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Dynamic Determinants in Global Iron Ore Supply Chain

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Abstract. The major downturn of the steel industry has given rise to significant changes in iron ore supply chains. As a result of the slowdown in the growth of steel production in China the demand for iron ore has decline and has given rise to major shifts in iron ore production on a global scale. This raises a series of key issues. How is the iron ore market evolving? How are these changes transforming the global iron ore supply chain? Above all, how is this impacting on ports and transportation infrastructures? The objective of the paper is to provide a descriptive synthesis of the various determinants of global iron ore supply chain based on extensive bibliographical search. It presents many aspects of this market investigation such as the production volumes of steel and iron ore, their evolution, the geographical distribution, the main actors, import and export flows. Our analysis reveals the interrelationship between several determinants of the iron ore supply chain: corporate structure, quality iron ores, contract design, inventory management, shipping costs, ocean freight rates and transportation infrastructure. This allows assessment of supply chain vulnerability in terms of production risks, transportation capacity, commercial conditions and environmental hazards.

Keywords: Iron ore market, supply chain, transport infrastructure.

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1. THE IRON ORE INDUSTRY

1.1. Iron ore supply

Iron ore accounts for 5% of the earth's crust, of which only a small part is concentrated in rich deposits. The grade of iron ore deposits varies from 20-30% for poorer sources to as much as 60-70% for the higher-grade deposits. World reserves of iron ore are estimated at 170 billion tons containing 81 billion tons of iron content. There is no likely shortage in the foreseeable future. Iron ore is not a homogenous commodity having specific chemical and metallurgical properties affecting iron ore price in terms of metal unit (Fe) contained in the ore. Usable ore includes lump ore, fines, concentrates and agglomerates (i.e. pellets, sinter, and briquettes). Australia holds the world's largest reserves of iron ore with 35 billion tons followed by Brazil and Russia with 31 billion tons and 25 billion tons respectively (Table 1).

Table 1. Global iron ore reserve, 2013

Country	Crude ore (Mt)	Iron content (Mt)
Australia	35 000	17 000
Brazil	31 000	16 000
Russia	25 000	14 000
China	23 000	7 200
India	8 100	5 200
United States	6 900	2 100
Ukraine	6 500	2 300
Canada	6 300	2 300
Venezuela	4 000	2 400
Sweden	3 500	2 200
Iran	2 500	1 400
Kazakhstan	2 500	900
South Africa	1 000	650
Other countries	14 000	7 100
World total	170 000	81 000

Source: U.S. Geological Survey, 2014

In 2013, global iron ore production is estimated at 1 928 million tons as compared to 1 255 million tons in 2004 – an average annual growth rate of 4,8%. The world's main producers of iron ore are Australia Brazil and China (Table 2). Their combined output accounts for 64% of world production. China's total production amounts to 269 million tons, but includes low grade ore that is entirely used for domestic steel production.

Table 2. Global iron ore production and exports, 2013

Country	Production		Exports	
	Thousand tons	**% of total**	**Thousand tons**	**% of total**
Australia	608 900	31,57	613 379	45,80
Brazil	364 030	18,88	329 639	24,62
China	269 200	13,96	0	0,00
India	136 100	7,06	14 426	1,08
Russia	102 497	5,31	25 580	1,91
Ukraine	83 696	4,34	37 986	2,84
South Africa	60 600	3,14	62 763	4,69
United States	52 000	2,70	11 041	0,82
Canada	41 841	2,17	38 023	2,84
Sweden	27 230	1,41	23 217	1,73
Other countries	182 516	9,46	183 113	13,67
World Total	1 928 610	100,00	1 339 167	100,0

Source: World Steel Association, 2014

1.2. Global iron ore demand

The percentage of world iron ore production traded internationally has risen from 682 million tons in 2004 to 1 339 million tons in 2013 – an average annual growth rate of 7,7%. Australia and Brazil are the largest iron ore exporters with 70% of global market share.

The volume of iron ore export of other countries is relatively low in comparison. A substantial share of the iron ore production of India, Russia and United States is used for domestic steel production (Jorgenson & Kirk, 2003)

The demand for iron ore is closely related to the world steel industry accounting for 98% of world iron ore consumption (Michaelis & Jackson, 2000a; 2000b). World growth of iron ore and steel generally expands and contracts in line with world economic growth (Priovolos, 1987; Labson, 1997). The main sectors of steel consumption are the construction sector notably non-residential and public works, the automotive sector and industrial equipment. The world has seen a dramatic development in steel production over the past years. World crude steel production reached 1,5 billion tons in 2013, compared to 848 million tons produced in 2000 – an average annual growth rate of 5%.

Asia produces 1,114 million tons of crude steel. This amounts to 83% of world production resulting in high demand for iron ore from these countries. On the demand side, Chinese steel makers dominate the market for iron ore (Toweh & Newcomb, 1991; Tcha & Wright, 1999). China imports 820 million tons of iron ore. This represents over 60% of world total (Table 3). Analysis of iron ore production and trade clearly indicates that the future of iron ore will depend on the growth of iron ore consumption in China through the country's presence in overseas joint ventures and surge in iron ore imports. China is driving global demand for ore primarily for infrastructure projects. China is the main engine of world steel production. China's steel production is estimated at 779 million tons in 2013 accounting for 49% of the world market share. Japan produces 110 million tons of steel, and imports 135 million tons of iron ore. Other countries of Asia, namely South Korea and Taiwan produce 169 million tons of crude steel relying on iron ore seaborne imports of 158 million tons. Crude steel production of the European Union amounts to 165 million tons. This volume is supported though the import of 157 million tons of iron ore. East Asia and the European Union account for 95% of seaborne iron ore imports.

Table 3. World steel production, 2013

Country	Crude steel production (thousand tons)	% of world total	Iron ore imports (Mt)	% of world total
China	779 040	49,23	820,1	61,25
Japan	110 570	6,99	135,9	10,15
Other Asia	169 541	10,71	158,9	11,87
European Union (27)	165 601	10,47	157,1	11,73
Other Europe	36 606	2,31	8,6	0,64
CIS	108 741	6,87	3,8	0,28
NAFTA	117 835	7,45	10,3	0,77
Other America	47 324	2,99	12,8	0,96
Africa and Middle East	41 575	2,63	30,4	2,27
Oceania	5 545	0,35	1,1	0,08
World total	1 582 378	100,0	1 339,0	100,0

Source: World Steel Association, 2014

In 2013, the total seaborne iron shipments amounted to nearly 1 billion tons, generating more than 4,5 trillion tonne-miles in ocean transport with East Asia and Europe being the main market destination. This trade also reflects transportation costs. Steel producers tend to buy iron ore from relatively nearby producers. Australia is the producer leader for ore imports in China, Japan, Taiwan and South Korea. Brazil is the producer leader for iron ore imported into Western Europe. Given the large amounts of steel needed for the rapid growth of East Asia, the ports of Brazil also figure prominently in the iron ore export trade. This long distance transportation creates a need for a large amount of bulk vessels. Very large ore carriers - above 300,000 dwt - are performing well on the itinerary between Brazil and East Asia traveling south of the Cape of Good Hope.

1.3. Key iron ore producers

World trade in iron ore is undertaken by few producers. Vale produces iron ore in Brazil mainly in the Carajas mineral province, state of Para (Vale, 2001-2014). Rio Tinto and BHP Billiton essentially operate in the Pilbara region in north-western Western Australia. The iron ore industry has undergone a massive consolidation over the past 15 years through mergers and acquisitions. North Ltd production is part of Rio Tinto production since 2000 (Rio Tinto, 2001-2014). In 2001, BHP has merged with Billiton while CVRD purchased Ferteco and merged with Caemi (BHP Billiton, 2001-2014). Table 4 reveals that three companies VALE, BHP Billiton and Rio Tinto control more than 43% of the iron ore production with a combined capacity of 1 140 million tons.

Table 4. Largest iron ore producers, 2014

Corporation	Country	Capacity (Mt)	Capacity (%)
Vale group	Brazil	451,7	17,17
Rio Tinto Group	UK	378,7	14,39
BHP Billiton	Australia	310,3	11,79
Fortescue Metals Group	Australia	81,5	3,10
ArcelorMittal Group	UK	79,6	3,03
AnBen group	China	55,7	2,12
Anglo American Group	South Africa	50,8	1,93
Evrazholding Group	Russia	46,4	1,76
Metalloinvest	Russia	46,8	1,78
LKAB Group	Sweden	45,2	1,72
Metinest Holding Group	Ukraine	44,7	1,70
Cliffs Natural Resources	United States	42,9	1,63
CVG Group	Venezuela	40,7	1,55
Shougang Beijing Group	China	37,3	1,42
Mining group	India	37,2	1,41
NMDC Group	India	34,1	1,30
Imidro Group	Iran	32,4	1,23
CSN Group	Brazil	29,2	1,11
US Steel Group	United States	24,6	0,94
Poltavsky	Ukraine	24,3	0,92
Top 20		1 869,6	71,06
World total		2 631,0	100,00

Source: World Steel Association, 2014

Market shares of the three largest companies based on seaborne sold iron ore reveal a market concentration above 70%. This corporate consolidation of the iron ore industry is being strengthened. Vale owns a share of an iron ore pellet plant in China and is expanding its operations in Guinea at Simandou. BHP Billiton is represented in Brazil though Samarco – a joint venture with Vale. Rio Tinto owns Iron ore Company of Canada.

1.4. Key steel producers

Most of the steel makers are connected to these firms and are dependent upon imports for their requirements. Concentration in steel making is less noticeable than in iron ore mining (Lacoste, 2008). The top 20 integrated iron and steel companies have a production capacity of 641 million tons amounting to 40% of world crude steel production (Table 5). Asian economies have embarked into investment decisions of large domestic steel expansion projects that can exploit relatively cheap labour to produce lower cost steel in order to keep pace with soaring internal demand (Crompton & Lesourd, 2008). Adequate supply of ore is secured through long-term contracts or joint ventures.

The South Korean firm Pohang Iron and Steel Co. owns 20% share of the BHP Billiton's Mining Area C (MAC) province in Western Australia. JFE Steel Corp. (Japan) has consolidated its presence in iron ore supply though a partnership with CRRD in the development of Fabrica Nova Mine located in the state of Minas Gerais, Brazil. China's Shanghai Baosteel Group has entered in a joint venture with Hamersley Iron Pty for the exploitation of a new iron ore deposit near Paraburdoo.

Table 5. Largest steel producing corporations, 2013

Corporation	Country	Tonnage (Mt)	% of world total
ArcelorMittal	Luxembourg	96,1	5,98
Nippon Steel & Sumitomo Metal Corp	Japan	50,1	3,12
Hebei Steel Group	China	45,8	2,85
Baosteel Group	China	43,9	2,73
Wuhan Steel Group	China	39,3	2,45
POSCO	South Korea	38,4	2,39
Shagang Group	China	35,1	2,19
Ansteel Group	China	33,7	2,10
Shougang Group	China	31,5	1,96
JFE	Japan	31,2	1,94
Tata Steel Group	India	25,3	1,58
Shandong Steel Group	China	22,8	1,42
U.S. Steel Corporation	United States	20,4	1,27
Nucor Corporation	United States	20,2	1,26

Tianjin Bohai Steel	China	19,3	1,20
Gerdau	Brazil	19	1,18
Maanshan Steel	China	18,8	1,17
Hyundai Steel	South Korea	17,2	1,07
Benxi Steel	China	16,8	1,05
Evraz Group	Russia	16,1	1,00
Top 20		641	39,91
World Total		1,606	100,00

Source: World Steel Association, 2014

1.5. China steel market

Analysis of China's steel industry reveals several key diagnostic features. First, the prospects for iron ore trade still hinge on assumptions about China's steel industry. Construction accounts for 50% of domestic steel demand. This includes infrastructure construction for highways, railways, bridges, buildings, machines and power stations in line with urbanization growth of 140 cities with more than 1 million inhabitants.

Second, the Chinese steel industry products are concentrated in low value added bulk steel (Ma, *et al*, 2002). Increasing iron ore input costs have not been matched by equivalent steel prices rises.

Third, the Chinese steel industry is composed of selected major groups and numerous small steel mills. There are limited numbers of large iron ore consumers. The steel market in China is composed of a great number of medium and small steel companies. The objective of the central government to rationalize and shut down small capacity steel mills and to develop inter-firm cooperation but this has met with limited success (Movshuk, 2004)

Fourth, the lack of ownership integration among China's steel mills reduces the capacity to negotiate with the main iron ore producers in the context of soaring demand. The creation of a state-backed iron ore import cartel (i.e. China Iron Ore and Steel Association) with the authority to distribute and enforce iron ore import licences has failed to impact on price negotiations or in establishing a benchmark in price determination process and flows (Wilson, 2012). Price is increasingly being aligned with supply and demand balances under a market-based quarterly index system.

Fifth, Chinese companies have been pursuing iron ore projects around the world with a view to control more of their raw material sources. Chinese companies are increasingly present in mining projects through investments abroad notably in Africa and South

America. This strategy is being met by the main iron ore producers committing expansion plans to limit the bargaining power of the Chinese entrants in mining operations.

Sixth, the surge in new blast furnaces that has increased steel mills' capacity has created unprecedented iron ore consumption growth (Biesheuvel, & Riseborough, 2014). In the absence of sufficient domestic growth, especially a decline in the real estate market, Chinese mills need to address the domestic surplus capacity through steel exports. China is currently the world's largest steel exporter with over 61 million tons of steel exports (Table 6).

Table 6. China steel imports and exports, 2000-2013 (Thousand tons)

Year	Imports	Exports
2000	20 710	11 159
2001	25 636	7 487
2002	29 287	6 642
2003	43 197	8 481
2004	33 221	20 074
2005	27 312	27 414
2006	19 105	51 706
2007	17 185	66 357
2008	15 622	56 304
2009	22 350	23 969
2010	17 181	41 646
2011	16 349	47 899
2012	14 154	54 793
2013	14 774	61 543

Source: World Steel Association, 2014

International trade of iron ore is changing with the increase of steel-making capacity in countries without domestic supplies of iron ore. Projections of iron ore needs and steel production suggest significant relocations of steel making plants to emerging economies in the Middle East, Sub-Saharan Africa and Turkey with concomitant geographical shifts in iron ore resource demands. In sharp contrast, the consumption of iron ore in the industrial countries is decreasing. The analysis demonstrates that the market displays various possibilities in using alternative sources of supply of iron ore on different continents. In addition, the potential of using alternative routes for transport is rendering the markets less sensitive to external shocks over time.

2. IRON ORE SUPPLY CHAIN

The structure of iron ore supply chain is underpinned by the interrelationship between several components: corporate structure, high quality iron ores, pricing system, contract design, inventory management, shipping costs, ocean freight rates and transportation infrastructure.

2.1. Corporate ownership

Exploration for new high quality iron ore reserves sufficiently large enough to sustain competition on the world market is very expensive. Ore exploration, mining operation, construction of transportation infrastructure facilities require mineral rights and licenses that have to be negotiated with relevant governments, a process taking several years (Warell & Lundmark, 2008). There are very few newcomers on the iron ore market. New findings of large and high quality iron ore deposits belong to existing main iron ore producers.

The enormous start-up costs associated with new mine development require sustainable and increase output. This gives a strong impetus for establishing joint ventures between producers and the steel industry in obtaining finance for new iron ore mining development. Mines in Australia and Brazil have a large element of foreign ownership (Jones, 1986; Schmitz Jr. & Teixeira, 2008). In 1970, 30% of iron ore purchases were supplied from captive mines. This increased to 80% in 1980. Some iron ore producers are owned by steel companies. ArcelorMittal is securing its raw material requirements through owned mines (ArcelorMittal, 2013). The withdrawal of North American steel companies in iron ore mines ownership is altering the structure of the industry and the flow of iron ore. Therefore, in recessionary conditions, new mining projects are being curtailed and old mines are call upon to support the downward trends in tonnage demand.

2.2. Iron ore quality

Relationship between supply and demand of iron ore remains a bilateral oligopolistic market with few producers selling ore to relatively few buyers. Producing regions tend to limit blending requirements and reduce the number of basic ore products. The objective is to supply a more concentrated product to reduce transportation costs. In sharp contrast, iron ore buyers are developing a portfolio of multiple site operations. Steel companies have focussed their demands on iron ore products with specific characteristics to maximise productivity.

There are two major processes for producing steel from iron ores and scrap. Basic oxygen steelmaking (BOF) which uses carbon-rich molten pig iron and scrap steel as feed materials; and electric arc furnace steelmaking (EAF), which uses direct reduced iron (DRI) or scrap steel as the main feed materials. Table 7 indicates that basic oxygen steelmaking (BOF) accounts for 71% of world steel production, 82% of energy consumption and 88% of CO_2 emissions.

Table 7. Production, energy consumption and CO_2 emissions of steel making

Steel making process	Production (%)	Energy consumption (%)	CO_2 emissions (%)
Basic oxygen	71	82	88
Electric arc furnace (scrap)	24	11	8
Electric arc furnace/ direct reduction iron (gas)	4	4	3
Electric arc furnace/ direct reduction iron (coal)	1	2	2

Note: Percentage do not add due to rounding
Source: Laplace Conseil, 2013

The competitiveness of the steel industry is increasingly tied to reducing energy consumption and CO_2 emissions (Yellishetty, *et al*, 2010; 2011). The replacement of basic oxygen process (BOF) by electric arc furnace (EAF) has proven to be more efficient method of steelmaking in terms of energy savings and concomitant environmental advantages. This is turn is driving demand for ferrous scrap and iron ore pellets.

Steel production can occur at secondary facilities which produce steel from recycled steel scrap. The volume, trade and traffic of iron and steel scrap from dealers, sorters and distributors represent an active and competitive market (Dahlstrom & Ekins, 2006). The rapid development of circular economy, with iron and steel scrap collection and recycling, has become a major industry. Steel scrap is used directly to make steel that is indistinguishable from steel made from virgin pig iron. The net effect is that less iron ore is required for the production of one ton of crude steel. Scrap recycling can offset the use of over 1200 kg of iron ore for a tonne of steel scrap used. When there is not enough recycled steel to meet growing demand, steel production is met with 70-90% of molten iron and 10%-30% steel scrap. Besides, steel produced from primary ore uses two and half times more energy than steel produced from scrap. According to available data, the world's steel scrap has increased by 12% annually from 1950 to 2008. Steel recycling in United States has increased from 66 Mt to 81 Mt for the period 1988 to 2013, an average annual growth rate of 0,8%. There is a correlation between scrap and iron ore consumption and steel production. There is a persistent trend which could be used to forecast iron ore consumption compared with steel production trends. The success of the scrap metals will be determined by the differential cost between retrieving, sorting and processing metals relative to the prices of primary iron ore.

The anticipated increase in steel production is expected to come from electric arc furnace (EAF) as more governments are implementing pollution controls. The need for steelmakers to operate more efficiently and with lower emissions is driving the demand for high quality iron ore. Pellets represent a solution to better control contaminants in steel products. In 2013, the global market for direct reduction pellets amounts to 75 million tons with Asia and the Middle East representing over 60% of world consumption.

This will result in increasing demand for high quality iron ore in the form of uniform quality fines or high grade iron ore pellets with low contaminants (Blanco, 2014; Chaigneau, 2014). In considering steel and iron ore production trends, Table 8 reveals higher average annual growth rate for iron ore pellets.

Table 8. Steel and iron ore production trends, 2015-2022 (Mt)

	2015	**2018**	**2020**	**2022**	**AAGR (%)**
Crude steel	1 681	1 815	1 908	2 004	2,5
Iron ore	2 100	2 262	2 374	2 479	2,4
Of which:					
Fines	1 485	1 589	1 660	1 725	2,1
Lump	252	265	273	280	1,5
Pellets	363	408	441	474	3,9

Source: Dempsey NMI, 2015

This trend should benefit high quality iron ore producers in terms of magnetite content, low phosphorus and low alumina.

2.3. Iron ore price

It is important to underline that there are different quality of ore and these characteristics affect price. Historic data illustrates the relationship between iron ore price and ore characterization. Iron ore fines has fluctuated from 130$/ton to 70$/ton, while iron ore pellets is commanding a higher price and fluctuates within a narrow range.

Since 2010, iron ore producer prices have decreased substantially. Future scenarios on iron ore price will be influenced by additional low cost iron ore supply from Australia and the capacity of Brazil to compete in the supply balance by forcing out higher cost producers. Prices should continue to fall if other producers are cutting their output (Brooks, 2014). Alternatively, downside price pressure is likely to continue.

There are complex set of conditions underpinning the pricing system of iron ore. The most important driver is the difference in iron ore contracts. Sukugawa (2010) has demonstrated that iron ore pricing system is moving towards shorter-price agreements.

2.4. Contract design and pricing

Iron ore can be sold under long-term contract or spot or short-term delivery contracts (Faria, 1991). Long term contracts account for more than half the world’s iron ore trade. Long term contracts establish quantitative sales and purchase obligation for duration between three and five years with wider tonnage option and possible price adjustment on parts of the contracted tonnage. Other clauses include quality specification and delivery schedule. The prices are generally negotiated annually between the major iron ore and steel producers in dominating ocean basin regions: Europe/Brazil in the Atlantic Basin and East Asia/Australia in the Pacific Basin. Prices settlement serves as a benchmark for global sales.

Annual contracts and spot sales pertain to purchase that cannot be met from buyers own resources or long-term contracts and are highly correlated with changes in prevailing economic activity. They account for approximately 30% of supply arrangements. The balance represents sales from captive mines wholly owned or controlled by steel companies.

Variation in contract design is a key element in enduring iron ore supply chain (Rogers, 1980; Rogers & Robertson, 1987). The methods of purchasing requirements of major importers are central to understand the pricing of iron ore. A gradual reduction in the stability provided by the long-term contract has been observed. Steel mills have accepted 60-70% of basic contractual tonnages increasing the tendency towards shorter contract durations. There is increasing level of independence in securing agreement on iron ore price. Traditionally the main corporate producers have been price setters.

But there are major differences in prices agreed by companies leading to difficulties in normalizing pricing benchmark negotiations. Vale and BHP Billiton have announced that they are adopting a quarterly pricing system. The new prices are based on a three-month average of price indexes ending one month before the start of the new quarter. This strategy allows aligning new prices with the movements in the spot market.

The analysis of iron ore contract design suggests differences between Pacific and Atlantic-based trade (Chang, 1994). Prices in the two markets are linked to the role of Brazil production that supplies steel mills in the two hemispheres thus acting as a price transmission mechanism.

2.5. Inventory control and management

Iron ore logistics is the control of inventory in relation to general economic activity level with a view to minimize costs and maximize services of iron ore movement. The movement of iron ore is a derived demand. The level of service to be given along the transportation chain cannot be predetermined. Suppliers who trade iron ore must be prepared to have storage facilities where iron ore can be handled and ship into the consignments of the size required by the customer. Continuous availability of iron ore is a precondition to satisfy market economy production. Receivers attempt to secure reliable transport services with a view to permit inbound transport to be directly integrated within the production process, but maintain a certain level of inventories to protect against irregularities in transport performance. Operational efficiency of iron ore logistics is also influenced by stock in transit. Iron ore reserves are required to meet interruption of vessel movements as a result of changes in navigation season. Storage can also be employed for speculating purposes in iron ore commodity markets where price changes may be anticipated and storage costs can be offset against future price gains. China, the largest iron ore importer, is attempting to become a trend setter in establishing the benchmark price. The evolution of Chinese iron ore port stocks is emerging as an indicator of price settlement. The level is currently fixed at 70 million tons (Fairplay, 2013). Above this volume China would limit its purchase with a view to reduce ore prices.

The core of iron ore business logistics management seeks to balance production capacity of shippers and receivers against inventory (Comtois & Lacoste, 2012). There are three principles governing iron ore inventory management:

- Inventory must be concentrated at strategic points minimizing stock required.
- Stock must be located to minimize small shipment transport costs.
- Level of inventory must permit maximizing sales while minimizing storage costs.

Production and consumption rates are not constant and iron ore availability is not unlimited. For this purpose storage facilities are used and secured at selected points along the transportation chain in relation with maximum stock level capacity, iron ore volume to be shipped/received and the transport mode employed. Vale is answering the challenges because of its distance from markets by opening distribution centres in the Middle-East and Southeast Asia (Blanco, 2014). These distribution centres in Oman, Malaysia and the floating platforms in the Philippines have capacities to stock 30-40 million tons per year.

2.6. Shipping costs

Iron ore only contributes between 10%-15% of the total cost of steel making. Shipping costs form a major component of this high volume sector of the mining industry and could amount to 50% of the landed price of iron ore on some trade routes. There is thus a strong impetus to shipping high-grade ore. Iron ore can be traded on a CFR or FOB basis.

The former case indicates that the price quoted by the supplier includes all expenses to a port of destination. Under this agreement, producers from distant sources have to keep down ore cost in order to compete with producers located closer to consumer markets. This represents a strong impetus to facilitate the entry of exporter into the shipping industry.

For FOB, the producer commits to load the ore on board a vessel designated by the buyer at the port of shipment. The importer is thus in control of the physical provision of shipping. This agreement allows the buyer sufficient flexibility in shipping arrangements to respond to changes in market conditions. Contracted FOB prices are determined in annual negotiations before actual shipments take place. These prices will not be affected by actual volume to be delivered. The shipments could differ from contracted quantities as a result of changes in supply conditions, steel demand and freight rates.

European prices are quoted CFR to European ports while Japan prices are quoted FOB from the mine’s terminal port. The same FOB price everywhere suggests that CFR costs of iron ore at different locations will differ. BHP Billiton has developed long-term alliances with shipping companies while Vale has developed its own fleet. The long-term prospect is the development of a benchmark price combining iron ore price with ocean freight rates.

Mines will collect premiums from mills of greatest proximity. In sharp contrast steel makers located further from the source are in a disadvantaged position. A seller’s market prevails when iron ore price is lower than FOB price. A buyer’s market is obtained for producers with higher iron ore supply price than quoted FOB price.

Deliveries of iron ore from Australia and Brazil to the remote mills in Europe and Asia respectively are sold at a discount. The iron ore producers are absorbing transport costs to reach more distant buyers. The premiums of Australian and Brazilian producers are obtained from mills of close proximity where they have comparative advantages.

2.7. Ocean freight rates

Iron ore production sites are often located far from demand locations. The maritime transport of iron ore is inevitable as it offers the lowest cost per ton-miles. Consumption centres own/charter ships or outsource to 3PLs/4PLs. The work on iron ore shipping logistics involving ship routing and scheduling is confronted with various conditions:

- The company assigns ships to meet customer orders, but the fleet is composed of ships varying in capacity and operating costs.
- The nature of the iron ore affects the maximum stowage capacity.
- Dry bulkers do not have fixed itineraries. A ship may call at a single production port, be loaded with specific volume of ore followed by a call at specific consumption port to be unloaded.
- The terms and conditions of freight rates for carrying iron ore cargo are negotiated between shippers and carriers in relation to demand and supply of bulk shipping services. Freight rates determine the decision of bulk carriers in adjusting fleet size.
- A ship can load or discharge only one material at a time and the limited number of jetties at each port imposes ship sequence for iron ore loading and unloading.

There is considerable diversity in the bulk vessel fleet. In part this reflects the wide range of cargoes carried. The nature of these different commodities and the markets involved give rise to different demands for bulk vessels, and has produced a range of vessel types. The smallest class of bulk ship is the Handysize (10,000 – 59,999 dwt capacity). Panamax ships are between 60,000 and 99,999 dwt. Capesize is a broad class of very large dry bulk carriers that range in size from 100,000 dwt up to 250,000 dwt (Table 9).

Table 9. Deadweight tonnage by classes of bulk vessels, 2014

Ship types	Dead weight tons	% of world bulk fleet
Capesize	100 000 +	15,8
Panamax	65 000 – 100 000	23,8
Supramax	40 000 - 65 000	30
Handysize	10 000 – 40 000	30

Source: Clarkson, 2014

A major contributing factor is the seaborne transportation cost. Larger trade volumes and bigger individual shipments reduce unit transport costs. The technological improvements in shipping as expressed by economies of scale are highly significant. The maritime trade of iron ore is extremely dependent on larger vessels. The vast majority of iron ore is being transported by Capesize vessels (Lundgren, 1996). The share of iron ore trade carried by vessels larger than 100,000 dwt accounts for approximately 70% of ocean trade. Only 5% of the iron ore is transported by vessels smaller than 40,000 dwt. The transportation savings enables both Australia and Brazil to compete in European and East Asian markets respectively.

The major part of iron ore traffic is concentrated along selected mainline ocean routes. Earnings of each route are calculated by taking the total revenue, deducting current bunker costs based on process at regional bunker ports, estimated port costs and then dividing the results by the number of voyage days (Alderton, & Rowlinson, 2010; Hoffmann & Kumar, 2010). A Capesize vessel is estimated to undertake 7 round-trips per year as compare to 10 for a Panamax ship. An important logistics issue is the empty backhaul of vessels (Aliozadeh, & Nomikos, 2010).

The great majority of shipping rates for all bulk commodities are negotiated through long-term contracts (Stopford, 2010). These rates fix exporters and importers cost over a long time period. In general freight rates are determined by the supply and demand of shipping services on a global scale. The state of the freight market is reflected by the proportion of the total dry bulk tonnage laid up (Tvedt, 2003). When tonnage available is in excess of demand, freight rates are expected to fall. Decline in ocean freight rates due to decline in oil prices will tend to favor spot rates that will be significantly lower than long-term rates (Fleming, 2010).

The price for moving commodities along various ocean routes by different type and size of ships is fixed by the Baltic Dry Index (BDI). The BDI has been falling over the past 5 years. This decline in freight rates is the results of several factors (Zhang, 2014). China is the largest bulk market in the world. China's demand for iron ore triggered the demand for Capesize vessels. As China's economy growth rate slows down, this precipitates a decrease of the BDI. The reduction in demand from the iron ore market will not absorb the same proportion of the fleet growth as in the past years (Massot, 2014).

The development of mega ore carriers concomitant with the slowdown in the demand for iron ore can expect to see a substantial overcapacity of Capesize vessels. The new tonnage to be delivered seems to be too large to be absorbed by iron ore volume. This excess supply of capacity is affecting the rates for Capesize ships.

There are not many opportunities to use excess capacity to transport other cargoes. The additional supply of Panamax ships can be absorbed by other cargoes such as grain ands and steel products. As a result, expansion of average earnings of bulk carrier owners is projected to grow at slower pace with concomitant slowdown of fleet growth. This reduction in transport cost benefits the steel makers. This could reduce the cost advantage of Australian producers on the Asian markets.

2.8. Transportation infrastructure

The main preoccupation of steel makers is transport cost. Any capacity exceeding design has seen a direct significant increase in costs. The capacity of mines and transportation are the main bottlenecks (Lu, *et al*, 2005).

As significant economies can be achieved with large vessels, improvements in the efficiency of port facilities and conveyor systems of exporting countries decrease transport costs to the buyer's benefit. Existing infrastructure primarily rail and port facilities is a key component in iron ore supply chain.

In moving iron ore from mines, the objective is to provide volume movement to the first stage of processing. The efficiency of iron ore movement is strengthened with the adaptation of transport vehicles for iron ore in terms of size, design or technology employed. Iron ore is subject to imbalance of traffic between directions of vehicle movements. The cost may be offset by diminishing the loading/unloading cost of terminal facilities.

Suppliers trading iron ore for overseas markets secure terminals where iron ore can be handled and ship in the consignment size required by the customers. This process of distribution involves ports where terminal operators have made important investment in highly mechanized handling facilities. Each terminal is marked by varied loading/unloading rates and variable loading and unloading quantities. Terminal operators have invested in automated operation embracing computer controlled conveyor systems with a view to increase the utilisation rate of facilities. The logistics service requirement at iron ore terminals pertains to handling capacity. Capacity refers to the volume of iron ore throughput produced for a given period of time.

The study reveals that producers with integrated mine-rail-port are likely to be the most reliable. Moreover, the price of iron ore is being influenced by traded cargo size, delivery port and delivery period. The demurrage charges and waiting times for bulk carriers is influencing iron ore market's future (Merk & Dang, 2012). Already, handling capacity at many Asian ports are facing saturation. Vessels have to wait regularly to unload their cargoes. As a result, additional cost savings can be realized due to faster loading and unloading times. Shorter waiting time at berth has been found to lead to lower freight rates. While better infrastructure may lead to higher port costs charged by the carrier, the latter will reduce freight rate charged to the importer or exporter because the gained time and reliability more than offsets the possible payments to the port. The less time ships spend in port the more cargo they can carry in a year. Reducing port time increases the supply of ships.

The competitiveness of the iron ore supply chain aims at reducing this degree of fragmentation with a view to integrate iron ore supplies and physical distribution activities. The iron ore shipping industry is adopting a more integrated approach. Producers develop inland depots and port terminals to accommodate needs of customers. Stakeholders enter in the bulk fleet shipping market. Ports undertake joint planning with maritime and inland transportation carriers. Various stakeholders synchronise and standardize their operations along the transport chain to insure the fluidity of iron ore traffic and information flows. The development of an integrated approach among actors and components of the iron ore supply chain creates value by increasing capacity, improving inventory management, reducing link uncertainties and achieving profitability.

In order to secure markets, Australian companies have financed expansion of port facilities at Constanza, Romania in return for iron ore purchases. South Korean steel companies have financed the expansion of the port of Paradip in India and built a new railway line to reduce bottlenecks.

3. IRON ORE SUPPLY CHAIN VULNERABILITY

The mission of the iron ore supply chain is to insure the fluidity and reliability of iron ore throughput. Risk assessment pertains to the location, frequency, concentration, duration, trends and magnitude of events that may negatively impact the capacity of the iron ore supply chain to perform its mission. Assessment of iron ore shipping vulnerability however cannot be limited to physical engineering design. Resilience analysis requires a system wide perspective encompassing people, facilities, information and activities within and outside the system. Interviews with stakeholders in the iron ore industry suggest four factors are affecting the resilience of iron ore supply chain: production risks, transportation capacity, economic and commercial conditions and environmental impacts.

3.1. Production risks

Production risks pertain to the possibility and cost of supply disruption. The above analysis demonstrates that existing iron ore resources are sufficient to meet current world demand. The known resource base of iron ore is currently estimated at above 300 years in the context of current world consumption rate. Mining capacity is geographically widespread. The total reserve is such that there are no concerns on long term supply inadequacies. Over-development of reserves in Australia and Brazil has resulted in long term excess capacity.

Iron ore surpluses have arisen due to several factors including economic recession and world steel industry restructuring. Large stocks of iron ore can accumulate during these events and may serve as inventories that can be made available in the event of increases demand.

The most important element in assessing production risks is the cost of production. The cost of iron ore production varies greatly across the world. As mining equipment costs vary only marginally, the cost of production is more affected by the richness of the ore and labour.

The main problem affecting iron ore production is that lead time for a new mine is up to ten years and current overcapacity ensures that alternative supplies are made available elsewhere. Besides, there is no guarantee that a high price-demand of quality iron ore will be retain indefinitely.

Manpower represents a volatile risk factor in iron ore production. Labour disruptions or low productivity have damaging consequences. But world iron ore supply overall is unlikely to be disrupted as a result of a local mining industry labour conflict since supply can be shifted elsewhere.

Labour intensity in mineral processing is low as compared to other branches of manufacturing. Considering labour requirements simply in terms of labour intensity neglects the issue of skills. Efficient production and high quality output are supported by technical and managerial skills. Capital-intensive operations are also skill-intensive. There are advantages for countries having a highly trained labour force with potential cost/efficiency advantages that can provide an international competitive advantage and attract investments from abroad.

A major challenge in developing a major iron ore deposit is that of attracting the presence of a major industrial group and securing forward sales contracts.

3.2. Transportation capacity

Transportation capacity relates to the possibility of disruption in the movement of iron ore from the site of production to the site of fabrication. The interaction between sea and land based transport system is critical to the entire risk assessment of iron ore supply chain. The share of the cost of iron ore in the cost of refined metal is low and thus important economies can be realized by increasing the efficiency of handling and transport.

The global iron ore trade is characterized by high volume shipments that depend on large vessels for efficient transport, scale economies and competitiveness. Transport by ship can be affected by dock strikes and natural weather conditions. Disruptions of deliveries at the ports rarely occur but would be very costly. Interruptions are more likely considering the extended shipping routes involved which incorporate several bottlenecks. The concept of freedom of the seas is disputed given some territorial claims affecting passage and vessel safety in some world regions. The main bottlenecks affecting iron ore trade include the Panama Canal, the English Channel, the Straits of Gibraltar, The Suez/Red sea route, the Strait of Hormuz and the Indian ocean/Strait of Malacca. Transport links are becoming more vulnerable, the expansion of trade is increasing the number of choke points and the possibility of disruption by natural means will grow.

On the land side, the bulk of iron ore movement is undertaken by rail. But the configuration of the railway network leaves very few options available for shippers in the event of disruption. The adoption of optimal allocations is often based on the propagation of cumulative impacts. But the properties and features of moving iron ore by rail are inherent to specific geographic scale and cannot be additively combined or scaled-up. Transport by rail can be interrupted by labour conflicts, shortage of rolling stock or natural disasters. A key to resilience is to focus on increasing land route choices available to export ore. Since distance to port of export tend to be long, transport of ore by slurry pipeline represents a viable alternative to reduce cost being least affected by difficult terrain and liable to environmentally-related problems.

3.3. Commercial conditions

The traditional predominance of iron ore in steel fabrication cannot be assured for any application in the longer term. The consumption of iron ore is affected by technological requirements that reduce the unit requirement for the mineral. There is a drive for lighter, stronger and cost-competitive products in all sectors of the steel industry. Besides, current substitute metal and scrap is being used in ever larger quantities and is frequently close to the steel industry.

The price of ore is determined by the market between producers that are in competition. Australia and Brazil effectively dominate world supplies of iron ore. Canada has limited power in fixing the price of iron ore. A merchant-free market operates for iron ore and published prices are available providing some element of competitiveness. The iron ore trade patterns and prices are unlikely to be affected politically. The attempts by the Chinese government imposing some control over imports have failed. Iron ore is particularly affected by shifting market conditions. Iron ore production is influenced by stagnating demand from the traditional United States and European markets and the emergence of growth markets in the Far East.

3.4. Environmental impacts

Occupying critical sites in the hinterland, mines have an important impact on ecosystems. Mine development inevitably consumes an enormous amount of land encompassing not only present use but also space for expansion. Ecosystem disturbance is evident and it is not just the mining activity that has such an environmental impact. Accompanying human settlements and transport systems are also involved. Growth in iron ore production generates an increasing volume of waste related to mine daily operations. Waste generated by mining operations notably process water and tailing sites raise serious problems, since they may contain contaminated elements that are harmful to human health and to ecosystems when discharged into the environment.

Mining activities imply depleting non-renewable resources. The mining industry has developed a comprehensive set of tools and indicators driving performance and ensuring the management of key mining risks. But the study of mining legacy is a critical issue in several countries. There is a widening gap between citizens and local communities' perception of the residual adverse economic, ecological and social effects of mine closure and the industry's concern with resource extraction. This gap is a major source of difficulties in elaborating sustainable iron ore developments. The main challenge for industry stakeholders consists in searching for compromise between cost of iron ore production and cost of recycling that often implies the development of performance indicators and a modification of firm's organizational strategies in terms of waste management and used-sites rehabilitation and redevelopment.

4. CONCLUSION

Global iron ore supply chain is an important marker of global economic processes. Changes in the volume and direction of traffic describe the level of global integration of the iron ore industry.

As far as supply is concerned our analysis suggests a better understanding of the network economy in terms of industry concentration (i.e. mining and steel making) and corporate cross-participation (i.e. capital ownership and management type) with a view to understand the grip or dominant position of key players on the iron ore supply chain. Capital costs of mining and processing complexes have escalated in the last decade resulting in changes in the financing of mineral development. Iron ore mine development is likely to occur only with the active participation of mining companies, international financing organizations, steel corporations and producing countries government. In addition, the availability of raw material with high iron ore content is a major factor in the cost of steel production. This is motivated by the growing trend of direct reduction process in steelmaking. Specifically, the process using natural gas in direct reduction steelmaking has become a leading feature of the industry. The availability of high quality ore or pellets is essential. Steel makers are willing to pay a premium for pellets. The premium price could be 35-50% higher than sinter fines.

On the demand side, due account should be taken of the excess steelmaking capacity of industrialized economies. Such overcapacity is fuelling the trend towards some form of protectionism via intra-firm transactions and plant closures. As a result, contractual terms of traded iron ore have been adjusted between importers and exporters in line with shift from long-term contract to contracts with recession-type clauses. However, this shift masks the variation in the rates of growth worldwide. Declining growth rate in steel consumption with levelling off in the metal-intensiveness of North America and Europe must be contrasted with growth of internal demand in developing countries. The demand for steel being directly related to the rate of economic growth, high GDP growth rates due to low energy costs, notably cheap natural gas could result in possible growth in steel demand. There is room for expansion of steel processing in East Asia. Besides, various proposals are being forwarded to build home-base steel plants in Northern Africa and energy-rich Middle East countries. The direct reduction/electric arc furnace process offers the best possibility to expand steel processing since it is the least capital intensive for the direct reduction of iron ores.

Transport costs will determine a country's ability to sell iron ore in the overseas global market places. Freight costs increase with the length of haul and decrease with the size of ships. Since bunker fuel is an important factor in influencing transport costs, the decline in the price of fuel oil will have a positive effect on the net price of iron ore delivered around the world.

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