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"Resource based industrialisation: evidence from the Iron-Ore project in Brazil"

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Resource based industrialisation: evidence from the Iron-Ore project in Brazil

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Abstract

This paper aims to engage in the contemporary debate around the opportunity to diversify and upgrade a country's economic system through the contribution of natural resource sectors. Adopting a revisitation of Hirschman's linkage theory, the analysis looks at mining arguing that the outsourcing process changed the dynamics of the sector, which is now characterised by the promotion of high-level technology and innovation. By focusing on the Brazilian mining sector, the development of consumption and backward linkages is examined in relation to the S11D iron ore project. The specificity of the case presents an in-depth analysis, permitting a case-by-case, one size-does-not-fit-all evaluation approach, which is crucial in formulating appropriate policy solutions to problems facing developing economies. It is argued that, overall, mining had a positive impact on the region where it operates, with strong consumption linkages. Nonetheless, due to an absent formal public policy, while backward linkages related to innovation and knowledge services are well-developed and very often at the technological frontier, the ones related to capital goods are weak and in the hands of foreigner subsidiaries.

Keywords: industrial policy, structural change, natural resources, value-chain

JEL: O14, O25, Q32, F21

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1. INTRODUCTION

Diversification is considered a priority for countries that try to move up the developmental ladder. The rise of the South in the world economy has been characterised by an increasing share of global manufacturing that benefited developing countries, in terms of knowledge dissemination, through the deverticalisation and fragmentation process that started in the 1970s. The controversial debate around the role of natural resources is still one of the main pillars in the development agenda for two reasons. On the one hand, countries that succeeded in a more sustained and better growth are the Asian countries that are generally poor in exportable natural resources but are labour abundant. On the other hand, the growth of the latter has increased the demand for commodities to resource rich countries that, despite the promising potential, had overall disappointing performances. This prospect increases the debate between scholars that believe in the necessity of diversification from the natural resources' sectors for developing countries to grow and prosper and a literature that challenges this view and that sustains that developing countries can and have to build their industrial sectors evolving from their natural resources wealth. This paper addresses the debate paying particular attention to natural resource constraints, and their opportunity to trigger innovation, through the interaction between intrinsic and contextual determinants in order to develop linkages within the local economy as a way towards a sustained growth (Morris et al., 2012).

The first theories on the role of natural resources in economic growth go back to the positive view of the classical economists that rooted the first elements of the debate: natural resources were overall considered a blessing but their scarcity started to be considered a threat to future growth. This perspective entered the marginalist and then the neoclassical debate focusing on the scarcity of given resources not taking account of technological change for over a century (Pasinetti, 2015). The resurgence of the debate about commodities means it is fundamental to go back to the old debate and insert important neglected elements such as technological change and the opportunity it has to overcome natural resource constraints.

The recent price instability along with the commodity boom at the beginning of the century and the following fluctuations posed, once again, a structural question for resource rich developing countries: could they enjoy sustainable and rapid growth from natural resources? Could natural resource sectors that are mainly capital-intensive trigger economic growth?

Recently, the perspective that privileges natural resource based industrialisation got a foothold in the literature. Digging up Hirschman's linkages theory, Morris et al. (2012) adopted the theory of unbalanced growth and shed light on the synergetic links between natural resources and the manufacturing sector, where the latter has been stimulated by the linkages of the former.

The paper is divided into four sections. It begins by introducing the debate on natural resource constraints: a brief examination of the main pillars in the natural resource literature is followed by the recent evidence that challenge the mainstream view on the detrimental effects of commodities. The analysis will develop along two main axes: on the one hand Hirschman linkages theory revisited by 'making the most of commodities' and, on the other hand, the importance to 'open the black box of resource constraints' (Andreoni, 2015) whilst looking at linkages development path. The second section narrows down to a specific type of natural resource analysing the challenges of the mining sector. It will be argued that despite being capital intensive and a highly logistic industry, mining has important potential for local economies. The third section examines the Brazilian case of the iron ore industry in the Southern Para' region where the Brazilian company Vale undertook the construction of the biggest mine in the world (the S11D) creating new opportunities for linkages' development and economic upgrade. The fourth section will examine the main findings about the relationship between natural resource constraints, looking at the S11D project, and the development of consumption and production linkages.

As a methodological note, this paper builds on existing research and analyses secondary data. Particularly, the examination builds on data from the Brazilian government (IBGE and RIAS) in terms of GDP and formal job creation, firm data level (Vale SA company) and informal interviews conducted both with Vale employees and within the academic sector in Brazil.

2. NATURAL RESOURCES CONSTRAINTS: READING THE OLD BOOK THROUGH NEW LENSES

Either good or bad, the dichotomy of the old book

The last fifty years have predominantly seen the commodity sector as an enclave activity delinked from the rest of the economy, with low technological development and weak linkages both in terms of job creation and spill-overs to other sectors. The debate around natural resources (NR) had different phases and has been rooted in the economic discipline since when classical economists started to raise the first concerns about the interlinked concepts of rent and land scarcity. This embryonic analysis of NR presented two possibilities in terms of deepening future economic theories. Faced with the choice of analysing either technological improvement or increasing limitations and constraints, classical economists from the 19th century wrongfully focussed on the latter and paved the way for decades of NR scarcity debate (Pasinetti, 2015:49).

Despite being one of the most important contributors to the classical economic theory, Smith did not provide a clear contribution on NR (Pasinetti, 2015); being an unfatigued optimist he strongly believed in agricultural progress and the blessing of commodities' wealth. The optimism is reflected in Smith's theory of increasing returns and the almost exclusive importance he gave to producibility, believing as Mill did, that nature was generous and the world was far from facing quantity constraints (Barbier, 1989). This perspective was partially compensated by Malthus's pessimism and it is reflected in his theory of scarcity: despite its importance for future economic ideas, the theory was rather an analysis of population and NR scarcity was more asserted than demonstrated (Barbier, 1989). Ricardo, on a different level, focussed his attention on the 'antagonism coexistence' between producibility and scarcities (Scazzieri et al., 2015); he saw scarcity as a relative element rather than an absolute one. In both Ricardo and Malthus's discourse the law of diminishing returns played an important role (Krautkraemer, 2005); despite a few opponents, Andersen and Cannan among the most influential (Pasinetti, 2015), the idea that technology does not change and, if it does, it is not strong enough to overcome diminishing marginal returns, shaped economic theory about NR for a long time. History proved that the predictions about unavoidable scarcities and their consequent limitations for economic growth were wrong (Tahvonen, 2000) but meanwhile the technical change and innovation vanished from the economic analysis for almost a century (Pasinetti, 2015).

The view of NR as a blessing for economic growth persisted after the end of World War II where there was a surge of optimism in the commodities debate. Despite few important exceptions (Prebisch (1950) and Singer (1950) with the most relevant counterarguments), the literature recognised NR as a fundamental trigger to spur economic growth. Rostow (1961) argued that NR was crucial to place developing countries on the runway to industrial take-off (Singer, 1975: 9). Balassa (1980), on a similar path, expressed the importance of NR in order to provide funds for industrial development (Joya, 2014). Innis (1956), with his famous Staple Theory, showed how the growth of a new country such as Canada is influenced by the commodities it exports to the global market (Hirschman, 1977). These authors were positively influenced by the experiences of their time such as the cases of the United States, Australia and Britain. As history changed its actors and their performances so did the economic theory. A fundamental change of perspective is found in the 1980s which

saw a watershed between the positive and the negative view of NR (Gerelma and Kotani, 2016) and a time where the Prebisch-Singer hypothesis became dominant. Looking at resource rich developing countries, Prebisch (1950) and Singer (1950) expressed their concern about the deterioration of the terms of trade which would change in favour of manufacturing with consequent detrimental effects for commodities exporters. There is a rather mixed picture on the actual deterioration of the terms of trade for developing countries (Singer, 1975). The literature presents both findings on the consistency of their argument (Ocampo and Parra, 2006) and on its incongruity. The latter encourages a deeper understanding of other variables such as the type of commodity (Harvey et al., 2010) and a more careful analysis of the commodities prices in the last fifty years that reveals a random trend rather than a downturned one (Cuddington et al., 2007: 172), as shown in Figure 1 for hard commodity prices. Even Singer in his later contributions found that trade for underdeveloped countries was more favourable in the post-war period than in the 1930s and acknowledged that what matters in terms of development is not the commodity type but who develops the technology (Singer, 1975).

Hard Commodity Prices

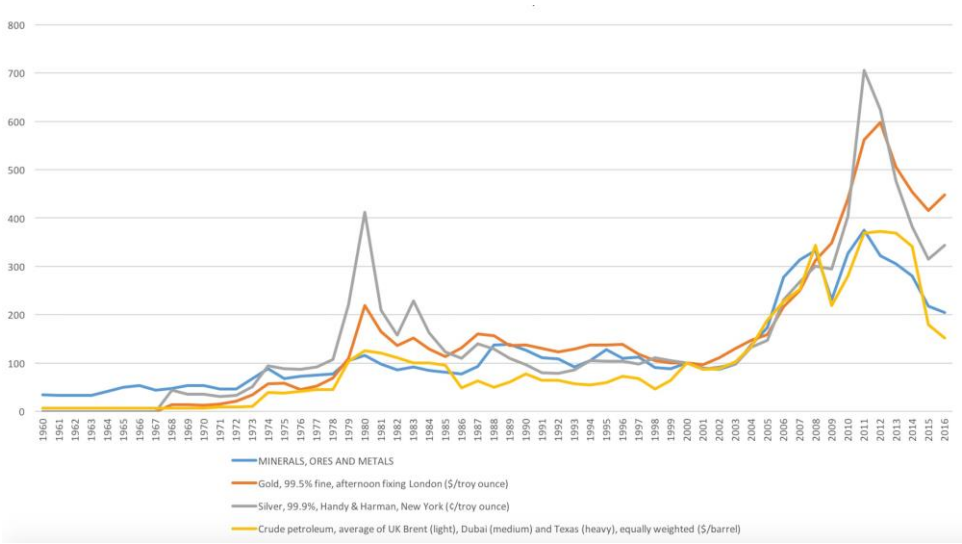

Figure 1. Source: Author's own construction based on Data from UNCTAD.

The first pillar of the negative view about NR emerged with the Dutch-disease theory which stems from the Dutch experience of natural gas discoveries. It is a clear example of what happens when there is a NR boom: the appreciation of the currency leads to a decline in competitiveness of the non-commodities related exportable goods with a consequent decline of export diversification (Cordon, 1984). The United States and Australia left their outstanding experiences to the disappointing performance of Africa and Latin America where commodities exports consistently hindered the manufacturing sector. The Dutch disease as a first element of the debate paved the way for what Gelb (1988) theorised and Auty (1993) defined as the 'resource curse': the inability of rich resource developing countries to boost their economic growth through their resources wealth.

The two main causes of the resource curse are volatility and the enclave nature of NR sectors: the former depresses long-term development because it increases uncertainty with a following drop in investments (Humphreys, 2007; Ramey and Ramey 1995; Alsharif et al., 2017). Therefore, instability increases the distrust in the well-functioning of the market and this is found to be quite apart from trends in commodity prices (Badeeb et al., 2016). As Nissanke (2011) argues it was the increasing financialisation of commodities that had a strong impact on volatility in the last decades. The latter is related to the nature of NR activities considered a weak source of linkages to local suppliers because of low technologies, narrow possibilities of spill overs to other sectors and mainly capital-intensive activities with no space for the creation of more and better jobs (Singer, 1950; 1975).

These arguments were empirically proven by a rich set of contributions from Sachs and Warner (1997; 1999) that tested the negative correlation between natural resource endowments and economic growth. These models have contributed to the sequel of the mainstream consensus on the damaging effects of NR; nonetheless, more recently, a different type of approach disentangled the econometric analysis and examined the negative trend à la Sachs and Warner as a statistical mirage (Badeeb et al., 2016: 19). These arguments can be summarised along three dimensions. Firstly, the proxies of resource dependence in output, intended as the measure a country relies on NR revenues, is often treated as resource abundance in stock, which indicates the geological endowment of a country's subsoil. This is misleading because a country which is resource abundant may not be resource dependent if it diversifies its economy. Lederman and Maloney (2007) examines Sachs and Warner's method and found a bias in their principal measure for resource abundance, which is resource export as share of GDP; this indicates export diversification rather than NR impact and processes of diversification historically stem from a strong resource base (Leaderman and Manoley, 2007). If a more precise indicator for resource abundance, measured as net resource exports per capita (Leamer, 1984), was used the negative impact of NR would disappear. Brunnschweiler and Bulte (2008) reached the same conclusion raising the endogeneity problem if the ratio resource export of GDP is used as a variable.

Secondly, Gerelma and Kotani (2014) criticise the least squared approach used by the main literature: this method is considered problematic because a single set of parameters is used for an entire sample and it does not take into account the differences across each stage of the developmental process. With the use of the quantile approach heterogeneity is contemplated. Their analysis finds that while the correlation is negative between the 1970s and the 1990s, this changes in the period from 1990 to 2010 where it is positive and with higher levels of significance in the second quartile.

Thirdly, the problematic issue of causality in the main view has been challenged. Davies (1995), studying the performances of mineral and non-mineral economies in relation with the Human Development Index found that the causality of a slower growth in some resource rich countries is underdevelopment rather than NR wealth. NR effects on different countries present a huge variation which leads to the conclusion that the resource curse is not inevitable rather it depends on good governance and resource management capacities (Mehlum and Torvik, 2006; Torvik, 2009).

New lenses for NR debate, the role of linkages and innovation

The structuralist perspective

Natural resources scarcity has been the first concern in the economic analysis. This, according to Scazzieri (2015), has been narrowly analysed from the allocation point of view à la Malthus-Ricardo implying a static vision of national wealth as stock to be allocated with a particular attention paid to the interlocked

relationship between limited supply and price under market constraints (Scazzieri et al., 2015:450). Nonetheless, a different perspective is possible through the structural lenses that see national wealth as a flow of goods that are constantly reproducible; NR scarcities are observed as obstacles that can be overcome through progress and technical knowledge (Scazzieri et al., 2015; Andreoni, 2015).

Historically, there have been few important exceptions to the aforementioned trend about the 'forgotten technologies' (section 2.1) as part of the production function (Andreoni, 2015). On the one hand, Leontief (1977) acknowledges the inter-dependencies between 'circular flows' of products and the commodities in any economic system (Scazzieri, 2015:452). He considers technology as a factor of a production function whose elements are fixed–therefore predetermined and not substitutable (Leontief, 1977). On the other hand, Kuznets (1973) recognised the importance of technology in order to better understand the behaviour of natural processes and their modifications. He believed in the presence of "a mechanism for self-sustaining technological advance, to which […] there are no obvious proximate limits" (Kuznet, 1973: 250). Despite the important contributions, both authors failed to include in their theory the dynamics between the unfolding mechanism of NR constraints and manufacturing development, which is discontinuous and does not run along specific and predetermined lines (Andreoni, 2015: 409).

The structuralist point of view (Scazzieri et al., 2015) allows an opening up of the debate turning NR constraints into technological opportunities to be discovered. This perspective disentangles the internal trajectories of each sector and aims to 'open the black box of resource constraints' (Andreoni, 2015: 410). The dichotomy of the old debate, whether NR are detrimental or beneficial *per se*, leaves space for a more complex analysis that narrows down towards a sectoral level examination. NR are characterised by an uneven and heterogeneous dynamic process that leads to issues of compatibility between the different techniques activated in the whole economic system (Andreoni, 2015). NR scarcities as well as bottlenecks in the production can be overcome through a dynamic process of structural learning (Andreoni, 2014) which has the opportunity to create space for resource based industrialisation (RBI) strategies.

The lack of consensus on NR debate (Rosser, 2006) led to a reconsideration of the main axes that influenced the economic theory for a long time. Gerelma and Kotani (2016) showed that the Dutch disease theory does not hold anymore: based on a cross country analysis during different time horizons, they found that the Dutch disease, while consistent with empirical analysis between 1970 and 1990, is not verified for the three decades 1990-2010. Their conclusion is twofold: on the one hand, the relationship between NR and growth is not as clear as Sachs and Warner pointed out as it is necessary to consider other factors; on the other hand, they state that NR may have a positive effect if a country is able to build a strong manufacturing sector to escape the Dutch disease effects. Knudsen and Parnes (1975, cited by Perez et al., 2014) challenged the vision of the potential negative association between unstable export prices and growth. The lack of consensus as well as new contributions paved the way for the resurgence of the RBI theory as a potential growth channel through the development of different types of linkages. In this sense, Bonaglia and Fukasaku (2003) argued that resource-rich countries should industrialise through the processing of their commodities instead of following the conventional path of low-skill manufacture that could involve a slower and costlier process.

Resource Based Industrialisation

An important step towards the reopening of the debate about RBI was the change in the global scenario due to the key role of India and China among other fast-growing countries. Their demand of commodities and supply

of manufacturing newly shaped prices trends in the last decades contributed to a less clear picture about the commodities-manufactures terms of trade for present and future times (Morris et al., 2011).

It is not clear whether RBI could be a better channel to achieve development goals (Roemer, 1979). Its main weaknesses in terms of employment creation and spill-overs are a matter of concern for at least three different reasons. Firstly, multinational companies (MNCs) dominate the commodities sector in the majority of developing countries and create entry barriers in the processing sectors entrenching the dual economy especially within the extractive sector (Baldwin 1956 cited by Roemer, 1979). Secondly, advanced economies raised their protections vis a vis imports from developing countries. Finally, in NR sectors, economies of scale are more difficult to reach especially if the domestic market is not large enough (Roemer, 1979). Despite these concerns, recent literature sustains that RBI can work both as a path to economic growth and development (Perez, 2016; Morris et al., 2012) and as a way to escape the resource curse (Gelband and Grasman, 2010; Joya, 2014).

The perspective that NR could represent an important stepping stone for resource rich developing countries is embraced and enriched by Carlota Perez's contributions. The fact that "there are many ways to heaven" (Amsden, 1989) entails that development can be reached in different ways according to the time period and technological level characterising each country's economic sector. As South Korea benefited from the *basic good production strategy* (mainly heavy industries) aiming at reducing dependence from the world trade, and East Asian economies used *export oriented industrialisation* to upgrade their economies, recent contributions claim a new window of opportunities in terms of *primary export processing* (Myint, 1971) for resource rich developing countries (Roemer, 1979). The latter discourse is related to the 'technological opportunity space' defined by the innovation potential: Perez et al. (2014) argued that NR industries experienced a transformation process that shed light on sectors that are now considered a pool of opportunities in terms of technology and innovation. The Information and Communication Technology (ICT) revolution has provided new potential for NR to support innovation and learning both upstream and downstream (Perez, 2010). Moreover, the fragmentation of production changed local interactions' dynamics and challenged traditional trends: for example, the tradition to process NR close to the users (advanced economies) could change in favour of a proximity to the source if and when the countries at the source have the ability to process in a competitive and innovative way (Perez, 2016).

The following section will expand on one of the most relevant contributions in terms of RBI which is the project called 'making the Most of Commodities Programme', whose framework is used in this paper to examine the Brazilian case of the mining sector. Expanding on Hirschman theory (1981) about the importance of the interactions between different stakeholders across the economy, Morris et al. (2012) challenge the view that enclave industries are an endogenous characteristic of the extractive sector. Instead, they believe that the unbalanced growth and its evolutionary movement are processes along which especially production linkages –both backward and forward- disentangle developmental dynamics (Figueiredo and Piana, 2016).

The building up of local linkages in a globalized economy: intrinsic and contextual determinants

RBI considers diversification as a path dependence process (David, 1985) with several constraints imposed by past technological achievements (Andersen et al., 2015). There is consistent evidence of 'synergetic links' between NR and the manufacturing sectors whose restructuring at a global level reinforced the scope for linkages' development (Morris et al., 2012). Globalization reshaped production both in developed and developing countries: the former started to target core competencies where they had a unique competitive

advantage (Morris et al., 2012: 22), whilst the latter became active participants in the non-core activities that were outsourced. In this sense, the high segmentation of production led to a deep specialisation in tasks rather than in final products (Milberg and Winkler, 2013; Gereffi et al., 2005), which contributed to a change of attitude within MNCs, from exclusion towards a stimulation of local networks between and within different suppliers' levels (Urzúa 2007; Milberg and Winkler, 2013; Perez et al., 2014). Stemming from the global value chain analysis, Kaplinsky (2011) shed light on the fact that global linkages (Gereffi et al., 2005) have to be combined with local linkages' activation in order to have both qualitative and quantitative development.

Outsourcing and globalisation trigger a market driven process of linkage development characterised by the interaction between and within intrinsic and contextual determinants (Morris et al., 2012). This paper will focus on the dynamics and role of the four contextual determinants. These are, firstly, the ownership of lead firms where a local firm presents advantages over the MNCs: it is more embedded in the local economy and has a higher commitment to local development. Secondly, an efficient infrastructure system that binds economic activities. Thirdly, a coherent pool of skills and capabilities that should stem from high level education and training. Lastly, there is the policy element which is "the single most important factor" (Morris et al., 2012: 412). This is crucial as it provides the opportunity to either spur success or undermine single policy measures. In this sense, an alignment between different actors and interests is important. For example, an unbalanced FDI policy –which often imply exemption on duties on imports– may undermine the development of backward linkages if local suppliers do not have any exemption (Morris et al., 2012).

Following Hirschman's idea (1981) that linkages from the NR sector are the most likely to provide economic diversification, this paper will focus both on NR constraints as a possible trigger for innovation and on the contextual determinants to examine the development of consumption and production linkages from the S11D mining project in Brazil.

3. THE MINING SECTOR

Overview

The perception about the enclave nature of activities based on NR is still strong and widespread. Among these, mining is considered particularly weak both in terms of linkages creation and of possible spill-overs to other sectors: its capital intensive and enclave nature contributed to shape the idea of a low technological sector with weak effects on employment creation (Bartos, 2007). This aspect, which maintains mining delinked from the rest of the economy, is associated with the risk of entrenching the dual economy of a country in the absence of government intervention (Roemer, 1979). Despite being regarded as the 'sterile classes' by Francois Quesnay (Bleischwitz, 2001: 26) and as non-productive activities by the physiocrats (Andersen et al., 2015), mining has been at the core of different developmental experiences.

Specifically, in these experiences resource rich countries became advanced economies with an industrialisation process that stem from natural endowments. The aforementioned Staple Theory (Innis, 1956) focussed on the Canadian trajectory and the importance that the export of NR had for the development and diversification of the economy. Australia, on a similar path, emerged as a key actor both in mining products and in the supply of mining industry equipment (Urzúa, 2007). South Africa, a highly diversified mining industry, took advantage of the large number of potential customers and developed many specialist suppliers that made the country a leader in the production of mining inputs (Kaplan, 2012).

The US (United States) had an iron ore based type of industrialisation. During the first part of the 20th century the US experienced a boom in its exports and its economy: between 1879 and 1940, the content of

the export was intensive in non-renewable natural resources (Wright, 1990). An earlier study from Lipsey (1963) noticed that as part of the industrialisation there was a change in the manufacturing production towards mineral origin products, especially iron ore. The driving force behind the US development has to be found in the link between the exploitation of NR (iron ore) and the expansion of the related manufacturing export (steel) (Irwin, 2000).

3.2 Outsourcing and sector reconstruction

The mining sector experienced a reconfiguration of production systems with a better and more active involvement of local suppliers as well as more awareness of environmental issues (McMahon and Van der Veen, 2009). Local suppliers have been involved especially to develop knowledge based activities that contributed to the creation of learning linkages. This can be traced along two main trends.

The first more common trend stems from the process of outsourcing that started to spread in the 1970s and involved the mining sector two decades later (Figueiredo and Piana, 2016: 405). From being highly verticalised, MNCs in the mining sector started to outsource the provision of capital goods, intermediaries and also knowledge services. This led to the emergence of the specialised knowledge intensive mining service providers (KIMS) (Urzúa, 2007). For instance, a successful example of KIMS development is the SRK in South Africa that started as a service provider for the MNC Anglo American and became a global consultancy for earth and water resource industries (Kaplan, 2012). The outsourcing mechanism enabled a two-way model of linkage development: on the one hand, MNCs decided to focus on core competencies and allowed for a knowledge dissemination among local suppliers (win-win linkages). On the other hand, MNCs continued to maintain barriers and be reluctant to see the widespread of the learning processes concerning their core tasks (win-lose linkages) (Morris et al., 2011: 23). Overall, the process of deverticalisation led to a gradual rejuvenation of the productive structure in mining industries (Perez, 2001) because of the emergence of new innovation paradigms and opportunities for linkages' development. This change enables a perspective that considers mining industries characterised by high technological level with *in situ* application. The fact of being location specific facilitated the role of local suppliers not only as an opportunity but also as a necessity (Morris et al., 2011).

The second trend is what can be found in the Brazilian mining experiences. The biggest company in the mining sector is the nationally owned Vale SA whose activities in the iron ore sector are at the core of this paper. Through specific arrangements with the government, Vale extensively used suppliers' development programmes (OECD, 2017: 57) to develop high technology innovation. As it will be further argued, the specific contextual determinants in the case of Vale were important triggers in the formation of local linkages.

The rejuvenation of the whole productive structure (Perez, 2016) shed light on the technological level and innovation potential of mining. These aspects were considered to be low because of the conventional indicator for their measure which is R&D expenditure as a share of annual cash flow. Considering the 10% average that the mining industry spends on R&D, and comparing with other sectors' R&D expenditures, like the 50% of the pharmaceutical industry, it has been concluded that mining has a low technological level (Bartos, 2007: 155). Nonetheless, this is a misleading analysis because as Kaplan (2012) pointed out much of the product development expenditure along the mining value chain is not classified as R&D. Industries that supply equipment, intermediate goods and sophisticated services are the places where technological change happens (Kaplan, 2012: 426). In particular, Original Equipment Manufacturers are one of the main recipients of R&D and a key source of innovation in the industry (Bartos, 2007; Fessehaie, 2015).

It is important to mention also the surge in demand of mining products which imposed the necessity to find new and better techniques to be more productive. In this sense, obstacles in terms of scarcity have acted as

triggers for the discovery of new deposits, more productive ways of extraction and more sustainable techniques to process raw materials. As an example, the Australian mining industry experienced a productivity growth of 130% between 1986 and 2003, four time faster than other sectors (Urzúa, 2007).

Iron ore value chain

The iron ore industry outcome depends for 98% on its use in the steel industry (Michaelis and Jackson, 2000). Due to the demand increase from developing countries, iron ore production went from 682 million tons produced in 2004 to 1339 million tons in 2013 (World Steel Association, 2014). A key role is played by China and its investments in steel production (19% of the world market share), especially in infrastructure projects (Comtois and Slake, 2016: 3). The demand of steel, and therefore of iron ore, is likely to follow the upward path (Figure 2) without scarcity constraints appearing in the foreseeable future (Leontief, 1977; Comtois and Slack, 2016). In terms of costs, the iron ore price depends on its concentration level (which depends on its production) and on its quality.

Global Iron Ore and steel consumption

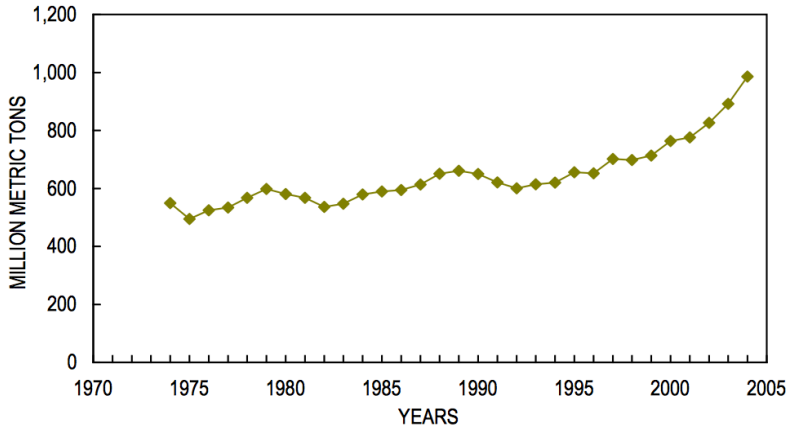

Figure 2. Source: US Geological Survey (2008)

During the last fifteen years, the industry went through a massive consolidation with mergers and acquisitions whose result is a scenario with a few big actors. This can be explained considering the long and expensive procedures that are related with the industry: for example, during the first preliminary step of exploration, costs soar considerably because of the investment for the equipment and the long licensing process with governments. Investments have to be sustained for long periods, since a new mine can require up to more than ten years (Warell and Lundmark, 2008).

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 Gr.	Australia	81,5	3,1
ArcelorMittal Gr.	UK	79,6	3,03
AnBen group	China	55,7	2,12
Anglo American Gr.	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 Gr.	Ukraine	44,7	1,7
Cliffs Natural Resource	United States	42,9	1,63
CVG Group	Venezuela	40,7	1,55
Shougang Beijing Gr.	China	37,3	1,42
Mining Group	India	37,2	1,41
NMDC group	India	34,1	1,3
Imidro Group	Iran	32,4	1,23
CNS Group	Brazil	29,2	1,11
US Stell Group	United States	24,6	0,94
Poltavsky	Ukraine	24,3	0,92
Top 20		1869,6	71,06
World Total		2631	100

Table 1. Source: Author's own construction based on Comtois and Slack (2016)

Looking at the iron ore value chain, represented in Figure 3, one of the crucial elements is logistics. Infrastructures both in terms of railways and ports are a key component and one of the major bottlenecks along the value chain (Lu et al., 2005). These factors are part of the reasons why, as presented in a study from Lu et al. (2005), big integrated firms with mine-rail-ports are the most reliable ones.

Iron Ore Value Chain

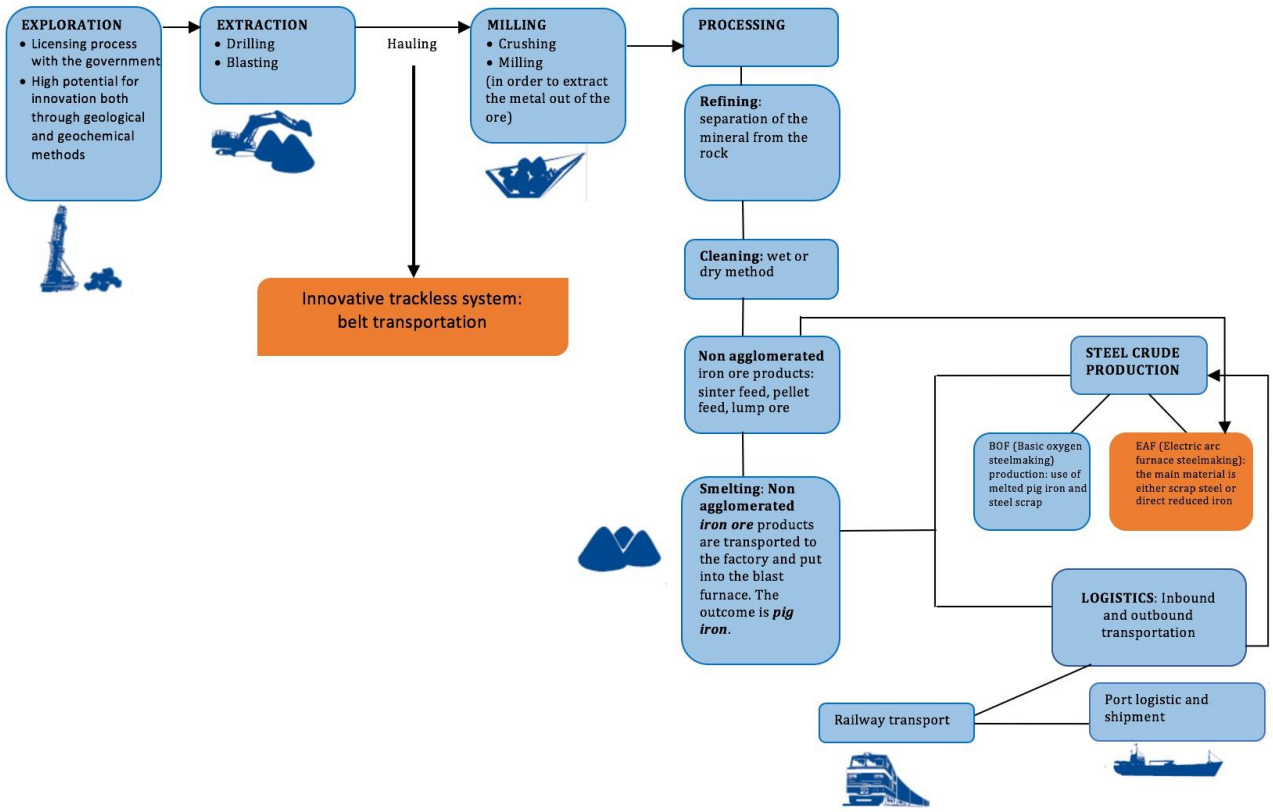

Figure 3. Source: Author's own construction

Developing production linkages in a "logistic industry"

This section will briefly indicate the possible interactions, development and dissemination of production linkages in the iron ore industry. The analysis argues that, despite the common belief that relegates mining as an enclave activity, it has important opportunities for direct production linkages (Morris et al., 2011) whose policies are the most likely to trigger the development of a diversified economic structure (Hirschman, 1981: 69). Recalling Hirschman's definition, backward linkages are related to the investment in input supplying equipment whilst forward linkages concern the investment in output facilities (Hirschman, 2013: 160). Production linkages from the iron ore industry are briefly summarised in Figure 4.

Production Linkages in the Iron Ore Industry

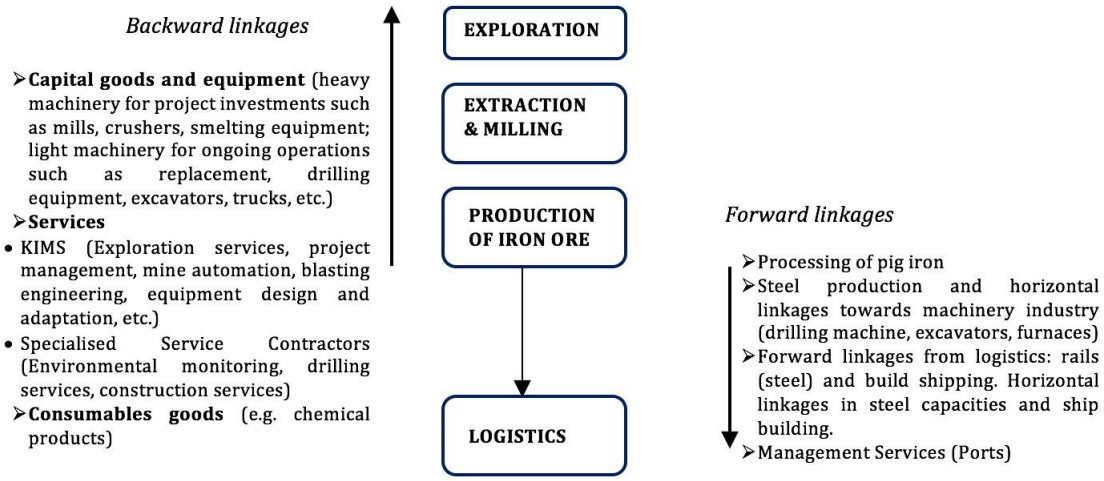

Figure 4. Source: author's own construction based on Urzúa (2012).

Regarding forward linkages, in the iron ore industry the most direct downstream linkage is related to the production of steel and steel materials. These linkages are difficult to develop even though policymakers have attempted to address the issue in the past through investment and formal public policies (Morris et al., 2012; UNIDO, 2011; Figueiredo and Piana, 2017). Differently, the development of backward linkages largely stems from the positive interaction between suppliers and lead companies' interests even when active policies are not involved.

The success or failure of developing backward and forward linkages depends on the knowledge linkages that act as a base and a precondition: in order to develop and adapt new technologies it is necessary to have the adequate capacities in terms of engineering capacity and sufficient investment in R&D to spur innovation and adapt it to other sectors (Urzúa, 2013).

4. BRAZIL IRON ORE CASE STUDY: THE S11D

Overview of the Brazilian mining economy

Mining is a strategic sector in the Brazilian economy, even if its impact is not unquestioned. The extractive sector (with gas and oil included) accounts for 3% of GDP and mining alone employs

2.2 million people, less than 1% of the Brazilian population (Figueiredo and Piana, 2016: 406).

Nonetheless, these numbers have to be balanced with at least two other evidences. Firstly, Brazil mineral export was a fundamental component in the turnaround of the country's external balance (minerals

constituted 33% of total export in 2010) (ICMM, 2013). Secondly, even if employment data is not large in absolute terms, it has a strong impact at a regional level, especially in the poorest areas where mining activities are located.

The mining sector in Brazil has a long history that has been shaped by the legislation characterised by the alteration, through privatisation and nationalisation, of government's involvement in mining activities (OECD, 2017). An important watershed occurred in 1934 when there was a re-nationalization of subsoil rights, through the creation of a separate Mining Code and the new Constitution (Triner, 2011). The trigger behind the re-nationalisation is to be found in two coordination problems that were impeding large iron ore and steel projects: the transportation infrastructure and fixed investment in factories and equipment.

Some decades later, with the implementation of the Real Plan (1994-1999), the Brazilian economy showed more consistency and mining, among other sectors, became more diversified with investments in services and engineering education. The sector is expected to increase following the path of the last years (IBRAM reported that between 2000 and 2009 the size of the industry grew fivefold) considering the low level of Brazilian subsoil exploration. In comparison with Brazil, Peru invested the double amount in geological surveys despite having less than one seventh of Brazilian land (Falco et al., 2011).

Among the different minerals Brazil is endowed of, iron ore, which accounts for 82.65% of Brazil metal exports (Falco et al, 2011), has a key role since the colonial era. Even during general Vargas' dictatorship, iron ore export was considered the trigger that could generate sufficient revenues in order to promote steel production without the need for public subsidy (Triner, 2011). In 1942, the biggest Brazilian mining company, Vale do Rio Doce (Vale), was created as a SOE with the aim of solving problems of capital accumulation and technological coordination. Vale, that was privatised in 1997, is still Brazil's biggest mining firm and operates mainly in iron ore, the dominant mineral in Brazilian production. Looking at the data between 2012 and 2016, investments in iron ore have been considerably more significant than any other minerals: US$

46.03 billion compared with US$ 7.82 billion for potassium which constitutes the second largest investments[2].

In terms of Brazilian government revenues from the mining sector, iron ore companies account for 65% of total revenues (Falco et al., 2011). The amount is collected and managed by the three agencies responsible for the mining industry, which are the Ministry of Mines and Energy, the DNPM (National Department of Mineral Production) and the CPRM (Brazilian Geological Service). A recent reform (2017) changed the royalty system increasing the amount of royalties to be paid by 2%, 3% or 4% depending on company and mineral. Additionally, the basis of the calculation will go from the net revenue to the company's gross revenues (from the second half of 2017).

Vale, iron ore world leader

Vale is the second biggest company in Brazil and the world's fifth largest mining firm with annual revenues of US$ 33.2 billion (Worldatlas data). Privatised in 1997, the company remained one of the key actors in the public debate, because of the impact of its activities in the poorest regions of Brazil and its commitment to raising socio-economic standards. It is the leading mining firm with 52.3% of domestic mineral production and it operates in 13 different states across the country and in 37 countries around the world (Figueiredo and Piana, 2016).

[2] DNPM data, 2012.

The extreme success of Vale is related to its high level of integration and deep presence throughout Brazil. On the one hand, because of its logistic network Vale has a clear advantage and a high level of reliability both with suppliers and customers along the value chain (Economis, 2010). The company built more than 10.000km of railways across the country and it owns more than 216 locomotives, nine ports and a consistent fleet of ships (Falco et al., 2011). Beyond its historical presence in the state of Minas Gerais, a few decades ago Vale started to set up mines in the Southern Pará region which is the location of the last big project named S11D.

One of the most important investments that Vale made in the last years is in sustainable practises in order to both comply with federal standards and make its operations more accepted by the communities. Apart from different measures adopted to lower the environmental impact of the S11D project, which will be examined in the next section, the company established the Vale Technology Institute (VTI) which is the largest public private research partnership ever achieved in Brazil (Falco et al., 2011). Overall, in 2010 Vale spent US$ 1 billion in social and environmental investments (ICMM, 2013). Vale is actively involved in different innovation development projects. For example, the company was part of the testing, occurred of an environmental sustainable system developed by the Brazilian company New Steel N/A in Minas Gerais in 2010. They set up and patented, in Brazil and in the United States, the first fully dry iron ore tailing process that was adopted also in the S11D mine. Before, the flotation system that was used to raise the content of fine iron ore required an average of 1000 litres per ton. This is a major innovation for mining that is ranked second among water consumption industries (Mining News, 2016).

As a mining company operating in underdeveloped regions the licensing process is one of the most crucial aspect for Vale that needs to go through various negotiations before setting up a new project[3]. As an example, in the case of the licensing process for S11D there were three main parts to be negotiated: the company, a representative of the state and a representative of the communities involved. Normally, the approval comes from state authorities but if one project affects more than one state it is conducted at a federal level (e.g. in the case of the railways extension for the S11D both Pará and Maranhão states were involved) with the supervision of the IBAMA (Brazilian Institute of Environment and Renewable Natural Resources).

Since when the preliminary project was approved in 2001, Vale also carried the responsibility to increase the socio-economic indicators of the region where it started to operate. These are set as conditionalities[4], a very common instrument in Brazilian industrial policy, that the company has to meet in order to obtain and maintain its permission.

S11D case study

The project of the biggest mine in the world started in the 2000s and its operations took place in the Carajá Region. It entailed the construction of the mine and the expansion of the railways and the Madeiro port: the states of Pará and Maranhão were both involved. Mining operations at S11D are believed to last for 39 years, until the depletion of the deposit. The total investment for the construction of S11D was US$ 14.3 billion, divided between US$ 6.4 invested in the mine and US$ 7.9 in logistics (Vale doubled the railways that already existed) and port equipment (Vale, 2012b). The Brazilian National Economic and Social Development Bank (BNDES) financed the project with a loan of R$ 6.2 billion. Despite the fact that the investment value in absolute terms is not that impressive compared to Brazil's magnitude, Vale investment in

[3] The licensing process for the S11D was discussed during a telephone interview with a Vale employee in July, 2017

[4] In Brazilian mining conditionalities mainly take the form of local employement requirements (OECD, 2017)

Pará between 2011 and 2014 represents 32% of the total investment in the national mining sector and account for 15-20% of the state GDP (ICMM, 2013).

The decision to undertake this project is related to the high quality of mineral extracted in the region which has an average of 66% of iron, one of the purest in the world. The optimum quality and the increase in productivity made the S11D highly competitive, as the record production of 349 million tons reached in 2016 confirmed (Reuters, 2017).

Moreover, the mine is a centre of innovation and technology in the mining industry (Vale, 2012b). Production technology and logistics in the S11D were designed to lower the environmental impact in at least three ways. Firstly, the trackless system that transports the ore through a belt system which is not an innovation in itself but the first time in an iron ore mine of this magnitude. Secondly a fundamental innovation occurred in the cleaning step of the process with the use of the dry method that sifts through natural humidity (this led to 95% less of water consumption than traditional system). Lastly, there was an important reduction of emissions due to the new electric system that transport the main equipment of S11D (Vale, 2012b).

S11D impact: consumption and production linkages

The S11D had an important impact in the Southern Parà region both during its construction and since the running of the site started in 2016. This section will analyse the impact of Vale's S11D project, examining consumption and production linkages, focussing on backward linkages as they are an 'important and unrealised potential for industrial development' (Hirschman, 1971).

Consumption linkages

Consumption linkages are found when an activity generates more income than is spent in the local economy. At the beginning the new income is spent on imports that should later be substituted by domestic production (Hirschman, 2013: 161). Consumption linkages from the S11D are analysed looking at two indexes, GDP and the creation of formal labour. The data refer to the two municipalities where the project S11D has a major impact. As the state of Parà is very big and diverse it would be misleading to consider data at a state level: it was necessary to deepen the analysis at the two municipalities of Parauapebas and Canaã dos Carájas. Figure 6 shows the GDP in the two municipalities that surged considerably during the S11D operations.

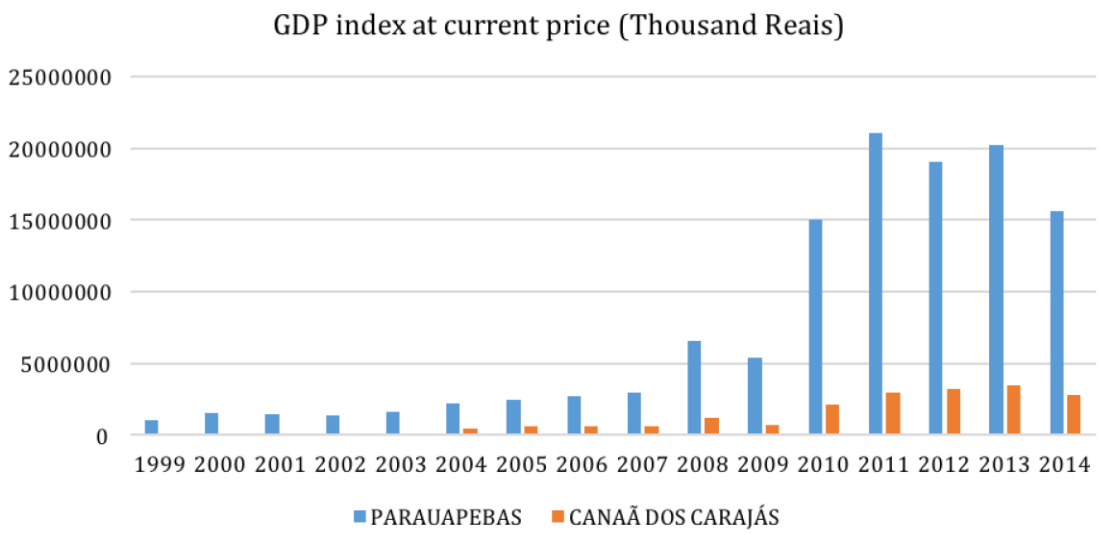

Figure 5. Source: Author's own construction based on IBGE dataset.

As mentioned before, the absolute number of Brazilians employed in the mining sector is negligible but considering the Southeast Parà region the direct employment in mining is highly significant, reaching 20% of the total. Indirect effects are believed to be large as well due to the partnership developed between Vale and the state government (ICMM, 2013; OECD 2017).

Figure 6 and 7 show the creation of formal labour obtained through the analysis of RIAS Brazilian government dataset on formal employment creation. In addition, a study conducted by the MME[5] found that the multiplier effect in the mineral sector is 1:13, which means that for every employment creation in mining another thirteen (direct employments) are created along the value chain.

[5] Study conducted in 2012 by the Ministry of Mines and Energy's Secretariat for Geology, Mining and Mineral Processing. Source IBRAM, 2012.

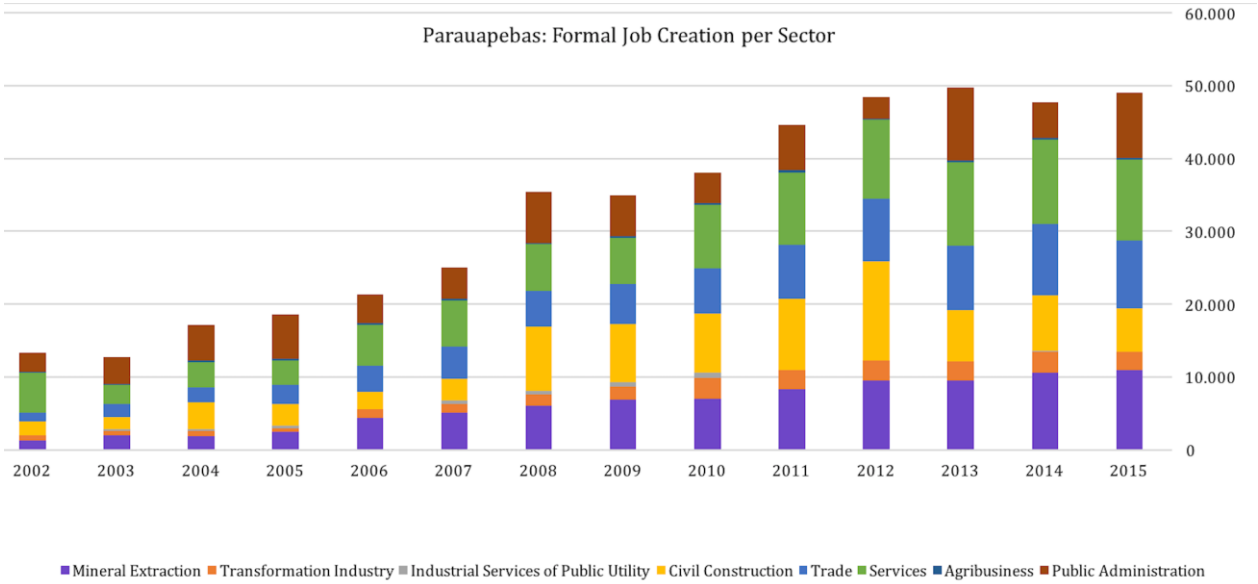

Figure 6. Source: Author's own construction based on RIAS dataset

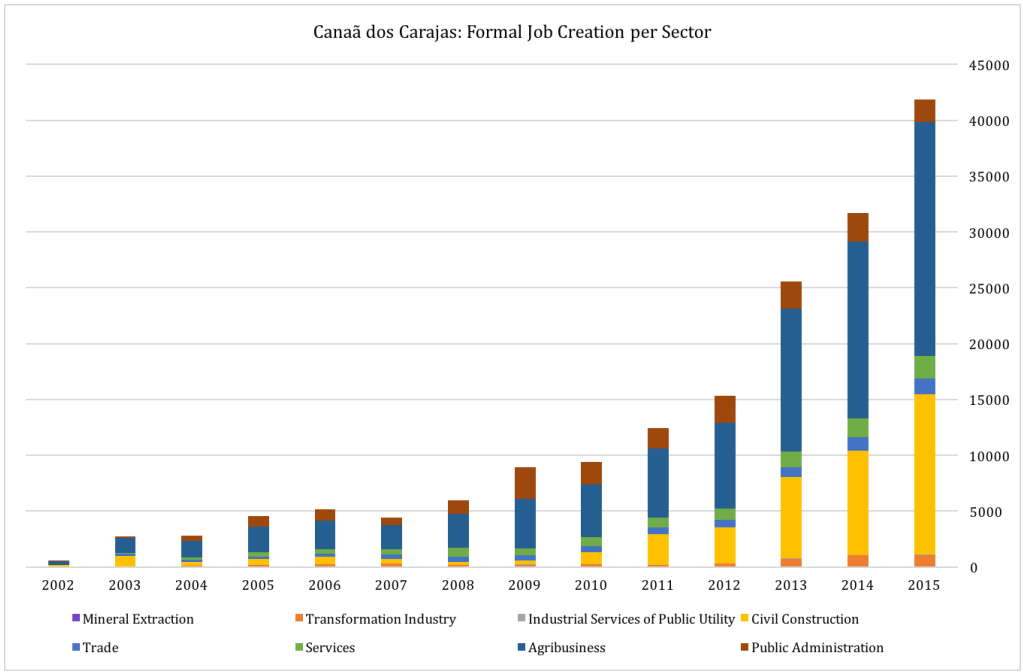

Figure 7. Source: Author's own construction based on RIAS dataset.

The two municipalities had a rapid increase in formal job creation especially in mineral extraction (Parauapebas) and civil construction (Canaã dos Carájas); according to SINE (National Employment System), due to the high demand, wages in mining have increased in the last decade. Also, other sectors like Agribusiness, Services and Public Administration present a sustained increase.

Vale (2012b) reported that, during the construction of the S11D, 30,000 jobs have been directly created between Pará and Maranhão. It is important to consider that not all the jobs created were permanent. Many of them

have been dismissed but as the graph related to Canaã dos Carajá municipality shows in Figure 8 the balance has been positive.

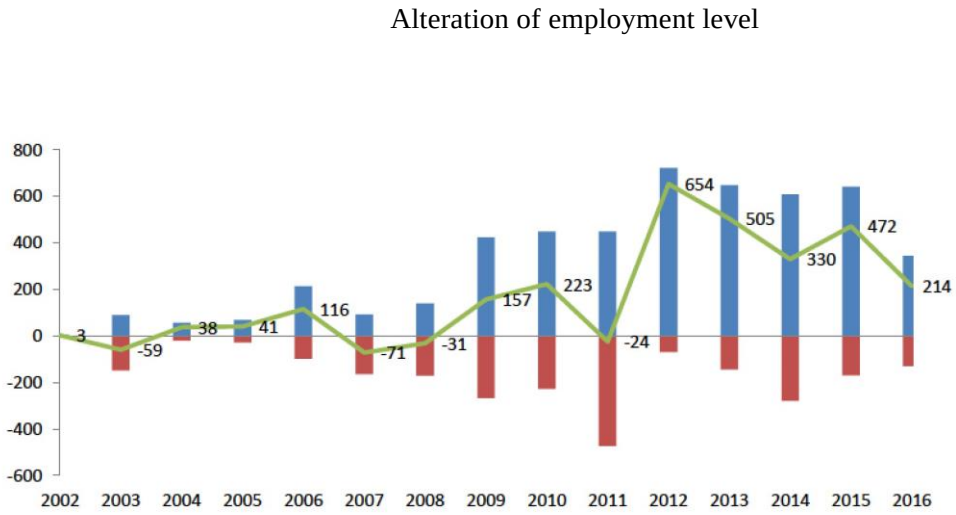

Figure 8. Soruce: MTE, Vale (2017:89)

Production Linkages

Forward linkages

Forward linkages from the iron ore industry, as analysed in section 3.2, are related to the production of steel (98% of iron ore outcome is linked to the steel industry). Brazilian steel production has fluctuated in the last decade and is highly dependent on external shocks (Figure 9). The domestic consumption of steel is around 26.5 Mt and Brazil needs to import 4 Mt of this amount (Soto-Viruet, 2016).

Figure 9. Source: World Steel Association

Brazil also imports a considerable amount of steel products like machinery parts whose import value in the trade balance is US $41.2 billion[6].

One of the biggest missed opportunities in terms of forward linkages for the S11D project is related to the construction of the colossal vessels VALEMEX, whose production has been undertaken in South Korea (7 vessels produced by Saewoo Shipbuilding and Marine Engineering), in China (12 vessels produced by Jiangsu Rongsheng Heavy Industries), and in Japan (in charge of the biggest vessel that will be delivered in 2019)[7]. Brazil did not have the manufacturing capacities to build vessels of this magnitude (Vale, 2016).

Backward linkages

[6] Data obtained from the Observatory of Economic Complexity *http://atlas.media.mit.edu/en/profile/country/bra/*

[7] Skype Interview with Vale employee. July, 2017.

Backward linkages are a complex and often overlooked tool of industrial sector analysis. In Brazil the opportunity to develop backward linkages from the iron ore value chain mainly stem from services and consumable goods whilst it is weak from capital goods equipment.

For the S11D, Vale invested locally with an average annual procurement in Southeast Pará of R$ 1.3billion (22% of the total according to Figure 10) (ICMM, 2013: 44).

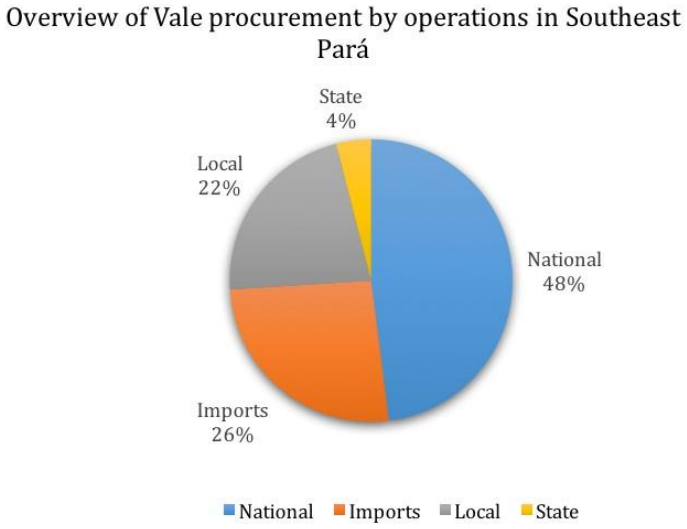

Figure 10. Source: Author's own construction based on Diagonal (2006, 2010)

Procurement by operations, as illustrated in Figure 10, does not distinguish between capital goods provision and services. This final part of the section on production linkages tries to shed some light on this aspect.

Interviews within the Brazilian academic and research sector confirmed that the market for capital goods for the mining sector is characterized by two aspects. On the one hand, the high and long-lived presence of foreigner companies through their subsidiaries made the market saturated[8]. On the other hand, foreigner subsidiaries do not have a passive presence. Instead, they actively engage with local suppliers for the innovation and adaptation of new technology. MNCs were decentralised in Brazil and developed locally, working together with Vale –and to a lesser extent with local suppliers[9] to build innovative products and capabilities. Positive interactions have been numerous: the aforementioned NEW/Steel dry method innovation and an updated version of the belt conveyor for the S11D, which was the result of a joint work between the subsidiary of the MNC 3M[10] and the local supplier PUREquipamentos, are two example of the active dynamic.

This interaction and international presence is the main reason why in Brazil the equipment supply market is more mature than the services supply market. But it is less embedded in domestic

[8] Telephone Interview with Doctor Paulo Figueiredo. August, 2017.

[9] Ibidem

[10] 3M is the US Minnesota Mining and Manufacturing Company. For a complete analysis of this case see Figueiredo and Piana (2016: 409)

industries. The role of Vale in this aspect is ambiguous: despite having triggered a working network between foreigner subsidiaries and local suppliers (Figueiredo and Piana, 2016) the company does not act in a systematic way.

The weakest aspect in terms of backward linkages is related to the foreigner subsidiaries that supply machinery for the mineral sector (for example, Volvo, Komatsu, Caterpillar). Much of this machinery fabricated in Brazil relies on US suppliers for parts and components such as belt conveyors, crushers equipment and drilling machines.[11]

Nonetheless, the presence of international subsidiaries did not completely impede the rise of Brazilian companies. There are manufacturing suppliers competing with high-level technology and benefiting from technology transfer agreements. Some domestic companies such as Dedini, Jaraguá, and Randon have important shares in the market (ITA, 2017). Linking up with local suppliers has been important both for Brazilian companies and for MNC because Brazil has very high import tariffs on mining equipment.

In the Southern Pará region, the creation of backward linkages stems mainly from KIMS and specialized service contractors. The number of companies related to mining services are growing because of an increasing demand, as data from the *brasil.infomine.com* show. In terms of engineering services, exploration and equipment maintenance services, the interviews held both with the academic sector and with Vale employees confirm the almost exclusive reliance on Brazilian suppliers regarding KIMS. For example, the two companies Techint and Montcalm Montagens Industriais were responsible for the assembling services and electro-mechanic equipment related to the remote control, automation and communication systems of the belt conveyor in the S11D. The outstanding role of Brazilian service companies is particularly true for SMEs in knowledge services that are based in Minas Gerais, which is a state where mining activities have been present for a long time. In the Northern region where the S11D project is located SMEs are not that spread, but important programs have been put in place, such as Inove and REDES[12]. The former is promoted by Vale to improve local SMEs with training to service providers, financial solutions and incentives for business initiatives. The latter is promoted by Vale and other mining companies in order to support relationships between large and local firms in the Pará state (OECD, 2017).

A closer analysis of the project reveals a substantial local procurement placed side by side with imports of capital goods equipment especially in terms of big new structures whose design and construction was imported, mainly from China.

For the construction of the plant, the S11D used the modularization system that was applied for the first time to an iron ore project. 109 modules have been built: the material for the first module was imported from China and built with the supervision of two Chinese specialists (Vale, 2017). The rest was built in Brazil. For the modularization process, more than half of the equipment came

[11] Looking at global imports, Brazil does import 2.2% of stone processing machines and 5.4% machines to crush and stone (Observatory of Economic Complexity Data)

[12] See *http://www.redesfiepa.org.br/quem-somos*

from China (e.g. 64 vessels, 14.000 tracks, etc.) (Vale, 2016). Excavators were exclusively imported from the US companies Bucyrus, John Deere and Caterpillar[13].

As for the extension of the Madeiro port, this was the biggest port infrastructure ever realised in Latin America and it was managed by Brazilian contractors. The Cant Traveler company managed the construction of the two bridges that guarantee the access to the big VALEMEX vessels, both of them were fabricated by Maranhão companies. Overall, 41% of the contracts signed for the enlargement of the port are from Maranhão (Vale, 2015).

The extension of the railways was managed by Brazilian contractors and the railways were fabricated both in Brazil and imported by Brazil, Japan, US and Eastern Europe (Vale, 2015).

5. LINKAGES DEVELOPMENT: OUTCOME AND POLICY IMPLICATIONS

The creation of production and consumption linkages is triggered by the interaction of what Morris et al. (2012) call contextual determinants. The impact of the S11D in the Southern Pará presents a positive dynamic in terms of consumption and backward linkages. Despite the fact that the capital goods market seems pretty saturated, there are important opportunities for backward linkages, especially related to local suppliers of specialised technology services. Brazilian companies already play a key role in the service sector within the mining industry.

This paper addresses the development of market-driven linkages as being triggered by two elements, which are the location specific constraints and the dynamics between the four contextual determinants individuated by Morris et al. (2012). In the S11D case, constraints that triggered developmental dynamics are related both to the rejuvenation of the sector (section 3.2), which shed light on the innovation potential of mining, and to iron ore specificities in the examined Southern Parà region. The specificity of the deposits in the Carajá region together with the urgency to comply with environmental standards led to the emergence of important innovations which allowed for the exploitation of pure iron ore extraction whilst operating in a sustainable way.

As for the contextual determinants, the first is the ownership of the company, where a national owned company presents advantages over a MNC for the development of linkages. A national company such as Vale is more embedded in the local economy therefore it is more aware of the socio-economic environment and it could play the role of a facilitator in the absence of formal policies (Figueiredo and Piana, 2016). The second determinant is infrastructures, whose importance relies in the fact that it binds all economic activities. Infrastructures were crucial in the case of Vale and the S11D. The impact of infrastructure depends on their reliability and, as discussed above, the high level of Vale integration made the infrastructure system an important advantage. The type of commodity played a role in the positive impact of the infrastructure systems: iron ore needs large scale non-commodity specific transportation as railroads that have positive externalities for suppliers, for example in terms of lowering logistic costs. The expansion of the railways from the Southern State of Pará to the North of Maranhão is an important upgrade for the regional infrastructure and transportation issues.

[13] Telephone Interview. July, 2017.

The third determinant is related to the generation of domestic capabilities and innovation. Mineral extraction and high-scale projects require various skills. The availability of an appropriate pool of skilled people determines whether the jobs will be occupied either by locals or by foreigners. Vale developed an outstanding relationship with Brazilian universities that was fundamental in creating and giving inputs to the knowledge linkages development that could act as a basis both for local employability and innovation knowledge creation (Figueiredo and Piana, 2016).

Lastly, the fourth element is policy. Industrial policy is a fundamental tool in the Brazilian economy: despite the important effort in setting stringent conditionalities, the alignment between different measures is not always effective. For instance, local employment requirements are not matched by local content requirements in the mining sectors which is a fundamental aspect in order to explore the little space left in the capital goods market and to upgrade the industrial sector. There have been efforts in this direction but not sufficient: for example, the plan Bigger Brazil that aims to promote domestic manufacturing through a fiscal stimulus package, between 2011 and 2017, did not produce the expected results (OECD, 2017). There is still important space and demand for corporate and government policies.

CONCLUSION

The paper engaged in the debate surrounding the role of natural resources in the economic upgrade and diversification process. The "unanswered question" (Torvik, 2009) of whether there is a casual effect from resource abundance to growth, found a positive response in this case study. The analysis has been carried out through the examination of consumption and production linkages dynamics in the iron ore value chain focussing on the S11D project. It was found that the very specific conditions of this case allowed for a positive development of both consumption linkages and backward linkages. The contextual determinants were used as a framework to better understand the reasons behind the positive creation of linkages. As Vale is a nationally owned company which has deep interactions with universities and a key role in the infrastructure apparatus it could played a dynamic role in the disentangling of linkages.

Consumption linkages are found to be strong because of active state government policies that demand local worker employment creation as a conditionality. Backward linkages are found to be on a disentangling phase especially in relation to knowledge and technological services. The weakest aspect in terms of local backward linkages development is related to the active role of international subsidiaries that keep on importing parts and components from aboard. It is important to promote policies that aim to spur economic diversification and local content in the industry.

The two-way framework of NR sector specific constraints and contextual determinants has been useful and could be replicated to proceed on a case by case study in order to better understand why a linkage development policy may work in one context but not in another. The analysis

carried out within this paper could be improved with a complete dataset on Vale suppliers for the S11D project and with a future following-up research in order to examine whether the socio-economic gains of the S11D will effectively trespass the construction phase.

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