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A study on the ore grade, operating costs and investment value of iron ore miners amid China's "Dual Carbon" policy

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2022

I hereby declare that this dissertation is my original work and it has been written by me in its entirety. I have duly acknowledged all of the sources of information which have been used in this dissertation.

This dissertation has also not been submitted for any degree in any university previously

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Yao Shunyi

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A Study on The Ore Grade, Operating Costs and Investment Value of Iron Ore Miners Amid China's "Dual Carbon" Policy

Yao Shunyi

Abstract

With the growing demand for steel in significant economies, iron ore remains a vital investment in the long run. Although many iron ore miners have recently generated significant returns for investors, some have not performed well financially. The existing literature does not provide an integrated theoretical framework to explain this problem. The study examines the mechanisms determining the investment value of iron ore miners when China establishes carbon peaking and carbon neutrality goals ("Dual Carbon" policy). Further, based on the findings, this study also proposes investment strategies for iron ore miners in the future, which also has a high practical value.

With a case study approach, this study summarizes the theoretical logic of the impact of carbon emissions reduction on iron ore prices; using an interrupted time series analysis model, it discusses the implications of China's "Dual Carbon" policy on the price differentiation of different iron ore grades, and forecasts iron ore prices for the future. It analyzes in depth how iron ore grade affects firms' investment value regarding global carbon emission reductions and oligopolistic market structures using the case study method. Finally, it discusses selecting iron ore investment targets based on the previous analysis.

The study found that: (1) high-grade iron ore can help reduce energy consumption and carbon emissions in the steel-making process. With China’s progress in promoting the "Dual Carbon" policy, the demand for high-grade iron ore continues to grow, resulting in a premium for high-grade ore and a discount

for low-grade ore. (2) The investment value of iron ore miners is determined by the profit per ton of ore produced. Since grade has a significant impact on the premium/discount rate, revenue and cost of iron ore, the investment value of an iron ore miner is a function of the grade of the iron ore it produces. (3) At the low point of the price cycle, iron ore oligopolies squeeze out firms that produce low-grade iron ore at high operating costs through predatory pricing. Therefore, iron ore miners' investment value is determined by the difference in profit per ton from oligopolies.

The findings of this study have important implications for the search for quality targets. First, in the coming period, the investment logic of iron ore miners has changed. Previously, investors purely emphasized cost leadership strategy and now tend to an overall cost leadership/differentiation strategy. Under the new investment logic, we must focus on operating cost, grade, and profit per ton determined by cost and grade. The target will only have investment value if its profit per ton is not at an extreme disadvantage compared to the oligopolies. Secondly, since oligopolies already monopolize most of high-grade mines in the world, the promotion of China's "Dual Carbon" policy will strengthen the power of oligopolies in the market. Third, counter-cyclical operation is an essential tool for long-term investment in the iron ore industry, and purchase should take place when the oligopoly's profit per ton is around 0. Fourth, the mining country will benefit from the beneficiation and processing of raw ore, which will increase employment and taxation, and will play a significant role in reducing carbon emissions, which will be a crucial factor for China's future international investments.

Keywords: iron ore, grade, investment value, "Dual Carbon" policy

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Thanks are extended to the other teachers and students at CKGSB. CKGSB brings together the best professors and elites from various industries. They are the ones who learn and communicate with me and share the joy of learning, the experience and lessons known in practice and opinions and understandings in life. I feel the valuable teacher-student love and fellowship with them, as they provided me with strong spiritual support for my writing.

I would also like to thank my team of assistants who arranged the critical information and had weekly in-depth discussions with me on the proposal, constantly deepening our understanding of investment in iron ore miners.

1 Introduction

1.1 Background

Since the industrial revolution, steel has occupied a significant position in the industrial field and is the core metal material for building a modern society. Taking the United States as an example, steel has been the material of choice for construction from the 19th century to the present, including the Brooklyn Bridge in New York and the Home Insurance Building in Chicago, the world's first wire suspension bridge and steel skyscraper. Steel production has been steadily increasing in recent years around the globe, further enhancing its ability to drive the global economy. Data from the International Iron and Steel Institute (2022) show that in the last 20 years, except for a brief decline in 2009 due to the financial crisis, world steel production as a whole has continued to grow - global crude steel production has increased from 852 million tons in 2001 to 1.951 billion tons in 2021, a 129% increase in production.

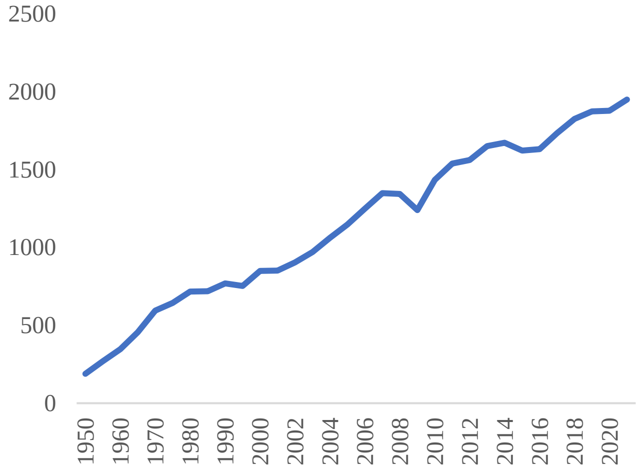

Figure 1.1 Global crude steel production (million tons)

Source: International Iron and Steel Institute (2022).

Steel production usually keeps pace with economic development. The major steel producers in the second half of the 20th century were mainly from developed Western countries. However, crude steel production in post-industrialized countries such as the United States, Japan, and South Korea remained at high levels. In 2021, Japan produced 96.334 million tons of crude steel; the United States produced 85.791 million tons, and South Korea produced 70.418 million tons, among others (International Iron & Steel Institute, 2022). These post-industrialized countries still have a strong demand for steel after the completion of industrialization to renovate obsolete infrastructure. For example, on November 15, 2021, President Joe Biden signed the most extensive infrastructure bill in the United States in half a century, involving a whopping USD1.2 trillion.

The rise of China as a manufacturing and industrial powerhouse in the last 20 years, following the completion of industrialization in developed countries such as the United States and Western Europe, has led to a surge in demand for steel. Most of China's steel is for construction and infrastructure. Over the past four decades, the structure of urban housing in China, as well as urban infrastructures such as road systems, sewage systems, and power generation and distribution systems, has led to a dramatic increase in demand for steel. According to statistics, in 2021, China's total social investment in fixed assets was RMB 55,288.420 billion, of which real estate developers invested RMB 14,760.208 billion[1]. At the same time, as the "world's workshop", China also has a large amount of steel for the manufacture of machinery, automobiles and household appliances and other industrial products. According to the International Iron and Steel Institute, China's crude steel production reached

1 Source: website of China National Bureau of Statistics

1.033 billion tons in 2021, exceeding 1 billion tons for the second consecutive year. In 2020, China's pig iron, crude steel and steel production was 887.52, 1,053 and 1,324.89 million tons, respectively. Figure 1.2 shows the distribution of world crude steel production in 2021 (larger circles indicate more significant production), which shows the absolute dominance of China's natural steel production scale. Moreover, we can also see that with continuous industrialization, some developing countries, such as India and Brazil, also have sizeable crude steel production.

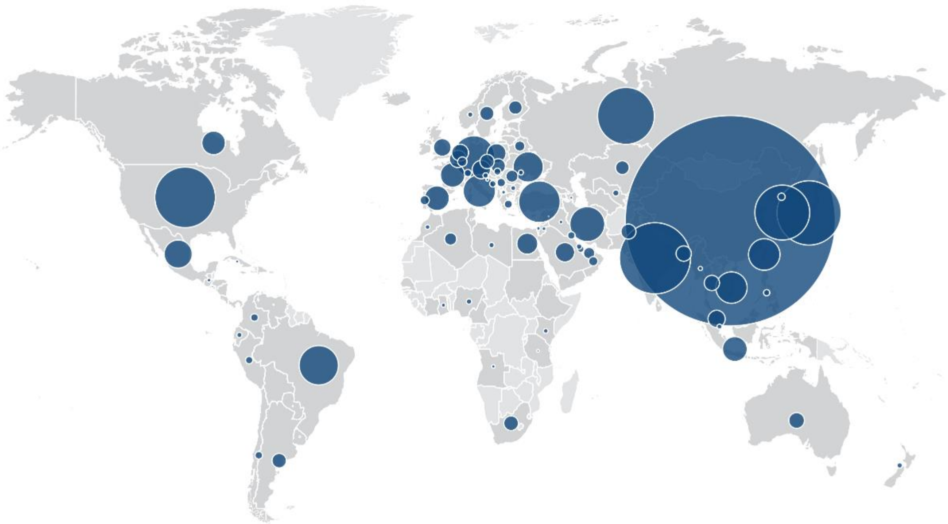

Figure 1.2 World crude steel production distribution in 2021 (thousand tons)

Source: International Iron & Steel Institute (2022).

The steel industry is one of the core drivers of the global economy. Studies show that in 2017, the added value of the steel industry was close to USD500 billion. For every dollar of the added value generated by the steel industry, through the purchase of raw materials, semi-finished products, energy, and the cost of external expenditures for services, the steel industry generates USD2.50 of added value in other economic sectors around the globe. In terms of employment, there are over 6 million workers in the steel industry globally. In the entire supply chain, every two jobs in the steel industry can create 13 jobs for the global steel supply chain, which means that the total number of employees in the steel industry's global supply chain is about 40 million (Worldsteel Association, 2019). Along with the rapid growth of the steel industry, the upstream iron ore mining industry has also grown by leaps and bounds. As of 2019, global crude iron ore production reached 2.3357 billion tons, up 122.4% from 1.05 billion tons in 2000[2]. Correspondingly, the share prices of many iron ore miners rose sharply, such as BHP Billiton, whose stock closed at just USD8.15 on the NYSE on October 31, 2001, and rose to USD58.79 on August 23, 2022.

Figure 1.3 BHP Billiton (NYSE: BHP) share price chart

However, there are still firms whose iron ore investments have not been successful. For example, in 2006, CITIC Pacific invested USD415 million to purchase the Sino-Iron and Balmoral Iron Ore projects in Western Australia, each with 1 billion tons of magnetite mining rights, from Mineralogy, i.e., the

2 Source: Worldsteel Association.

Sino-Australian SINO iron ore project. Various good things pushed up CITIC Pacific's share price in early stages. However, the Sino-Australian SINO iron ore project soon came out with negative news and the share price started a sharp decline. It was also the Sino-Australia SINO iron ore project that eventually triggered the departure of Rong Zhijian. Another example is the Carrara iron ore. It has been in the red since Anshan Iron & Steel cooperated with Gindalbie Metals Ltd to develop it in 2007, eventually leading to Gindalbie's de-listing in disgrace. In 2019, when the iron ore prices were low, Ansteel acquired all of Gindalbie's shares and became the 100% owner of the Carrara mine. While this additional investment paid off handsomely in 2020-2022 as iron ore prices continued to rise, the future of the Carrara mine remains uncertain should iron ore prices fall.

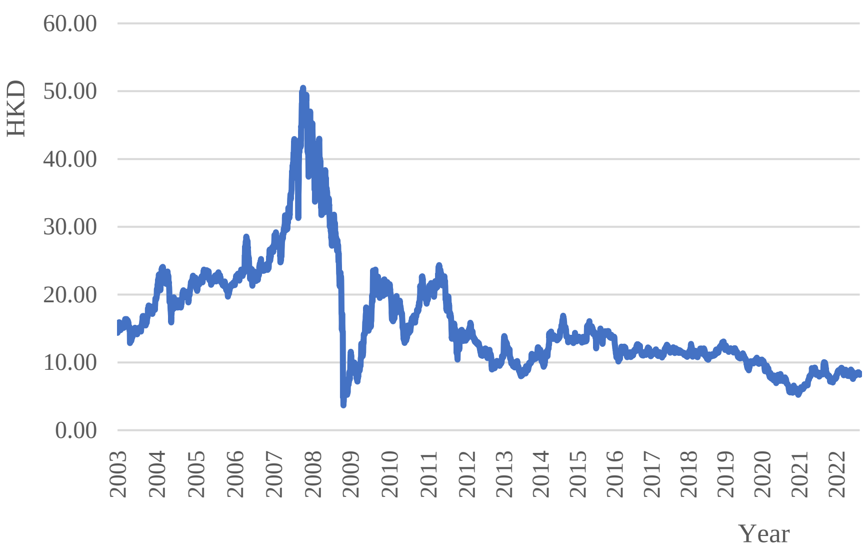

Figure 1.4 CITIC Pacific (CITIC shares) share price chart (2003-2022)

Source: CITIC’s website

The failure of China's overseas iron ore investments may be attributed to the fact that the targets of these investments are magnetite mines with low grades. Low-grade mines may pose two problems: first, low-grade mines imply higher carbon emissions. As a result of the global carbon reduction policy, the market demand for low-grade ores has decreased, thus leading to discounting. Second, low-grade ore beneficiation is required to obtain higher-grade finished ore that can be used in blast furnaces, which increases costs. In addition, the iron ore industry is an oligopolistic market structure: the four significant oligopolies, Vale S.A., Rio Tinto Plc, BHP Billiton Plc and FMG (Fortescue Metals Group Ltd), not only monopolize most of the global iron ore trade but also own most of the high-grade mines and have a generally lower Cost Index than other miners, so they can drive competitors out of the market through predatory pricing. The foregoing means that iron ore miners mining lower-grade ores are subject to a triple squeeze: higher costs, lower prices and predatory pricing by the oligarchs. Under these circumstances, investors must be extremely cautious about their iron ore investment targets.

As the world's largest steel producer, China announced by President Xi Jinping on September 22, 2020, at the 75th General Debate of the United Nations General Assembly, to adopt more robust policies and measures to peak CO2 emissions by 2030 and strive to achieve carbon neutrality by 2060, i.e., China's "Dual Carbon" policy. The increasingly stringent carbon emission policy may make the price disadvantage of low-grade ore more apparent and will profoundly affect the investment logic of iron ore miners. To enlighten the iron ore investment strategy in the future amid the "Dual Carbon" policy, this study focuses on the following three questions: (1) What is the impact of the "Dual Carbon" policy on the iron ore market? (2) What is the logic of determining the investment value of iron ore miners in the context of the "Dual

Carbon" policy? (3) What are the implications for iron ore investment strategies?

1.2 Significance

1. Identifying the decisive impact of the "Dual Carbon" policy on the iron ore industry. The energy consumption of the iron and steel industry has reached a staggering 10-12% of the total energy consumption in China (Wu et al., 2019; Wang et al., 2020). More studies have discussed how the steel industry can adapt to carbon reduction policies through technological changes (e.g., Lin et al., 2011; Zhang et al., 2012; Ah et al., 2014; An et al., 2018; Tan et al., 2019; Long et al., 2020; Ren et al., 2021; Li et al., 2022). However, they ignore that the carbon reduction policy will shape the steel industry's market structure. This study is an essential addition to the literature in this area, which has important implications for how to value iron ore miners in the context of "Dual Carbon".

2. Improving the capital asset pricing-related theory. Exploring the determinants of value is an important theme in value management research (Firk et al., 2016; Burkert & Lueg, 2013). This study constructs a formula of cost per ton and profit per ton determined by iron ore grade and premium/discount rate. It thus obtains the theoretical logic of investment value of iron ore miners, which has important theoretical significance.

3. Enriching the theory related to the industrial organization about the oligopolistic market. Existing studies discuss the effect of oligopolistic market structure on pricing (e.g., McGee, 1980; Ordover & Willig, 1981; Elzinga & Mills, 2001; Edlin, 2012) and also note that oligopolies may drive competitors out of the market through predatory pricing (e.g., Edwards & Geoff 2002). However, these studies do not provide an in-depth discussion of the mechanisms at play concerning the practice in the iron ore industry. This study uses a case

study approach regarding the performance of micro-firm players in different price cycles such as long, medium and short in oligopolistic markets, which helps further expand the theory of industrial organization.

4. Making clear the direction for China's overseas iron ore investment. China is the world's largest demander of iron ore, but due to the constraints of resource conditions, the total amount of iron ore in China is small and the grade is low, which is challenging to meet the enormous demand. Against the background of China's overseas iron ore dependence of over 80%, Chinese firms have actively gone global and made overseas iron ore investments, but the results have not been satisfactory. This study identifies the logic judging the investment value of iron ore miners in the context of the "Dual Carbon" policy. It is of great importance both to Chinese firms for their global deployment in the future (e.g., the Simandou mine in Guinea, which Chinese firms are investing in) and to break the oligopoly of the four major players.

5. Providing a reference for resource-based investment. As iron ore is a typical resource-based commodity, its characteristics have a certain degree of universality. Then, the findings of this study can be extended to other similar industries, such as oil, copper, aluminum, etc., to provide a reference for investment decisions in these industries

1.3 Arrangement

This study develops in a manner set forth in Figure 1.5.

Chapter 1 mainly introduces the research background, significance, ideas and arrangement. Chapter 2 is the theoretical review, which reviews the research on carbon emission reduction in the iron and steel industry, the research on the characteristics of the iron ore industry and its market structure, and the research on the factors influencing the value of firms to lay the literature foundation for this study.

Chapter 3 is the research design, which gives this study’s methodological choices and data sources.

Chapter 4 discusses the impact of the "Dual Carbon" policy on iron ore price differentiation. This chapter summarizes the relationship between the "Dual Carbon" policy, grade and iron ore premium/discount rate through a case study approach. After that, it conducts an empirical study using ISTA and AR/ARIMA.

Chapter 5 is about the grade, oligopolistic market and the investment value of iron ore miners. Using a case study approach, it summarizes the effect of iron ore grade on corporate value in an oligopolistic market.

Chapter 6 presents the conclusions, implications and shortcomings of this study.

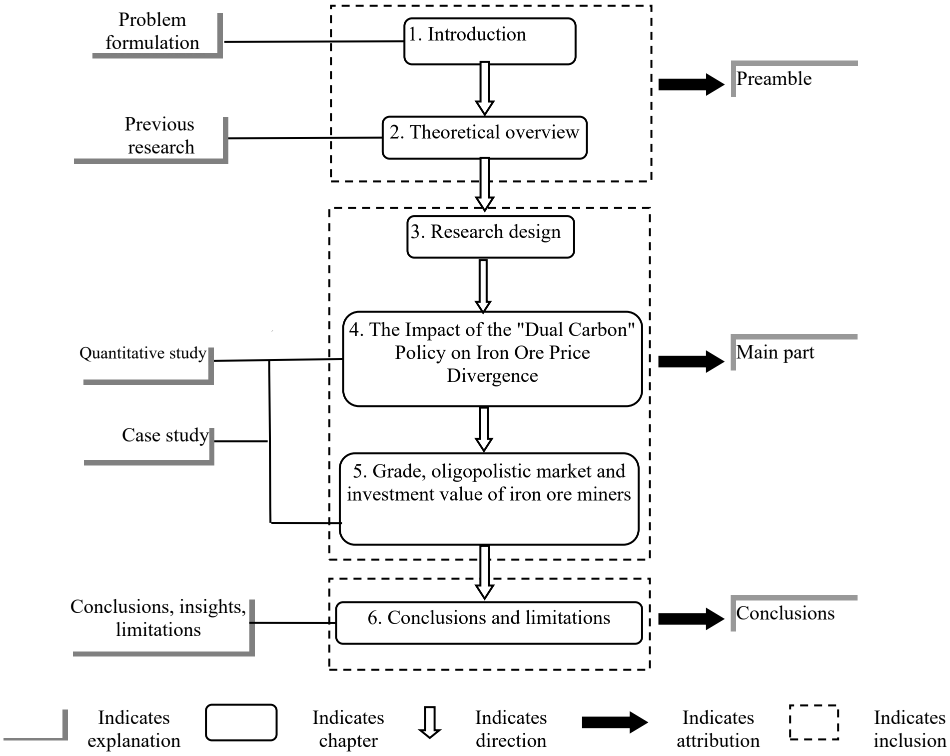

Figure 1.5 Chapter arrangement

2 Theoretical overviews

This chapter is a theoretical review that lays the literature foundation for subsequent studies. This chapter begins with a review of carbon reduction in the steel industry, noting that the steel industry is one of the most important sources of carbon emissions in China. Therefore, many studies have discussed the factors that influence carbon emissions in the steel industry and the strategic path to "carbon reduction". It then reviews iron ore’s characteristics and market structure, pointing out that iron ore has characteristics such as scarcity, uneven distribution, intermediate product and standard product, which lead to global trade patterns and oligopolistic market structures for iron ore. Finally, it provides an overview of the factors influencing corporate value, discusses the factors influencing the importance of corporate investment from the theory of corporate value management and the impact of internal control on corporate value, and reviews the factors influencing the value of miners on this basis.

2.1 Research on carbon emission reduction in the steel industry

The growth of carbon emissions is one of the leading causes of global warming. Many countries are trying to achieve carbon neutrality to mitigate global warming (Chen et al., 2021; Zameer et al., 2021). In response to the severe global climate change situation, China has guided to peak CO2 emissions by 2030 and carbon neutrality by 2060 to honor its commitment to the Paris Agreement. In the coming period, China will deploy and implement carbon emission peaking actions, clearly transmit pressure and tasks to regions and industries, and specify peaking targets, roadmaps, action plans, and supporting measures for areas and key sectors to achieve the targets by 2030 (Hu et al., 2021).

Due to the constraints of economic development, technology level, policy costs, and other conditions, it isn't easy to control the industry-wide carbon reduction targets in the short term. If some industries can be held for the carbon emission control target, it will significantly improve the accuracy and efficiency of the policy and reduce the policy cost. China proposed that critical sectors for carbon emission reduction are mainly high-emission industries with direct carbon emissions (Chen et al., 2017). The iron and steel industry are a vital carbon emitter in China. Data show that the energy consumption of China's steel industry accounted for about 11% of domestic energy consumption in 2018 (Wang et al., 2020); CO2 emissions accounted for about 15% of China's total CO2 in 2015 (Zhang et al., 2018). Under the carbon neutrality target, the Chinese steel industry has become an important entity responsible for energy conservation and emission reduction.

Existing literature discusses the reasons for the high carbon emissions of the Chinese steel industry and it believes capacity and energy efficiency are key factors affecting the CO2 trajectory (Li et al., 2022). Some also blame on the irrational industrial structure as they state that only a tiny percentage of Chinese steel production originates from short-process ironmaking techniques (SHET). Large and small steel firms face technological upgrading challenges (Ren et al., 2021).

For the low carbon development strategy of the Chinese steel industry, Li et al. (2022) suggests methods to reduce carbon emissions and achieve carbon neutrality targets in the Chinese steel industry, arguing that we must make efforts to improve energy efficiency; optimize production processes to reduce energy consumption per ton of steel; and design emission reduction targets according to the best carbon emission mitigation pathways, etc. Ren et al. (2021) comprehensively reviewed carbon reduction technologies in the steel industry and concluded that it is possible to achieve ultra-low carbon development in the Chinese steel industry. On this basis, Ren et al. (2021) proposed strategies for low-carbon development in the Chinese steel industry: in the short term, for the blast furnace-converter process, eliminate outdated capacity and promote cost-effective optimal available technologies; for the electric arc furnace process, promote the development of the scrap recycling industry and increase the power of the electric arc furnace. In the medium term, promote natural gas/coke oven gas-based Direct Reduction Iron (DRI) and carbon capture, utilization and storage demonstrations based on Natural gas/coke oven gas in integrated steel firms to assess their GHG emission reductions and to address engineering issues associated with these technologies. Promote the use of renewable energy in the steel industry and build a hydrogen energy supply chain. In the long term: determine the optimal scale of application of hydrogen-based DRI and carbon capture, utilization and storage demonstration technologies in China based on the results of the preliminary projects conducted in the medium term, and adjust the production structure to achieve ultra-low GHG emissions from the steel industry. Of course, there is a close connection between sectors, and there are significant synergistic effects in the drivers and behaviors of industries to carry out carbon emission reduction. Therefore, it is necessary to accelerate the construction of a national carbon emission trading market and to include energy-intensive sectors such as petroleum processing and coking, chemical raw materials and chemical products, non-metallic mineral products, smelting and pressing into the national carbon emission trading market planning as soon as possible, and strive to build a green supply chain and significantly play the role of the market to improve the energy efficiency and energy intensity of energy production.

In addition, it also reveals the impact of iron ore grade itself on emission reduction in the steel industry. In practice, steelmakers tend to shift to higher grades of iron ore to maximize the amount of steel produced from as few inputs as possible, resulting in a premium for higher-grade iron ore and a discount for lower-grade iron ore (Russell, 2021).

2.2 Studies on the characteristics of the iron ore industry and its market structure

2.2.1 Characteristics of the iron ore industry

Iron ore resources are an essential source of raw materials for industry and agriculture and provide primary material and energy security for human beings. Compared with other natural resources, iron ore resources have some inherent characteristics, such as scarcity, uneven distribution, intermediate products, standard products, etc.

2.2.1.1 Scarcity

Iron ore resources evolve over a long period under specific geological conditions. Since this evolutionary cycle is much higher than the cycle of human history, and it isn't easy to regenerate these resources once mined. Therefore, mineral resources are limited and non-renewable, thus making iron ore resources scarce as the mining continues. Many mines are facing a resource crisis nowadays, which adversely affects the sustainable socio-economic development, so the mineral resources should be mined on schedule and the sustainable development industry of mineral resources land is getting more and more attention (Henckens et al., 2016; Calas, 2017).

2.2.1.2 Uneven distribution

The formation of mineral resources requires certain geological conditions, and the movement of the earth's crust is uneven, so the quantity and quality of mineral resources in different regions will differ, which is uneven in the distribution of mineral resources. In addition, the output of mineral resources is also uneven and there are geographical differences because of the different degrees of development, exploration technology and external environment in other places (Calas, 2017; Song et al.2019). The global distribution of iron ore resources is highly uneven, with South America and Australia owning the most considerable iron ore resources in the world. Countries have different resource endowments, and the global iron ore supply and demand structure have significant geographical differences (Christmann et al., 2007; Garufu, 2016).

Even though certain regions, such as China, have more extensive iron ore reserves, the grades are lower and their mining is highly influenced by the environment, with higher mining costs and risks (Sonderegger et al., 2020). The mining conditions in the modern mining industry are becoming more and more complex; on the one hand, it will only be more and more difficult to mine and the mining grade is becoming poorer and poorer; on the other hand, the mining cost will also become higher and higher. Therefore, to obtain the best economic benefits from the investment, a feasibility study should be tailored to the exploratory and risky nature of the deposit development so that it can play a role in ensuring the sound technical and economic benefits of the proposed mine and minimizing the investment risk (Christmann, 2018).

2.2.1.3 Intermediate product

Minerals are generally not part of the final product but rather the inputs used to produce the final product (also known as “capital goods”) and are referred to as intermediate demand. The link between intermediate demand and final demand is evident. However, the general laws of final order are insufficient to explain intermediate need as intermediate demand is not only governed by the factors influencing final demand, but also depends heavily on the production process technology and the availability of complementary input factors (Yuan et al., 2012).

Yuan et al. (2012) also point out that intermediate demand is not only governed by various influencing factors of final demand, but also by the following factors:

(1) Final demand. An increase or decrease in the market for the final product associated with an intermediate product will cause a corresponding up or down in demand for that intermediate product.

(2) Production technology. Changes in technology have a more significant impact on the need for intermediate products. When the production technology improves the productivity of an input factor or its complementary factors, the demand for the factor increases. When the production technology improves the productivity of the alternative elements of an input factor, the need for the factor decreases.

(3) Input factor ratio. When the ratio of a factor to other input factors increases or decreases, the demand for the elements will increase or decrease.

(4) Price of other factors. The rise or fall of the price of an input factor's

complementary factor will cause the factor's demand to decrease or increase and the rise or fall of the cost of an input factor's substitute factor will cause the factor's need to increase or decrease. On the other hand, the rise or fall of the price of the substitute factor will make the production cost rise or fall accordingly, and make the output lower or higher. Therefore, the demand for the factor will also be reduced or increased accordingly. Thus, the change in the price of a substitute element has two opposite effects on the demand for that factor, and its combined effect is difficult to generalize.

2.2.1.4 Standard product

As a commodity, iron ore has more fixed standards. For example, the Dalian Commodity Exchange has set strict delivery quality standards for iron ore. For example, the iron ore delivered by the Exchange is the powder and concentrate formed from naturally mined iron ore after crushing and beneficiation processes for the production of iron ore sinter, pellet ore and other artificial lump ore. It contains 61.0% iron (Fe), 4.5% silicon dioxide (SiO_2), 2.5% aluminum trioxide (Al_2O_3), less than or equal to 0.10% phosphorus (P) and less than or equal to 0.03% sulfur (S). If the above criteria cannot be met, the Dalian Commodity Exchange has also developed a complex approach for quality differences and quality premiums of substitutes.

Internationally, the Platts Index is mainly used to price iron ore of a certain standard. The Platts Index is a benchmark valuation of the physical spot price of iron ore. It is based on Qingdao’s CFR (COST and FREIGHT) of 62% iron ore fines. Platts publishes the Platts Index daily through the S&P Steel Markets Daily. It makes clear how other iron ores of different grades, qualities and types are priced through the application of premiums and deductions to reflect the difference in quality compared with 62% iron ore fines and how iron ore lumps, pellets and concentrates are priced.

It is because it is a standard product that the source of competitive advantage for iron ore miners is primarily low cost. This means that cost control is vital for iron ore miners - whoever has low prices will be able to compete in the market. Economies of scale are an essential way to reach a low-cost strategy, leading to more giant monopolies having lower costs and thus, the ability to drive competitors out of the market by driving down prices.

2.2.2 Market structure of iron ore

2.2.2.1 Oligopoly pattern

There has been a general upward trend in world iron ore production. According to USGS, global iron ore production reached 2.4 billion tons in 2020, mainly concentrated in Australia and Brazil, with a combined share of 54.2%. In addition, India, China and Russia account for 9.6%, 14.2% and 4.0% of total global iron ore production, respectively.

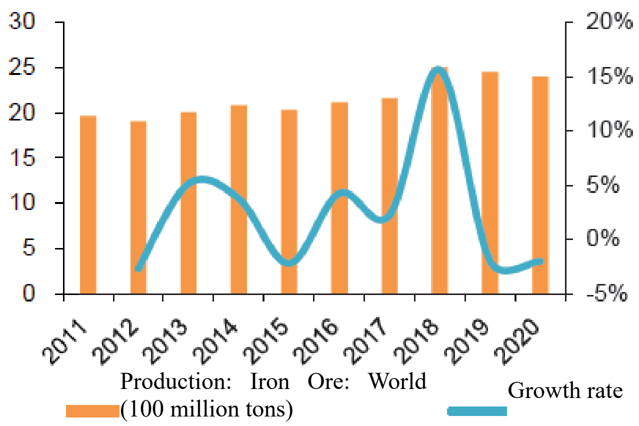

Figure 2.1 Trend of global iron ore production in the past ten years

Source: USGS

Iron ore is an oligopolistic market for sellers and exporters (Wu et al., 2016). According to the World Steel Association (WSA)[3] global iron ore reserves are relatively concentrated in these giant iron ore mines, such as Hamersley in Australia, Carajás "Iron Quadrangle" and Urukum in Brazil, and El Mutun in Bolivia and the firms associated with these mines are Vale, Rio Tinto, BHP Billiton, etc. Australia and Brazil are the world's largest iron ore suppliers, having 37.2% and 19.2%[4] of global iron ore reserves respectively in 2019, according to the U.S. Geological Survey (USGS), while the four major miners supply Australian and Brazilian iron ore production. By 2008, the largest producers in the iron ore market were multinational miners Vale, Rio Tinto and BHP Billiton (Warell & Lundmark, 2008). Since its first iron ore shipment in 2008, Australia's FMG has quickly grown to become the world's fourth largest iron ore producer. In 2020, the four iron ore giants accounted for more than 60% of the world's total iron ore exports. Among them, Vale, Rio Tinto, BHP Billiton and FMG exported 300 million tons, 285 million tons, 255 million tons and 208 million tons of iron ore, respectively, or a total of 1,048 million tons.

From the demand side, most of the global steel production takes place in China, and thus iron ore is one of the largest commodities imported by China. In 2020, China imported 1.17 billion tons worth more than RMB 822.8 billion, accounting for more than 82% of China's total iron ore consumption (Figure 2.2).

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[3] Source: https://www.worldsteel.org/zh/

[4] Source: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-iron-ore.pdf

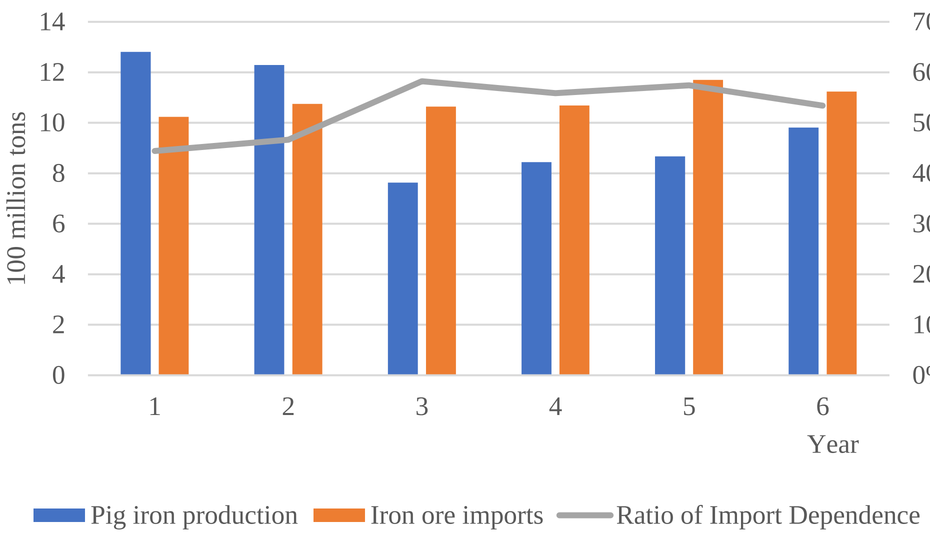


Figure 2.2 Iron ore imports, pig iron production and dependence on imported iron ore in mainland China

Source: Metallurgical Product Prices and Quotations

As a result, the global iron ore trade mainly starts in Australia, South America and North America. On the demand side, the Asian region, especially China, is the leading importing country. Figure 2.3 gives the global iron ore trade route from 1992-2017.

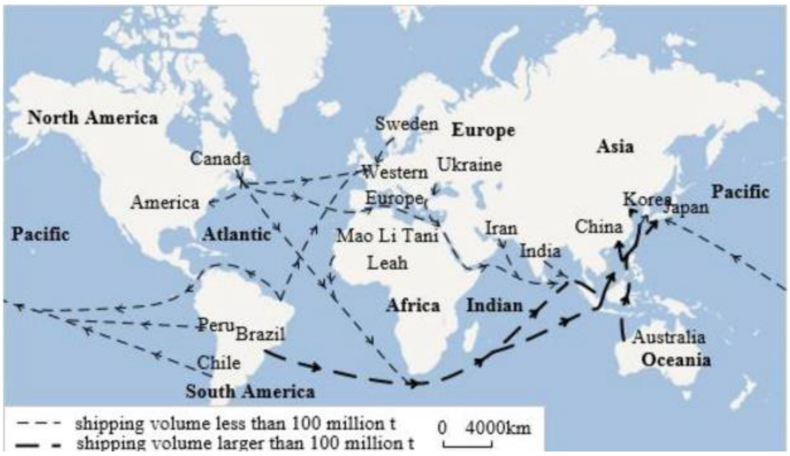


Figure 2.3 Global iron ore trade routes 1992-2017

Source: Hao et al. (2018)

2.2.2.2 Predatory pricing and price cycles of iron ore oligopolies

Due to the distribution of iron ore and its mining characteristics, the iron ore market may have the prospect of a cartel and further leads to the control of the market by monopolies (Jones, 1986). High market concentration is considered a significant cause of high iron ore prices and large fluctuations in recent years (Su et al., 2017). Studies have argued that the Rio Tinto and BHP-B merger will put more significant upward pressure on the price of iron ore (Warell & Lundmark, 2008), and iron ore miners that occupy a monopoly position can rely on their market position to obtain higher monopoly prices (Pustov et al., 2013). Many studies by Chinese scholars have also pointed out that the oligopoly structure in the iron ore market largely contributes to the weak bargaining power of Chinese steel firms (e.g., Xu, 2016; Zhang & Lu, 2020; Hong & Sun, 2018; Wang, 2011; Hong & Zhang, 2019).

Firms occupying a monopoly position may also squeeze other firms out of the market through predatory pricing (McGee, 1980; Elzinga & Mills, 2001; Edlin, 2012). Predatory pricing refers to a firm's behavior that lowers a product's price to exclude competitors from the market (Edwards & Geoff, 2002). In practice, a monopoly firm can sell its product at a price below cost. After it excludes competitors from the market or curbs potential competitors, it raises the price to a monopoly price above marginal cost (Ordover & Willig, 1981), which in turn leads to cyclical fluctuations in iron ore prices.

From the 1880s until the beginning of the 21st century, global iron ore prices remained relatively stable. At this time, the international price of iron ore was mainly negotiated by and among several steel giants from the EU, Japan and Korea and the "Big Three" of Vale, Rio Tinto and BHP Billiton. During the long-term negotiation process, the model of "first pricing, market following" and the pricing principle of "LTA price, FOB price, same increase for the same species" were formed, and the international price of iron ore was stabilized at 20-25 USD/ton (Wilson, 2012; Massot, 2020).

After 2003, China surpassed Japan and topped others in iron ore imports, and the import volume increased at a faster pace, breaking the previous market equilibrium. By this time, the global iron ore trade network had formed an oligopoly of mining giants such as Rio Tinto, BHP Billiton, and Vale. The mining giants gained market power and began monopolistic pricing (Ma, 2013). They (1) modify the long-established pricing model and principles, replacing the LTA price mechanism with a price index pricing model, the FOB price with the CIF price, and the same species with the same rate of increase with different rates of growth for the same species. The price index pricing model makes it easier to manipulate iron ore prices in the case of high supply-side concentration (Wu et al., 2016). (2) adopt discriminatory pricing strategies to designate different prices for different countries and regions. This monopolistic pricing approach has led to high iron ore prices, which rose to USD160-170/ton in 2011, much higher than the previous USD20-25/ton (Wang, 2015).

However, monopolies may still manipulate the market and squeeze out competitors by offering low prices. As a typical example, in 2011, China's economic transition and slowdown led to a decrease in demand. The four mining giants expanded production against the trend with their low-cost advantage, making the supply and demand structure of iron ore unbalanced (Massot, 2020). As shown in Figure 2.4, although the CIF price of Chinese iron ore imports rose again to over USD 150/ton in 2012, it dropped to below USD 70/ton in 2014.

This was followed by several minor price cycles, such as 2014 and 2016, when iron ore prices bottomed out. It rose to USD 68.15/ton in late 2016, USD 70.99/ton in 2017, and the monthly average price of 62% grade domestic iron ore was USD 84.5/ton in 2018 (Jia et al., 2019). The Brazilian iron ore dam collapse and the Australian hurricane in 2019 delayed iron ore delivery and iron ore prices went all the way up when other metal prices fell, with the average Chinese import price of 62% grade iron ore peaking at more than USD110/ton, before quickly falling back to around USD90/ton (Jia et al., 2019; Jégourel, 2020). Iron ore price fall continued in the first half of 2020 due to the epidemic. In May, when the epidemic was somewhat controlled, iron ore prices started to rise and by 2021, they had been increased to a maximum of more than USD 200/ton. On May 19, 2021, the Chinese government deployed commodity supply and price stabilization efforts to curb its unreasonable price increases. Under the trend of frequent Chinese policies to strictly control price increases, iron ore prices began to fall sharply from the second half of 2021 and soon fell back to around USD 100/ton.

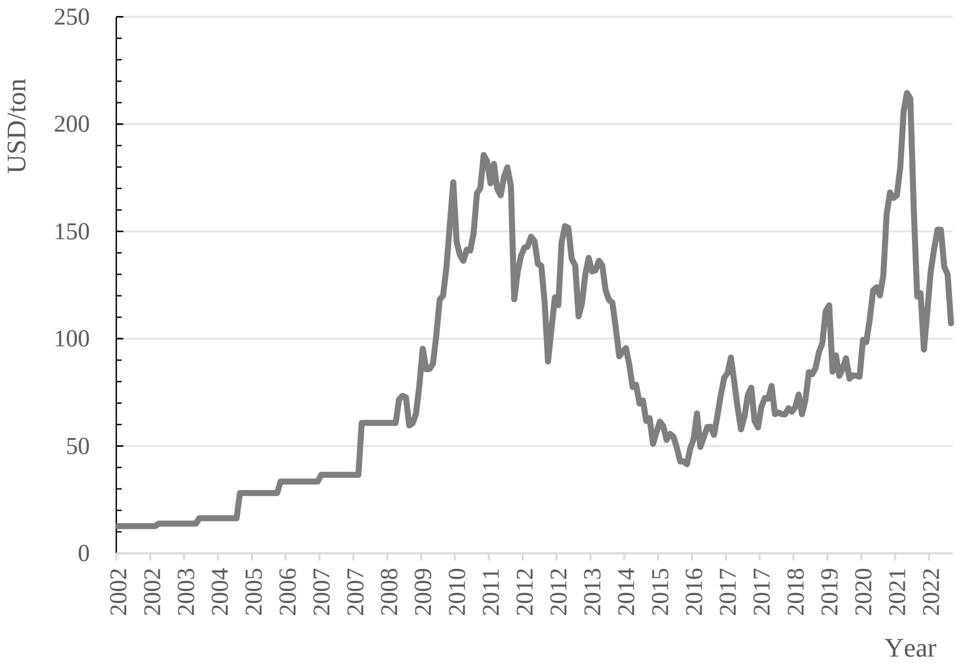


Figure 2.4 Iron ore prices (2002-2022) (USD/ton)

2.3 Research on factors influencing the corporate value

2.3.1 Theory of corporate value management

Value-based management (VBM) is one of the fundamental theories of contemporary management (Arnold, 1998; Ronte, 1998). According to its central hypothesis, firms use tangible and intangible resources to create value, and in this process, unique and rare resources and their combinations, can provide a competitive advantage to the firm (Arnaboldi et al., 2015; Hitt et al., 2016; Lado & Wilson, 1994; Copeland et al., 1990; Bartlett & Ghoshal, 1993; Stewart, 2003). Over the years, this perspective and its assessment methods have been developed and supplemented. In business operation segments, the dynamic analysis of VBM includes supply, production, and sales (Zhang et al., 2016; Caputa, 2015; Othman & Sheehan, 2011; Seal, 2010; Lepak et al., 2007; Copeland, 1994). In the primary stage of value management, it is generally assumed that the resources of the production process create value (Barney, 2001; Penrose, 1959). Of course, on this basis, many studies have included customers and suppliers in the value assessment of the firm (Sirmon et al., 2008; Sirmon & Hitt, 2003; Bowman & Ambrosini, 2000).

With the emergence of sustainable development (SD), stakeholder theory has enriched value management in all materials (Zielinski & Botero, 2015; Adamczyk, 2008; Nahapiet & Ghoshal, 1998; Pennings et al.,1998; Freeman, 1984). It suggests that the corporate value is created by the producers and their customers and suppliers and the participants in the industry and the economy as a whole. As a result, value creation acquires a multidimensional dimension and a more macroscopic perspective (Bernat & Karabag, 2019; Black, 2000; Kensinger et al., 2000; Shrestha et al., 2003).

Of course, some studies dismiss the contribution of sustainable development (SD) to value creation because of the lack of direct and measurable impact of this concept on market or book value (Crifo et al., 2016; Ding et al., 2016; Lock & Seele, 2016; Rhou et al., 2016; Hang & Chunguang, 2015; Chen & Gavious, 2015). However, we can perceive that unreliable supplier selection will lead to a decrease in quality; neglecting customers may cause them to switch to competitors, and damaging environmental and social relations may threaten reputation. These situations directly lead to lower sales and lower financial performance, thus reducing corporate value. Therefore, it is difficult to deny the contribution of stakeholders to the value creation process.

2.3.2 Impact of internal control on corporate value

As the main reason for the influence of corporate value, the internal control of a firm has been the focus of an academic and practical circle, which includes corporate capital structure, equity structure, personal characteristics of managers, corporate finance and others.

Corporate capital structure refers to the value of various kinds of capital and its proportional relationship. The relationship between capital structure and corporate value has been a hot topic of research by domestic and foreign scholars. However, different studies have different measurement methods for variables, measurement indicators and the industries studied, so the results of these studies have both similarities and differences (Fu, 2014). Some scholars argue for a negative relationship between capital structure and corporate value (Kodongo et al., 2015; Dang et al., 2019), while others argue for a positive relationship between them (Fu, 2014; Zhu et al., 2017). Although there are differences in the research results, most studies show an influence between corporate capital structure and corporate value (Ruan et al., 2015; Azhou, 2016).

Specifically, most studies focus on the relationship between the level of debt and corporate value in capital structure. Similarly, there are different research findings on the relationship between debt level and corporate value. Scholars represented by Ross believe that debt is positively related to corporate value creation (Ross, 1973; Zhou & Liu, 2016). They believe that increasing debt will positively affect corporate value as debt can avoid tax. Some believe the two are negatively related (Awunyo-vitor & Badu, 2012; Zhu et al., 2019). These scholars, on the other hand, based on the theory of preferential order financing, argue that firms will finance in the order of internal financing, debt financing, and equity financing and that a high debt ratio indicates a lack of internal capital and poor operations, and thus a lower corporate value. Therefore, the capital structure is negatively related to corporate value. On the other, found an inverted U-shaped relationship between the level of corporate debt and corporate value, and either too high or too low corporate debt ratios are detrimental to the increase of corporate value (Li, 2016). There has also been coverage of the optimal capital structure by scholars. Xu et al. (2014), based on the financial data of Chinese listed firms in the equipment manufacturing industry from 2006-2013, applied a nonparametric approach to argue that there is a capital structure that maximizes corporate value, and the optimal gearing ratio is 32.87%. Zheng (2015) argues that the optimal debt ratio interval is 0.24-0.4, within which, debt is positively related to corporate value, just as the findings of Li's study. Overall, there is an inverted U-shaped relationship between the level of corporate debt and corporate value.

The relationship between equity structure and corporate value is also a major research topic. Previous studies on these two have mainly focused on the relationship between equity concentration and corporate value. The relationship between equity structure and corporate value has not been conclusively established at home and abroad because of different scholars' differences in research perspectives and selection of variables. Some scholars believe that a more robust equity structure can enhance corporate value (Reyna et al., 2012). According to theirs, the higher the concentration, the faster the decision-making efficiency, and the stronger the supervision of shareholders, which can avoid free-riding behavior and thus enhance corporate value. While some other scholars believe that a decentralized shareholding structure is more conducive to corporate value (Al-Saidi & Al-Shammari, 2014; Wu & Guo, 2018). In other words, a decentralized shareholding structure is more protective of the interests of middle and small shareholders, thus enhancing the corporate value. However, the results of most scholars show an inverted U-shaped relationship (Wang & Chen, 2014; Wei, 2014), and the optimal equity structure is that when the corporate value reaches its maximum when the level of corporate debt is in the middlemost position.

With the development of behavioral finance, the personal traits of managers have increasingly become the focus of scholars' attention, especially the trait of overconfidence. Business managers can be more confident and optimistic than the average employee (Heaton, 2005). Most researchers agree that "overconfidence" can be measured by personal traits, and usually affects corporate value by influencing other factors. Some scholars argue that overconfident managers are more likely to seize opportunities for innovation and are risk-averse investors, thus contributing to corporate value under high environmental uncertainty (Tian et al., 2018; Hirshleifer et al., 2021). It is also argued that overconfident managers will adopt more aggressive tax avoidance policies and increase the degree of corporate tax avoidance, which leads to lower corporate value (Zhou & Huang, 2019). On the other hand, He and Zhang (2015), show that overconfident managers will prefer to use debt financing, which will increase corporate value. Therefore, overconfident managers can affect corporate value to different degrees and from different directions through the action of other factors.

Studies on corporate finance and corporate value, on the other hand, focus on financial performance. Generally, good financial flexibility helps reduce firms' financing constraints, seize investment opportunities, and increase firm returns, thus enhancing corporate value (Arslan-Ayaydin et al., 2014; Ma et al., 2015). On the other hand, good financial flexibility can increase a firm's debt and cash flexibility, thus reducing its financing costs and increasing its value. Environmental uncertainty has a positive moderating effect on the relationship between financial flexibility and corporate value. The higher the environmental uncertainty, the stronger the positive impact of financial flexibility on corporate value (Tong, 2021). Similarly, it has been argued that the relationship between financial flexibility and corporate value is an inverted U-shaped relationship, with either too high or too low being detrimental to the creation of corporate value (Chen, 2020).

2.3.3 Research on the factors influencing the value of miners

Accounting methods usually use net asset data in the balance sheet to represent corporate value, but the value of some asset’s changes over time, and this change depends on corporate profits, so generally, corporate value is linked to corporate financial profits (Qu & Zhang, 2015). Many people would judge corporate value directly through the firm's stock price, in which case, the corporate value depends on investors' willingness and ability to invest, but their decisions in turn depend on the firm's financial performance, industry outlook, and economic conditions, so in any case, the primary determinant of corporate value is the firm's economic value, which in turn is determined by revenues and costs (Bluszcz & Kijewska, 2016).

Most of the studies on the value of miners have focused on corporate value assessment, while less research has been done on the factors influencing corporate value. Bluszcz & Kijewska (2016), in their study of the factors influencing the increase in the economic value of miners, found that the monetary value increase is driven by factors including sales, operating margins, tax payments, fixed capital investments, working capital investments, duration of value growth, and cost of capital. However, studies also found that economic value added does not dominate the impact on corporate value because mining is a capital-intensive industry from an industrial perspective, requiring significant investment and therefore carries a high financial risk. Moreover, the miners' products have high unpredictability of revenues and costs compared with other products. On the one hand, the quality and quantity of mineral products are affected by geological and mining conditions beyond the control of producers. On the other hand, mining conditions are becoming increasingly complex, so the mining cost industry is subject to many uncertainties (Jonek-Kowalska, 2018). Jonek-Kowalska (2018) and Long & Xie (2009) argue that macroeconomic factors have a more significant impact on the value of miners, arguing that the economic cycle of an industry dominated by commodity trading, especially a cyclical industry typically represented by miners, is also inextricably linked to the macroeconomic cycle. Wang (2014) presents that macroeconomic fluctuations directly affect the stocks of listed firms of miners. That is to say, the ups and downs of miners' value are directly affected by macroeconomic factors, and prove through empirical evidence that the return on net assets of the mining industry is affected by macroeconomic factors to a certain extent. The foregoing effect is specifically shown by the fact that before a round of economic cycles reaches its peak, industrial base metal prices experience a sharp rise and a sharp decline when the economic cycle comes to its peak.

In addition, miners are faced with a complex value creation process compared with other firms. It is influenced by geological conditions, deposit abundance, etc., and the unstable market environment. Therefore, miners should enhance corporate value mainly in these three areas: (1) price risk monitoring and hedging; (2) improving and strengthening relationships with suppliers and customers; and (3) developing relationships with internal and external stakeholders using corporate social responsibility hypothesis (Kowalska Styczen & Owczarek, 2016).

It is important to note that the uneven ores distribution make miners mine across borders. In cross-border investments, factors such as political risk and institutional environment may lead to higher costs and lower profits for firms (North, 2017). Considering that political violence and judicial issues threaten the security of property rights (Gonchar & Greve, 2022), we believe this leads to the withdrawal of international investments (Busse & Hefeker, 2007). These issues can be deemed political risks. Political risk is "the risk of confiscation of all or part of a foreign firm's property resulting from the intervention of a national government to prevent a commercial transaction or to change the terms of an agreement (Kobrin, 1979). In practice, political risks are arbitrary government actions on investment projects, including expropriation, confiscation, forced renegotiation, political violence, or regulatory intervention (Kobrin, 1979; Simon, 1984). These risks are often accompanied by regime collapse or political instability in developing countries (Boddewyn & Brewer, 1994; Feinberg & Gupta, 2009). Even developed countries may affect the implementation of ownership or control of multinational firms due to changes in the relevant policies (Taarup-Esbensen, 2019). Of course, miners' withdrawal of international investments is much lower, subject to significant investments in dedicated assets (Sottilotta, 2016). To address the challenges posed by political risks, many miners mitigate these risks by developing stakeholder engagement programs, such as encouraging community participation (International Council for Mining and Metals, ICMM, 2015). Of course, many miners are also involved in political interventions in the countries in which they are located and therefore bring a bad reputation (Bebbington et al., 2008; Jones & Bradshaw, 2015).

2.4 Summary

The steel industry is a significant source of carbon emissions. Amid the global carbon emission reduction, the existing literature has coverage on carbon reduction in the steel industry. However, literature has mainly focused on the causes of carbon reduction in the steel industry, the potential for reduction, and the smelting technologies that promote reduction. However, it ignores the importance of iron ore grade for carbon emission reduction and the issue of carbon emission reduction policies, especially China's "Dual Carbon" policy that leads to a premium or discount for different grades of iron ore. Moreover, it does not discuss the impact of the "Dual Carbon" policy on the investment value of the iron ore industry and iron ore miners. Although this study is based on existing literature, it will focus on making up for the deficiencies of the existing literature.

3 Research design

Chapter 1 presents the three questions highlighted in this study, including what is the impact of the "Dual Carbon" policy on the iron ore market. What is the logic of determining the investment value of iron ore miners in the context of the "Dual Carbon" policy? And what is the investment strategy for iron ore in the coming period? To this end, this chapter describes the research framework and the methodology used in this study. It first introduces the framework of research ideas and the corresponding specific research components and draws the research framework diagram. The methodological choices of this study are introduced based on this and this chapter proposes that this study uses a combination of qualitative and quantitative research methods. Finally, it details the data sources, model settings, etc. for each research method.

3.1 Research idea

This study focuses on the investment value of iron ore under the "Dual Carbon" policy. In this context, we must first identify that the "Dual Carbon" policy affects the iron ore market and further influences the underlying mechanism of business operations. As mentioned in the theoretical review, as an energy-intensive industry, the iron and steel industry is a significant source of GHG emissions in China (Zhang et al., 2018; Wang et al., 2020; Li et al., 2022). The iron and steel industry has mainly achieved emission reductions using technological upgrading (Ren et al., 2021). However, it has been noted in the existing literature that high-grade iron ore helps to reduce coke consumption in the steelmaking process and consequently lowers carbon emissions. Taking the ironmaking branch of Xiangtan Iron & Steel, China, as an example, a 1%

reduction in grade would increase the coke ratio by 1.6268. Moreover, processed pellet ore can further reduce the coke ratio; e.g., for every 10% of metalized pellet ore used, 33.7 kg/t of coke can be saved, which is equivalent to 6.8% of the fuel ratio (Wu et al., 2019). It can be speculated that with the implementation of the "Dual Carbon" policy, the steel firms will come to know high-grade iron ore's advantage in carbon reduction and want to buy more high-grade ores, which will lead to the short supply of high-grade ore and further drive the premium for high-grade ore and discount for low-grade ore. Existing literature does not address this logic. However, it is the underlying hypothesis of this study. For this reason, this study focuses on the impact of the "Dual Carbon" policy on the price differentiation of different iron ore grades in Chapter 4. The study includes three parts: first, to analyze the relationship between iron ore grade and carbon emission reduction and the mechanism that affects the iron ore premium/discount rate; second, to empirically test whether the proposed "Dual Carbon" policy really changes the trend of iron ore premium/discount rate; third, if the proposed "Dual Carbon" policy does change the trend of iron ore premium/discount rate, then further forecast it.

Based on the determination that the "Dual Carbon" policy changes the trend of the premium/discount rate of different iron ore grades, Chapter 5 further discusses the significance of this mechanism for the investment value of iron ore miners at the micro level. To this end, this study then comes to in-depth discussion regarding the impact of the grade of iron ore produced on the investment value of iron ore miners in an oligopolistic market. First, in terms of profit per ton of ore, both revenue and cost are correlated with ore grade. Thus, the profit per ton of an iron ore miner is a function of the iron ore produced, thus establishing a direct link between iron ore grade and corporate value. Then, considering that market structure is an essential factor affecting corporate value (Lee, 2009), we further discuss the theoretical mechanism by which an oligopoly's profit per ton affects the investment value of iron ore miners. Again, monopolies can rely on their market power to squeeze out some weak firms through predatory pricing (McGee, 1980; Elzinga & Mills, 2001; Edlin, 2012), eliminating those firms that lack competitive advantage and therefore do not have long-term investment value. To this end, this study discusses the impact of the profit gap per ton with oligopolies on the investment value of iron ore miners during the downward iron ore price cycle.

Chapters 4 and 5 are the central part of this study. Chapter 6 summarizes the results of the previous part and draws out the theoretical framework of iron ore grade and the investment value of firms under the "Dual Carbon" policy. On this basis, Chapter 6 shows us the implications of the findings of this study for investment practice and the shortcomings hereof.

3.2 Methodology

This study focuses on the logic of the investment value of iron ore miners in the context of global carbon emission reduction policies, especially the "Dual Carbon" policy in China. Although the effect of cost and profit on the investment value of firms is common knowledge, as we mentioned in the theoretical review, existing studies do not address the impact of the "Dual Carbon" policy on the iron ore price and the operation of iron ore miners. Therefore, the issue of interest in this study is an exploratory one. Case studies are more suitable for exploratory issues, so it is appropriate to use a case study approach.

Case studies are mainly designed to distill some concepts with the help of certain cases and to elaborate the relationships between these concepts, thus requiring continuous screening and collection of case data and integration and comparative analysis of the collected case data to discover theories in new areas (Eisenhardt & Ott, 2017). This study uses case studies to summarize the theoretical logic of carbon emission reduction policies affecting iron ore prices and to provide an in-depth analysis of the mechanism of action of iron ore grades affecting investment value in the context of global carbon emission reduction and oligopolistic market structure. Main theories developed relate to the following areas:

First, what is the impact of the "Dual Carbon" policy on the price of different grades of iron ore? How does the impact function?

Secondly, supposing that the promotion of the "Dual Carbon" policy leads to the divergence of iron ore prices among different grades, what is the mechanism by which this divergence will lead to changes in the profitability of iron ore miners and, consequently, to changes in the investment logic of iron ore miners?

Third, in the context of the "Dual Carbon" policy, if the price of iron ore of different grades is differentiated, what investment rules should be followed in the iron ore industry as an oligopoly market?

Fourthly, what kind of issues should be considered in the investment of iron ore miners considering the price cycle of iron ore?

An essential hypothesis of this study is the heterogeneity of the impact of the "Dual Carbon" policy on iron ore prices. To test this hypothesis, we also use an interrupted time-series analysis (ITSA) model to analyze the impact of

China's "Dual Carbon" policy on the price of different grades of iron ore, i.e., to analyze the treatment effect of the "Dual Carbon" policy on price differentiation. Further, this study also selects the Autoregressive model (AR) and the Autoregressive Integrated Moving Average Model (ARIMA) to forecast the future trend of iron ore prices based on the characteristics of secondary data. The questions to be studied in this study and the corresponding methods are shown in Figure 3.1.

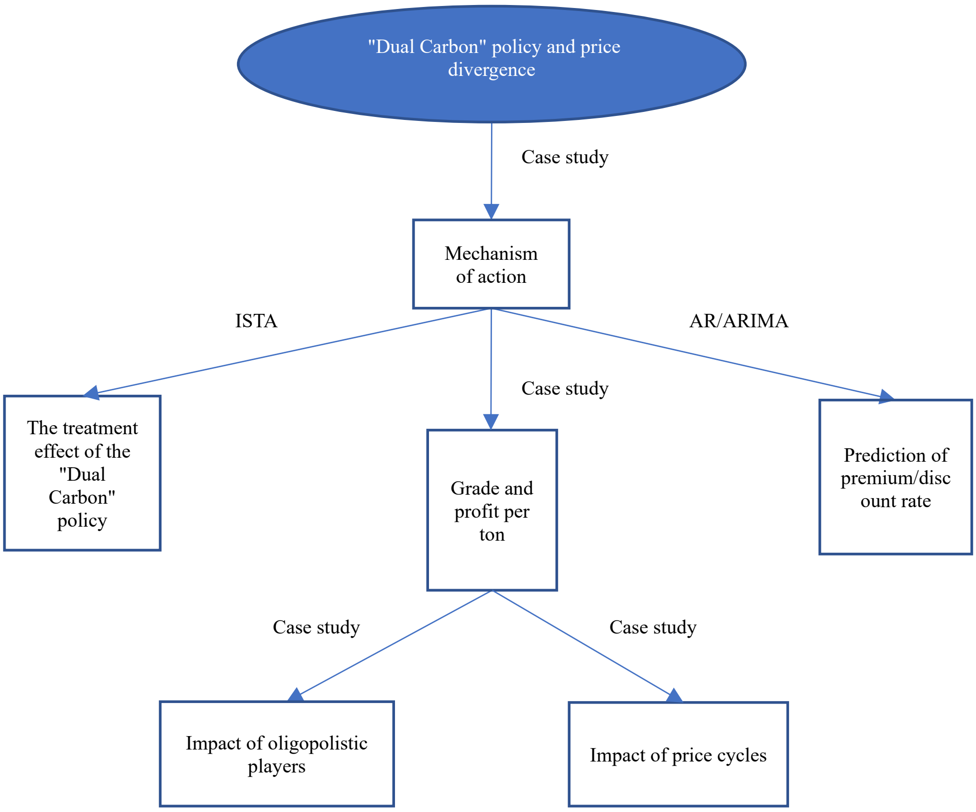


Figure 3.1 Choice of research methodology

The framework of this study and its corresponding research methods are shown in Figure 3.2. First, we make clear our research target: iron ore investment strategy in the context of "Dual Carbon", and the factors influencing the investment value of iron ore miners and their internal mechanism of action in the context of global carbon emission reduction. On this basis, we explain the background and significance of this study, as well as the structure thereof. To prepare the literature for the research, this study conducted a theoretical review from several aspects such as carbon emission reduction in the iron and steel industry, industrial characteristics of iron ore and determination of corporate value. After that, we designed our research, which was presented in more detail regarding research ideas, method selection, and data sources respectively. We propose two research strategies in the methodological arrangement: the case study approach and the empirical test. The former explores the impact of the "Dual Carbon" policy on iron ore price differentiation and discusses two aspects of iron ore grade, oligopolistic market structure and corporate value. The latter uses historical data on iron ore prices to examine the treatment effect of the "Dual Carbon" policy and to forecast the future trend of the premium/discount rate of different iron ore grades. Then, based on the obtained data, we derive the results, propose a theoretical framework, and examine the relationship between the variables. Finally, we draw conclusions based on our analysis results and discuss this study's limitations.

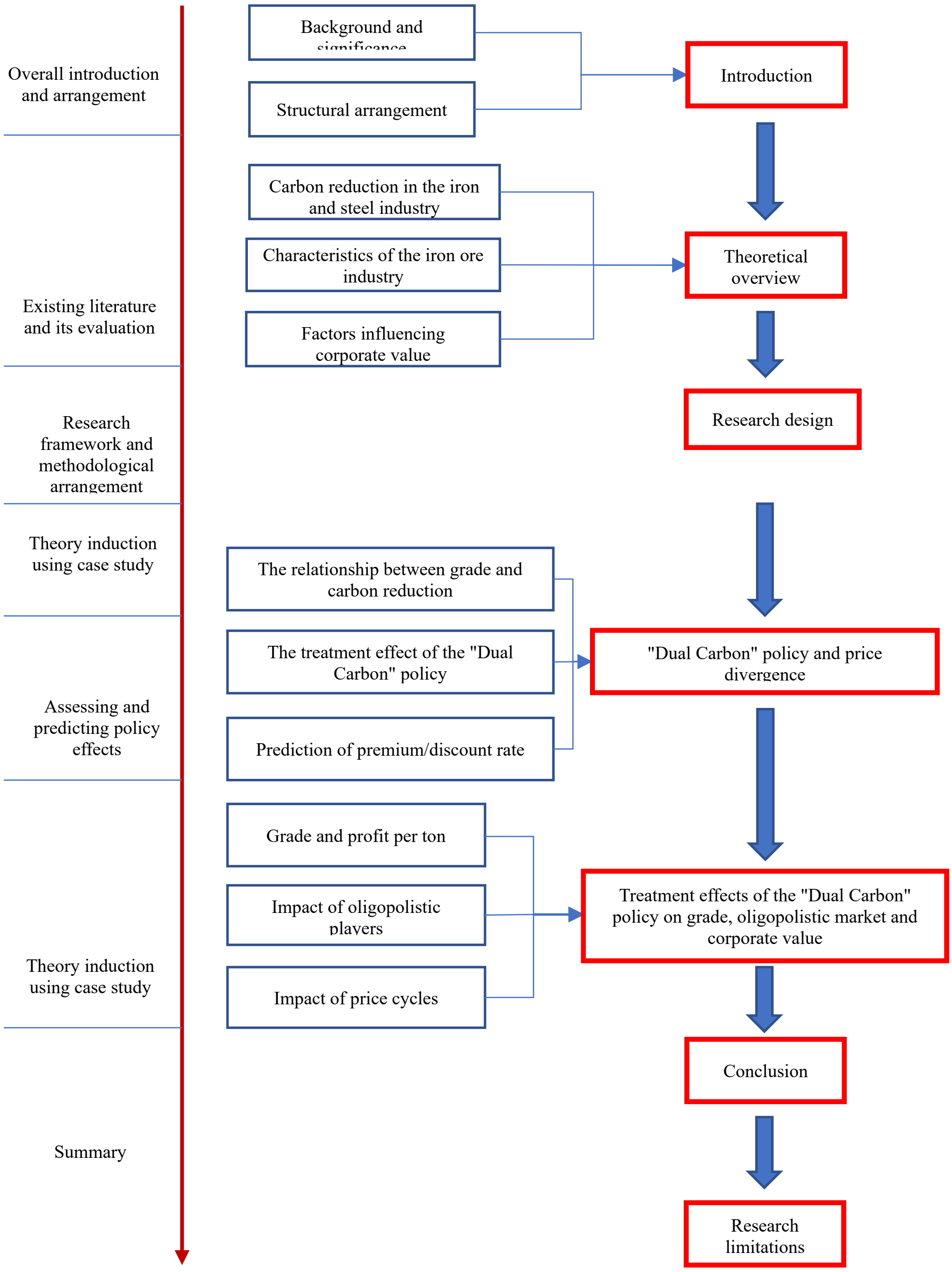


Figure 3.2 Framework and methodological arrangement

3.3 Case selection and data analysis

3.3.1 Case selection

As an important theoretical research method, a case study enhances the reliability and validity of research through "replication logic" (Yin, 1984). Like a series of related laboratory experiments, cases are individual experiments but are also part of the iterative, comparative, and extended study. While individual cases can also be valid, multiple case studies are usually more convincing. For the number of cases, 4-12 is generally considered appropriate (Eisenhardt & Graebner, 2007). To ensure reliability and validity, this study needs multiple iron ore miners for study purposes.

The case study was sampled theoretically, i.e., cases were selected for theoretical rather than statistical reasons, and extreme situations and extreme types of cases were selected to observe the issues of interest. This study discusses the impact of ore grade on the investment value of iron ore miners in a "Dual Carbon" context. Therefore, the firms we select must meet several requirements: first, they are mainly involved in the iron ore business; second, there are differences in the grade of iron ore produced; and third, there are differences in the performance and thus in the investment value. Based on the above requirements, this study selects eight different types of iron ore miners.

The first type is the more successful iron ore miners, including FMG and Champion Iron. FMG discovered iron ore resources in Western Australia in 2004 and shipped its first shipment of iron ore to China in 2008, which took only four years. FMG's iron ore grade is less than 58%. Before the "Dual Carbon" policy was introduced, the firm produced iron ore at a low discount, but the cost control was very excellent, so it grew very fast and has become the third largest iron ore producer in Australia and the fourth largest in the world. However, the "Dual Carbon" policy highlights FMG's disadvantage in iron ore grade, leading it to change its previous strategy and launch higher-grade iron ore concentrates. Unlike FMG, Champion Iron has an iron ore grade below 30% and was initially less competitive in the market. However, Champion Iron responded to the change in policy environment by processing low-grade ore into 66% or higher iron ore concentrate at low cost and thus gaining better growth.

The second type is the iron ore miners with more failed operations, including Mount Gibson Iron, Alderon Iron Ore Corp and Northland Resources SE. The common feature of these iron ore miners is their low iron ore grade and relatively disadvantageous position in the market competition. Especially in the context of global carbon emission reduction, these three firms have encountered great operational difficulties, and Alderon Iron Ore and Northland Resources SE have been delisted.

The third type is the traditional iron ore oligarchs, namely BHP, Vale S. A and Rio Tinto. These three iron ore miners own most of the world's high-grade iron ore resources, have also been known for their low operating costs and have been considered the dominant players leading the market.

3.3.2 Data acquisition and analysis

Data and information in the case study can be obtained through surveys, historical archives, and press materials (Eisenhardt & Ott, 2017). Although interviews have a powerful advantage in obtaining helpful information, secondary sources can also be used extensively in some studies, subject to conditions. A typical example is Chandler (1962, 1994) who conducted a fruitful case study based on historical information. Just like our predecessors, we obtain data for case studies, mainly through annual reports of listed firms, reports of consulting firms, Internet sources, and interviews with industry professionals. We accessed each case firm's website to download its annual reports. Through

Karara is not listed, we got the relevant information by checking the website of its parent firm, Gindalbie Metals. Table 3.1 reports the firms under survey involved in this study and the annual reports collected.

Table 3.1 List of sample firms

Firms	Source	Data No.
BHP	2001-2021 Annual Reports	BHP-1—BHP-21
Vale S. A	2001-2020 Annual Reports	VALE S. A-1—VALE S. A-20
Rio Tinto	2001-2021 Annual Reports	Rio Tinto -1—Rio Tinto -21
Fortescue Metals Group (FMG)	2003-2021 Annual Reports	FMG -1—FMG -19
Champion Iron	2014-2021 Annual Reports	Champion -1—Champion -8
Mount Gibson Iron	2002-2021 Annual Reports	Mount Gibson -1—Mount Gibson -20
Alderon Iron Ore	1999-2018 Annual Reports	Alderon -1—Alderon -20
Northland Resources SE	1999-2013 Annual Reports	Northland -1—Northland -15

This study follows the case study process proposed by Eisenhardt and Graebner (2007), which consists of several stages, initiation, case sampling, case design, data collection, data analysis, hypothesis formation and literature dialogue, and research results. This study mainly collects qualitative data. To let readers, understand the research processes and results more clearly, we refer to the methods outlined in Mile & Huberman (1984), which make data visualization through tools such as graphs and tables, and codes to effectively avoid the destruction of raw data. After an in-depth analysis of the collected data, this study abstracts the relationship between the variables and draws a block diagram of the relationship between them.

3.4 ITSA model

As mentioned earlier, after the theoretical propositions are made in the case study, it is still necessary to empirically test whether the "Dual Carbon" policy impacts the iron ore market. To this end, we collect historical iron ore price data and use an ITSA model to examine the effect of the proposed "Dual Carbon" policy on the prices of different iron ore grades. As a quasi-experimental design, ITSA is primarily used to assess the impact of interventions when randomized controlled trials are not feasible (Grimshaw et al., 2020; Harris et al., 2006; Linden, 2015). ITSA models time series data combined with visual graphics to compare changes in trends in dependent variables before and after interventions to evaluate the effects of interventions and is widely used in public policy and many other areas of effect evaluation (O' Donnell, 2019).

This study uses the Platts Index for 58%, 62% and 65% iron ore from January 3, 2017, to March 31, 2022, for empirical analysis. The Platts Index only publishes prices for iron ore with grades of 58% and 62%, but starting in January 2020, it publishes prices for iron ore with a grade of 65% in parallel. Historical data shows a discount for 58% iron ore and a premium for 65% iron ore compared to 62% iron ore. To understand the impact of the "Dual Carbon" policy on iron ore prices, we use the premium/discount rates of 65% and 58% iron ore (set as α; wherein the 58% discount rate is $\alpha 1$ and the 65% premium rate is α_2) as the object of our study, i.e., to test whether the "Dual Carbon" policy has changed the trend of α.

For our analysis, we first excluded missing data dates and obtained 1205 daily price data. The 65% price index is only available from January 20, 2020, so there are 1205 pieces for both the 58% and 62% price indexes, but only 508 pieces for the 65% price index.

We calculate the daily premium/discount rate (α) and its difference based on the 58%, 62% and 65% price indices. The calculation formula is:

α_1= (58% price index - 62% price index)/62% price index.

α_2= (65% price index - 62% price index)/62% price index.

Difference = 65% premium rate – 58% discount rate.

Considering that the ITSA model can only perform regression analysis on data with regular change intervals, we convert daily premium/discount rate data from January 3, 2017, to March 31, 2022, into weekly average and monthly average premium/discount rate data for analysis. We start each year as the first week, e.g., January 3, 2017, as the first week of 2017, denoted as 2017w1 and January 2017 as 2017m1. Where the weekly average price index is calculated as follows:

1. calculating the corresponding natural week based on the date;

2. calculating the average price index for each grade for each week;

3. calculating the average of the weekly premium/discount rates based on the average price index for each grade for each week.

The monthly average data is calculated by finding the average of the monthly premium/discount rate based on the natural month.

September 20, 2020, is when President Xi Jinping proposed the Dual Carbon target, which corresponds to the 38th week of 2020 (2020w38), and the month is September 2020 (2020m9), so 2020w38 and 2020m9 are considered as intervention time points.

The ITSA model is shown in Equation (3-1), wherein P_t is the dependent variable, which denotes the value of α at time t. In Equation (3-1), T_t is the time variables and valued at 1, 2, 3, ..., and n, which corresponds to the time points of each sample data. ε_t is the random error term. X_t is the dummy variable for the intervention implementation, which is assigned to 0 if the "Dual Carbon" target has not been proposed at the time of the study. If President Xi Jinping has proposed a "Dual Carbon" goal at the UN General Assembly, the value is 1. Since President Xi Jinping proposed the "Dual Carbon" goal at the UN General Assembly on September 22, 2020, this study uses that date as the intervention time point, setting the previous period as the period when the "Dual Carbon" policy was not proposed and the subsequent period as the period when the "Dual Carbon" policy was proposed. For the coefficients, where γ_0 is the intercept, i.e., the α value at the beginning of the time series; γ_1 is the slope before the intervention, reflecting the change in the α value before the "Dual Carbon" policy; γ_2 is the change in the intercept after the intervention, i.e., the change in the α value after the "Dual Carbon" policy is proposed; γ_3 is the change in the slope before and after the "Dual Carbon" policy, i.e., the change in the α value before and after the "Dual Carbon" policy is proposed; then, $\gamma_1+\gamma_3$ is the slope after the “Dual Carbon" policy, i.e., the changing trend of α value after the introduction of the "Dual Carbon" policy.

$$P_t = \gamma_0 + \gamma_1 T_t + \gamma_2 X_t + \gamma_3 T_t * X_t + \varepsilon_t \quad \text{(Equation 3-1)}$$

The significance of each coefficient in the ITSA model is shown in Figure 3.3.

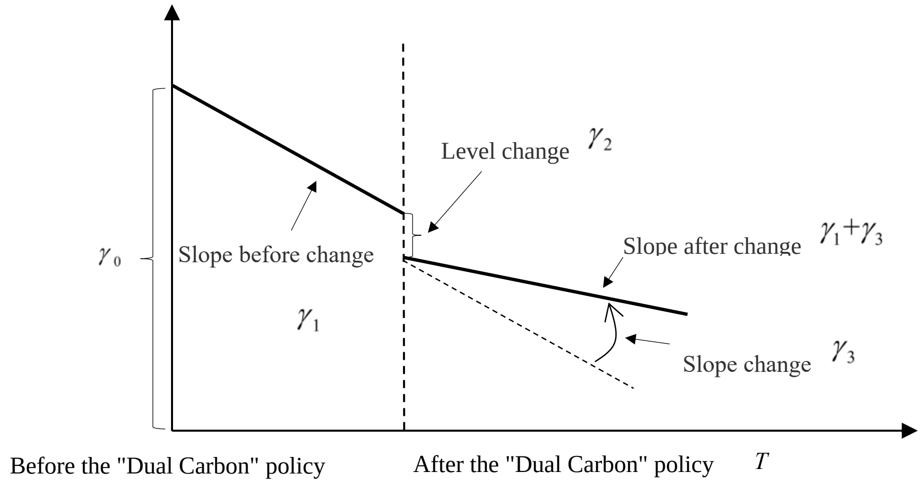


Figure 3.3 ITSA diagram

3.5 ARIMA model

The ITSA model can only be used to test the treatment effect of the "Dual Carbon" policy, but it cannot predict the trend of α in future periods. Suppose the future direction of α is different from the previous one, e.g., the continuation of the "Dual Carbon" policy only changes the price trend of different grades of iron ore in the coverage period, the hypothesis of this study still lacks foundation. For this reason, we also need to forecast the future trend of α.

Time series models can forecast the future based on a collection of historical data at different points in time to understand the long-term trend of the variable (Wooldridge, 2010). The mainstream time series models are the ARIMA model, GARCH and VAR. Considering the data structure of α, we perform a time series analysis using ARIMA and forecast the future trend of α.

Table 3.2 gives the unit root test results for the 58% discount and 65% premium. From Table 3.2, we can see that the t-statistic and p-value of the 58% discount rate series are -3.277 and 0.0162 respectively, suggesting that 58%

discount rate series is a stationary time series; the t-statistic and p-value of 65% premium rate series are -2.438 and 0.1318 respectively, which indicate that 65% premium rate series is a non-stationary series. So, we use the difference method to transform the 65% premium. The t-statistic and p-value of the first-order difference series of 65% premium are -24.540 and 0.0000, respectively, indicating that the first-order difference series of 65% premium is a stationary time series. The above results indicate that the data are stationary and a stationary time series model can be established.

Table 3.2 Unit root test results

Original hypothesis	t-statistic	p-value	Conclusion
The 58% discount rate series has a unit root	-3.277	0.0162	The original hypothesis is rejected
The 65% premium rate series has a unit root	-2.438	0.1318	The original hypothesis cannot be rejected
The first-order difference series of the 65% premium has a unit root	-24.540	0.0000	The original hypothesis is rejected

Table 3.3 gives the autocorrelation and partial autocorrelation analysis results of the first-order difference series of the 58% discount rate and the 65% premium rate. Table 5-5 reveals that the partial autocorrelation function of the 58% discount rate series has a trailing phenomenon, so the AR model is used to describe its dynamic path. The AR (14) model is also chosen as the partial autocorrelation function shows a relatively large change from period 14 onwards. The model is set as:

$$y_t = c + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots + \alpha_i y_{t-i} + \cdots + \alpha_{14} y_{t-14} + \varepsilon_t$$

Where $y_t$denotes the 58% discount rate in the tth period; y_{t-i}denotes the 58% discount rate in the $t-i$th period, i.e. The 58% discount rate in the ith lagged period; α_i is the autoregressive coefficient; and ε_t is the random error term.

Table 3.3 shows the autocorrelation and partial autocorrelation functions of the first-order difference series of the 65% premium have a trailing phenomenon, so the ARMA model is used to describe its dynamic path. Since the autocorrelation function starts from the seventh period and the partial autocorrelation function starts from the ninth period with a relatively significant change, we choose the ARMA (9,7) model. The specific model is set as:

$$y_t = c + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots + \alpha_i y_{t-i} + \cdots + \alpha_9 y_{t-9} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \cdots + \theta_j \varepsilon_{t-j} + \cdots + \theta_7 \varepsilon_{t-7}$$

Wherein, y_t denotes the first-order difference term at 65% premium in the tth period; y_{t-i} denotes the first-order difference term at 65% premium in the $t-i$th period; α_i and θ_j are the autoregressive coefficient and moving average coefficient, respectively; ε_t is the random error term.

Table 3.3 Results of autocorrelation and partial autocorrelation function analysis

Lag	58% discount rate series		First-order difference series of 65% premium	
	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.517	0.517	-0.071	-0.071
2	0.513	0.335	0.097	0.092
3	0.511	0.248	0.031	0.044
4	0.509	0.195	-0.101	-0.107
5	0.506	0.159	0.012	-0.009
6	0.506	0.138	-0.006	0.014
7	0.503	0.115	-0.05	-0.043
8	0.501	0.101	-0.001	-0.02
9	0.499	0.088	-0.065	-0.058
10	0.497	0.077	0.01	0.008
11	0.494	0.068	-0.055	-0.052
12	0.492	0.06	0.003	-0.005

Lag	58% discount rate series		First-order difference series of 65% premium	
	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
13	0.489	0.053	-0.033	-0.036
14	0.486	0.046	-0.04	-0.044
15	0.481	0.036	-0.022	-0.033
16	0.48	0.035	-0.054	-0.055
17	0.478	0.032	0.057	0.052
18	0.477	0.03	0.081	0.087
…	…	…	…	…
35	0.417	0.005	0.169	0.169
36	0.413	0.001	0.012	-0.003

4 Impact of the "Dual Carbon" policy on iron ore price divergence

One of the core hypotheses of this study is that the proposed "Dual Carbon" policy leads to price differentiation among different iron ore grades. This chapter aims, to summarize the impact of global carbon reduction policies on iron ore price differentiation and the mechanisms involved using a case study approach. Second, suppose the case study shows that the carbon emission reduction policy leads to the divergence of iron ore prices, to empirically test the theoretical proposition derived from the case study, this chapter further analyzes the effect of the proposed Chinese "Dual Carbon" policy on the premium/discount rates of 65% and 58% iron ore using the ISTA model. Third, a time series ARIMA model is used to forecast the future trend of the premium/discount rate to further strengthen the core hypothesis of this study. Through this chapter, we can clarify that the "Dual Carbon" policy is an important reason for the structural changes in the iron ore market and lay the foundation for introducing the analysis of the investment value of iron ore miners in Chapter 5.

4.1 "Dual Carbon" policy, grade and iron ore premium/discount rate

4.1.1 Relationship between iron ore grade and carbon emissions

The iron and steel industry are energy-intensive, accounting for approximately 25% of direct GHG emissions from the global industrial sector (Ren et al., 2021). As the largest producer and consumer of steel and the largest carbon emitter, China has developed many GHG reduction strategies. In the steel sector, many low-carbon technologies are used to reduce carbon emissions from steel production processes, which include material handling and pretreatment, coking, sintering, pellet production, ironmaking, steelmaking, rolling, and power systems (for related studies, see He & Wang, 2017; Wang et al., 2020; Ren et al., 2021). However, these studies may ignore that the grade of iron ore, as raw material, has important implications for carbon reduction. First, high-grade ores tend to contribute to higher blast furnace productivity, e.g.:

VALE S. A-2/3: our high-grade iron ore has increased blast furnace productivity.

Along with increased productivity, high-grade ores also help reduce coke consumption and reduce energy use, e.g.:

VALE S. A-20: our iron ore has lower impurity levels, which typically results in lower processing costs. For example, when compared with Australian ore, it has shallow alumina content in addition to high grades, reducing coke consumption and increasing blast furnace productivity.

Like coke consumption is reduced in the steelmaking process, high-grade ore helps reduce carbon emissions. The ironmaking process also shows that a reduction in ore grade means an increase in the coke ratio and carbon emission. Taking the ironmaking branch of Xiangtan Iron & Steel, China, as an example, a 1% reduction in grade would increase the coke ratio by 1.6268. Moreover, the coke ratio can be further reduced by using processed pellet ore: for every 10% of metalized pellet ore used, 33.7 kg/t of coke can be saved, which is equivalent to 6.8% of the fuel ratio (Wu et al., 2019). The emission reduction effect of high-grade ores is also clearly indicated by our firms under survey, such as:

RIO TINTO-17: our product has played a role in the transition to a low-

carbon economy. Our high-quality iron ore is more energy efficient and has a relatively short distance to market.

RIO TINTO-20: we produce high-quality iron ore pellets and high-grade, low-impurity concentrates that enable our customers to operate more efficiently and reduce emissions.

FMMOUNT GIBSON-19: the average mass recovery of 67% iron ore is 29.4%, while the average mass recovery of magnetite minerals is 22.7%.

CHAMPION-8: the Bloom Lake Phase I plant produced 66.2% high-grade iron ore concentrate with low levels of contamination.

The case study above shows that improving ore grades means more than just higher total iron content and increased iron output; it also helps reduce energy consumption and CO2 emissions and increase productivity. This suggests that, in addition to substantial technological innovation, steelmaking firms can achieve carbon reduction by purchasing higher-grade iron ore. In practice, technological innovations for carbon reduction often imply large investments with some risks (Bi et al., 2015). For risk-averse investors, purchasing high-grade ore instead of technological innovation is a rational alternative. Of course, with the continuous promotion of carbon emission reduction, many firms tend to buy high-grade ores along with technological innovation. In this case, the market demand for high-grade ore will keep increasing.

Table 4.1 shows an example of the relationship between iron ore grade and carbon emissions.

Table 4.1 Relationship between iron ore grade and energy reduction and carbon emissions

Scope	Index	Example
Energy reduction and carbon reduction	Grade	VALE S. A-2/3: our high-grade iron ore has increased blast furnace productivity. VALE S. A-20: our iron ore has lower impurity levels, which typically results in lower processing costs. For example, when compared with Australian ore, it has shallow alumina content in addition to high grades, reducing coke consumption and increasing blast furnace productivity. RIO TINTO-17: our product has played a role in the transition to a low-carbon economy. Our high-quality iron ore is more energy efficient and has a relatively short distance to market. RIO TINTO-20: we produce high-quality iron ore pellets and high grade, low-impurity concentrates that enable our customers to operate more efficiently and reduce emissions. FMMOUNT GIBSON-19: the average mass recovery of 67% iron ore is 29.4%, while the average mass recovery of magnetite minerals is 22.7%. CHAMPION-8: steel mills recognize that higher iron ore grades help optimize production while significantly reducing CO2 emissions in the steelmaking process. CHAMPION-8: the Bloom Lake Phase I plant produced 66.2% high-grade iron ore concentrate with low levels of contamination.

4.1.2 Carbon reduction policies and changes in iron ore demand structure

Implementing the "Dual Carbon" policy has given Chinese steel firms a greater incentive to implement carbon reduction and green production processes. Considering the direct relationship between iron ore grade and carbon emissions in the steelmaking process, we believe that the promotion of carbon emission reduction policy brings challenges to iron ore miners on the one hand and opportunities for high-grade ores on the other. In fact, in the "Dual Carbon" policy, currently, we must turn the blast furnace for low carbon ironmaking (Wu et al., 2019). Firms under survey also mentioned the opportunities brought by the carbon reduction policy, such as:

BHP-21: we are one of the world's lowest carbon emission intensity iron ore producers.

RIO TINTO-21: we are working with stakeholders to remove carbon from steel manufacturing.

FMMOUNT GIBSON-18: the transition to a low carbon economy presents opportunities and risks, and we are taking steps to mitigate and manage these risks and optimize the opportunities.

Many countries, particularly China, are pushing forward with carbon reduction policies, so the value of high-grade ores for carbon reduction has come to the fore. In response to carbon reduction policies, many iron ore miners are actively producing high-grade ores to gain a competitive advantage, such as:

BHP-21: we will focus on producing higher quality iron ore ...... as steel makers prefer higher quality raw materials for higher productivity and lower emission intensity, the quality difference is an important factor in determining the price of iron ore.

CHAMPION-6: China's increasing focus on reducing steelmaking emissions has positively impacted the price of our higher-grade iron ore.

RIO TINTO-20: demand for high-grade ore may grow as the global steel industry becomes increasingly concerned *about emissions and decarbonization.*

Further, carbon emissions policies have led to a structural shift in steelmaking methods and iron ore demand, which provides strong supports for the demand for high-grade iron ore. Case studies have mentioned the preference of customers for higher grade iron ore, such as:

BHP-17: there is a preference for higher grade ore.

RIO TINTO-16: customers are demanding higher quality ore.

RIO TINTO-17: the global iron ore industry is shifting from production growth to a focus on quality. This has a positive impact on our high-grade products.

RIO TINTO-18: the market demand for the high-quality, high-grade iron ore we produce remained strong in 2018.

Moreover, this shift in demand is structural and long-term,

VALE S. A-1: we believe that global demand for pellets in *the long term will continue to grow at a higher rate than overall iron ore.*

VALE S. A-20: the price difference between high-grade and low-grade iron ore is a structural change that should continue to influence the market in the coming years and support demand for high-quality ore as China implements stricter environmental policies and shifts to more efficient steel industry.

CHAMPION-8: the steel industry's increasing focus on reducing GHG emissions from iron and steelmaking processes may lead to rising demand for higher-grade ore.

CHAMPION-8: the steel industry is undergoing a structural shift in its approach to steelmaking, which may lead to rising demand for higher-grade ore.

CHAMPION-6: the global iron ore is changing rapidly, especially with the growing demand for higher-grade ores.

In this new market dynamic, miners have invested in the mining of higher-grade ores, such as:

BHP-18: we have also invested in the future and will increase the average grade of ore production.

VALE S. A-20: we launched GF88 in 2019, opening up a new market for *our high-quality product portfolio.*

CHAMPION-8: the Bloom Lake Phase I plant produces a 66.2% high-grade iron ore concentrate, proving to be more attractive than 62% iron ore concentrate.

The introduction of carbon emission reduction policies globally, especially in China, has created a great demand for high-grade ore. Moreover, carbon emission reduction as a long-term policy objective has led to structural changes in the iron ore market. This in turn induces iron ore miners to invest in the mining of higher-grade ores, thereby establishing their competitive advantage. In reality, we can also see that the high-grade iron ore from RIO TINTO and VALE S. A is very popular in the market. As RIO TINTO's 2022 financial report shows, RIO TINTO's iron ore sales at Chinese ports in 2021 were 14 million tons, an increase of 1.54 times year-on-year. VALE S. A 2021 production and sales report also shows that VALE S. A's iron ore production in 2021 grew by 5% year-on-year and sales volume went up by 9% year-on-year.

Table 4.2 Carbon emission reduction policies and structural changes in the iron ore market

Scope	Index	Example
Structural changes in the iron ore market	Opportunity	BHP-21: we are one of the world's least carbon-intensive iron ore producers RIO TINTO-21: we are working with stakeholders to remove carbon from steel manufacturing. FMMOUNT GIBSON-18: the transition to a low carbon economy presents opportunities and risks, and we are taking steps to mitigate and manage these risks and optimize the opportunities.
	Demand	BHP-21: we will focus on producing higher quality iron ore ...... as steel makers prefer higher quality raw materials for higher productivity and lower emission intensity, the quality difference is an essential factor in determining the price of iron ore. RIO TINTO-20: demand for high-grade ore may grow as the global steel industry becomes

Scope	Index	Example
		increasingly concerned about emissions and decarbonization. CHAMPION-6: China's increasing focus on reducing steelmaking emissions has positively impacted the price of our higher-grade iron ore. CHAMPION-8: the steel industry's increasing focus on reducing GHG emissions from iron and steelmaking processes may lead to rising demand for higher-grade ore.
	Market changes	BHP-17: there is a preference for higher grade ore. BHP-18: we have also invested in the future and will increase the average grade of ore production. VALE S. A-1: we believe that global demand for pellets in the long term will continue to grow at a higher rate than overall iron ore. VALE S. A-20: the price difference between high-grade and low-grade iron ore is a structural change that should continue to influence the market in the coming years and support demand for high-quality ore as China implements stricter environmental policies and shifts to more efficient steel industry. VALE S. A-20: we launched GF88 in 2019, opening up a new market for our high-quality product portfolio. RIO TINTO-16: customers are demanding higher quality ore. RIO TINTO-17: the global iron ore industry is shifting from production growth to a focus on quality. This has a positive impact on our high-grade products. RIO TINTO-18: the market demand for the high-quality, high-grade iron ore we produce remained strong in 2018. CHAMPION-6: the global iron ore is changing rapidly, especially with the growing demand for higher-grade ores. CHAMPION-8: the Bloom Lake Phase I plant produces a 66.2% high-grade iron ore concentrate, proving to be more attractive than 62% iron ore concentrate. CHAMPION-8: the steel industry is undergoing a structural shift in its approach to steelmaking, which may lead to rising demand for higher-grade ore.

4.1.2 Relationship between iron ore grades and premium/discount rates

Reasons are strong demand for high-grade iron ore, a premium exists for high-grade ore and ore treated by the pelleting process (Galdón-Sánchez & Schmitz Jr., 2002; Comtois & Slack, 2016). On the contrary, there is a discount for low-grade iron ore. There are premium/discount rates as mentioned by different firms, such as:

RIO TINTO-18: 62% grade iron ore prices remained relatively stable and 58% grade iron ore prices fell by 42% to 62% on average.

CHAMPION-6: 66.2% grade iron ore prices are based on an average of P65 and an average of P62 at a 15% premium.

CHAMPION-8: there is a 12.1% premium of the P65 index over the P62 index for the past year ending March 31, 2021.

MOUNT GIBSON-20: 65% Fe grade ore prices have averaged USD174 per ton over the past year, representing a premium of approximately 8% compared to 62% grade, while 58% ore has averaged USD128 per ton, an average discount of roughly 11%.

NORTHLAND-15: a premium need to be paid for high-quality ore.

Consistent with the introduction of carbon reduction policies, productivity gains from higher grades are also driving price disparities for different grades of iron ore, such as:

BHP-18: The price gap between different grades of iron ore remains large because of the plant's focus on maximizing productivity.

Table 4.3 Iron ore grades and premium/discount rates

Scope	Index	Example
Grade and premium/discount rate	Production rate	BHP-18: The price gap between maximizing different iron ore grades remains large because of the plant's focus on productivity.
	Premium/discount rate	RIO TINTO-18: 62% grade iron ore prices remained relatively stable and 58% grade iron ore prices fell by 42% to 62% on average. CHAMPION-6: 66.2% of the iron ore price is based on the average of P65 and the average of P62 with a 15% premium CHAMPION-8: there is a 12.1% premium of the P65 index over the P62 index for the past year ending March 31, 2021. MOUNT GIBSON-20: 65% Fe grade ore prices have averaged USD174 per ton over the past year, representing a premium of approximately 8% compared to 62% grade, while 58% ore has averaged USD128 per ton, an average discount of roughly 11%. NORTHLAND-15: a premium need to be paid for high-quality ore.

The above analysis shows that higher grades of iron ore help reduce carbon emissions and help improve blast furnace productivity, leading to a significant increase in market demand. This change in market demand is structural and long-term, leading to a sizable premium for high-grade ores and a discount for low-grade ores.

From the historical data, the quoted price for iron ore is based on a 62% grade, which brings roughly a 10%-30% premium when the grade is greater than 62%, and a 10%-30% discount when the grade is less than 62%. As shown in Figure 4.1, there is a discount for 58% grade iron ore and a premium for 65%

grade compared to 62% grade iron ore. China's mainstream furnace charge structure is "about 75% sintered ore +about 15% pellet ore + about 10% natural lump ore", which has a rigid demand for high-grade iron ore. More importantly, under the background of global carbon balance management and China's dual control of energy consumption, the global market for high-grade high-quality iron ore will continue to increase, and the international price difference between high-grade and low-grade imported ore will gradually expand, and the fluctuation range of premium/discount rate of different grades of iron ore will continue to widen. Figure 4.1 shows that the gap between the premium rate of 65% grade iron ore and the discount rate of 58% grade iron ore keeps widening from the end of 2020.

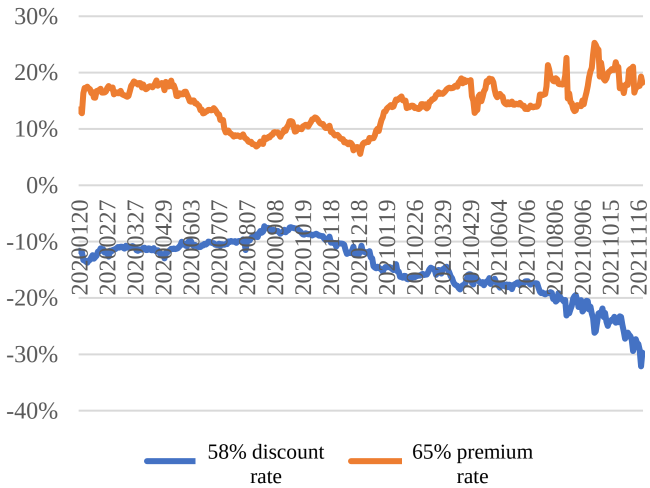


Figure 4.1 Graphical representation of the change in premium/discount rate of iron ore

In general, we can summarize the above discussion into the theoretical framework in Figure 4.2: First, iron ore grades, by increasing blast furnace productivity, reducing coke ratio and increasing steel production to reduce energy consumption and carbon emissions in the steelmaking process. Secondly, the carbon emission reduction policy leads to a long-term change in the market demand structure, i.e., the market demand for high-grade ores has increased significantly and consequently determined a considerable premium for high-grade ores. At the same time, there is a discount for low-grade ores.

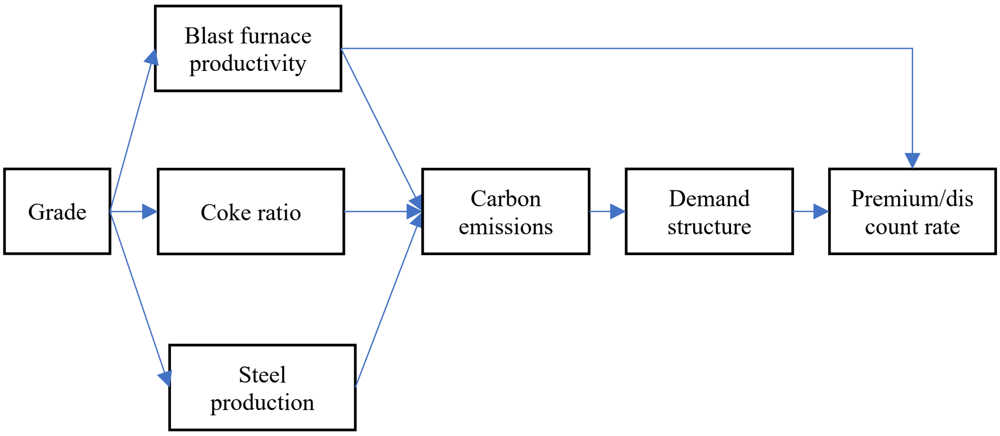


Figure 4.2 Relationship between iron ore grade and premium/discount rates under the carbon emission reduction policy

The more stringent the carbon emission reduction policy, the more pronounced the advantage of high-grade ore. China is the world's largest steel producer and consumer and the largest carbon emitter. The "Dual Carbon" policy proposed by it will significantly impact on the iron ore market. As China's implementation of its "Dual Carbon" policy continues to tighten, especially when steel demand weakens, steel mills tend to shift to higher-grade iron ore to maximize the amount of steel produced from as few raw inputs as possible. Reports also point out that when China is under pressure to conserve electricity, steel mills will try to make as much steel as possible while conserving energy, leading to a premium for higher-grade iron ore (Russell, 2021). This implies that the premium/discount rate of iron ore will change depending on time and major policy events. Therefore, this study is to empirically test the following questions:

1. Whether the introduction of China's "Dual Carbon" policy has led to an increase in the premium for high-grade ores;

2. Whether the introduction of China's "Dual Carbon" policy has led to an increase in the discount rate of low-grade ores;

3. Whether the introduction of China's "Dual Carbon" policy has led to a widening of the difference between the premium and the discount rate.

4.2 Testing the impact of the "Dual Carbon" policy on the premium/discount rate of iron ore

4.2.1 Descriptive statistics

The descriptive statistics of the data are shown in Table 4.4. Longitudinally, the mean, standard deviation, minimum and maximum values of the variables in the daily, weekly and monthly data are not significantly different, which indicates that the data are reliable.

Horizontally, the mean values of 58% price index, 62% price index and 65% price index differed significantly, regardless of the daily, weekly and monthly data, where the mean value of 65% price index was higher than the mean value of 62% price index. The latter was higher than the mean value of 58% price index. Similarly, there is a difference between these three variables in terms of minimum and maximum values, and the difference between 65% and 62% is greater than that between 62% and 58%.

Table 4.4 Descriptive statistics

	Mean	Standard deviation	Minimum value	Maximum value	Observed value
Daily data					
58% price index	86.55	33.64	44.54	192.1	1205
62% price index	101.56	39.78	54.26	230.59	1205
65% price index	155.76	45.01	92.52	261.45	508
58% discount rate	-0.15	0.05	-0.327	-0.06	1205
65% premium rate	0.15	0.04	0.06	0.25	508
Difference	0.30	0.08	0.16	0.51	508
Weekly Data					
58% price index	86.11	33.53	45.04	186.31	272
62% price index	101.07	39.65	54.64	223.43	272
65% price index	155.72	44.96	93.73	254.18	113
58% discount rate	-0.15	0.05	-0.29	-0.06	272
65% premium rate	0.15	0.04	0.07	0.24	113
Difference	0.30	0.08	0.16	0.49	113
Monthly data					
58% price index	86.01	33.39	46.93	175.00	63
62% price index	100.99	39.59	56.72	212.42	63
65% price index	154.45	44.99	97.94	244.26	27
58% discount rate	-0.15	0.05	-0.27	-0.07	63
65% premium rate	0.15	0.04	0.07	0.22	27
Difference	0.30	0.08	0.17	0.45	27

4.2.2 Empirical results

Before conducting the ITSA model analysis, we conducted an autocorrelation test on the data. Table 4.5 shows the results of the autocorrelation test, which shows that all models are autocorrelated. In the weekly data, 58% discount rate model lagged 12 periods are autocorrelated, so we choose the 12th lag term to correctly solve the model's autocorrelation problem. Similarly, the 65% premium rate model uses a 3rd lag term to solve the autocorrelation of the model; the difference model uses an 8th lag term to solve the autocorrelation of the model. Similarly, in the monthly data, the 58% discount rate model chooses the 2nd lag term to solve the autocorrelation of the model; the 65% premium rate model chooses the 1st lag term to solve the autocorrelation of the model and the difference model prefers the 1st lag term to so do.

The corresponding lag of each model is selected for ITSA analysis, and the obtained results are shown in Table 4.6. The results show that the change in slope before and after the intervention of the "Dual Carbon" policy is statistically significant for both weekly and monthly data, among which the weekly data are all significant at the 0.01 level. The monthly data are all significant at the 0.01 level except for the 65% premium and the difference before the intervention, which are both significant at the 0.05 level. However, neither the weekly nor the monthly data are significant regarding level change.

After the policy intervention, the slope coefficient of the 58% discount rate changes from positive to negative. That is, the 58% discount rate becomes smaller over time before the intervention but becomes more extensive over time after the intervention. This indicates that the discount of low-grade iron ore becomes more severe after the "Dual Carbon" policy.

Table 4.5 Autocorrelation test results

Lag	Weekly Data						Monthly data					
	58% discount rate		65% premium rate		Difference		58% discount rate		65% premium rate		Difference	
	chi2	P value	chi2	P value	chi2	P value	chi2	P value	chi2	P value	chi2	P value
1	254.24	0.00	61.64	0.00	85.25	0.00	45.46	0.00	3.06	0.08	13.37	0.00
2	82.98	0.00	11.46	0.00	25.32	0.00	9.80	0.00	1.48	0.22	2.23	0.14
3	48.31	0.00	3.56	0.06	14.96	0.00	2.05	0.15	2.09	0.15	0.15	0.70
4	33.13	0.00	1.63	0.20	11.31	0.00	0.24	0.62	0.64	0.42	4.57	0.03
5	24.03	0.00	0.26	0.61	8.00	0.00	0.12	0.73	0.01	0.94	2.78	0.10
6	17.96	0.00	0.04	0.85	5.60	0.02	0.02	0.90	0.01	0.92	1.06	0.30
7	13.70	0.00	0.27	0.60	4.60	0.03	0.09	0.77	0.40	0.53	0.07	0.80
8	10.49	0.00	0.82	0.36	3.57	0.06	0.52	0.47	1.84	0.18	0.02	0.90
9	7.61	0.01	1.77	0.18	1.59	0.21	1.19	0.28	0.24	0.62	0.09	0.77
10	5.40	0.02	2.78	0.10	0.41	0.52	2.10	0.15	0.10	0.75	0.97	0.33
11	3.89	0.05	2.39	0.12	0.07	0.79	3.35	0.07	2.77	0.10	1.49	0.22
12	2.84	0.09	2.11	0.15	0.03	0.87	3.99	0.05	1.43	0.23	1.41	0.24
13	1.90	0.17	2.15	0.14	0.68	0.41	3.69	0.05	0.43	0.51	2.49	0.11
14	1.13	0.29	2.67	0.10	2.93	0.09	1.84	0.17	0.84	0.36	0.11	0.74
15	0.74	0.39	1.52	0.22	3.43	0.06	0.65	0.42	0.05	0.83	0.80	0.37

The results also show that the slope of the 65% premium rate changed from negative to positive before and after the policy intervention, indicating that the premium rate of 65% iron ore became progressively smaller before the policy intervention. Still, the premium rate of high-grade ore became progressively larger after the implementation of the "Dual Carbon" policy.

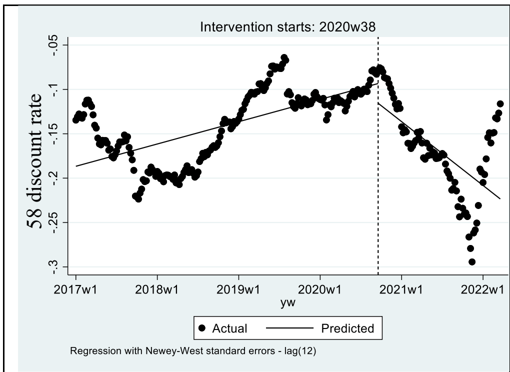
Similarly, the slope of the difference between the 65% premium rate and the 58% discount rate also changed from negative to positive before and after the policy intervention, indicating that the difference between the 65% premium rate and the 58% discount rate is getting smaller before the policy intervention, but becomes larger after the "Dual Carbon" policy was proposed. This result further indicates that the "Dual Carbon" policy has widened the premium for high-grade ores and the discount for low-grade ores, i.e., the advantage of high-grade mines is more prominent, the same as the disadvantage of low-grade mines.

Table 4.6 ITSA results

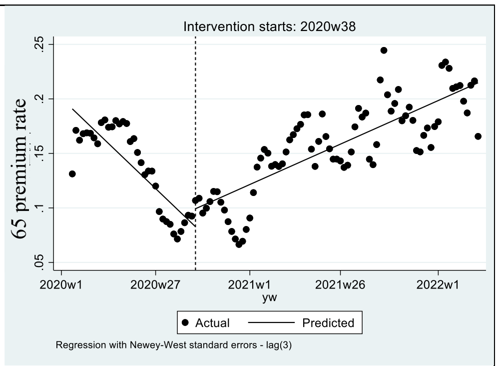
		Level change (β2)	Pre-intervention slope (β1)	Post-intervention slope (β3)	Observed value
Weekly data	58% discount rate	-0.0222 (0.0227)	0.005*** (0.0001)	-0.0019*** (0.000)	272
	65% premium rate	0.0165 (0.0146)	-0.0032*** (0.0006)	0.0047*** (0.0006)	113
	Difference	0.0462 (0.0283)	-0.0044*** (0.0008)	0.0072*** (0.0011)	113
Monthly data	58% discount rate	-0.0168 (0.0229)	0.0020*** (0.0006)	-0.0081*** (0.0029)	272
	65% premium rate	0.0012 (0.0255)	-0.0104** (0.0047)	0.0168*** (0.0048)	113
	Difference	0.0200 (0.0350)	-0.0139** (0.0055)	0.0264*** (0.0064)	113

Note: Standard errors are in parentheses; ***, **, * denote 1%, 5%, 10% significance levels, respectively

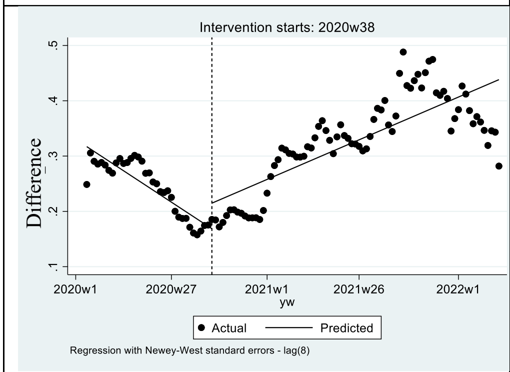
The visualization results are given in Figure 4.3 and Figure 4.4, and their significance is consistent with the results in Table 4.6. Although the change in the intercept level after the intervention is not statistically significant, the implementation of the "Dual Carbon" policy leads to a significant change in the trend of the 58% discount rate, the 65% premium rate and the difference between them. This result provides empirical support for the hypothesis that the "Dual Carbon" policy has changed the price trend of different iron ore grades, resulting in a higher premium rate for higher grades and a higher discount rate for lower grades.



58% discount rate model

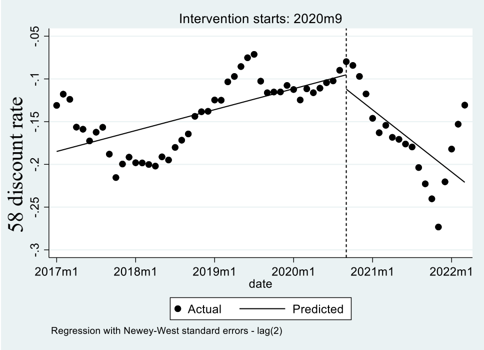


65% premium rate model

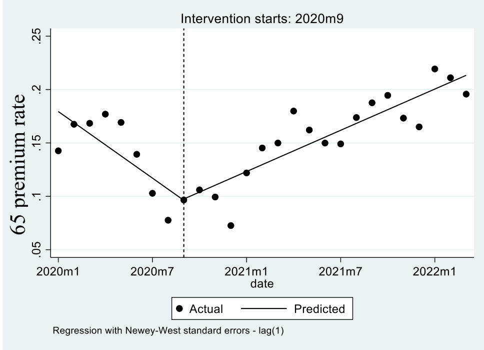


Premium/discount rate spread model

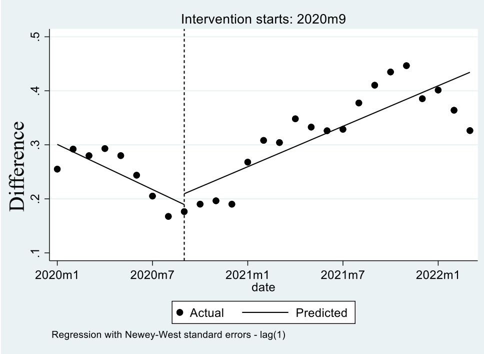
Figure 4.3 Weekly data change



58% discount rate model



65% premium rate model



Premium/discount rate spread model

Figure 4.4 Monthly data change

4.3 Future trend forecast of premium/discount rate

Table 4.7 gives the estimation results of the AR (14) model for the 58% discount rate series and the ARMA (9,7) model for the 65% premium rate first-order difference series. From the 58% discount rate series model shown in Table 4.7, we can figure out that the coefficient estimates are significant within the 10% confidence interval, thus identifying the dynamic path for the 58% discount rate series as the AR (14) process. In the 65% premium first-order difference series model, the coefficients are also estimated to be significant within the 10% confidence interval, thus determining the dynamic path for the 65% premium first-order difference series as the ARMA (9,7) process.

Table 4.7 Model estimation results

	58% discount rate - AR(14)	65% premium rate - ARMA(9,7)
AR(1)	0.100***	-1.075***
	(0.029)	(0.053)
AR(2)	0.088***	-0.348***
	(0.029)	(0.073)
AR(3)	0.082***	0.101*
	(0.029)	(0.058)
AR(4)	0.076***	-0.064*
	(0.029)	(0.036)
AR(5)	0.071**	0.302***
	(0.029)	(0.035)
AR(6)	0.071**	0.969***
	(0.029)	(0.039)
AR(7)	0.064**	0.906***
	(0.029)	(0.060)
AR(8)	0.062**	-0.073
	(0.029)	(0.066)
AR(9)	0.058**	-0.140***
	(0.029)	(0.046)
AR(10)	0.056*	
	(0.029)	
AR(11)	0.053*	
	(0.029)	
AR(12)	0.051*	
	(0.029)	
AR(13)	0.048*	
	(0.029)	
AR(14)	0.046	
	(0.029)	
MA(1)		1.016***
		(0.029)
MA(2)		0.385***
		(0.032)
MA(3)		-0.006
		(0.021)
MA(4)		0.034
		(0.021)
MA(5)		-0.431***
		(0.024)
MA(6)		-1.002***
		(0.030)
MA(7)		-0.950***
		(0.028)
C	-0.150***	0.000*

	58% discount rate - AR(14)	65% premium rate - ARMA(9,7)
	(0.018)	(0.000)
N	1194	516
R^2	0.4665	0.0964
Adj_R^2	0.4602	0.0674

Using the established model, we forecast the following 300 data points for the 58% discount and 65% premium rates. The results of the multi-step forward prediction is given in Figure 4.5. Figure 4.5 shows that the 65% premium slowly becomes more significant over time, gradually converging to 0.2, and similarly, the 58% discount expands over time, converging progressively to -0.15. Of course, we can also see that the difference between the 58% discount and the 65% premium will also widen.

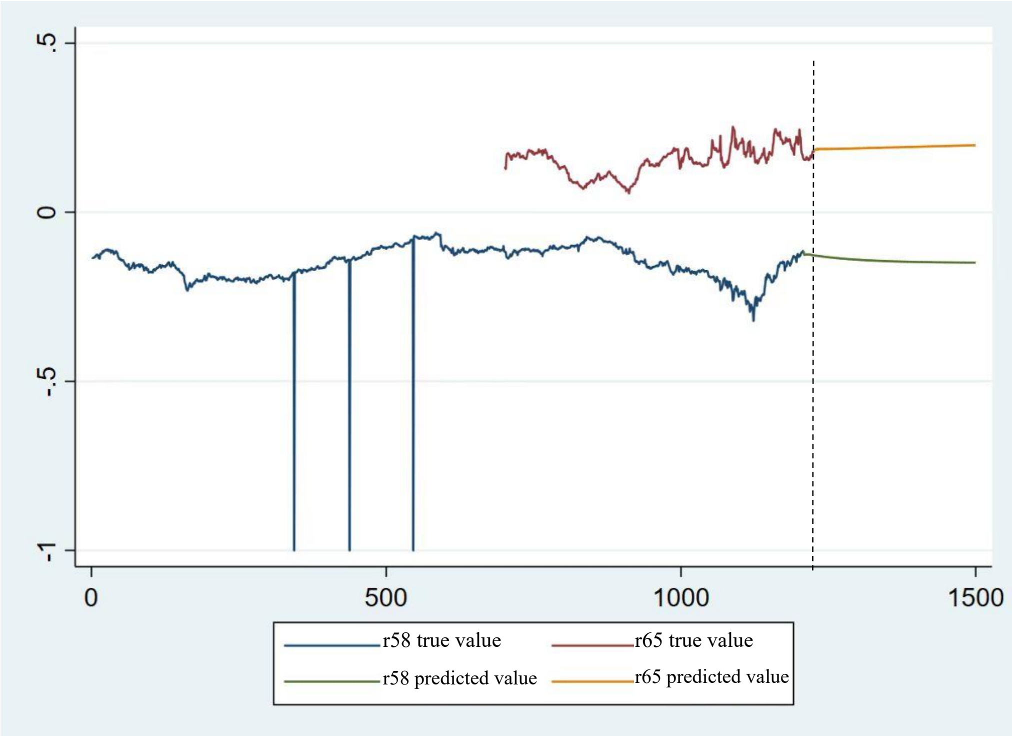


Figure 4.5 Graphical representation of the predicted results

As can be seen from Figure 4.5, the discount rate of 58% grade ore has a V-shaped trend, which affects our prediction of the future trend. The V-shaped trend may be due to the dramatic fluctuations in the carbon price at that time. As shown in Figure 4.6, the EU carbon price has been very volatile since the beginning of 2021. During this period, the overflow/discount ratio of different iron ore grades also showed a corresponding change trend.

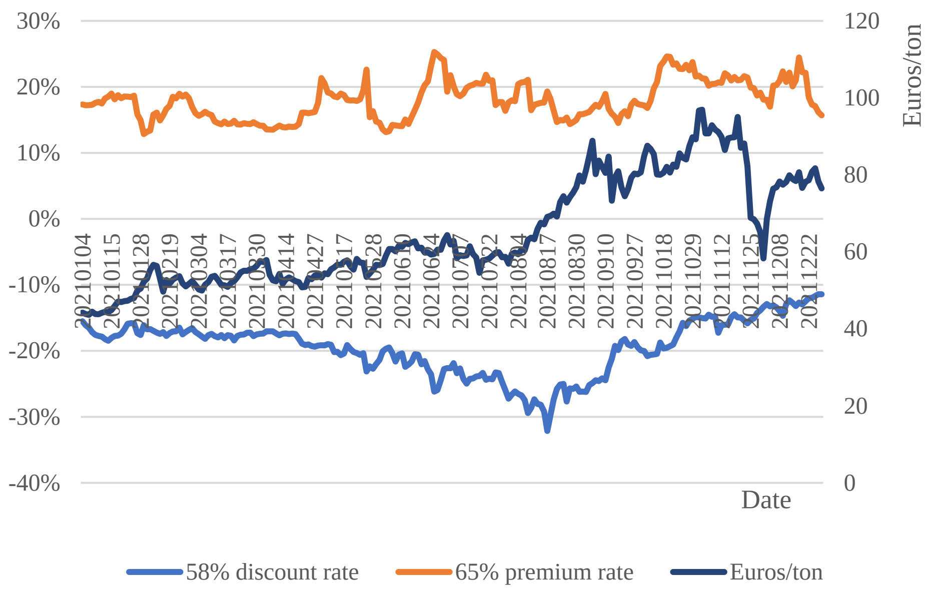


Figure 4.6 Schematic diagram of excess/discount rate and EU carbon price

In order to explore the relationship between the excess/discount rate and carbon price, this study collected the EU carbon emission trading price and conducted a regression analysis using the time-series analysis method. Table 4.8 shows a significant positive correlation between the carbon price and 65% grade ore and a significant negative correlation with the discount rate. This result indicates that the higher the carbon price is, the higher the absolute value of the premium rate and discount rate of high-grade ores. This empirical result indirectly confirms the impact of the "double carbon" policy on the price differentiation of different grades of iron ore. Also, it indicates that the large fluctuations of the excess/discount rate are due to the sharp fluctuations in the carbon price.

Table 4.8 Regression results of the carbon price and excess discount rate

	65% premium rate	58% discount rate
Carbon price	0.070***	-0.039***
	(0.005)	(0.008)
Constant	-0.113***	-0.027
	(0.022)	(0.034)
N	287	287
R^2	0.3742	0.0707
Adjusted R^2	0.3720	0.0675

4.4 Summary

To dig out the impact of the "Dual Carbon" policy on the investment value of iron ore miners, this study must first clarify the mechanism of the "Dual Carbon" policy on the iron ore price and empirically test the treatment effect proposed by the "Dual Carbon" policy. This chapter first uses a case study approach to summarize the impact of global carbon reduction policies on iron ore price differentiation and its mechanism of action. The case study shows that iron ore grade reduces energy consumption and carbon emissions in the steelmaking process by increasing blast furnace productivity, reducing the coke ratio, and rising steel production. Therefore, a long-term, structural change in the iron ore market demand has occurred due to carbon emission reduction policies, leading to a premium for high-grade ores and a discount for low-grade ores.

To empirically test the theoretical proposition derived from the case study, this chapter collects historical price data of different grades of iron ore and empirically tests the impact of China's "Dual Carbon" policy on the divergence of iron ore prices using the ISTA model, and uses the ARMA model to forecast the future trend of the premium/discount rate of 65% and 58% iron ore. The results show that: (1) the "Dual Carbon" policy has expanded the premium rate of high-grade ore and the discount rate of low-grade ore, i.e., the advantage of high-grade mines is more obvious, while the disadvantage of low-grade mines is also more apparent. (2) The future trend forecast of premium/discount rates of 65% and 58% iron ore shows that the premium rate of 65% iron ore will gradually become larger and converge to 0.2; the discount rate of 58% iron ore will also gradually expand and converge to -0.15. This result shows that the proposed "Dual Carbon" policy is essential for the divergence of different iron ore prices. Moreover, the price gap between low-grade and high-grade ores is widening as the implementation of the "Dual Carbon" policy continues to advance. In this case, if the iron ore miners produce higher-grade ore, they can enjoy the price advantage, which will maintain in the future. On the contrary, if the ore grade produced is lower, the firm will have a significant price disadvantage in the future period.

5 Grade and the investment value of iron ore miners in oligopolistic markets

Chapter 4 analyzes the theoretical roots of the premium/discount rate at the macro level. According to Chapter 4, the proposed "Dual Carbon" policy has led to a divergence in iron ore prices across grades - widening the premium for higher grades and the discount for lower grades. At a micro level, the "Dual Carbon" policy has led to a more pronounced advantage for high-grade mines and a more pronounced disadvantage for low-grade ones. This chapter is intended to explore the theoretical mechanism by which the "Dual Carbon" policy affects the investment value of iron ore miners by using case studies. The first section analyzes how the ore grade affects the investment value of iron ore miners by affecting their profit per ton(degree) in the context of the "Dual Carbon" policy; the second analyzes how the profit per ton(degree) of oligopolies affects the investment value of iron ore miners in an oligopolistic market; the third one covers a longer period and it analyzes how the difference in profit per ton(degree) with the oligopolies determines the life and death of iron ore miners in a downward iron ore price cycle. Finally, the chapter concludes with a summary of the results of the case study and a logic block diagram.

5.1 Ore grade, profit per ton and investment value

5.1.1 Ore grade and profit per ton (degree)

The "Dual Carbon" policy leads as a whole to a premium for high-grade iron ore and a discount for low-grade iron ore. At the micro level, firms are more concerned with the profit they make from iron ore production. Operating costs and profits are the main determinants of the value of a miner (Bluszcz & Kijewska, 2016), while a firm's profit can be obtained by subtracting costs from revenues. Considering the grade of iron ore and the resulting premium/discount in the context of the "Dual Carbon" policy, we can conclude that the revenue of iron ore miners is related to the grade of iron ore and its premium/discount rate. The firm's cost is also related to the grade. Taking direct shipment ore (DSO) for an example, there are significant cost savings because there is no beneficiation or processing. However, although low-grade magnetite ore can help obtain higher-grade ore or pellets, the high beneficiation cost greatly reduces its market competitiveness. In addition, high grades can help cut costs of firms such as

VALE S. A-20: we have lower iron ore impurities, which typically results in lower processing costs.

Iron ore miners make a profit of revenue minus costs for every ton of iron ore sold. Platts Index reports price indices for 58%, 62% and 65% grades of iron ore. In contrast, for other grades of iron ore sold by iron ore miners, the market generally refers to the iron content of 62% grade iron ore to calculate the iron content of a single ton of iron ore, i.e., the grade index per ton (grade/0.62), and multiplies it by the price of 62% grade iron ore and the premium/discount rate α. Considering that costs are also affected by grade, we believe that the operating profit of an iron ore miner per ton of ore is a function of its iron ore grade (as shown in Equation 5-1).

$$profit = \text{income-cost} = \frac{grade}{0.62} * price * \alpha - \text{cost} = \frac{grade}{0.62} * price * f(grade) - g(grade)$$

(5-1)

where profit is the profit per ton of iron ore, price is the price of 62% grade iron ore; grade is the grade of iron ore, and α is the premium/discount rate; wherein, $\alpha=1$ when grade=62; when grade>62, $1<\alpha<1.3$ and $0.7<\alpha<1$ when grade<62. Cost is the operating cost, and f(grade) and g(grade) are functions of iron ore grade.

In Equation (5-1), since the price is exogenously given, the key to an iron ore miner's profit per ton is the grade of its output iron ore and the premium/discount rate and operating costs determined by it. When the grade is higher, the premium/discount rate is also higher; the price is lower, and the likelihood of a higher corporate value is more outstanding.

Furthermore, considering the grade of iron ore, we can also calculate the "profit per ton degrees"(PPTD) of ore produced by an iron ore company, which is the profit per 1% of the iron content of the iron ore produced by the iron ore company. The specific formula of PPTD is shown in Equation (5-2). Based on the PPTD, the grade of ore produced by the target iron ore enterprise is further considered. So, when we compare the investment value of the iron ore enterprise, we only need to compare the PPTD of the ore produced by the enterprise. But, of course, in Equation (5-2), we can also see that iron ore grade also determines the PPTD of iron ore enterprises.

$$profit' = \frac{\text{income-cost}}{grade*100} = \frac{price*\alpha}{62} - \frac{\text{cost}}{grade*100} = \frac{price*f(grade)}{62} - \frac{g(grade)}{grade*100}$$

(5-2)

5.1.2 Rio Tinto case

Rio Tinto's experience illustrates the importance of iron ore grades and operating costs to business operations. As one of the world's largest iron ore suppliers, Rio Tinto has high-grade iron ore resources, most of which are over

60%. Even when the grade of its Canadian iron ore resources is below 30%, the firm does not sell the raw ore directly but follows the trend of global carbon reduction policies. The raw ore is processed into iron ore concentrate with a grade of 66% or higher to obtain a high premium. At the same time, Rio Tinto is reducing costs in several ways. In line with the meaning expressed in Equation (5-1), the investment in Rio Tinto Group has gained a high return.

Rio Tinto was founded in 1873 in Andalusia, Spain, on the Rio Tinto River. The firm name "Rio Tinto" is Spanish for the red river. In 1954, Rio Tinto sold most of its Spanish operations. Between 1962 and 1997, Rio Tinto acquired several influential miners around the world, and in 2000 acquired Australia's Northern Minerals, becoming a global leader in the exploration, mining and processing of mineral resources, known as one of the three iron ore giants.

Rio Tinto is headquartered in the United Kingdom and its Australian headquarters is in Melbourne. As a multinational minerals and resources group, Rio Tinto has production operations in 35 countries across six continents, with assets primarily in Australia and North America and significant operations in Asia, Europe, Africa and South America. Rio Tinto currently has more than 45,000 employees, 27,000 suppliers and over 2,000 customers worldwide. As the biggest in Australia and the second largest iron ore producer in the world, Rio Tinto has the largest market share in China by dint of its iron ore products. Rio Tinto's iron ore resources are located in two regions, the Pilbara in Western Australia, with a total production of 333 million tons in 2020 (of which Rio Tinto's equity production is 286 million tons), and in Canada, operated by The Iron Ore Company of Canada (IOC).

In the Pilbara, Western Australia, Rio Tinto operates a world-class integrated network of iron ore production operations, including 16 mines, four dedicated ship loading terminals, an 1800-kilometer rail network and supporting infrastructure. Rio Tinto's Pilbara iron ore mines have five segments, Hamersley Iron, Robe River Mining JV, Hope Downs JV, Channar Mining JV and BAO-HI Ranges JV). Figure 5.1 shows the distribution of mines, railroads and ports in Rio Tinto's Pilbara region.

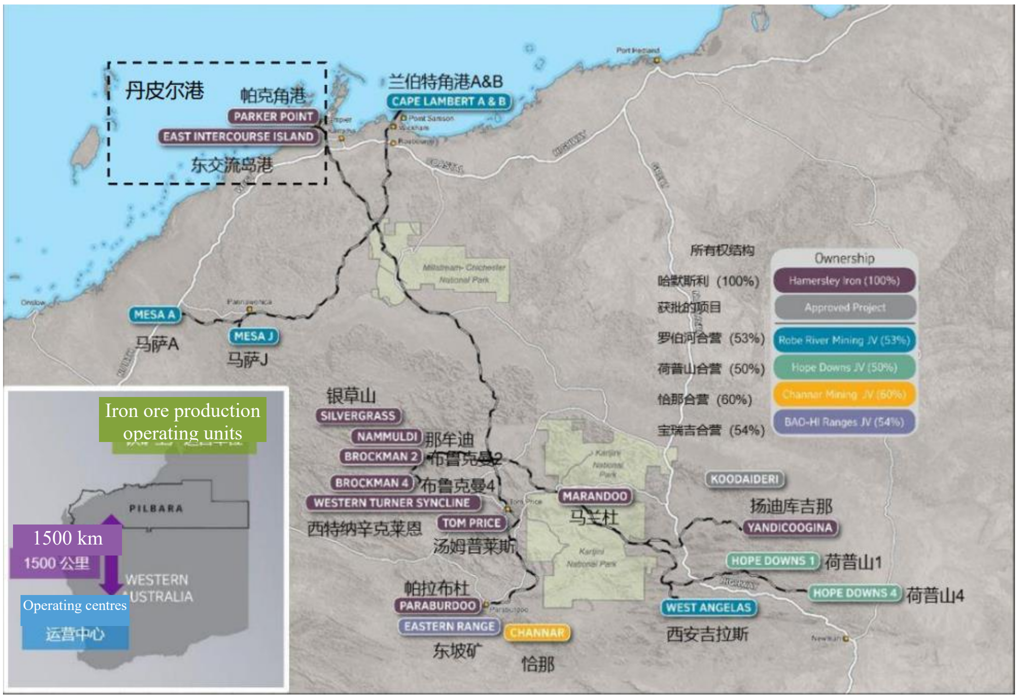


Figure 5.1 Distribution of mines, railroads and ports in the Pilbara region of Rio Tinto

Source: CITIC Futures Research

Hamersley Iron has 11 mines. Table 5.1 lists the mine capacity, reserves and ore grades of each mine. As we can see, the average grade of Hamersley Iron, the flagship mine of Rio Tinto, is 57.9% and the highest grade is 63.6%, which is generally higher.

Table 5.1 Hamersley iron ore mine production, reserves and ore grades

Mine	Date of commissioning	Production capacity (10,000 tons/year)	Reserves (2020/2017)	Average iron grade (2020/2017)
Brockman 2	1992	1000	87 million tons	61.1
Nammuldi	2006		150 million tons	61.5
Silvergrass	2017	1000	176 million tons	58.6
Brockman 4	2010	4000	280 million tons	60.6
Marandoo	1994	1500	162 million tons	57.9
Paraburdoo	1976		6 million tons (near depletion)	62.9
Mount Tom Price	1966	1500	40 million tons	63.6
Western Tumer Syncline	2010		278 million tons	61
Yandicoogina	1998	6000	460 million tons	58.3
Channar	1990	1000	12 million tons (near depletion)	60.8
Eastern Range	2004	1000	22 million tons (near depletion)	60.3

Source: CITIC Futures Research

Hope Downs Joint Venture, a joint venture between Rio Tinto and Hancock Prospecting, was established in 2005. Hope Downs has two producing mines, Hope Downs 1 and Hope Downs 4. Table 5.2 gives the production, reserves and ore grades of the Hope Hill iron ore mines, which also shows that both mines have high ore grades, with Hope Downs 4 having a grade of 63.2%.

Table 5.2 Iron ore production, reserves and ore grades at Hope Downs

Mine	Date of commissioning	Production capacity (10,000 tons/year)	Reserves (2020/2017)	Average iron grade (2020/2017)
Hope Downs 1	2007	3000	140 million tons	60.2
Hope Downs 4	2013	1500	98 million tons	63.2

Source: CITIC Futures Research

There are currently three producing mines under the Robb River iron ore, Mesa A, Mesa J and West Angelas. Table 5.3 gives the production, reserves and ore grades of the Robe River iron ore mines, and shows that while the lowest iron ore grade of 56.4% was achieved at the Robe River mine, the grade of 61.5% at the West Angelas mine.

Table 5.3 Production, reserves and ore grades of the Robo River iron ore mine

Mine	Date of commissioning	Production capacity (10,000 tons/year)	Reserves (2020/2017)	Average iron grade (2020/2017)
Mesa J	1994		326 million tons	56.4
Mesa A	2010	2500		
West Angelas	2002	3500	173 million tons	61.5

Source: CITIC Futures Research

Rio Tinto's Pilbara mine produces five main iron ore products, of which Pilbara Blend (PB fines and PB lumps) is the most globally recognized iron ore product and is the primary feedstock for sintering and blast furnace smelting. Pilbara Blend accounts for approximately 70% of Rio Tinto's iron ore portfolio and is currently the iron ore product with the largest market share and best liquidity.

However, Pilbara Blend grades are still only between 61% and 62% and are trending downwards as higher-grade ores are gradually depleted. However, there is a higher demand for higher grade ore. Therefore, Rio Tinto is selling Pilbara Blend at grades above 60% but at a slightly lower quality, under the name SP10, to ensure that the quality of Pilbara Blend is not compromised.

Outside of the Pilbara mine, there is Rio Tinto's Iron Ore Company of Canada (IOC). IOC is a leading North American pellet and iron ore concentrate producer with a network of production operations that includes a mine and processing plant in Labrador City, a port and yard in Sept-Iles, Quebec, and a railroad of approximately 418 kilometers that connects the mine to the port. Figure 5.2 shows the distribution of Rio Tinto Iron Ore Canada's mines, railroads and ports.

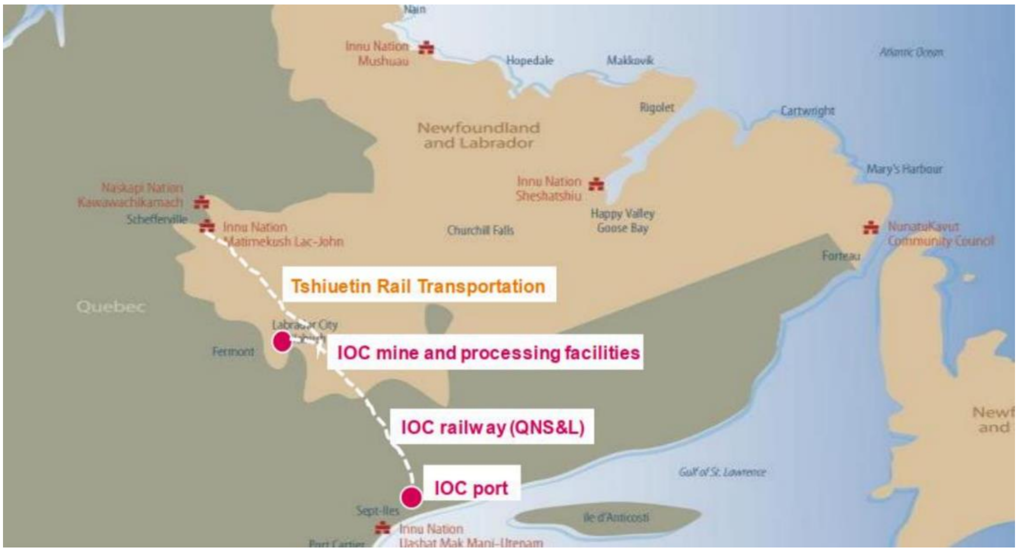


Figure 5.2 Rio Tinto Iron Ore Canada's mines, railroads and ports

Source: CITIC Futures Research

IOC's products are Iron Ore Pellets and Concentrate, with an average iron grade of over 66%. IOC's products cater to the higher value segments of the iron ore market. Its high grade and low impurity products enable steelmakers to operate more efficiently and produce higher quality steel, while conforming to increasingly stringent carbon reduction policies.

Of concern is that carbon reduction policies have led to a significant increase in market demand for higher-grade ore. To adapt to the changing market demand structure and ensure Rio Tinto's competitive advantage, Rio Tinto and the Port of Dalian worked together to launch in September 2019 a bonded blending business for Rio Tinto Blended Fines (RTBF). RTBF is a blend of high-grade Canadian concentrate (IOC concentrate) with medium-grade Australian SP10 iron ore fines. In this way, Rio Tinto can be very flexible in meeting the needs of different market segments: supplying the market with a flexible range of iron ore grades from 60% to 66%.

While meeting the differentiated demand, Rio Tinto also has good cost control capabilities. Data from Rio Tinto's annual report show that from 2015-2020, Rio Tinto's CIF costs were below USD30 per ton. IOC's raw ore is magnetite with low grade. However, the Quebec region of Canada has abundant water resources for in-situ beneficiation and the mine is not far from the coastline, so beneficiation costs and transportation costs are manageable. This suggests that Rio Tinto is, implementing an overall cost leadership differentiation strategy - with the ability to deliver high-grade iron ore to the market at low cost. In this case, RIO TINTO is making significant profits. As RIO TINTO's 2022 financial results show, RIO TINTO's consolidated sales revenue reached USD63,595 million in 2021, an improvement of nearly USD20 billion from 2020, and profits for the reporting period reached USD21,305 million, up 73% year-over-year. Investors were also well rewarded: RIO

TINTO's overall dividend payout for 2021, on the other hand, reached a staggering USD16.8 billion.

5.2 Impact of the profit gap per ton with oligopolies on the investment value

5.2.1 Impact of oligopolistic markets

The study in 5.1 has shown that profit per ton(degree), as determined by grade, significantly impacts the investment value of iron ore miners. However, the firm’s market structure is also an essential factor in corporate value (Lee, 2009). Iron ore is a very typical oligopolistic market. Oligopolies often use market power to force competitors out of business (Tepper, 2018). Then, even though some iron ore miners have certain advantages in terms of profit per ton(degree), these advantages may still be eroded by oligopolies.

There is evidence that Australia has created an informal iron ore export cartel for the benefit of producing firms to supply Asian markets (Lawrence & Nehring, 2015). An oligopolistic market for iron ore is clearly outlined for us in the annual reports of firms under survey, such as

FMMOUNT GIBSON-1: the supply of the industry has been dominated by major producers

FMMOUNT GIBSON-3: the biggest challenge is the dominance of iron ore supply by a few major producers, with the three major iron ore CVRD, RT and BHP now controlling around 75% of global seaborne iron ore supply, with RT's investment in the Hope Downs project further cementing this high concentration.

FMMOUNT GIBSON-5: our industry competitors are three of the world's largest miners.

NORTHLAND-15: the iron ore industry is highly concentrated, with the market dominated by four giants: Vale S.A (headquartered in Brazil), Rio Tinto, BHP Billiton and Fortescue Metals Group.

Oligopolies with market power may retaliate against other firms using predatory pricing (Stigler, 1947; Stigler, 1964) and crowd out other firms, especially new entrants, from the market (McGee, 1980; Elzinga & Mills, 2001. Edlin, 2012).

In this case, the commodity price fluctuated to some extent according to the needs of the monopolist. In practice, if the iron ore price does not fall below the average cash cost of the oligopolies, the oligopolies will not choose to reduce production but lower costs and increase efficiency by expanding production, reducing capital expenditure, improving production structure, and increasing production efficiency. This means that if costs are higher than those of the monopolies, they are easily squeezed out of the market due to price retaliation. Large-scale production oligopolies are more likely to achieve economies of scale. They therefore tend to have lower costs (as in Figure 5.3), giving the oligopolies the ability to enforce predatory pricing.

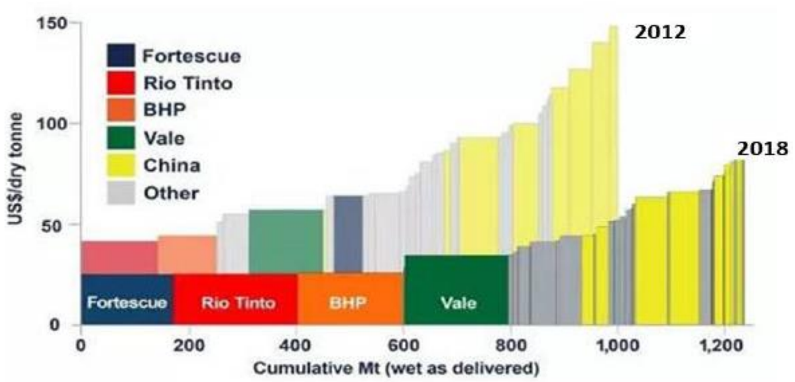


Figure 5.3 Comparison of cash costs of iron ore oligarchs and other miners

Source: S&P Global Intelligence

Table 5.4 Impact of oligopolies

Scope	Index	Example
Market structure	Oligopoly dominance	FMMOUNT GIBSON-1: the supply of the industry has been dominated by major producers FMMOUNT GIBSON-3: the biggest challenge is the dominance of iron ore supply by a few major producers, with the three major iron ore CVRD, RT and BHP now controlling around 75% of global seaborne iron ore supply, with RT's investment in the Hope Downs project further cementing this high concentration. FMMOUNT GIBSON-5: our industry competitors are three of the world's largest miners. NORTHLAND-15: the iron ore industry is highly concentrated, with the market dominated by four giants: Vale S.A (headquartered in Brazil), Rio Tinto, BHP Billiton and Fortescue Metals Group.
	Predatory pricing	FMMOUNT GIBSON-1: the oligarchs have effectively discouraged new players by limiting access to existing infrastructure in Western Australia - private railroads and ports FMMOUNT GIBSON-13: the logic of constant expansion is simply because of the availability of additional production, and when industry leaders follow, the market will be disrupted. FMMOUNT GIBSON-13: the market was threatened by oversupply from some large iron ore producers in 2015. CHAMPION-7: the oligarchs are expanding production even as ore prices fall, causing prices to hit annual lows.

The firms under survey also mention the oligarchs' ability to fight other miners in a variety of ways, such as:

FMMOUNT GIBSON-1: the oligarchs have effectively discouraged new players by limiting access to existing infrastructure in Western Australia - private rail and ports.

FMMOUNT GIBSON-13: the logic of constant expansion is simply because of the availability of additional production, and when industry leaders follow, the market will be disrupted.

FMMOUNT GIBSON-13: the market was threatened by oversupply from some large iron ore producers in 2015.

CHAMPION-7: the oligarchs are expanding production even as ore prices fall, causing prices to hit annual lows.

The above analysis shows that iron ore is a typical oligopolistic market where the oligopolies, with their ability to control costs, choose to expand production even when ore prices fall, leading to falling prices and eventually squeezing out iron ore miners with high expenses or weak profitability.

Of course, once iron ore prices fall below the oligarchs' costs, the oligarchs will lose money and use their monopoly advantage to dampen price declines through, for example, production cuts. Therefore, if certain iron ore miners have more cost advantages than the oligopolies, they will not fear retaliation from the oligopolies. Although they may suffer some losses in the short term due to being retaliated, they will still be able to make considerable profits in the long term. Moreover, the greater the cost advantage over the monopoly, the greater the likelihood of substantial profits in the long run. The higher the corporate value, and thus the greater the investment value. This shows that the investment value of an iron ore miner is a function of the difference between its profit per ton(profit gap per ton, PGPT) and the oligopoly's profit per ton (as shown in Equation 5-2).

$$\beta = profit - profit_m = \frac{price}{0.62} * grade * \alpha - \cos t - \frac{\sum_{i=1}^{3}(\frac{price}{0.62} * grade_{mi} * \alpha_{mi} - \cos t_{mi})}{3}$$

$$= \frac{price}{0.62} * grade * f(grade) - g(grade) - \frac{\sum_{i=1}^{3}(\frac{price}{0.62} * grade_{mi} * f(grade_{mi}) - g(grade_{mi})}{3}$$

(5-2)

Where β is the difference between the profit per ton of the iron ore miner and the average profit per ton of the three oligopolies; $profit_{mi}$ is the operating profit of the ith monopoly; $grade_{mi}$ is the iron ore grade of the ith monopoly; α_{mi} is the premium/discount rate of the ith monopoly, and $cost_{mi}$ is the operating cost of the ith monopoly. Equation 5-2 shows that the magnitude of β is a crucial determinant of the competitive advantage of non-oligopolistic iron ore miners and is a function of the grade of iron ore produced by the target firm and the oligopoly. This implies the extreme importance of iron ore grade in the competitive market without considering factors such as economies of scale.

Similarly, as per ton profit, we can calculate the difference between the profit per ton degrees (profit gap per ton degrees, PGPTD). As shown in Equation (5-4), the PGPTD of iron ore produced by an iron ore enterprise is a function of its ore grade and oligopolistic ore grade, which further illustrates the importance of iron ore grade to establish an enterprise's competitive advantage. From the perspective of investment target selection, if the PGPTD of ore produced by iron ore enterprise A is higher than that of iron ore enterprise B, it indicates that A has more investment value than B. PGPTD provides us with a convenient standard index to compare the investment value of iron ore enterprises.

$$\beta' = \frac{price * f(grade)}{62} - \frac{g(grade)}{grade * 100} - \frac{\sum_{i=1}^{3}\left(\frac{price * f(grade_{mi})}{62} - \frac{g(grade_{mi})}{grade_{mi} * 100}\right)}{3}$$

(5-4)

5.2.2 FMG and Champion Iron case

Similarly, both FMG and Champion Iron produce low-grade iron ore. FMG's iron ore grade is less than 58%, while Champion Iron's iron ore grade is below 30%. FMG and Champion Iron are facing challenges from the oligopolies with higher ore grades and lower costs amid the "Dual Carbon" policy. We use the case of these two iron ore miners to analyze the impact of the difference in profit per ton(degree) of the oligopolies on the investment value.

5.2.2.1 The FMG case

The full name of FMG is Fortescue Metals Group Ltd, a group firm of Fortescue Metals. Australian Andrew Forrest established FMG in 2003 through the acquisition of ASX (Australian Stock Exchange) listed firm Allied Mining & Processing and renamed it.

In 2004, FMG explored and found iron ore resources (the Cloudbreak property) in the Pilbara region. The firm subsequently proposed an AUD1.85 billion investment plan with an estimated annual production of 45 million tons of iron ore. In 2005, the firm was added to the S&P/ASX 200 stock index as FMG's stock soared. In February 2006, FMG's Headland port the construction began, and rail and mine construction began in succession. In May 2008, FMG shipped its first iron ore shipment to China when Cloudbreak iron ore came on stream. FMG is now the third-largest iron ore producer in Australia and the fourth-largest in the world, after Rio Tinto and BHP Billiton.

FMG's mines include the Chichester Hub, Solomon Hub, Western Hub and Iron Bridge Magnetite Project. The iron ore products from these mines are transported to the Headland port for shipment. Figure 5.4 shows a diagram of FMG's mines and ports, and Table 5.5 gives a breakdown of the product and capacity of each mine.

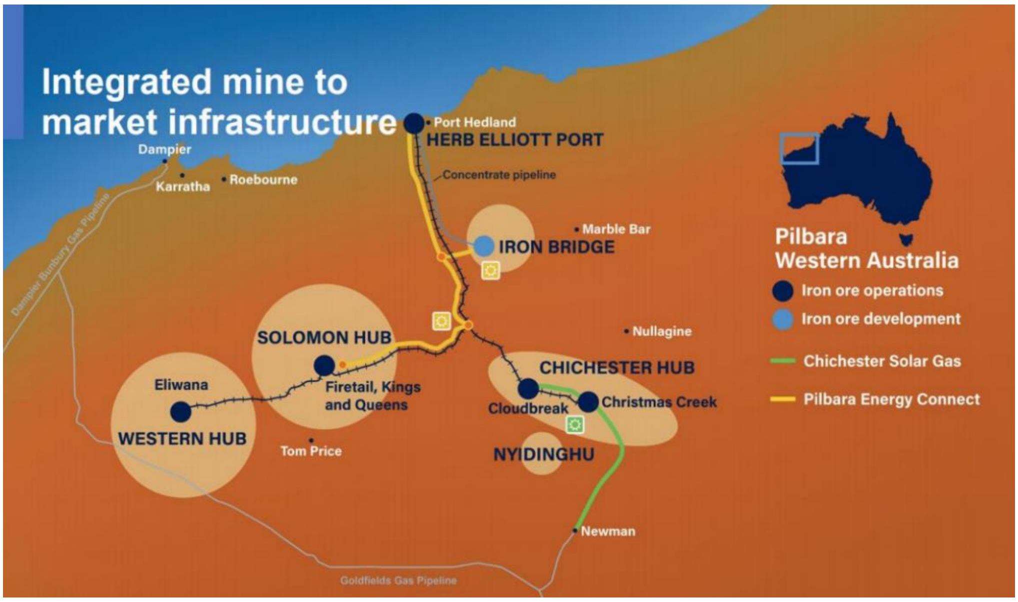


Figure 5.4 Map of FMG mines and ports

Table 5.5 FMG product and capacity by mine

Mine area	Mine	Date of commissioning	Product	Annual capacity
Chichester Hub	Cloudbreak	2008	Super special fine/west Pilbara Fines	100 million tons
	Christmas Creek	2001	Super special fine /blended fine	
Solomon Hub	Firetail	2013	Blended fine /west Pilbara Fines	75 million tons
	Kings Valley	2014	Kings fines/ super special fine	
	Queens Valley	2019	Kings fines	
Western Hub	Eliwana	2020	West Pilbara fines/super special fine	30 million tons
Iron Bridge Magnetite Project	-	December 2022	67% iron concentrate (magnetite)	22 million tons

As seen in Figure 5.4, FMG's iron ore projects are close and can share infrastructure very quickly. This is an essential reason for FMG's good cost-control ability. As an emerging iron ore miner, FMG has strongly emphasized the success of its cost leadership strategy, both in its annual reports and in related press presentations. Indeed, to date, FMG's cost control has been effective (as shown in Figure 5.5) and has indeed resulted in good financial performance.

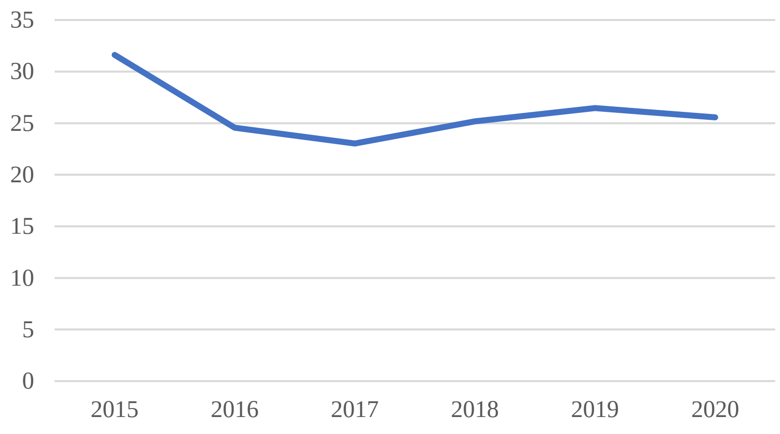


Figure 5.5 FMG's historical CIF costs (USD/ton)

However, it is important to note that the grade of iron ore produced by FMG is only 58.5%, and the grade is still declining. Figure 5.6 compares FMG's grades with other iron ore oligopolies. The average grades of BHP and Vale are relatively high, except for Rio Tinto, which has a slightly lower average grade. Vale, in particular, has a greater advantage in the supply of high-grade ore.

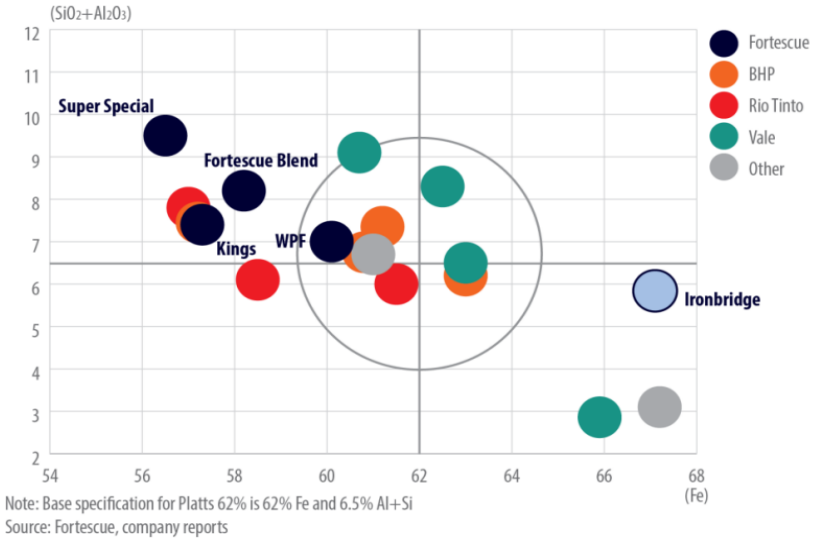


Figure 5.6 FMG's ore grades compared with other iron ore oligopolies

Because of FMG's low ore grade, we can expect FMG's outlook to be bleak in the context of the "Dual Carbon" policy. However, as oligopolies, Vale, Rio Tinto and BHP Billiton, produce iron ore at higher grades, such as 65% for Vale and 60% for Rio Tinto and BHP Billiton, and have relatively good cost control. Therefore, we collected the CIF cost data of the three oligopolies. As shown in Figure 5.7, the CIF cost of the three oligopolies is basically maintained in the range of 25-40 USD/ton. Considering the predatory pricing of the oligopolies, we believe that they can push the price of 62% grade iron ore to below USD40. This means that the three oligopolies are essentially an "anchor" for iron ore investment targets - in the long run, only iron ore targets with more good grades and costs than the three oligopolies will have investment value, and if no, it is better to invest directly in the three oligopolies.

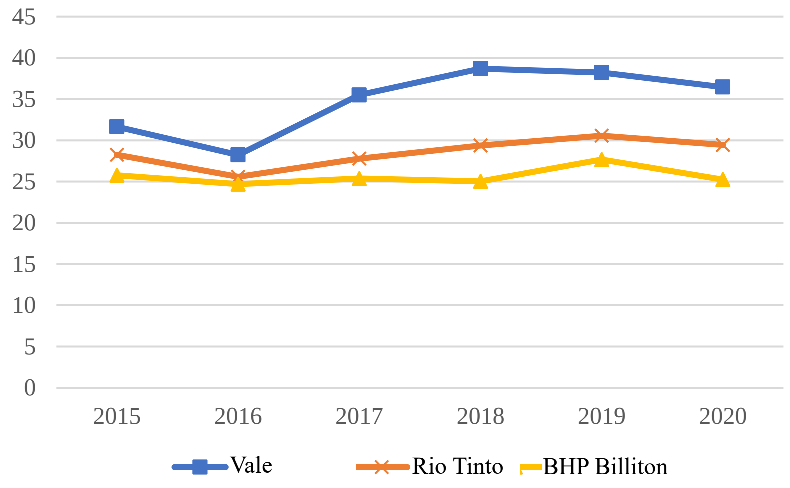


Figure 5.7 CIF cost (USD/ton) of the three oligopolies over the years

Using the operating costs of the Big Three oligopolies such as Rio Tinto, Vale, BHP and FMG, as well as the average grade data, and in combination with the iron ore price in each year, we calculate the PGPT and PGPTD for FMG compared with the Big Three according to equation 5-2. As shown in Figure 5.8, the low-cost strategy gained a competitive advantage for FMG when the carbon emission reduction policy was not yet severe, and the price divergence of different ore grades was insignificant. In particular, in the three years from 2016-2018, the PGPT between FMG and the three oligopolies was only about USD10. Under these circumstances, FMG did not fear predatory pricing from the Big Three oligopolies and even made significant profits when iron ore prices were relatively high.

However, as demand for low-grade ore declines with the advancement of the "Dual Carbon" policy, FMG's price discount on 58% ore is getting worse and worse and finally, FMG's profit gap per ton with the Big Three is getting worse - widened to around USD30 by 2019-2020. It means that at some low point in the price cycle, the Big Three oligopolies can cause significant losses to FMG through predatory pricing. It can also be seen from Figure 5.8 that the trend of FMG's PGPTD is the same as that of the PGPT.

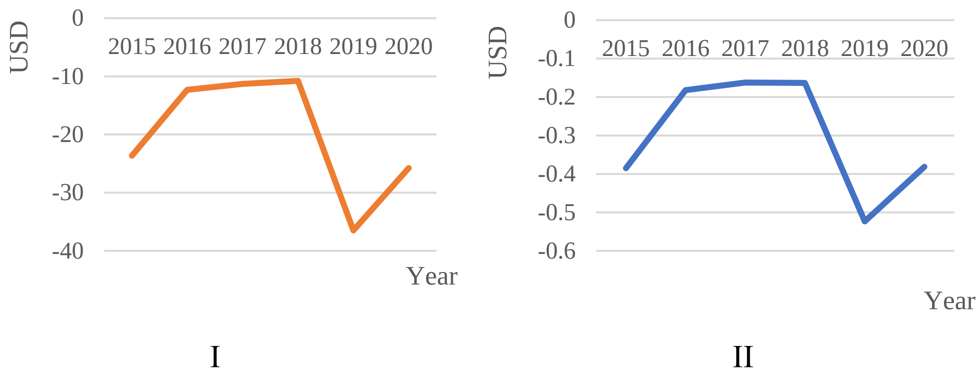


Figure 5.8 Graphical representation of the PGPT(I) and PGPTD(II) of FMG

Perhaps realizing the crisis, FMG began to change its strategy. In September 2020, FMG approved the Iron Bridge Magnetite Project (IBP) and completed a commercial evaluation in May 2021, with mine production expected in December 2022. The USD3.3 to USD3.5 billion project will provide 22 million tons per annum of 67% high-grade magnetite concentrate suitable for pellet making or blending with sinter fines. Like the Sino Iron Project and the Carrara Mine, the Iron Bridge Magnetite Project is a magnetite mine that obtains iron ore concentrate through beneficiation. However, the Iron Bridge Magnetite Project can share infrastructure with FMG's other mines and is also only 145 kilometers from the port, helping to achieve reasonable cost control.

Of course, it is essential to note that China, FMG's most important market, is pushing forward with its "Dual Carbon" policy, so the commissioning of the Iron Bridge Magnetite Project will not completely overshadow the growing disadvantages of the Chichester Hub, Solomon Hub and Western Hub. So, in the long run, if FMG is not a high-quality target.

5.2.2.2 The Champion Iron case

Champion Iron is located in the Quebec region of Canada and owns three iron ore projects, Bloom Lake, Fire Lake North and Kamistiatusset, of which only Bloom Lake is in active mining status. Champion Iron owns all magnetite mines, but through beneficiation, Champion Iron produces over 66% high-grade iron ore concentrate. Champion Iron has become the world's largest listed producer of high-grade iron ore concentrate, with sales to China, Japan, the Middle East, Europe, Korea, India and Canada. A location map of Champion Iron's mines is given in Figure 5.9.

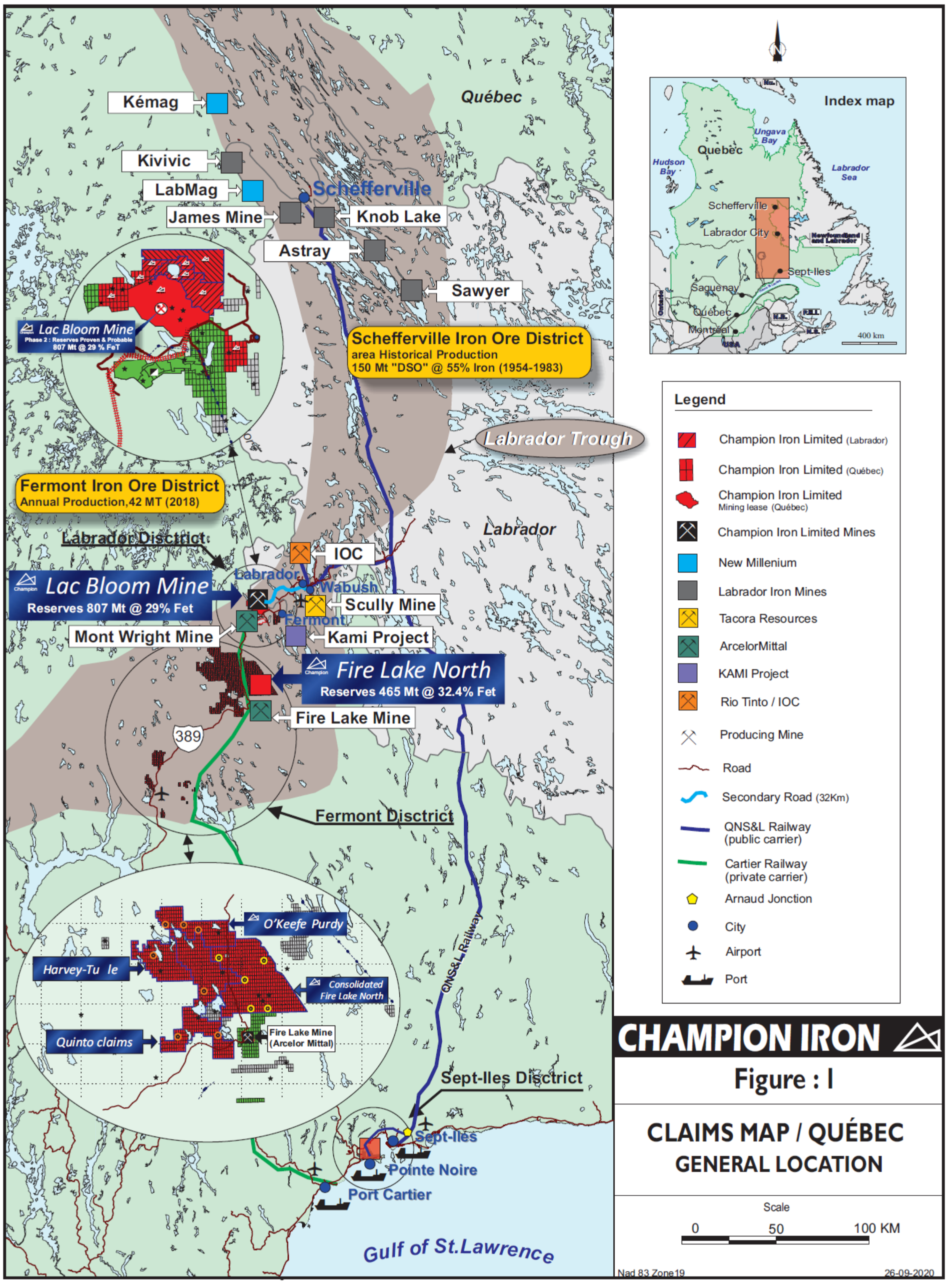


Figure 5.9 Location map of Champion Iron's mines

Source: Champion Iron's website

The Bloom Lake mine was acquired by Champion Iron from Cliffs Natural Resources in 2016 at a price of USD10.5 million. It came on stream in 2018. The mine is approximately 13 km north of Fermont, Quebec, and 10 km north of ArcelorMittal Mining Canada's Mt. Wright iron ore mining site. The Bloom Lake Mine consists of Phase I and Phase II. Phase I mineral reserves are estimated at 411.7 million tons at an average grade of 30%, while the Phase II expansion project

has estimated mineral reserves of 807 million tons at a middle grade of 29%. Despite the low grade, Champion Iron processes low-grade magnetite into a 66.2% high-grade iron ore concentrate through beneficiation, with a capacity of 7.4 million tons per year for Phase I and 15 million tons per year for the Phase II expansion project. Thanks to Bloom Lake's reasonable freshwater reserves and hydroelectric power generation capacity, as well as easy access to marine transportation routes, Bloom Lake's costs are higher than those of other iron ore oligopolies, but still relatively well controlled: Phase I is expected to average CAD 44.62/dmt (C1 cash cost), while Phase II expansion is expected to average CAD 46.6/dmt (C1 cash cost).

Low carbon technology is critical to the iron ore used in steelmaking, with less than 30% of the total iron ore produced each year having an iron grade above 65%, of which only 5% qualifies for direct reduction (DR). The anticipated steel industry transformation will increase the demand for DRI and Champion Iron's iron concentrates, reduce carbon emissions in the blast furnace/converter steelmaking process and enable the production of DR pellets that can participate in the DRI/electric furnace ironmaking process. Therefore, although Champion Iron's costs do not compare favorably with many Australian iron ore miners (in fact, C1 costs reached USD58/ dmt (CAD74/ dmt) in the second quarter of 2022), with market demand for high-grade ore and a significant premium, Champion Iron is not at a significant disadvantage to the iron ore oligarchs. As shown in Figure 5.10, until 2019, Champion Iron has a significant disadvantage due to high costs compared with the profit per ton of the three oligopolies. However, the "Dual Carbon" policy reveals Champion Iron's high-grade iron ore. After 2019, the benefit from the premium price of high-grade ore has turned Champion Iron's profit gap per ton with the giant three oligopolies from negative to positive. It can also be seen from Figure 5.10 that the trend of Champion Iron's PGPTD is the same as that of the PGPT. This means that in the long run, Champion Iron, which produces higher-grade ore, is better than FMG and more worthy of investment than the Big Three.

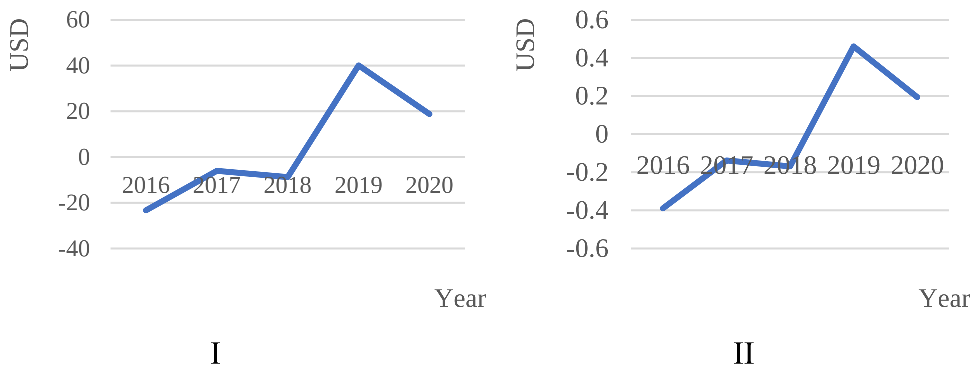


Figure 5.10 Graphical representation of the PGPT(I) and PGPTD(II) of Champion Iron

Champion Iron's financial performance in recent years also shows its better profitability. Champion Iron reported a net profit of AUD575 million in 2021, up 13% year-on-year. For this reason, Champion Iron decided to pay a dividend of 10 Canadian (11 Australian cents) per share in March 2022.

In addition, as shown in Figure 5.9, the Bloom Lake mine and Rio Tinto's IOC mine are in the same region, with similar resource endowments and similar products. That is to say, Champion Iron and IOC are executing similar strategies of supplying high-grade iron ore to meet differentiated demand at the high end of the market, while keeping costs under control. Both have, of course, achieved better financial performance.

5.3 Impact of the price cycle

5.3.1 Price cycle and investment risk

There is a price cycle in iron ore prices. When iron ore prices are high, as in 2021, the vast majority of iron ore miners can earn higher profits and iron ore investments can earn better returns. However, when iron ore prices are in a downward cycle, many iron ore miners will be under extreme pressure to lose money because of low profit per ton, especially those with profit per ton that is substantially below the oligopoly's profit per ton. Over the past 10 years, 62% iron ore prices fell as low as below USD40 per ton at the end of 2015, but topped out at USD200 per ton by 2021. One of the reasons for this is certainly the economic cycle. Over the last 20 years, iron ore prices have gone through 2 price cycles, one of which was the sharp decline that followed the 2002-2011 rise to the bottom in 2016. But then there was a gradual rise to a peak in 2021.

Firms under survey have mentioned the price cycle of iron ore, such as:

BHP-12: This economic cycle brought record annual production for all four commodities and ten business.

VALE S. A-2/3: factors related to the iron ore business and its dependence on the global steel industry, which is cyclical.

RIO TINTO-12: volatile iron ore market leads to large and rapid spot price swings

NORTHLAND-15: the global metals industry is subject to cyclical fluctuations in prices, general economic conditions and end-user markets.

Predatory pricing by oligopolies - even as iron ore prices were falling triggered by reduced demand, several major oligopolies were coincidentally increasing production. A typical example is a continuous decline in the iron ore price index from the first quarter of 2013 to the fourth quarter of 2015, which fell to its lowest point in nearly a decade by December 2015. However, Vale, Rio Tinto, BHP and FMG have increased production and have not maintained iron ore prices by cutting production (as shown in Figure 5.11).

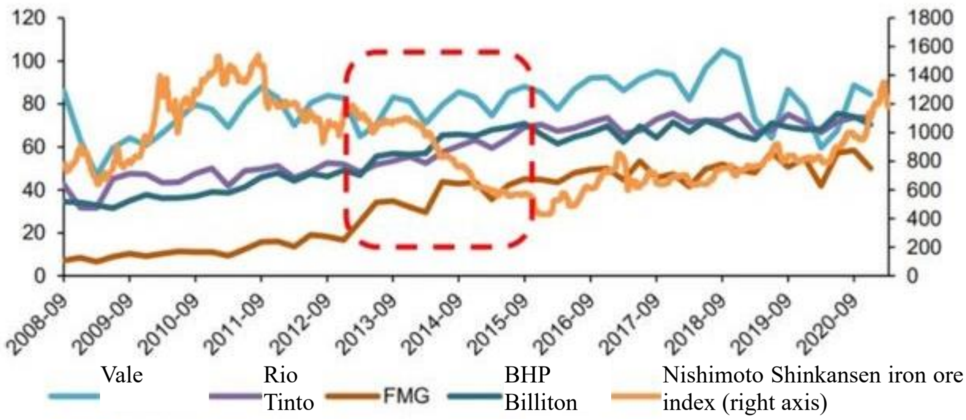


Figure 5.11 Single-quarter iron ore production by iron ore oligopolies (million tons), 2008-2020

Source: https://baijiahao.baidu.com/s?id=1716576493026160563&wfr=spider&for=pc

Many iron ore miners are exposed to greater risk when prices fall sharply:

CHAMPION-8: commodity price risk stems from the volatility of iron ore market prices. The firm is exposed to commodity price risk as its iron ore sales are mainly affected by prevailing market prices.

Perhaps some firms can withstand the risks associated with falling prices, but some firms, especially those that produce ore with low grades, are experiencing greater problems:

ALDERON-17: changes in the market price of iron ore, which has been highly volatile in the past, will affect the expected results of the firm's operations, financial position and cash flows.

ALDERON-17: fluctuations in ore market prices may result in *uneconomical low-grade ores.*

NORTHLAND-15: we forecast that the firm's growth will be primarily affected by the volatility of commodity prices.

NORTHLAND-15: the Board of Directors decided on November 14, 2013 to seek additional funding of up to approximately USD150 million due to lower iron ore prices, increased capital expenditures, disruptions and delays in the production or logistics chain.

Table 5.2 Price cycles and investment risk

Scope	Index	Example
Price cycle	Price volatility	BHP-12: This economic cycle brought record annual production for all four commodities and ten business. VALE S. A-2/3: factors related to the iron ore business and its dependence on the global steel industry, which is cyclical. RIO TINTO-12: volatile iron ore market leads to large and rapid spot price swings NORTHLAND-15: the global metals industry is subject to cyclical fluctuations in prices, general economic conditions and end-user markets.
	Risks	CHAMPION-8: commodity price risk stems from the volatility of iron ore market prices. The firm is exposed to commodity price risk as its iron ore sales are mainly affected by prevailing market prices. ALDERON-17: changes in the market price of iron ore, which has been highly volatile in the past, will affect the expected results of the firm's operations, financial position and cash flows. ALDERON-17: Fluctuations in mineral market prices may lead to uneconomical low-grade ores. NORTHLAND-15: we forecast that the firm's growth will be primarily affected by the volatility of commodity prices. NORTHLAND-15: the Board of Directors decided on November 14, 2013 to seek additional funding of up to approximately USD150 million due to lower iron ore prices, increased capital expenditures, disruptions and delays in the production or logistics chain.

In fact, due to poor operations, both ALDERON and NORTHLAND declared bankruptcy at the price trough in 2014 and 2019. This implies that under an oligopolistic market structure, *oligopolies* can squeeze firms like ALDERON and NORTHLAND out of the market during the iron ore down cycle using predatory pricing.

5.3.2 Alderon Resource case

The history of Alderon Resource (Alderon) vividly illustrates the intense pressure on low-grade iron ore miners during downward price cycles. Alderon is engaged in the *exploration*, development and mining of iron ore properties in the Labrador Trough geological belt in southwestern Newfoundland and Labrador, near the Quebec border. In 2010, Alderon acquired the Kamistiatusset ("Kami") mining rights in the Labrador Trough. The Kami project is located near the North Shore of Quebec and Labrador (QNS & L), southeast of Champion Iron's Bloom Lake mine. The Kami Project is also a magnetite mine, with grades below 30% (as shown in Figure 5.12).

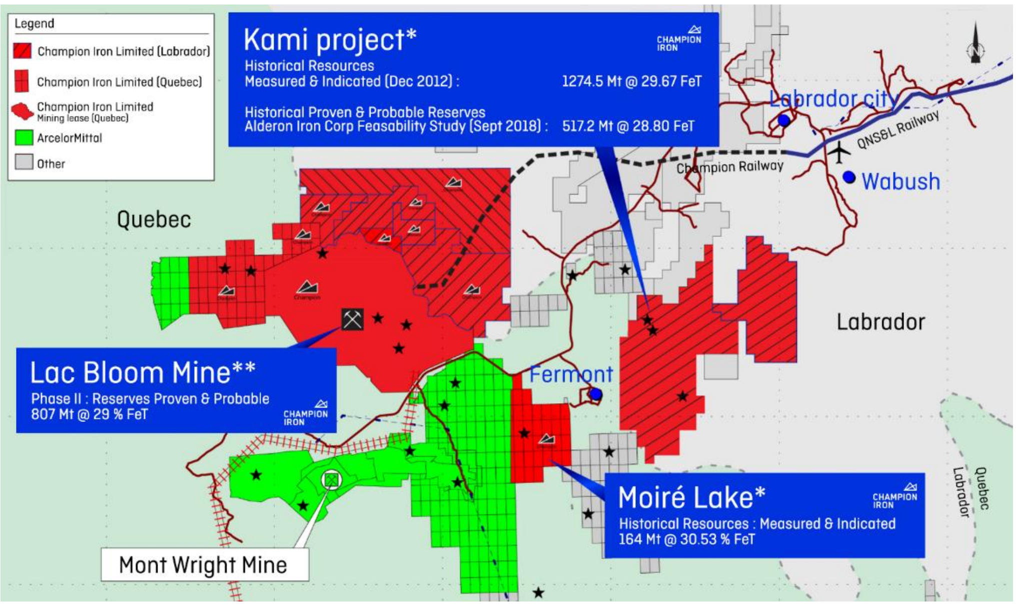


Figure 5.12 Graphical representation of the Kami Project

Source: https://www.championiron.com/project/kamistiatusset/

In response to China's vision to advance carbon reduction in the future, Alderon planned to concentrate the low-grade magnetite ore from the Kami project to obtain a 65.2% iron ore concentrate over a projected 23-year mine life, producing an average of 7.84 million tons of iron ore concentrate per year. However, the Kami project never came on stream. Alderon missed its goals and finally declared bankruptcy in 2020 and sold ownership of the Kami project to Champion Iron.

Why did Champion Iron's Bloom Lake mine succeed while Alderon's Kami project failed in a similar geographic setting? Two reasons are: First, iron ore prices were low from 2014-2020, which is not friendly to new entrants in the iron ore industry like Alderon. Secondly, Alderon was awarded the Kami project in 2010, when there was not much pressure to reduce emissions in the steel industry and the market demand for high-grade ore was not strong, which resulted in a smaller premium for high-grade ore. However, the cost pressures on Alderon were much higher than the iron ore oligopolies, so the mine received limited investment. In the end, Alderon sold the Kami iron ore project after being unable to repay a USD14 million loan. In contrast, shortly after the Bloom Lake mine came on stream, China imposed more stringent policies to promote carbon reduction. The demand for higher grade ore increased significantly, fueling Champion Iron's success.

5.4 Summary

This chapter utilizes a case study approach to develop theoretical propositions and further construct an integrated theoretical model based on the secondary data collected. The study results show that high-grade iron ore can improve blast furnace productivity, reduce the coke ratio and increase steel production and energy consumption and carbon emissions in the steel-making process. Under the carbon emission reduction policy, the market demand structure has changed in the long term, i.e., the market demand for high-grade ore has increased significantly and thus determines that high-grade ore receives a considerable premium. At the same time, there is a discount for low-grade ore. On this basis, we construct a theoretical model of iron ore miners based on grade, market structure and price cycles, which reveals to us the mechanism of determining the value of iron ore miners (as shown in Figure 5.13). The research in this chapter shows that, at the micro level, an examination of the investment value of iron ore miners must take into account the grade of the ore they produce, as well as the effects of market structure and price cycles. The iron ore grade determines the profit per ton(degree) of an iron ore miner by affecting the premium/discount rate and operating costs. In an oligopolistic market, the impact of profit per ton(degree) on corporate value is also subject to the market structure and price cycles at both ends of the oligopoly: if profit per ton(degree) and the oligopoly have an advantage, even if prices fall significantly, the firm can still withstand the risk posed by falling prices and build a long-term competitive advantage in the long run.

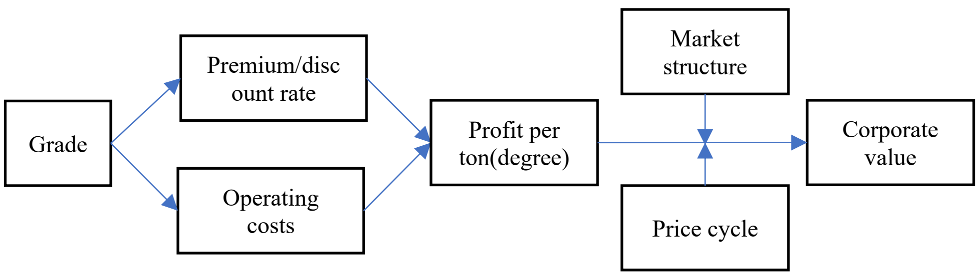


Figure 5.13 Relationship between iron ore grade and corporate value in an oligopolistic market

6 Conclusions, implications and shortcomings

6.1 Conclusions

With rapid economic growth, China has long been the world's largest steel producer and iron ore importer. Strong demand had kept the price of iron ore high for a long time, such as in 2021, when the futures price of 62% grade iron ore exceeded USD200 per ton in record time. Iron ore prices declined in 2022, but the 62% grade iron ore futures price was still above USD100 per ton. Against this backdrop, many funds are flocking to the iron ore sector in search of suitable investment targets. Using a combination of both qualitative and quantitative methods, we delve into the internal logic that determines the investment value of iron ore miners and draws the following conclusions:

1. The "Dual Carbon" policy has a decisive influence on the change in the iron ore market: high-grade iron ore can improve blast furnace productivity, reduce coke ratio, increase steel production and reduce energy consumption and carbon emissions in the steelmaking process. The demand for high-grade iron ore continues to grow, and this change is structural and long-term. This change in demand will result in a significant premium for high-grade iron ore and a discount for low-grade ore. According to the ISTA model-based empirical study, the "Dual Carbon" policy expands the premium of high-grade ore and the discount of low-grade ore. In other words, the advantage of high-grade mines is more obvious, and the disadvantage of low-grade mines is also more apparent. The forecast based on AR and ARMA model also indicates that the premium of 65% iron ore will gradually become larger and converge to 0.2 in the future. In contrast, the discount of 58% iron ore will also gradually expand and converge to -0.15.

2. The new logic that iron ore grade determines the value of iron ore miners: the high investment value of iron ore miners requires a higher profit per ton(degree) of ore. On the one hand, the grade determines the premium/discount rate of iron ore, and thus the firm’s revenue; on the other hand, low-grade ore requires beneficiation, which has a significant cost. Therefore, the ore grade further acts on the investment value of the firm by affecting the profit per ton(degree), i.e., the investment value of an iron ore miner is a function of the grade of the iron ore it produces.

3. The behavior of monopolistic oligarchs determines the long-term competitive advantage of iron ore miners: the iron ore market is a typical oligopolistic market, where oligarchs can use their cost advantages to squeeze out low-grade and high-operating-cost firms from the market at the low point of the price cycle through predatory pricing, so the investment value of iron ore miners needs to focus not only on their grade and operating costs, but also on the difference between their grade and oligarchs' grade and operating costs.

Figure 6.1 can visualize the results of the above study. This study’s conclusion implies that, in the context of the "Dual Carbon" policy, the advantages of high-grade iron ore will continue to expand. In contrast, the disadvantages of low-grade iron ore will become more and more obvious. Therefore, iron ore miners should focus on the cost and also on the grade of iron ore and the grade difference between them and the oligopolies: in the long run, iron ore miners will only be able to establish a long-term competitive advantage if they have an advantage in profit per ton(degree) compared with the oligopolies.

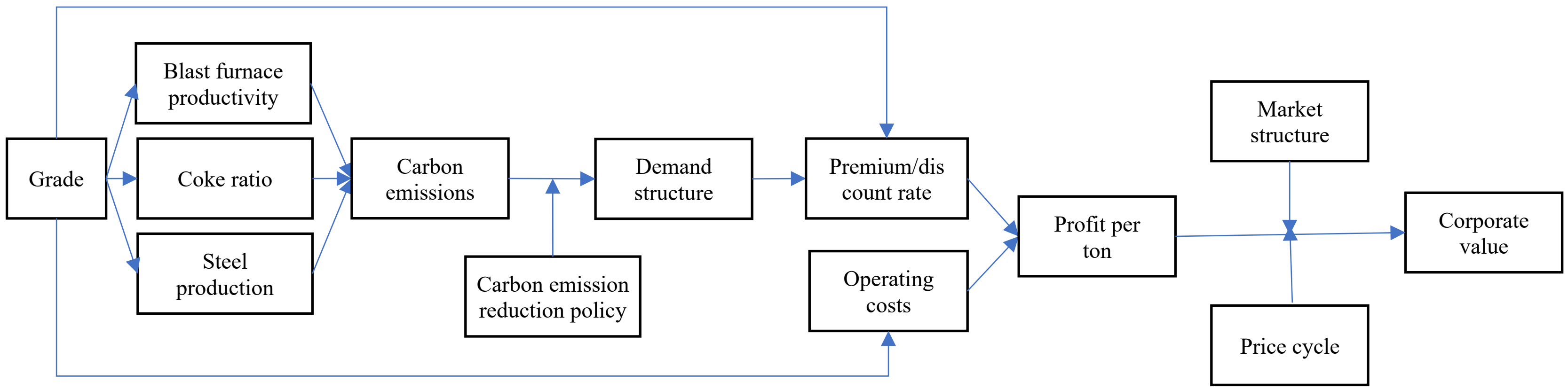


Figure 6.1 Relationship between iron ore grade and the investment value of firms in the context of "Dual Carbon"

6.2 Implications

With the high iron ore prices, many investments in Rio Tinto, FMG and other firms have obtained significant gains. However, we can also see that many of China's overseas iron ore investments have not turned out as well as expected. For example, CITIC Pacific's investment in Sino-Australia's SINO iron ore project and Ansteel's investment in the Carrara mine have not been profitable in the long run. Still, they have instead been the main culprits in dragging down the parent firm's financial performance. This study discusses in depth the logic of investment value determination of iron ore miners in the context of "Dual Carbon", which is an essential insight for us to find quality iron ore miners and avoid investment risks in the current and future periods.

6.2.1 Changing the investment logic of iron ore miners

Traditional mineral economics suggests that iron ore is a standard product; the competitive advantage for iron ore miners is mainly low cost. This means that cost control is extremely important for iron ore miners - whoever has low prices will be able to compete in the market. Economies of scale are an important way to reach a low-cost strategy, leading to larger monopolies having lower costs and thus the ability to drive competitors out of the market by driving down prices. Many iron ore miners, such as FMG and Rio Tinto, emphasize their cost advantage to attract investors' attention. However, the logic of value determination for iron ore miners has continued to change significantly in the context of the ongoing "Dual Carbon" policy: a significant premium has emerged for high-grade iron ore and, as the "Dual Carbon" policy continues to advance, the price gap between low-grade and high-grade ore is widening.

In this new dynamic, some iron ore miners will offer high-grade ore to the market to achieve product differentiation. While cost leaders serve the typical customer base in the industry, a differentiation strategy is an integrated set of actions to produce products and provide services (at an acceptable cost) in a way that customers find important (Hitt & Ireland, 2021). Certainly, iron ore miners should produce differentiated products at a competitive cost to reduce the pressure on customers from rising prices of high-grade ore. This means that the investment logic for iron ore miners has shifted from a pure emphasis on cost leadership strategy to an overall cost leadership/differentiation strategy over the coming period.

Under the new investment logic, we will have to focus on three factors when selecting targets: cost, grade and the profit per ton determined by cost and grade. For some lower-grade iron ore, as long as the cost is low enough, it is still worth investing. At the same time, if the cost is not low enough, the ore produced by the target must be of high enough grade. Of course, given that iron ore is an oligopolistic market, the oligarchs have the market power to squeeze out those firms with high costs and not high enough grades through predatory pricing. Therefore, when evaluating the profit per ton of the underlying iron ore miner, we must also compare it with the profit per ton of the oligarchs - the target is only worth investing in if it does not have a disproportionate disadvantage in profit per ton compared with the oligarchs.

The investment logic we have developed can be used to evaluate investment targets in the current market and assess the investment value of new iron ore projects. The Simandou deposit in Guinea is the largest undeveloped iron ore deposit in the world with the largest reserves and highest ore grades ever discovered. Simandou blocks 1 and 2 cover an area of 723 square kilometers and have proven high-quality open pit hematite reserves of approximately 5 billion tons, with an overall average ore grade of 65.5% and a CIF cost of USD40-45 per ton. Simandou has higher grades when compared with the big three oligopolies. As high-grade ore does not require beneficiation, there is no significant cost disadvantage for Simandou. Simandou's profit per ton is even more advantageous than the giant three oligopolies. This suggests that in the short term, Simandou is worth investing in. Moreover, in the long time, the continuous promotion of the "Dual Carbon" policy will further enhance the investment value of Simandou.

6.2.2 Overseas iron ore investment prioritizes local processing

As a result of the "Dual Carbon" policy, in recent years, not only the high-grade ore has a high premium, but also the iron ore processed into concentrate powder and DRI are also very popular in the market. Direct reduction is the basis of steel production's short process (compact process). The market respects the short process because it does not use coking coal, has low energy consumption, low investment per unit of capacity, short construction cycle, and low impact on the environment, etc. It is the direction of the development of the steel industry. DRI has three grades, namely Grade A (FeM minimum 81%), Grade B (FeM range 78-80%), and Grade C (FeM range <78%). Grade A (minimum 81% FeM) dominates the global DRI market. In addition to contributing to carbon reduction, DRI helps steel manufacturers produce high-quality steel products. In recent years, the DRI price in the international market has been rising and has a promising future.

For China's overseas iron ore investments, priority may be given to processing iron ore in the investing country - processing low-grade ore into high-grade refined iron powder, and further processing the refined iron powder into DRI where available. Taking Simandou as an example, the establishment of a DRI production line in Guinea will, on the one hand, help reduce costs and increase the added value of the product and on the other hand, help significantly reduce the pressure on the Chinese steel industry to reduce carbon emissions. At the same time, this solution also helps promote local economic and social development: the establishment of an integrated production system of ore production, processing, iron making, steel making, steel products and deep processing of steel helps to improve the local industrial chain, provide jobs, improve the quality of industrial workers, reserve talents for industrial development and continuously promote the industrialization of Guinea.

6.2.3 The oligopoly advantage will be more obvious

Not every iron ore mine has Simandou's grade and cost advantages. As mentioned earlier, most high-grade mines in the world are already monopolized by the three major oligopolies. The oligopolies monopolize the high-grade ores, resulting in only the mines producing low-grade ores being sold to Chinese firms. Moreover, after years of accumulation, the oligarchs have strong financial and technical strength to realize large-scale modernized mining and have powerful cost control ability. As a result, the oligarchs have a high profit per ton(degree). This high profit per ton(degree) helps the oligarchs drive their competitors out of the market through predatory pricing.

More importantly, China's dependence on imported iron ore has long been over 80%, and it spends a lot of foreign currency to import it every year. The importance of iron and steel to national security cannot be overstated, and

China's Ministry of Natural Resources has classified iron ore as a strategic mineral. In recent years, diplomatic disputes have arisen between China and iron ore-producing countries such as Australia and Canada. Due to geopolitical reasons, iron ore has become a sore point threatening China's strategic resource security. However, China's "Dual Carbon" policy has expanded the demand for high-grade ores, thus indirectly enhancing the competitive advantage of the oligopolies with high-grade mines. Especially in the downward iron ore price cycle, the oligopolies will easily squeeze out rivals from the market. Taking Chinese iron ore miners as an example, the cash cost of these firms is basically around USD80/ton. If iron ore prices fall below the cost of Chinese iron ore miners in the future, they will have to face severe cost pressure even if they have policy advantages. However, at this time, the oligarchs can still obtain higher profits by their grade and cost advantages, and they increase production instead to make up for the loss of profits due to the price drop, and force Chinese iron ore miners to stop production or even go bankrupt by continuously reducing prices. As a result, the oligarchs' monopoly position was consolidated and market power was strengthened. Finally, China, as the largest importer of iron ore, will further lose its right to speak, which will negatively impact the development of China's steel industry.

Of course, since the "Dual Carbon" policy has consolidated and enhanced the advantages of the oligarchs, investing in the oligarchs is an advantageous strategy from an investment point of view when no suitable target is found.

6.2.4 Counter-cyclical operation is an important tool for long-term investment

As already shown, iron ore prices are relatively influenced by the economic cycle and thus form cyclical fluctuations. Many investors wish to operate pro-cyclically, i.e., to invest more in iron ore miners during economic boom and iron ore price rise cycles, and to withdraw during recession and iron ore price fall cycles. In this case, pro-cyclicality will help up when it goes up and helping down when it goes down.

However, pro-cyclical operations also have a demerit. When a recession hits, investors may be unable to withdraw their investments added during the boom in time and therefore incur huge losses. Therefore, some investors tend to invest counter-cyclically, i.e., avoiding a significant increase in fixed asset investment, equity investment, and significant expansion of business scale, etc. during the boom period; instead, increasing fixed asset investment, purchasing equity, and expanding business scale, etc., against the trend during the recession period due to the significant decline in fixed asset and equity prices.

In practice, many successful investors often operate counter-cyclically. That is to say, sell when people are buying feverishly and buy substantially when everyone is trying to sell. Warren E. Buffett is considered a successful master of counter-cyclical operations. For example, when the U.S. stock market rose sharply in 1972, Buffett dumped a lot of stocks, keeping only 16% of the money invested in stocks and investing 84% of the money in bonds. But Buffett started buying heavily when everyone sold stocks by 1974, when the Dow Jones fell from 1,000 to 580. The steel industry also has many examples of successful counter-cyclical operations. Steel king Lakshmi Mittal built Arcelor Mittal, the world's largest steel firm, by merging small endangered mills 136 times and acquiring large world-class firms twice. Mittal did not make large-scale asset acquisitions at industry peaks. It instead used, during industry downturns, undervalued assets to mobilize all its reserve resources to make large-scale M&A investments, thus reducing asset costs, improving asset efficiency and laying the foundation for lucrative profits and capital market returns at the next peak.

However, none of these counter-cyclical operations address how to judge counter-cyclical operations' timing. Based on the findings of this study, while it is difficult to determine the market high, we can determine the low point at the price fall. When the price of iron ore falls to the point where the oligarchs' profit per ton(degree) is zero, the oligarchs will pull up the price by controlling the market. The judgment of the counter-cyclical investment point is essentially based on a comprehensive assessment of the oligarchs' market profit per ton(degree).

6.2 Shortcomings

There are still certain shortcomings in this study.

(1) The analytical information needs to be further expanded. All data and information in this study are from secondary sources including news reports, research reports and annual reports. Secondary information helps collect at a low cost and allows us to obtain information on major iron ore miners relatively easily. However, these sources still have some important drawbacks, such as poor timeliness and accuracy. More importantly, these sources are often collected and written by the original information producers for specific purposes. To express certain ideas of the original authors, these secondary sources may be inherently biased or intentionally conceal important information, which may interfere with the analysis of this study.

(2) The analysis method needs to be further enriched. Although this study

constructs the logic of determining the investment value of iron ore miners through a case study, it is still a qualitative study. In the theoretical logic constructed in this study, we can see the relationships between multiple variables. For these relationships, it remains to collect large sample data for empirical testing in the future.

(3) The variety of analyses needs to be further expanded. The characteristics of many resource-based industries are consistent with iron ore, such as copper, aluminum, coking coal, oil, natural gas, monocrystalline silicon, polysilicon, etc. This study does not make clear whether our conclusions can also be applied to the above resource-based industries. If applicable, do they require some corrections to the existing conclusions? Further depth of subsequent studies is needed for these questions.

(4) Influencing factors need to be further added. There are many factors affecting the investment value of a firm. Limited by space and personal ability, this study only focuses on the impact of iron ore grade in the context of the "Dual Carbon" policy. Other factors, such as macroeconomic situation and micro-level characteristics of firms, are not covered much in this study. To expand the depth and breadth of the study, we still need to further explore other essential factors that affect the investment value of iron ore miners.

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