attempt to Analyse Steelmakers' Economic and Financial Performance*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/sti/ind/Item%203.%20%20OECD%20Secretariat%20-%20Mr.%20Anthony%20De%20Carvalho.pdf

OECD. (2014a). *Background Document: Recent Developments in Steelmaking Raw Material Markets*. Organisation for Economic Co-operation and Development (OECD). https://www.oecd.org/sti/ind/Raw%20material%20background%20note%20final%20(revised).pdf

OECD. (2014b). *Developments in Steelmaking Capacity of Non-OECD Economies 2013*. OECD Publishing. https://doi.org/10.1787/steel_non-oecd-2013-en-fr

OECD. (2015a). Excess Capacity in the Global Steel Industry and the Implications of New Investment Projects. *OECD Science, Technology and Industry Policy Papers,* 18, 1–38. https://doi.org/10.1787/5js65x46nxhj-en

OECD. (2015b). *Excess Capacity in the Global Steel Industry: The Current Situation and Ways Forward*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/sti/ind/excess-capacity-in-the-global-steel-industry.pdf

OECD. (2015c). Iron and Steel Factsheet. In *Material Resources, Productivity and the Environment* (pp. 130–139). OECD Publishing. https://doi.org/10.1787/9789264190504-12-en

OECD. (2017). *The Steel Industry in the Context of GVC*. Organisation for Economic Co-Operation and Development (OECD). https://www.oecd.org/industry/ind/82nd_OECD_Steel_Committee_Gianpiero_Materrra_GVCs.pdf

OECD. (2020a). *OECD Secretary-General's Report to Ministers 2020*. OECD Publishing. https://doi.org/10.1787/27007c6c-en

OECD. (2020b). *OECD Steelmaking Capacity Database, 2000–2019*. Organisation for Economic Co-Operation and Development (OECD). https://stats.oecd.org/Index.aspx?datasetcode=STI_STEEL_MAKINGCAPACITY

OICA. (2021a). *2000 Production Statistics*. Organisation Internationale Des Constructeurs d'Automobiles (OICA). https://www.oica.net/category/production-statistics/2000-statistics/

OICA. (2021b). *2018 Production Statistics*. Organisation Internationale Des Constructeurs d'Automobiles (OICA). https://www.oica.net/category/production-statistics/2018-statistics/

Otsuka, K. (1990). *Keizai Hatten to Gijutsu Sentaku: Nihon no Keiken to Hattentojokoku (Economic Development and Technology Choice: Japan's Experience and Developing Countries)*. Bunshindo.

Otsuka, K., Ranis, G., & Saxonhouse, G. (1988). *Comparative Technology Choice in Development: The Indian and Japanese Cotton Textile Industries*. Macmillan Press.

Paul Wurth. (2012). *Tata Steel, India: Construction of New Blast Furnace "I" 2012*. https://www.paulwurth.com/wp-content/uploads/2020/08/Brochure-BF-Constructions-TATA-Steel-BF-I-en.pdf

Paul Wurth. (2020). *Hyundai Steel, South Korea: Construction of New Blast Furnaces 1, 2 & 3 2010/2013*. https://www.paulwurth.com/wp-content/uploads/2020/08/Brochure-BF-Constructions-Hyundai-BF-1-2-3-en.pdf

Perez, C., & Soete, L. (1988). Catching Up in Technology: Entry Barriers and Windows of Opportunity. In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, & L. Soete (Eds.), *Technical Change and Economic Theory* (pp. 458–478). Pinter Publishers.

POSCO. (2013). *POSCO Report 2013*. https://www.posco.co.kr/homepage/docs/eng6/jsp/dn/irinfo/posco_report_2013.pdf

Primetals Technologies. (2016). *Hot Rolling Mill from Primetals Technologies Produces First Coil in Vietnam for Formosa Ha Tinh Steel Co*. https://www.primetals.com/press-media/news/hot-rolling-mill-from-primetals-technologies-produces-first-coil-in-vietnam-for-formosa-ha-tinh-steel-co

Primetals Technologies. (2017). *Primetals Technologies Receives Facs for Four Continuous Casters from Formosa Ha Tinh Steel Co*. https://www.primetals.com/press-media/news/primetals-technologies-receives-facs-for-four-continuous-casters-from-formosa-ha-tinh-steel-co

Primetals Technologies. (2020a). *Blast Furnace No.1 & No.2: Dragon Steel Corporation, Taichung, Taiwan*. https://www.primetals.com/fileadmin/user_upload/content/01_portfolio/1_ironmaking/blast-furnace/DRAGON_STEEL_-_BLAST_FURNACE_NO1_AND_NO2.pdf

Primetals Technologies. (2020b). *Blast Furnace No.3 & No.4: JSW Steel Limited Torangallu, India*. https://www.primetals.com/fileadmin/user_upload/content/01_portfolio/1_ironmaking/blast-furnace/JSW_TORANAGALLU_-_BLAST_FURNACE_NO3_AND_NO4.pdf

Reuters. (2015). *Big China Steel Thrives, Stoking Export Fears*. https://www.reuters.com/article/us-china-steel-exports-idUSKBN0NH02D20150426

Rimini, M., de Carvalho, A., Mercier, F., Burrai, V., Liebman, B., & de Stefano, T. (2020). Barriers to Exit in the Steel Sector. *OECD Science, Technology and Industry Policy Papers*, *93*, 1–62. https://doi.org/10.1787/a26bced1-en

RINL. (2012). *Biggest Blast Furnace Goes on Stream at Vizag Steel. Rashtriya Ispat Nigam (RINL)*. https://www.vizagsteel.com/code/press/pressrelfiles/576Biggest%20Blast%20Furnace%20goes%20on%20stream%20at%20Vizag%20Steel.pdf

Rodrik, D. (2006). What's So Special About China's Exports? *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.832651

SAIL. (2013). *India's Largest Blast Furnace Becomes Operational at SAIL's Rourkela Steel Plant*. Steel Authority of India Limited (SAIL). https://www.sail.co.in/en/sail-news/indias-largest-blast-furnace-becomes-operational-sails-rourkela-steel-plant

SAIL. (2014). *India's Largest Blast Furnace Blown-in at ISP, Burnpur. Steel Authority of India Limited (SAIL)*. https://www.sail.co.in/en/sail-news/indias-largest-blast-furnace-blown-isp-burnpur

SAIL. (2018). *2.8 Mtpa Blast Furnace of SAIL's Bhilai Plant Blown In, Important Milestone in Sail Modernisation*. Steel Authority of India Limited (SAIL). https://www.sail.co.in/en/sail-news/28-mtpa-blast-furnace-sails-bhilaiplant-blown-important-milestone-sail-modernization

Sato, H. (2006). Keizai Jiyuka Iko no Indo Tekkogyo no Henyo (Transformation of the Indian Steel Industry After Economic Liberalisation). In S. Uchikawa (Ed.), *Yakudo suru Indo Keizai: Hikari to Kage (The Dynamic Indian Economy: Light and Shadow)* (pp. 217–241). Fuko-sha. http://doi.org/10.20561/00032139

Sato, H. (2008a). Ajia Shokoku no Tekkogyo: Kenkyu no Kadai to Impurikeshon (The Steel Industry in Asia: Research Agenda and Implications). In H. Sato (Ed.), *Ajia Shokoku no Tekkogyo: Hatten to Henyo (The Steel Industry in Asia: Development and Restructuring)* (pp. 3–46). Institute of Developing Economies Japan External Trade Organisation (JETRO). https://doi.org/10.20561/00042524

Sato, H. (Ed.). (2008b). Tekkogyo Kanren Yogo ni Kansuru Chushaku (Notes on Terms Related to the Steel Industry). In *Ajia Shokoku no Tekkogyo: Hatten to Henyo (The Steel Industry in Asia: Development and Restructuring)* (pp. vi–xi). Institute of Developing Economies Japan External Trade Organisation (JETRO). http://hdl.handle.net/2344/00011656

Sato, H. (2009). The Iron and Steel Industry in Asia: Development and Restructuring. *IDE Discussion Paper*, 210, 1–35. http://hdl.handle.net/2344/855

Sato, H. (2010). Ajia Chiiki no Tekkogyo ni okeru Kozo Henka to Gijutsu Sentaku (Structural Change and Technology Choice in the Steel Industry in Asia). *The Journal of Science Policy and Research Management*, 24(4), 327–337. https://doi.org/10.20801/jsrpim.24.4_327

Sato, H. (2013). Ajia Shokoku ni okeru Tekkogyo no Hatten to Gijutsu (Development and Technology of the Steel Industry in Asia). In T. Baba (Ed.), *Ajia no Sangyo Gijutsu (Economic Development and Industrial Technology in Asia)* (pp. 165–182). Nakanishiya.

Sato, H. (2014). Kyatchiappugata Kogyoka Ron to Tekkogyo: Gashienkuron vs Hashuman o Megutte (Catch-up Industrialisation Theories and the Steel Industry: On "Gerschenkron vs. Hirschman").

Ajia Keizai (Quarterly Journal of Institute of Developing Economies), 55(4), 8–38. http://hdl.handle.net/2344/1396

Sato, H. (2016). Advantages of Backwardness and Linkage Effects: The Steel Industry in Asia. In Y. Sato & H. Sato (Eds.), *Varieties and Alternatives of Catching-Up: Asian Development in the Context of the 21st Century* (pp. 153–181). Palgrave MacMillan. https://doi.org/10.1057/978-1-137-59780-9_6

Sato, Yuri. (2008). Indoneshia no Tekkogyo: Kiro ni Tatsu Kokuei Kigyo no Ikkan Seisan Shisutemu (Indonesia's Steel Industry: The State-Led Integrated Steel Production System at a Crossroads). In H. Sato (Ed.), *Ajia Shokoku no Tekkogyo: Hatten to Henyo (The Steel Industry in Asia: Development and Restructuring)* (pp. 203–249). Institute of Developing Economies Japan External Trade Organisation (JETRO). https://doi.org/10.20561/00042529

Sato, Yukihito. (2008). Taiwan Tekkogyo no Seicho oyobi Kodoka no Mekanizumu: Jidosha Sangyo ni Izon Shinai Hatten no Purosesu to Kanosei (Mechanism of the Growth and Upgrading of the Taiwanese Steel Industry: Could It Develop without Strong Support from the Automobile Industry?). In H. Sato (Ed.), *Ajia Shokoku no Tekkogyo: Hatten to Henyo (The Steel Industry in Asia: Development and Restructuring)* (pp. 83–111). Institute of Developing Economies Japan External Trade Organisation (JETRO). https://doi.org/10.20561/00042526

Sato, Y. (2012). Kyatchiappu Gata Kogyoka Ron no Saikento to Kaihatsu Shugi Kokka Ron no Gen Dankai (Revisiting the Catch-Up Theory of Industrialisation and the Current Stage of Developmentalist State Theory). *Chosa Kenkyu Hokoku Sho (Research Reports)*, 31 – 43. https://www.ide.go.jp/library/Japanese/Publish/Reports/InterimReport/2011/pdf/423_ch3.pdf

Sato, Y., & Sato, H. (2016). Introduction: Varieties and Alternatives of Catching Up: Asian Development in the Context of the Twenty-First Century. In Y. Sato & H. Sato (Eds.), *Varieties and Alternatives of Catching-Up: Asian Development in the Context of the 21st Century* (pp. 1–26). Palgrave MacMillan. https://doi.org/10.1057/978-1-137-59780-9_1

Schott, P. K. (2007). The Relative Sophistication of Chinese Exports. *Economic Policy*, 23(53), 5–49. https://doi.org/10.1111/j.1468-0327.2007.00195.x

Schumacher, E. F. (1993). *Small is Beautiful: A Study of Economics as if People Mattered*. Vintage Books.

SEAISI. (2020). *The ASEAN Steel Industry Situation*. South East Asia Iron and Steel Institute (SEAISI). https://www.oecd.org/industry/ind/Item_5_SEAISI_March_2020.pdf

Sekiguchi, N., Otsuka, H., de Carvalho, A., & Silva, F. (2016). Capacity Developments in the World Steel Industry. *Unclassified OECD Document DSTI/SU/SC(2015)8/FINAL*, 3–26. https://www.oecd.org/industry/ind/Capacity-Developments-Steel-Industry.pdf

Setyastuti, R., Adiningsih, S., & Widodo, T. (2018). The Dynamics of Comparative Advantage in the ASEAN Region. *MPRA Paper*, 86541, 1–44. https://mpra.ub.uni-muenchen.de/86541/1/MPRA_paper_86541.pdf

Severstal. (2021). *History*. https://www.severstal.com/eng/about/company_history

Shibata, T., & Kodama, F. (2004). Gijutsu Sentaku no Jiremma o Koete: Fuanakku ni okeru Jiremma no Chokoku (Beyond the Technology Choice Dilemma: Overcoming the Dilemma in FANUC). *RIETI Discussion Paper Series*, 04-J-047, 1–23. https://www.rieti.go.jp/jp/publications/dp/04j047.pdf

Shin, J. (2015). *The Economics of the Latecomers: Catching-Up, Technology Transfer and Institutions in Germany, Japan and South Korea* (Routledge Studies in the Growth Economies of Asia). Routledge.

Shougang. (2017). *Shougang Jingtang United Iron & Steel Co., Ltd*. https://www.shougang.com.cn/en/ehtml/IronSteelIndustry/20170329/833.html

Shougang. (2019). *Striving Ahead and Advancing Bravely, Shougang Has Made Brilliant Achievements in the Past Hundred Years - 100th Anniversary of Shougang's Founding*. https://www.shougang.com.cn/en/ehtml/GroupCulture/20190827/1267.html

Siemens VAI. (2010). *India Hungry for Steel*. https://www.primetals.com/fileadmin/user_upload/metals-magazine/2010_01/011_Metals-Magazine_1-2010_India.pdf

Silva, F., & de Carvalho, A. (2016). Research and Development, Innovation and Productivity Growth in the Steel Sector. *Unclassified OECD Document DSTI/SU/SC(2015)5/FINAL, 1–59*.

https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=DSTI/SU/SC(2015)5/FINAL&docLanguage=En

Silva, F., & Mercier, F. (2020). The Changing Characteristics of Steel Firms: Insights from the New OECD Steel Database. *OECD Science, Technology and Industry Policy Papers*, 97, 1–52. https://doi.org/10.1787/879ea670-en

Simeonov, S. (2020). Path Dependence: Determinants and Impacts of Technology Adoption. *Economic Alternatives*, 2, 300–310. https://doi.org/10.37075/ea.2020.2.07

Smil, V. (2016). *Still the Iron Age: Iron and Steel in the Modern World*. Butterworth-Heinemann.

SMS Group. (2013). *Sms Siemag Arcess® EAF with a Production of 2.5 Million Tons of Steel per Year*. https://www.sms-group.com/ru/press-media/press-releases/press-detail/sms-siemag-arccessr-eaf-with-a-production-of-25-million-tons-of-steel-per-year-147

Stats Guild. (2021). *Kruskal-Wallis Kentei go no Tajuhikaku no Shuho (Method of Multiple Comparisons after Kruskal-Wallis Test)*. https://www.stats-guild.com/analytics/13251

Steel Plantech. (2017). *Formosa Ha Tinh Steel Corporation, Vietnam Muke Tenroseiko Puranto no Kanko (Completion of Converter Steelmaking Plant for Formosa Ha Tinh Steel Corporation, Vietnam)*. https://steelplantech.com/ja/news/4867/

Steel Recycling Research. (2014). *Indo Tekkojuyo oyobi Tekko Sangyo no Genjo to Tembo kara Mita Nihon Tetsu Sukurappu Yushutsu no Kanosei (The Potential for Japanese Steel Scrap Exports from the Perspective of Current and Prospective Steel Demand and Steel Industry in India)*. http://srr.air-nifty.com/home/files/140630.pdf

Steel Recycling Research. (2015). *Tekkimboko no Seisanshutai ha Yudoro Rirorarengo: Indo Tetsu Sukurappu Yushutsu wo Kangaeru Sono Yon (Induction Furnaces and Re-Rollers Are the Main Producers of Rebar Steel: India's Steel Scrap Exports Part 4)*. http://srr.air-nifty.com/home/files/150213.pdf

Steel Recycling Research. (2021). *Iran Tekko Jukyu no Genjo to Tetsugen Potensharu (The Current Situation of the Iranian Steel Supply and Demand, and Iron Source Potential)*. http://srr.air-nifty.com/home/files/210208.pdf

Steelonthenet.com. (2021a). *Basic Oxygen Furnace Route Steelmaking Costs 2021*. https://www.steelonthenet.com/cost-bof.html

Steelonthenet.com. (2021b). *Electric Arc Furnace Steelmaking Costs 2021*. https://www.steelonthenet.com/cost-eaf.html

Stewart, F. (1972). Choice of Technique in Developing Countries. *The Journal of Development Studies*, 9(1), 99–121. https://doi.org/10.1080/00220387208421433

Suehiro, A. (2008). *Catch-Up Industrialisation: The Trajectory and Prospects of East Asian Economies*. NUS Press.

Sugimoto, T. (1993). The Chinese Steel Industry. *Resources Policy*, 19(4), 264–286. https://doi.org/10.1016/0301-4207(93)90040-t

Sugimoto, T. (2008). Chugoku no Tekkogyo: Bakuhatsuteki Kakudai no Shosokumen (China's Steel Industry: Aspects of Its Explosive Growth). In H. Sato (Ed.), *Ajia Shokoku no Tekkogyo: Hatten to Henyo (The Steel Industry in Asia: Development and Restructuring)* (pp. 203–249). Institute of Developing Economies Japan External Trade Organisation (JETRO). https://doi.org/10.20561/00042527

Suzuki, Y. (1991). The Rise and Decline of Steel Industries: A Business Historical Introduction. In E. Abe & Y. Suzuki (Eds.), *Changing Patterns of International Rivalry: Some Lessons from the Steel Industry (International Conference on Business History Proceedings)* (pp. 1–17). University of Tokyo Press.

Swalec, S., & Shearer, C. (2021). *Pedal to the Metal: No Time to Delay Decarbonising the Global Steel Sector*. Global Energy Monitor. https://globalenergymonitor.org/wp-content/uploads/2021/06/Pedal-to-the-Metal.pdf

Tamamura, C. (2016). Kenjiteki Hikaku Yui (RCA) Shisu no Kangaekata to Tekisetsu na Riyoho: Barassa Rebyu o Fumaete (Reconsideration of the Index of Revealed Comparative Advantage (RCA): In Association with Balassa's Study). In H. Kuwamori, Y. Uchida, & C. Tamamura (Eds.), *Boeki Shisu Detabesu to Bunseki: Higashi Ajia Chiiki o Chushin to Shite (Compilation and Analyses of Trade Indices in East Asia)* (pp. 83–105). Institute of Developing Economies Japan External Trade Organisation (JETRO).

Tanaka, A. (2008). Tekko: Nihon Moderu no Hakyu to Kakusan (Steel: Extension and Spread of the Japanese Model). In H. Shioji (Ed.), *Higashi Ajia Yui Sangyo no Kyosoryoku: Sono Yoin to Kyoso Bungyo Kozo (East Asia's Competitive Industries: The Factors and the Structure of Competition and Division of Labour)* (pp. 15–49). Minerva Publishing.

Tanaka, A., & Isomura, M. (2020). Tekko: Nihon Moderu no Seijukuka to Kaigai Tenkai (Steel: The Maturation of the Japanese Model and Overseas Expansion). In H. Shioji & A. Tanaka (Eds.), *Higashi Ajia Yui Sangyo: Tagenka Suru Kokusai Seisan Nettowaku (East Asia's Competitive Industries: Divergence of International Production Networks)* (pp. 121–136). Chuokeizai-sha.

Tang, R. (2010). *China's Steel Industry and Its Impact on the United States: Issues for Congress*. Congressional Research Service.

Tata Steel. (2007). *Tata Steel Completes £6.2bn Acquisition of Corus Group Plc*. https://www.tatasteel.com/media/newsroom/press-releases/india/2007/tata-steel-completes-62bn-acquisition-of-corus-group-plc/

Tata Steel. (2008). *Tata Steel Works in Jamshedpur Moving Towards 10 Mtpa Capacity*. https://www.tatasteel.com/media/newsroom/press-releases/india/2008/tata-steel-works-in-jamshedpur-moving-towards-10-mtpa-capacity/

Tata Steel. (2011). *Tata Steel Announces Completion of 100 Years of Its A-F Blast Furnace's Existence*. https://www.tatasteel.com/media/newsroom/press-releases/india/2011/tata-steel-announces-completion-of-100-years-of-its-a-f-blast-furnace-s-existence/

Tata Steel. (2016). *Tata Steel Starts Export of Tata Ferroshots from Its Kalinganagar Steel Plant*. https://www.tatasteel.com/media/newsroom/press-releases/india/2016/tata-steel-starts-export-of-tata-ferroshots-from-its-kalinganagar-steel-plant/

Tata Steel. (2017). *Tata Steel India Analyst Day 2017 Kalinganagar*. https://www.tatasteel.com/media/5210/tata-steel-india-analyst-day-2017-kalinganagar.pdf

Thirlwall, A. P. (1983). A Plain Man's Guide to Kaldor's Growth Laws. *Journal of Post Keynesian Economics*, 5(3), 345–358. https://doi.org/10.1080/01603477.1983.11489375

Toda, H. (1970). *Ajia no Tekkogyo (Asian Steel Industry)*. Institute of Developing Economies Japan External Trade Organisation (JETRO).

Toda, H. (1984). *Gendai Sekai Tekkogyo Ron (Modern World Steel Industry)*. Bunshindo.

Toda, H. (1987). Kozo Henka ka no Sekai Tekkokigyo Senryaku (Strategies of Global Steel Firms under Structural Change). In H. Toda (Ed.), *Tekkogyo (Steel Industry)* (pp. 54–90). Nikkei Inc.

UNCTAD. (2013). *The Iron Ore Market Situation – Views of UNCTAD*. United Nations Conference on Trade and Development (UNCTAD). https://www.oecd.org/sti/ind/Item%207.%20UNCTAD%20-%20Mr.%20Alexei%20Mojarov%20%E2%80%93%20July%202013.pdf

UNFCCC. (2015). *Paris Agreement*. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

United Nations Economic Commission for Africa Office for North Africa. (2013). *Diversification and Sophistication as a Lever for the Structural Transformation of North African Economies*. https://archive.uneca.org/sites/default/files/PublicationFiles/diversification_sophistication_eng.pdf

University of Sheffield. (n.d.). *Kruskal-Wallis in SPSS*. https://www.sheffield.ac.uk/polopoly_fs/1.714567!/file/stcp-marshall-KruskalSPSS.pdf

Verdoorn, P. J. (2002). Factors that Determine the Growth of Labour Productivity. In J. McCombie, M. Pugno, & B. Soro (Eds.), *Productivity Growth and Economic Performance* (pp. 28–36). Palgrave Macmillan. https://doi.org/10.1057/9780230504233_2

Vernon, R. (1966). International Investment and International Trade in the Product Cycle. *The Quarterly Journal of Economics*, 80(2), 190. https://doi.org/10.2307/1880689

Widodo, T. (2009). Comparative Advantage: Theory, Empirical Measures and Case Studies. *Review of Economic and Business Studies*, 4, 57–82.

Willoughby, K. W. (1990). *Technology Choice*. Westview Press.

Wood Mackenzie. (2018). *Steel Capacity Outlook*. Wood Mackenzie. https://www.oecd.org/industry/ind/84th_OECD_Steel_Committee_Item_4-2_Wood_Mackenzie_Final.pdf

World Bank. (2021). *World Development Indicators Database: GDP, PPP (Constant 2017 International $)*. https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD

World Steel Association. (n.d.). *Glossary*. https://www.worldsteel.org/about-steel/steel-glossary.html

World Steel Association. (2012). *The White Book of Steel*. https://www.worldsteel.org/en/dam/jcr:7b406f65-3d94-4e8a-819f-c0b6e0c1624e/The+White+Book+of+Steel_web.pdf

World Steel Association. (2013). *Overview of the Steelmaking Process*. https://www.worldsteel.org/en/dam/jcr:339d5d30-3650-49e7-8470-3d9ce3672ee5/Overview%2520of%2520the%2520Steelmaking%2520Process.pdf

World Steel Association. (2018). *The Chinese Steel Industry at a Crossroads*. https://www.worldsteel.org/en/dam/jcr:295ce643-fff1-4a23-8db8-d24bf3b154f2/PPT%2520for%2520MB%2520iron%2520ore%2520conference%25202018_EN_final.pdf

World Steel Association. (2019a). *Economic and Social Impact of the Steel Industry*. https://www.worldsteel.org/steel-by-topic/statistics/steel-industry-economic-impact.html

World Steel Association. (2019b). *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

World Steel Association. (2019c). *World Steel in Figures 2019*. https://www.worldsteel.org/en/dam/jcr:96d7a585-e6b2-4d63-b943-4cd9ab621a91/World%2520Steel%2520in%2520Figures%25202019.pdf

World Steel Association. (2020a). *Steel Markets*. https://www.worldsteel.org/steel-by-topic/steel-markets.html

World Steel Association. (2020b). *Steel Statistical Yearbook 2020*. https://www.worldsteel.org/en/dam/jcr:5001dac8-0083-46f3-aadd-35aa357acbcc/Steel%2520Statistical%2520Yearbook%25202020%2520%2528concise%2520version%2529.pdf

World Steel Association. (2020c). *The Steel Industry in Modern Society*. https://www.worldsteel.org/media-centre/press-releases/2020/edwin-basson-presentation-gfsec-october-2020.html

World Steel Association. (2020d). *Top Steel-Producing Companies 2019*. https://www.worldsteel.org/steel-by-topic/statistics/top-producers.html

World Steel Association. (2021a). *Apparent Steel Use (Finished Steel Products)*. https://www.worldsteel.org/steel-by-topic/statistics.html

World Steel Association. (2021b). *Blog: COP26 – The Last Best Chance?* https://www.worldsteel.org/media-centre/blog/2021/Blog--COP-26---the-last-best-chance-.html

World Steel Association. (2021c). *Climate Change and the Production of Iron and Steel*. https://www.worldsteel.org/en/dam/jcr:228be1e4-5171-4602-b1e3-63df9ed394f5/worldsteel_climatechange_policy%2520paper.pdf

World Steel Association. (2021d). *Exports of Semi-finished and Finished Steel Products*. https://www.worldsteel.org/steel-by-topic/statistics.html

World Steel Association. (2021e). *Steel and Raw Materials*. https://www.worldsteel.org/en/dam/jcr:16ad9bcd-dbf5-449f-b42c-b220952767bf/fact%2520sheet%2520raw%2520materials%25202021.pdf

World Steel Association. (2021f). The Steelmaking Process. https://www.worldsteel.org/en/dam/jcr:643fdaa0-ce90-4512-925c-897415bf2d22/Steelmaking%2520process.pdf

World Steel Association. (2021g). *Total Production of Crude Steel*. https://www.worldsteel.org/steel-by-topic/statistics.html

World Steel Association. (2021h). *World Steel in Figures 2021*. https://www.worldsteel.org/en/dam/jcr:976723ed-74b3-47b4-92f6-81b6a452b86e/World%2520Steel%2520in%2520Figures%25202021.pdf

World Steel Association. (various years). *Steel Statistical Yearbook*. https://www.worldsteel.org/steel-by-topic/statistics/steel-statistical-yearbook.html

WTO. (2008). *World Trade Report 2008: Trade in a Globalising World*. World Trade Organisation (WTO). https://www.wto.org/english/res_e/booksp_e/anrep_e/world_trade_report08_e.pdf

WTO. (2021). *Anti-Dumping Initiations: By Sector*. World Trade Organisation (WTO). https://www.wto.org/english/tratop_e/adp_e/AD_InitiationsBySector.pdf

WV Stahl. (various years). *Statistisches Jahrbuch Der Stahlindustrie (Statistical Yearbook of the Steel Industry)*. Stahleisen GmbH.

Yoneyama, K. (1990). *Tekisei Gijutsu no Kaihatsu to Iten: Mareshia Tekkogyo no Sosetsu (Development and Transfer of Appropriate Technology: The Creation of the Malaysian Steel Industry)*. Bunshindo.

Zhu, S., & Fu, X. (2013). Drivers of Export Upgrading. *World Development*, 51, 221–233. https://doi.org/10.1016/j.worlddev.2013.05.017

The internet resources were last retrieved on 22 November 2021, unless otherwise noted.

Appendices

Table 1: List of steel products

HS code	Broad detail	Medium level detail		High level detail
'720610	INGOTS/SEMI-FINISHED PRODUCTS	INGOTS/SEMI-FINISHED PRODUCTS	INGOTS	INGOTS: NON ALLOY
'720690				BLOCKS/LUMPS: NON ALLOY
'721810				INGOTS:STAINLESS STEEL
'722410				INGOTS:ALLOY STEEL
'720711			SEMIS	BLOOMS/BILLETS:C<0.25%
'720712				SLABS: C<0.25%
'720719				ROUND/OTHER SEMIS: C<0.25%
'720720				SEMIS: C>0.25%
'721891				SLABS : STAINLESS
'721899				BLOOMS & BILLETS : STAINLESS
'722490				SEMIS : ALLOY STEEL
'721310	LONG PRODUCTS	WIRE RODS	BARS AND ROD IN COILS	DEFORMED REINFORCING ROD
'721320				ROD:FREE CUTTING
'721391				ROUND ROD: <14MM
'721399				ROD >14MM OR NON CIRCULAR
'722100				ROD:STAINLESS
'722710				ROD: HIGH SPEED STEEL
'722720				ROD: SILICO MANGANESE STEEL
'722790				ROD: OTHER ALLOY
'721420		BARS	DEFORMED REINFORCING BARS	DEFORMED REINFORCING BARS
'721430			HOT ROLLED BARS AND FLATS	HR BARS/FLATS:FREE CUTTING
'721491				HR FLATS : NON ALLOY
'721499				HR BARS : NON ALLOY
'722211				ROUND BARS : STAINLESS
'722219				OTHER HR BARS/FLATS : STNLS
'722820				BARS/FLATS: SI MN
'722830				HR BARS/FLATS:TOOL/ENG
'722880				HOLLOW DRILL BARS
'721510			COLD FINISHED BARS AND FLATS	BRIGHT/CF BARS/FLATS:F/CUT
'721550				BRIGHT/CF BARS/FLATS:N/A
'721590				BARS/FLATS:CLAD OR F/W
'722220				CF BARS/FLATS: STAINLESS
'722810				BARS/FLATS: HIGH SPEED
'722850				CF BARS/FLATS:TOOL/ENG
'722860				F/W BARS/FLATS:TOOL/ENG
'721610		SECTIONS	HOT ROLLED LIGHT SECTIONS	LIGHT U/I/H SECTIONS:<80MM
'721621				LIGHT ANGLES:<80MM
'721622				LIGHT TEES:<80MM
'721650				BULB FLATS/SPECIAL SECTIONS
'722240				SECTIONS:STAINLESS
'722870				SECTIONS: OTHER ALLOY
'721631			HOT ROLLED HEAVY SECTIONS	HEAVY U SECTIONS:>80MM
'721632				HEAVY I SECTIONS:>80MM
'721633				HEAVY H SECTIONS:>80MM
'721640				HEAVY ANGLES/TEES:>80MM
'730110				SHEET PILING
'730210		RAILS	RAILS AND ROLLED ACCESSORIES	RAILS: NEW AND USED
'730240				FISH/SOLE PLATES

'720810	FLAT PRODUCTS	HOT-ROLLED SHEETS/COILS	HOT ROLLED WIDE STRIP	W/STRIP: FLOORPLATE IN COILS
'720825				WIDE STRIP : PICKLED >4.75
'720826				WIDE STRIP PICKLED 3<4.75MM
'720827				HR WIDE STRIP PICKLED <3MM
'720836				WIDE STRIP UNPICKLED >10MM
'720837				WIDE STRIP UNPICKLED 4.75<10
'720838				WIDE STRIP UNPICKLED 3<4.75
'720839				WIDE STRIP UNPICKLED <3
'721911				WIDE STRIP:>10MM STAINLESS
'721912				WIDE STRIP:4.75<10MM STNLS
'721913				WIDE STRIP: 3<4.75MM STNLS
'721914				WIDE STRIP:<3MM STAINLESS
'722530				WIDE STRIP : OTHER ALLOY
'720854			HOT ROLLED SHEETS	HR SHEET: <3MM THICK
'721924				HR SHEET:<3MM STAINLESS
'721113			HOT ROLLED STRIP	UNIVERSAL PLATES: 150<600MM
'721114				HR STRIP: >4.75MM <600MM
'721119				HR STRIP: <4.75MM <600MM
'721260				CLAD STRIP :<600MM WIDE
'722011				HR STRIP:>4.75MM STAINLESS
'722012				HR STRIP:<4.75MM STAINLESS
'722691				HR STRIP:OTHER ALLOY
'721113			HOT ROLLED STRIP	UNIVERSAL PLATES: 150<600MM
'721114				HR STRIP: >4.75MM <600MM
'721119				HR STRIP: <4.75MM <600MM
'721260				CLAD STRIP :<600MM WIDE
'720840		PLATES	HOT ROLLED PLATES	FLOORPLATE IN LENGTHS
'720851				HR PLATE : >10MM THICK
'720852				HR PLATE : 4.75<10MM THICK
'720853				HR PLATE : 3<4.75MM THICK
'720890				HR PLATE/SHEET: F/WORKED
'721921				HR PLATE:>10MM STAINLESS
'721922				HR PLATE:4.75<10MM STAINLESS
'721923				HR PLATE:3<4.75MM STAINLESS
'722540				HR PLATE/SHEET:OTHER ALLOY
'722599				F/W PLATE/SHEET : O/ALLOY
'720915		COLD-ROLLED SHEETS/COILS	CR PLATE/SHEET:COILS/LENGTHS	CR COIL PLATE
'720916				CR COIL SHEET : 1<3MM THICK
'720917				CR COIL SHEET 0.5<1MM THICK
'720918				CR COIL SHEET <0.5MM THICK
'720925				CR PLATE
'720926				CR SHEET : 1<3 THICK
'720927				CR SHEET : 0.5<1MM THICK
'720928				CR SHEET : <0.5 THICK
'720990				CR PLATE/SHEET: F/WORKED
'721931				CR PLATE:>4.75MM STAINLESS
'721932				CR PLATE:3<4.75MM STAINLESS
'721933				CR SHEET:1<3MM STAINLESS
'721934				CR SHEET:.5<1MM STAINLESS
'721935				CR SHEET:<.5MM STAINLESS
'721990				PLATE/SHEET:F/WORK STAINLESS
'722520				HR/CR PLATE/SHEET:HIGH SPEED
'722550				CR PLATE/SHEET:OTHER ALLOY
'721123			COLD ROLLED STRIP	CR STRIP : <600MM C<.25%
'721129				CR STRIP: <600MM C>.25%

'721190				CR STRIP: <600MM S/T OR F/W
'722020				CR STRIP:<600MM STAINLESS
'722090				F/WORKED STRIP:<600MM STNLS
'722620				HR/CR STRIP:<600MM H/SPEED
'722692				CR STRIP: <600MM O/ALLOY
'722699				F/W STRIP: <600MM O/ALLOY
'721011		TIN PLATES AND TIN-FREES	TINPLATE AND TFS	TINNED SHEET: >0.5M
'721012				TINPLATE/T.SHEET : <0.5MM
'721050				ECCS (TFS) SHEET
'721210				TINPLATE/T STRIP<600MM WIDE
'721030		ZINC COATED SHEETS	ZINC COATED SHEET AND STRIP	ELECTRO ZINC COATED SHEET
'721041				HD GALV CORRUGATED SHEET
'721049				HOT DIP GALVANISED SHEET
'721220				EZ STRIP : <600MM WIDE
'721230				HD GALV STRIP: <600MM WIDE
'722591				ELECTRO ZINC CTD SHEET : O/A
'722592				HOT DIP GALV SHEET : O/ALLOY
'721020		OTHER COATED SHEETS	OTHER COATED SHEET AND STRIP	TERNE PLATE
'721061				AL/ZN COATED SHEET
'721069				ALUMINIUM COATED SHEET :N/A
'721070				PAINT/PLASTIC COATED SHEET
'721090				OTHER METAL COATED SHEET
'721240				PAINT/PLASTIC STRIP: <600MM
'721250				O/METAL COATED STRIP: <600MM
'722693				ELECTRO ZINC CTD STRIP : O/A
'722694				HOT DIP GALV STRIP : O/ALLOY
'722511		ELECTRICAL SHEETS	ELECTRICAL SHEET	CR WIDE STRIP SHEET:SI EL GO
'722519				OT HR/CR WIDE STRP/SHT:SI EL
'722611			ELECTRICAL STRIP	CR STRIP : SI EL GRAIN ORIEN
722619				HR/CR STRIP : SI ELECTRICAL
'730410	PIPE AND TUBE PRODUCTS	SEAMLESS TUBES	STEEL TUBES, SEAMLESS	LINEPIPE: SEAMLESS
'730411				SEAMLESS LINEPIPE, STAINLESS
'730419				SEAMLESS LINEPIPE, OTHER
'730421				DRILL PIPE : SEAMLESS
'730422				DRILL PIPE, STAINLESS
'730423				DRILL PIPE, OTHER
'730424				CASING, STAINLESS
'730429				CASING/TUBING : SEAMLESS
'730431				TUBES: SMLS CD/CR NON ALLOY
'730439				OTHER SEAMLESS TUBES:N/A
'730441				TUBES:SMLS CD/CR STAINLESS
'730449				OTHER SMLS TUBES : STNLS
'730451				TUBES:SMLS CD/CR OTHER ALLOY
'730459				OTHER SMLS TUBES:OTHER ALLOY
'730490				TUBES: SEAMLESS NON CIRCULAR
'730511		WELDED TUBES	STEEL TUBES, WELDED	LINE PIPE:S/ARC WELD>406.4
'730512				LINE PIPE:LONG WELD>406.4
'730519				LINE PIPE: SPIRAL WELD>406.4
'730520				CASING:WELDED >406.4MM
'730531				TUBES: LONG WELD>406.4MM ED
'730539				TUBES: SPIRAL WELD >406.4MM
'730590				TUBES: NOT WELDED>406.4MM ED
'730610				LINE PIPE: WELDED <406.4MM
'730611				WELDED LINEPIPE, STAINLESS

'730619				WELDED LINEPIPE, OTHER
'730620				CASING/TUBING: WELDED<406.4
'730621				WELDED CASING, STAINLESS
'730629				WELDED CASING, OTHER
'730630				TUBES: WELDED <406.4MM N/A
'730640				TUBES:WELDED<406.4 STAINLESS
'730650				TUBES: WELDED<406.4 ALLOY
'730660				N/CIRC WELDED HOLLOWSECTIONS
'730661				RHS
'730669				OTHER HOLLOW SECTIONS
'730690				TUBES: NOT WELDED<406.4MM ED
'730721		STEEL TUBE FITTINGS	STEEL TUBE FITTINGS	TUBE/PIPE FLANGES: STAINLESS
'730722				ELBOWS ETC: THREADED STNLS
'730723				BUTT/W FITTINGS STNLS
'730729				OTHER FITTINGS STAINLESS
'730791				FLANGES: NOT STAINLESS
'730792				ELBOWS ETC: THREADED NOT ST
'730793				BUTT/W FITTINGS : NOT STNLS
'730799				OTHER FITTINGS:NOT STAINLESS
'721710	OTHER STEEL PRODUCTS	OTHER STEEL PRODUCTS	WIRE	UNCOATED WIRE
'721720				ZINC COATED WIRE
'721730				METAL COATED WIRE
'721790				PLASTIC COATED WIRE
'722300				WIRE:STAINLESS
'722910				WIRE: HIGH SPEED STEEL
'722920				WIRE: SILICO MANGANESE STEEL
'722990				WIRE: OTHER ALLOY STEEL
'721410			FORGED BARS	FORGED BARS:NON ALLOY
'722230				FORGED OR F/W BARS/FLATS:ST
'722840				FORGED BARS/FLATS:TOOL/ENG
'732619			FORGINGS	DIE FORGINGS UNWORKED
'860719			TYRES, WHEELS AND AXLES	TYRES WHEELS/AXLES
'730230			POINTS/SWITCHES/CROSSINGS	POINTS/SWITCHES/CROSSINGS
'730290				OTHER RAILWAY MATERIALS
'721669			FORGED/COLD FINISH SECTIONS	OTHER COLD FINISHED SECTIONS
'721699				SECTIONS FURTHER WORKED
'721661			COLD FORMED SECTIONS	UNCOATED COLD FORMED SECTS
'721691				COATED COLD FORMED SECTIONS
'730120			WELDED STRUCTURAL SECTIONS	WELDED SHAPES AND SECTIONS
'732599			STEEL CASTINGS	OTHER IRON /STEEL CASTINGS

Source: Author based on ISSB (2010)

Table 2: Steel exports by product (the whole OECD steel industry)

HS code	Medium level detail	High level detail	Value Million USD	Share %
'720610	INGOTS	INGOTS: NON ALLOY	84.7	0.0
'720690		BLOCKS/LUMPS: NON ALLOY	140.5	0.1
'721810		INGOTS:STAINLESS STEEL	245.8	0.1
'722410		INGOTS:ALLOY STEEL	486.7	0.2
'720711	SEMIS	BLOOMS/BILLETS:C<0.25%	1,526.2	0.6
'720712		SLABS: C<0.25%	3,296.5	1.4
'720719		ROUND/OTHER SEMIS: C<0.25%	313.5	0.1
'720720		SEMIS: C>0.25%	1,074.7	0.5
'721891		SLABS : STAINLESS	588.9	0.2
'721899		BLOOMS & BILLETS : STAINLESS	622.1	0.3
'722490		SEMIS : ALLOY STEEL	1,439.8	0.6
'721310	BARS AND ROD IN COILS	DEFORMED REINFORCING ROD	1,485.0	0.6
'721320		ROD:FREE CUTTING	746.5	0.3
'721391		ROUND ROD: <14MM	4,418.7	1.9
'721399		ROD >14MM OR NON CIRCULAR	582.8	0.2
'722100		ROD:STAINLESS	1,289.1	0.5
'722710		ROD: HIGH SPEED STEEL	84.2	0.0
'722720		ROD: SILICO MANGANESE STEEL	251.3	0.1
'722790		ROD: OTHER ALLOY	2,153.7	0.9
'721420	DEFORMED REINFORCING BARS	DEFORMED REINFORCING BARS	6,444.6	2.7
'721430	HOT ROLLED BARS AND FLATS	HR BARS/FLATS:FREE CUTTING	222.9	0.1
'721491		HR FLATS : NON ALLOY	980.3	0.4
'721499		HR BARS : NON ALLOY	1,920.9	0.8
'722211		ROUND BARS : STAINLESS	732.1	0.3
'722219		OTHER HR BARS/FLATS : STNLS	287.3	0.1
'722820		BARS/FLATS: SI MN	100.1	0.0
'722830		HR BARS/FLATS:TOOL/ENG	3,968.5	1.7
'722880		HOLLOW DRILL BARS	85.6	0.0
'721510	COLD FINISHED BARS AND FLATS	BRIGHT/CF BARS/FLATS:F/CUT	689.4	0.3
'721550		BRIGHT/CF BARS/FLATS:N/A	967.2	0.4
'721590		BARS/FLATS:CLAD OR F/W	340.3	0.1
'722220		CF BARS/FLATS: STAINLESS	2,289.7	1.0
'722810		BARS/FLATS: HIGH SPEED	439.8	0.2
'722850		CF BARS/FLATS:TOOL/ENG	1,681.2	0.7
'722860		F/W BARS/FLATS:TOOL/ENG	189.4	0.1
'721610	HOT ROLLED LIGHT SECTIONS	LIGHT U/I/H SECTIONS:<80MM	209.1	0.1
'721621		LIGHT ANGLES:<80MM	618.5	0.3
'721622		LIGHT TEES:<80MM	140.3	0.1
'721650		BULB FLATS/SPECIAL SECTIONS	621.1	0.3
'722240		SECTIONS:STAINLESS	395.7	0.2
'722870		SECTIONS: OTHER ALLOY	340.3	0.1
'721631	HOT ROLLED HEAVY SECTIONS	HEAVY U SECTIONS:>80MM	827.7	0.3
'721632		HEAVY I SECTIONS:>80MM	1,557.6	0.7
'721633		HEAVY H SECTIONS:>80MM	3,078.9	1.3
'721640		HEAVY ANGLES/TEES:>80MM	594.7	0.3
'730110		SHEET PILING	1,034.3	0.4
'730210	RAILS AND ROLLED ACCESSORIES	RAILS: NEW AND USED	1,610.9	0.7
'730240		FISH/SOLE PLATES	122.7	0.1
'720810	HOT ROLLED WIDE STRIP	W/STRIP: FLOORPLATE IN COILS	240.5	0.1
'720825		WIDE STRIP : PICKLED >4.75	957.1	0.4

'720826		WIDE STRIP PICKLED 3<4.75MM	2,107.2	0.9
'720827		HR WIDE STRIP PICKLED <3MM	3,250.3	1.4
'720836		WIDE STRIP UNPICKLED >10MM	982.1	0.4
'720837		WIDE STRIP UNPICKLED 4.75<10	2,762.3	1.2
'720838		WIDE STRIP UNPICKLED 3<4.75	4,009.1	1.7
'720839		WIDE STRIP UNPICKLED <3	6,950.5	2.9
'721911		WIDE STRIP:>10MM STAINLESS	125.5	0.1
'721912		WIDE STRIP:4.75<10MM STNLS	1,658.8	0.7
'721913		WIDE STRIP: 3<4.75MM STNLS	2,445.0	1.0
'721914		WIDE STRIP:<3MM STAINLESS	744.4	0.3
'722530		WIDE STRIP : OTHER ALLOY	3,523.8	1.5
'720854	HOT ROLLED SHEETS	HR SHEET: <3MM THICK	328.0	0.1
'721924		HR SHEET:<3MM STAINLESS	35.1	0.0
'721113	HOT ROLLED STRIP	UNIVERSAL PLATES: 150<600MM	148.8	0.1
'721114		HR STRIP: >4.75MM <600MM	521.1	0.2
'721119		HR STRIP: <4.75MM <600MM	1,224.5	0.5
'721260		CLAD STRIP :<600MM WIDE	214.7	0.1
'722011		HR STRIP:>4.75MM STAINLESS	106.2	0.0
'722012		HR STRIP:<4.75MM STAINLESS	93.6	0.0
'722691		HR STRIP:OTHER ALLOY	581.9	0.2
'720840	HOT ROLLED PLATES	FLOORPLATE IN LENGTHS	213.9	0.1
'720851		HR PLATE : >10MM THICK	6,790.4	2.9
'720852		HR PLATE : 4.75<10MM THICK	2,152.0	0.9
'720853		HR PLATE : 3<4.75MM THICK	696.2	0.3
'720890		HR PLATE/SHEET: F/WORKED	369.3	0.2
'721921		HR PLATE:>10MM STAINLESS	1,325.2	0.6
'721922		HR PLATE:4.75<10MM STAINLESS	1,010.9	0.4
'721923		HR PLATE:3<4.75MM STAINLESS	225.9	0.1
'722540		HR PLATE/SHEET:OTHER ALLOY	3,311.5	1.4
'722599		F/W PLATE/SHEET : O/ALLOY	2,048.7	0.9
'720915	CR PLATE/SHEET:COILS/LENGTHS	CR COIL PLATE	192.3	0.1
'720916		CR COIL SHEET : 1<3MM THICK	3,252.2	1.4
'720917		CR COIL SHEET 0.5<1MM THICK	4,180.7	1.8
'720918		CR COIL SHEET <0.5MM THICK	1,277.5	0.5
'720925		CR PLATE	45.9	0.0
'720926		CR SHEET : 1<3 THICK	387.8	0.2
'720927		CR SHEET : 0.5<1MM THICK	207.7	0.1
'720928		CR SHEET : <0.5 THICK	43.2	0.0
'720990		CR PLATE/SHEET: F/WORKED	120.9	0.1
'721931		CR PLATE:>4.75MM STAINLESS	561.3	0.2
'721932		CR PLATE:3<4.75MM STAINLESS	1,432.6	0.6
'721933		CR SHEET:1<3MM STAINLESS	4,890.1	2.1
'721934		CR SHEET:.5<1MM STAINLESS	3,401.7	1.4
'721935		CR SHEET:<.5MM STAINLESS	528.0	0.2
'721990		PLATE/SHEET:F/WORK STAINLESS	666.2	0.3
'722520		HR/CR PLATE/SHEET:HIGH SPEED	0.0	0.0
'722550		CR PLATE/SHEET:OTHER ALLOY	2,703.3	1.1
'721123	COLD ROLLED STRIP	CR STRIP : <600MM C<.25%	1,016.8	0.4
'721129		CR STRIP: <600MM C>.25%	657.6	0.3
'721190		CR STRIP: <600MM S/T OR F/W	281.7	0.1
'722020		CR STRIP:<600MM STAINLESS	3,137.1	1.3
'722090		F/WORKED STRIP:<600MM STNLS	333.5	0.1
'722620		HR/CR STRIP:<600MM H/SPEED	54.9	0.0
'722692		CR STRIP: <600MM O/ALLOY	1,016.5	0.4
'722699		F/W STRIP: <600MM O/ALLOY	467.9	0.2

'721011	TINPLATE AND TFS	TINNED SHEET: >0.5M	79.9	0.0
'721012		TINPLATE/T.SHEET : <0.5MM	3,617.1	1.5
'721050		ECCS (TFS) SHEET	724.5	0.3
'721210		TINPLATE/T STRIP<600MM WIDE	78.7	0.0
'721030	ZINC COATED SHEET AND STRIP	ELECTRO ZINC COATED SHEET	2,169.0	0.9
'721041		HD GALV CORRUGATED SHEET	40.3	0.0
'721049		HOT DIP GALVANISED SHEET	14,178.7	6.0
'721220		EZ STRIP : <600MM WIDE	214.8	0.1
'721230		HD GALV STRIP: <600MM WIDE	1,585.3	0.7
'722591		ELECTRO ZINC CTD SHEET : O/A	1,158.6	0.5
'722592		HOT DIP GALV SHEET : O/ALLOY	5,369.1	2.3
'721020	OTHER COATED SHEET AND STRIP	TERNE PLATE	7.9	0.0
'721061		AL/ZN COATED SHEET	951.1	0.4
'721069		ALUMINIUM COATED SHEET :N/A	716.6	0.3
'721070		PAINT/PLASTIC COATED SHEET	5,209.3	2.2
'721090		OTHER METAL COATED SHEET	813.4	0.3
'721240		PAINT/PLASTIC STRIP: <600MM	680.7	0.3
'721250		O/METAL COATED STRIP: <600MM	496.9	0.2
'722693		ELECTRO ZINC CTD STRIP : O/A	0.0	0.0
'722694		HOT DIP GALV STRIP : O/ALLOY	0.0	0.0
'722511	ELECTRICAL SHEET	CR WIDE STRIP SHEET:SI EL GO	1,586.4	0.7
'722519		OT HR/CR WIDE STRP/SHT:SI EL	1,127.2	0.5
'722611	ELECTRICAL STRIP	CR STRIP : SI EL GRAIN ORIEN	366.6	0.2
722619		HR/CR STRIP : SI ELECTRICAL	271.9	0.1
'730410	STEEL TUBES, SEAMLESS	LINEPIPE: SEAMLESS	0.0	0.0
'730411		SEAMLESS LINEPIPE, STAINLESS	180.3	0.1
'730419		SEAMLESS LINEPIPE, OTHER	1,189.5	0.5
'730421		DRILL PIPE : SEAMLESS	0.0	0.0
'730422		DRILL PIPE, STAINLESS	36.9	0.0
'730423		DRILL PIPE, OTHER	263.6	0.1
'730424		CASING, STAINLESS	918.6	0.4
'730429		CASING/TUBING : SEAMLESS	2,805.7	1.2
'730431		TUBES: SMLS CD/CR NON ALLOY	1,037.3	0.4
'730439		OTHER SEAMLESS TUBES:N/A	1,606.5	0.7
'730441		TUBES:SMLS CD/CR STAINLESS	1,514.8	0.6
'730449		OTHER SMLS TUBES : STNLS	984.3	0.4
'730451		TUBES:SMLS CD/CR OTHER ALLOY	411.3	0.2
'730459		OTHER SMLS TUBES:OTHER ALLOY	1,305.8	0.6
'730490		TUBES: SEAMLESS NON CIRCULAR	701.8	0.3
'730511	STEEL TUBES, WELDED	LINE PIPE:S/ARC WELD>406.4	1,790.1	0.8
'730512		LINE PIPE:LONG WELD>406.4	559.9	0.2
'730519		LINE PIPE: SPIRAL WELD>406.4	412.4	0.2
'730520		CASING:WELDED >406.4MM	200.7	0.1
'730531		TUBES: LONG WELD>406.4MM ED	958.8	0.4
'730539		TUBES: SPIRAL WELD >406.4MM	266.2	0.1
'730590		TUBES: NOT WELDED>406.4MM ED	64.3	0.0
'730610		LINE PIPE: WELDED <406.4MM	0.0	0.0
'730611		WELDED LINEPIPE, STAINLESS	121.4	0.1
'730619		WELDED LINEPIPE, OTHER	1,130.8	0.5
'730620		CASING/TUBING: WELDED<406.4	0.0	0.0
'730621		WELDED CASING, STAINLESS	21.6	0.0
'730629		WELDED CASING, OTHER	931.7	0.4
'730630		TUBES: WELDED <406.4MM N/A	4,911.1	2.1
'730640		TUBES:WELDED<406.4 STAINLESS	2,819.9	1.2

'730650		TUBES: WELDED<406.4 ALLOY	507.6	0.2
'730660		N/CIRC WELDED HOLLOWSECTIONS	0.0	0.0
'730661		RHS	3,811.1	1.6
'730669		OTHER HOLLOW SECTIONS	368.1	0.2
'730690		TUBES: NOT WELDED<406.4MM ED	539.0	0.2
'730721	STEEL TUBE FITTINGS	TUBE/PIPE FLANGES: STAINLESS	756.4	0.3
'730722		ELBOWS ETC: THREADED STNLS	688.7	0.3
'730723		BUTT/W FITTINGS STNLS	622.7	0.3
'730729		OTHER FITTINGS STAINLESS	1,624.3	0.7
'730791		FLANGES: NOT STAINLESS	1,003.3	0.4
'730792		ELBOWS ETC: THREADED NOT ST	686.6	0.3
'730793		BUTT/W FITTINGS : NOT STNLS	927.1	0.4
'730799		OTHER FITTINGS:NOT STAINLESS	2,819.3	1.2
'721710	WIRE	UNCOATED WIRE	1,931.6	0.8
'721720		ZINC COATED WIRE	1,083.2	0.5
'721730		METAL COATED WIRE	665.8	0.3
'721790		PLASTIC COATED WIRE	209.0	0.1
'722300		WIRE:STAINLESS	1,342.4	0.6
'722910		WIRE: HIGH SPEED STEEL	0.0	0.0
'722920		WIRE: SILICO MANGANESE STEEL	270.8	0.1
'722990		WIRE: OTHER ALLOY STEEL	1,331.8	0.6
'721410	FORGED BARS	FORGED BARS:NON ALLOY	110.6	0.0
'722230		FORGED OR F/W BARS/FLATS:ST	428.8	0.2
'722840		FORGED BARS/FLATS:TOOL/ENG	823.3	0.3
'732619	FORGINGS	DIE FORGINGS UNWORKED	2,728.3	1.2
'860719	TYRES, WHEELS AND AXLES	TYRES WHEELS/AXLES	2,139.2	0.9
'730230	POINTS/SWITCHES/CROSSINGS	POINTS/SWITCHES/CROSSINGS	423.3	0.2
'730290		OTHER RAILWAY MATERIALS	288.9	0.1
'721669	FORGED/COLD FINISH SECTIONS	OTHER COLD FINISHED SECTIONS	102.0	0.0
'721699		SECTIONS FURTHER WORKED	157.7	0.1
'721661	COLD FORMED SECTIONS	UNCOATED COLD FORMED SECTS	915.7	0.4
'721691		COATED COLD FORMED SECTIONS	562.6	0.2
'730120	WELDED STRUCTURAL SECTIONS	WELDED SHAPES AND SECTIONS	329.3	0.1
'732599	STEEL CASTINGS	OTHER IRON /STEEL CASTINGS	2,358.1	1.0

Note: The definition of steel products was based on ISSB (2010)
Source: Author’s calculation based on data from the ITC (2021)

Notes:

In this research, Chapters 1, 2, 3 and 4 were written based on the following papers, with major changes.

Chapter 2:

Chapter 3:

Chapters 1 and 4: