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DOCTORAL THESIS

INDUSTRIAL ORGANIZATION DYNAMICS: Bounded Capabilities and Technological Interfaces of the Brazilian Shipbuilding and Offshore Industry

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Tese de Doutorado apresentada ao Programa de Pós-Graduação em Administração da Universidade Federal do Rio Grande do Sul, área de concentração Inovação, Tecnologia e Sustentabilidade, como requisito para a obtenção do título de Doutor em Administração.

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To my wife and daughter
À minha esposa e filha

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ABSTRACT

Technological progress and Innovation are generally accepted as the fundamental phenomenon of economic development of nations. However, understanding the underlying mechanisms behind 'development' still seems to be a challenge. This requires an empirical assessment into the way economic activity is created and distributed across firms and markets giving the shape and scope of industrial organization. Drawing on evolutionary and transaction costs, industrial organization is defined as economic relations of technological complementarities where bounded capabilities connect through technological interfaces. The way firms and markets deal with their capability *boundedness* will determine the dynamic potential that can be generated in the economic system. This research begins by asking *what determines shape and scope of industries and its underlying dynamics?* In order to address this question, this thesis will analyze the recent developments of the Brazilian Shipbuilding and Offshore Industry where government has put in place an entire institutional arrangement to boost industrial/market competitiveness and technological catch-up in the hopes of generating economic development. The scenario of a re-emerging complex sector where the capabilities of firms are under construction, allows the examination of the dynamics behind the organization of the industry through the analysis the different technological interfaces involved. The research begins by first analyzing the evolution and dynamics of the shipbuilding sector worldwide and later, it explores the recent shape, scope and dynamics of the Brazilian Shipbuilding Industry by assessing, describing and analyzing the set of technological interfaces and bounded capabilities found at one shipyard. Results show that despite of the policies designed to promote the development of the sector, the industry depends on the ability of the various economic agents absorb the necessary knowledge and give cohesion to technological interfaces. Paradoxically, project stability seems to precede industrial dynamics in order to accelerate learning process and effectively succeed in catching-up. It depends on the internal and external integration of the different actors involved. While the analyzed site has current specific assets that denote a competitive potential, it sought to overcome the limits of knowledge through the intensification of technology transfer. Instability at the interfaces play against learning. This is increasingly improving through the intensification of knowledge transfer with the international partner. Despite the favorable institutional environment intended to provide the industry with some time to catch up, the window of opportunity created by it may not be long enough. Therefore, the industry needs to find a way to learn faster. Technological transfer mechanisms should be used to reduce the costs of building capabilities.

Key-words: Industrial Organization Dynamics, Technological Interfaces, Bounded Capabilities, Shipbuilding and Offshore Industry.

RESUMO EXPANDIDO

O progresso tecnológico e a inovação são geralmente aceitos como propulsores do desenvolvimento econômico das nações. No entanto, a compreensão quanto aos mecanismos subjacentes ao desenvolvimento ainda parece ser um desafio tanto para pesquisa quanto para a formulação de políticas públicas. Isso requer uma avaliação empírica na forma como a atividade econômica é criada e absorvida pelos diferentes agentes econômicos dando a forma e escopo da organização industrial em uma região ou setor. Tendo com base a teoria evolucionária da mudança técnica e na teoria dos custos de transação, organização industrial é definida como relações econômicas de complementaridades tecnológicas onde as firmas estabelecem interfaces tecnológicas com outras em função dos seus próprios limites. A forma com que firmas lidam com os seus próprios limites, irá determinar o potencial dinâmico da organização industrial. Está pesquisa visa responder a seguinte pergunta: *o que determina a forma e o escopo da indústria e sua dinâmica subjacente?* Para responder essa questão, este estudo irá analisar os recentes desenvolvimentos da Indústria da construção naval brasileira e offshore Brasileira onde, nos últimos anos, houve uma grande mobilização institucional para viabilizar o catch-up de tecnologia e competitividade no setor. O cenário recente de construção e ampliação de capacidades das empresas em uma indústria complexa permite observar a dinâmica da organização industrial por meio da análise das interfaces tecnológicas. A pesquisa traz uma revisão da dinâmica e evolução da indústria naval nos principais polos produtores do mundo e, posteriormente, parte para a análise detalhada do desenvolvimento de da indústria no Brasil através da descrição do conjunto de interfaces tecnológicas e relações industriais inerentes ao arranjo de um grande estaleiro. Os resultados mostram que, apesar da elaboração de políticas que visam favorecer o desenvolvimento do setor, a indústria depende da capacidade dos diversos agentes econômicos absorverem os conhecimentos necessários e dar coesão às interfaces tecnológicas. Paradoxalmente, precede à geração de uma dinâmica industrial, buscar dar estabilidade às interfaces tecnológicas com o intuito de acelerar o processo de aprendizagem. Isso depende da integração dos diferentes atores envolvidos. Embora o estaleiro analisado detenha os ativos específicos que denotam um potencial competitivo, o mesmo busca superar os limites de conhecimento por meio da intensificação de transferência de tecnologia que lhe permita utilizar as tecnologias e, principalmente, dar fluxos e rotinas necessárias para operar de forma mais eficiente. Apesar do ambiente institucional favorável que deu origem ao ressurgimento do setor, a janela de oportunidade criada pelas instituições é limitada. Portanto, o setor precisa encontrar maneiras de aprender mais rápido, porém é preciso escolher mecanismos que economizem nos custos de construção de capacidades. Dado os limites das capacidades das empresas brasileiras, mecanismos de transferência de tecnologia parecem ser uma das principais estratégias para reduzir esses custos.

Palavras-Chave: Dinâmica da Organização Industrial, Interfaces Tecnológicas, Capacidades Limitadas, Indústria Naval e Offshore.

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SUMARY

1. Introduction

This study is an assessment on industrial organization dynamics. It parts from one simple premise largely discussed and agreed in the literature: technological change and innovation are on the basis of economic development. This process is the direct result of the internal dynamics produced within an economic system composed of multiple bounded capable economic agents (firms and consumers) that linkup through technological interfaces and transactions giving the shape and scope to industries. Analog to the idea of the division of labor by Adam Smith (1776), industrial organization is the result of the division of capabilities across firms and markets. From the way economic agents are able to deal with their "boundedness", arises the different possibilities of organizing an industry and, consequently, the types of technologies that can be nurtured. However, understanding the underlying mechanisms behind the emergence and structuring of industries and its dynamic potential seems to be a challenge in the academic research.

This study aims at advancing in this direction by posing the following research question: *what determines the shape and scope of an industry and its underlying dynamics?* To do so, it analyzes the recent developments of the re-emerging Brazilian Shipbuilding and Offshore Sector, its achievements, pitfalls and implications for both a theory of industrial organization dynamics and for policy-making. In less than a decade, Brazilian national industrial policy has elected the shipbuilding and offshore construction as one of its strategic sectors for technological development, industrial growth and job creation. With little less than a decade, this sector has experienced a sudden growth in the country with several new yards being constructed in different locations. As a complex product system (Hobday, 1998), this re-emerging sector can be thought of as a practical experiment on industrial organization dynamics in the making. Nonetheless, before entering the empirical issues of this research and specifically about this industrial sector, it is necessary to begin by defining 'industrial organization dynamics' and why this is important.

When one looks for answers within the mainstream field of industrial organization (IO), it is possible to observe that the fundamental questions have largely drifted away from Smiths first inquiry on the division of labor and wealth creation. Drawing on neoclassical economics, the field focuses on the effects of prices and information on the movements of the market's "invisible hand". According to Jong and Shepherd (2007, pg. *xix*) in their book on the *Pioneers of Industrial Organization*, the primary focus of the field is "(i) competition, the driving force of most modern markets, and (ii) monopoly power, which interferes with competition's good results". Examples of these developments evolved from monopolistic and imperfect competition (Chamberlin, 1932; Robinson, 1933); market-structure (Mason, 1939); game-theory (Von Neumann and Morgenstern, 1944), structure-conduct-performance (Bain, 1956), economics of information and oligopoly (Stigler, 1961; 1964), to contestable markets (Baumol, 1982). These lenses examine the problem of the economics of industries from a macro-perspective where clear conceptual boundaries between industries and markets can be blurred. In fact, industries and markets are often treated as interchangeable terms (Phillips and Stevenson, 1974; Carlton and Perloff, 2004; Jong and Shepherd, 2007).

However, while these issues are important, three concerns can be draw about the mainstream field of IO. First, it is not the main concern of the filed to describe what outlines the way the industry will be organized from a more refined empirical perspective. According to Coase (1973) up until then, not only we were "appallingly ignorant about the forces which determine the organization of the industry" (p. 64), but also there was no real filed of industrial organization. In his words, such field should describe "the way in which activities are undertaken within the economic system and divided up between firms" (p.61). Second, only after Schumpeter (1911) and Coase (1937) that the role of the firm had been highlighted at the center of this process. In fact, the general neoclassical view in economics takes the firm as a 'black box' that transforms factors of production into outputs (Teece and Winter, 1984). Third, mainstream IO has is not well suited to explain how the dynamics of technological change and innovation affect the configuration of an industry (Carlsson, 1987).

After all, industrial organization is the organization of the microeconomic activity. In this sense, in order to take account for the dynamic process of how economic activity are undertaken and divided up between firms, it is necessary to understand how firms and markets are intertwined in a more refined matter. Firms are key elements to this process and can be the focus of research on their own. Nevertheless, when seen at the industry level, they are only limited holders of a particular repertoire of technological know-how, routines and capabilities that economically exist to fulfill the needs of some other limited capable economic agent.

This research shares a similar view with Coase (1973) regarding the starting point of the industrial organization. While "the field has moved far beyond the mere description of how industries are organized, this is the basic level where the discussion must begin" (Panzar, 1989, p.4). In addition, any analysis on industrial organization should not neglect the changing nature of industrial structure that result from technological progress, which makes it essentially dynamic and co-evolving (Nelson, 1995).

In this sense, two main approaches are highlighted. First, transaction costs economics (TCE) was the first formal approach to follow in the direction Coase was demanding. By setting the transaction as the unit of analysis, Williamson (1985) showed that economic features of the transaction are the key determinants to how an industrial arrangement will be organized. TCE advances in the marshy boundary of the firm and the market. At this interstice of firms and market resides a certain quantity of bounded rationality about the best option between hierarchy or market. This bounded condition results in the need for two economic agents to connect in order to complement each other's limits. TCE acknowledges this connection as the transaction, whenever technological 'nonseparabilities' are not significant (Englander, 1988). Whenever technological interfaces can be separated, an economic transaction may take place as the most efficient solution.

However this first approach is insufficient as the sole explanation of how industries will be organized. Technology and economics are intertwined giving shape and scope to industrial organization. Neoschumpeterian perspectives on the evolutionary process of technical change (Nelson and Winter, 1982) highlight the role of the routines and capabilities of the firm in the definition of its boundaries. What will determine the choice among different solutions is the extent to which firms are able to cope with different sets of knowledge through technological and organizational capabilities efficiently. Whenever firms reach their capability boundaries they must linkup with others (Langlois, 1989).

Any economic relation is the concrete result of *technological interfaces* connecting two different clusters of applied knowledge (*bounded capabilities*) to solve a specific problem through an *economic transaction*. In this sense, industrial organization is seen as the unfolding consequence of economic relations of technological complementarities. By distinguishing a transaction from technological interfaces, we advance in the marshy zone between industries and markets. When different economic agents are connected in a semi-stable techno-economic (market) relation, we have an industry. While technology gives the *shape* to an industry by defining the technical sequence of activities that must happen, economics will delineate the *scope* of industrial relations by organizing how a particular technological sequence will be distributed across different economic agents creating firms and markets.

Change in the scope of an industry, may follow TCE reasoning, however it is usually a short-run phenomena (Langlois, 1992). In the long-run, eliminating the gap between firm and market requires the increment of applied knowledge beyond industrial boundaries, altering shape and scope of the industry. In other words, altering the dynamics of the organization of the industry. In this sense, the analytical emphasis shifts from the content of the industry to the movements of its boundaries. The question changes from "how the industry is organized" to how its boundaries move irreversibly by the increments of new technologies across different economic agents. It is as if bridges are constantly being built, destroyed and rebuilt across firms and markets altering shape and scope of the industry. Industrial organization theory, therefore, should provide a clear understanding of how economic activity is *created*, *distributed*, *eliminated* and *re-created* across different economic agents. To do so, technological and economic determinants must be taken into account altogether.

This research acknowledges the introductory efforts to establish a field of dynamic economics (Klein, 1977) and industrial dynamics (Carlsson, 1987, 1989, 1992) and also that of National Systems of Innovation (NSI) (Freeman, 1987, 1995; Lundvall, 1992; Nelson, 1993) in the analysis of the dynamic process industrial and economic development in various levels (firms, sectoral and regional).

This study argues that the answer to what determines industrial configuration (its shape, scope and dynamics) will be found as we analyze the movements of the techno-economic boundaries, which is referred to as technological interfaces. If, on the one hand, technology directs development and production, on the other, economics validate the system through firms and markets. As a continuous moving system, industrial organization evolves through techno-economic interactions between economic agents.

1.1. Research Goals and Relevance

This is study was motivated by the recent developments of the Brazilian Shipbuilding and Offshore Industry. Since 2003 a slow movement to re-structure the Brazilian Shipbuilding and Offshore Sector began. This process received an important boost in 2005 with the findings of large oil fields in ultra-deep waters of the Brazilian coastline. Institutions were set to encourage production of several vessels with 70% of local content, which have put Brazilian public and industrial actors facing a challenge: how to strategically plan and develop a local chain of technological interfaces for production and innovation for the sector?

In this sense, governmental strategic intentions to nurture the Shipbuilding and Offshore Sector have generated a unique opportunity for studies aimed at understanding the dynamics of industrial organization and innovation. This sector, therefore, offers the conditions to observe the emergence and dynamics of the process of building capabilities and industrial relations that will ultimately give shape and scope to an industrial sector.

This study will explore the dynamics of industrial organization based on the analysis of the evolutionary movements of the boundaries of firms and markets. In order to understand the determinants of industrial shape, scope and dynamics, this analysis will explore the technological interface connecting bounded capabilities as the unit of analysis.

The following goals are specified:

- To review and analyze the evolution of an industrial sector worldwide
- To analyze the evolution of the same sector in Brazil
- To map the chain of technological interfaces in this industry
- To identify the technological determinants of industrial *shape*
- To describe the techno-economic factors that define industrial *scope*
- To explain the sources of change and innovation across the whole chain and how it affects technological interfaces
- To critically analyze the overall competitiveness of the industry regarding technological gaps and economic challenges

The structure of this research is presented in the next sub-section.

1.2. Structure of this Study

This study is organized as follows. Chapter 2 presents an essay on the nature of industrial organization as how economic agents (firms and markets) engage in economic relations of technological complementarities based on their different set of capabilities. In economic terms, industrial organization can be seen as the evolution of the very division of labor.

Chapter 3 presents the concept of technological interfaces as the unit of analysis for understanding industrial organization and explore the dynamics behind the process of appearing and disappearing of technological interfaces as firms expand, reduce and move the position of their capability boundaries. Three important dimensions are highlighted in the definition and change of interfaces: *standards* define technical interfaces; *modularity* creates interfaces and help define capability boundaries; and innovation capabilities can “creatively destroy” technological interfaces and redefine this relations.

Chapter 4 discusses the determinants of industrial Shape, Scope and Dynamics. In this section, three main groups of theories that form the historical backbone of industrial organization are analyzed seeking their complementarities: mainstream neoclassical approach to industrial economics and the notion of ‘technological possibility set’ highlight the fact that, at a giving point in time, technologies available give the shape of industrial activity setting the technical sequence of production. Transaction costs puts emphasis on the economic determinants behind modes of governance and efficient distribution of economic activity across different firms and markets, in other words, influencing the Economic Scope of industries. Finally, Evolutionary economic of technical change explain the role of knowledge, routines and capabilities that influence not only the scope of bounded capabilities, but also the eventual change and dynamics of shape and scope of industrial organization.

Chapter 5 presents the methodological procedures and research design. The research used the method of building theories from case study using the Shipbuilding and Offshore Industry. By using multiple sources of data such as: literature review on the evolution of international and Brazilian shipbuilding, and a deep case study based on interviews, observations and internal data provided by the firm, the research provides a detailed description of the capability boundaries and interfaces that account for the industry’s current shape and scope.

Chapter 6 presents the Shipbuilding and Offshore industry, its evolution around the world and key technological and economic determinants behind the main firms and markets.

Chapter 7 describes the historical evolution of the Brazilian Shipbuilding and the recent institutional set-up that allowed its re-emergence. The section presents the current organization of the Brazilian shipbuilding industry from oil discoveries, the major industrial policies set to support the re-emergence of the sector and the role of Petrobras as the engine of this process.

Chapter 8 describes the findings from the case study conducted. A detailed description of the capabilities and technological interfaces behind industrial shape and scope is presented. A description of the productive technological sequence is described as well as the organizational interfaces that direct production (industrial shape). Later, the analysis of the scope of the industry was conducted by describing the number and types of firms present in the arrangement and the types of complementarity industrial relations they established with the shipyard. As capabilities are bounded, the case study presents dynamics as the constant pursuit to solve interface frictions and increase learning.

Chapter 9 discusses the theoretical implications for industrial organization dynamics and the main challenges posed to the Brazilian Shipbuilding and offshore industry regarding the costs of building capabilities (in spite of the governmental/market incentives). Stability and dynamics are intimately related as the dynamic process of capability building requires stability in order to improve learning, productive skill and routines.

Chapter 10 presents the final remarks, policy, methodological and managerial implications as well as future research opportunities.

2. The Nature of Industrial Organization: *Firms and Markets, Boundaries*

In a classical economic sense, inherent to any economic system is the ability to satisfy human needs through the production and consumption of goods and services following an efficient allocation of scarce resources[1]. The concern with the way individuals organize economic activity is, therefore, an old one and can be traced back to ancient times. If in earlier periods, economic activity could be organized through the simple division of labor, mediated by exchange, in modern dynamic and more complex times, this organization is achieved through industrial production and consumption mediated by transactions[2] among different economic agents that are part of several industrial arrangements.

Industrial organization, then, can be seen as the natural evolution of the division of labor into a progressively more complex techno-economic social setting. However, even in complex system, the essence of how economic activity is organized remains the same. It is the ultimate result of the interplay between *sellers* and *buyers* that, by engaging in an economic exchange, become *firms* and *markets*.

In order to be able to draw any assumption on the emergence and evolution of industrial organization, these two economic institutions must be addressed. Why are there firms? Why are there markets? How do they change over time? Although it may be possible to talk about one or the other in isolation, their very existence and dynamics really dependent upon one another.

2.1. Firms and Markets

As the main institutions of the economic system, *firms* and *markets* are on the basis of industrial organization and are inexorably inseparable. In fact, it is almost impossible to define these two institutions in isolation once they are mutually dependent and bounded by each other. While the market was historically the first interest of economic theory, definitions on the firm have a wider retrospect.

The firm can be regarded in many ways, from: simple production functions (Marshall, 1898), alternative ways to coordinate economic activity (Coase, 1937), collection of productive resources (Penrose, 1959), nexus of contracts and treaties (Alchian and Demsetz 1972; Williamson, 1985, Aoki, et al, 1990), set of skill, routines and capabilities (Nelson and

[1]To Robbins (1935), "Economics is the science which studies human behavior as a relationship between ends and scarce means which have alternative uses"

[2]According to Commons (1932) and Williamson (1985), within the context of a formal institutional environment, transactions (instead of exchange) are the pattern of activity that governs the relations among agents following the principles of conflict, mutuality and order.

Winter, 1982), storehouse of information (Prescott and Visscher, 1980), a set of assets under common ownership (Hart, 1986), are repository of knowledge (Winter, 1991), or a complex mechanisms for coordinating and motivating individuals' activities (Holmström and Roberts, 1998). All of these definitions are complementary, but they seem to hide the essence of the firm, which is a locus of productive knowledge and assets that needs to transact in order to exist. The firm is a techno-economic agent that must be able of producing some valuable solution to fulfill a knowledge (used to supply different needs) market gap with efficiency (Zawislak et al, 2012). The firm only exists to a market and the market endorses the firm through the mechanism of selection.

As the firm's inexorable counterpart, the *Market* has often been defined vaguely or simply taken for granted in theory. Markets are commonly defined as the group of buyers and sellers that meet to exchange specific goods or services. Hodgson (1988) maintains that the closest definition to a market is the one provided by Mises (1949) where he states:

> "The market economy is the social system of the division of labor under private ownership of the means of production […] The market is not a place, a thing, or a collective entity. The market is a process, actuated by the interplay of the actions of various individuals cooperating under the division of labor." (Mises, 1949, p.257)

Markets are necessarily a social construct (Samuels, 2004) and thus, an institution (Hodgons, 1988) with some pre-established "rules of the game" that outlines its structure, based on the expectations, needs and desires. Following Lazonick (1991), in the market, buyers and sellers pursue self-interest independently both in defining their goals and in the activities to achieve those goals. Buyers will engage in market exchange with the seller only insofar as the personal (or firm-specific) capabilities[3] of the seller in some way enter into the use-value of the good or service to be bought.

If one reads closely, the definition of 'market' by Mises is not too different to that of the firm. Ronald Coase (1937) inaugurated the transaction costs approach by describing firms and markets as alternative ways of coordinating economic activity. A firm will emerge whenever an entrepreneur-coordinator is able to obtain marginal gains by coordinating a particular transaction under an organizational structure or, as Williamson (1975) called, under a *hierarchy*. The distribution of economic activities among firms and markets may vary as frictions (transaction costs) shift the efficient possibilities of organization favoring one over the other.

[3] By capabilities it is presume the set of applied knowledge (technology) and skills, translated into the firm's routines and search routines necessary to operate and change.

As these conditions change firms have to decide on what activities to integrate (*make*) and what activities to contract out (*buy*). However, this decision is not so trivial. As Coase (1988b) argues, this view often concentrates on the firm as a ‘purchaser’ of inputs it will use and it neglects the main activity of the firm, which is ‘running a business’. He continues arguing that a full understanding on the nature of the firm depends on a comparison of the costs’ differences in organizing certain economic activities among different firms. Still, through this view, ‘running the business’ and the firm existence *per se* is a matter of economizing and less of strategizing (Williamson, 1991).

Somehow, transaction costs economics approach seem to leave aside or (at least) take for granted an important part of transaction, that is, *sales*. Rather than being ‘purchaser’ continuously faced with the ‘make or buy’ dilemma, ‘running the business’ more often than not, means to figure out market gaps to be fulfilled with solutions brought about through the firm’s capabilities (Zawislak, et al 2012).No firm exists by itself, rather, it relies on the completion of a transaction (through sales) with another economic agent (Tello-Gamarra & Zawislak, 2013).

While a real organization may survive (for a while) without transacting in the market, a firm is only valuable as long as it is able to fulfill some market gap and, consequently, sell and profit from whatever solution it provides. In this sense, a hierarchy in TCE terms will always emerge and expand up to the point where it inevitably meets the market (to buy or sell), in other words, where it can establish a transaction with another economic agent (be it another firm, or a consumer).

If, as Adam Smith once said “the division of labor was limited by the extent of the market”, the extent of the market is also limited by the possibility of dividing labor. Ultimately, a market (and market structure) could be defined with reference to the position of a single seller or buyer (Mason, 1939) where the division of labor occurs. In this sense, industrial structure can be defined in terms of the mastering (by some) of the necessary applied knowledge for producing solutions to fulfill a market gap. What determines who will be on each end of the transaction is the relative knowledge of individual economic agents about forming a firm.

The firm is hence a technological entity by definition. By technology it is meant the practical application of knowledge[4]. It is a set of some kind applied knowledge to solve some

[4]The Merriam-Webmaster defines technology in three main forms **a:** the practical application of knowledge especially in a particular area **:** engineering 2 <medical *technology*>**b:** a capability given by the practical application of knowledge <a car's fuel-saving *technology*>**2:** a manner of accomplishing a task especially using technical processes, methods, or

kind of economic problem and justify a transaction. Figure 1 attempts to illustrate how technology and economics play out mediated by firms and markets. In order to exist, a firm needs a 'workable market'. A workable market is a market where there is a sufficient set of buyers that can potentially engage in exchange with the firm and generate economic returns (revenues and profits). If a firm finds a market for its capabilities, a *transaction* is expected (upper-left quadrant).

Figure 1. Firms and Markets resulting from technology and economics

		TECHNOLOGY	
		FIRM Present	**FIRM Absent**
ECONOMICS	**Workable MARKET**	*Transaction*	*Market failure*
	Not Workable MARKET	*Obsolete industry*	*Impossible market*

On the contrary, if an existing firm is not capable of encountering a respective market to which its capabilities are the perfect fit, this specific firm is no longer needed. In this situations, the firm was either replaced by new firms with new or better solutions (thus creating a new market), or markets (in a Coasean sense), have found more efficient ways of coordinating the same activities within other firms. Either way, the existing firm or industry has become *obsolete* (lower-left quadrant).

If any firm does not fulfill a market at all, it might be because the imagined solution (even if technically feasible) is not economically viable and therefore, the deemed market is *impossible* (lower-right quadrant). Conversely, whereas a firm could fulfill a market gap but a firm is *absent*, we have a market failure[5] and a potential opportunity for innovation just waiting for the right technology or business model to address the problem (upper-right quadrant). A market failure can be understood as the lack of appropriate technology to deal with the economic need of allocating resources efficiently.

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knowledge <new *technologies* for information storage>**3:** the specialized aspects of a particular field of endeavor <educational *technology*>

[5]An economic term that encompasses a situation where, in any given market, the quantity of a product demanded by consumers does not equate to the quantity supplied by suppliers. This is a direct result of a lack of certain economically ideal factors, which prevents equilibrium. Read more: http://www.investopedia.com/terms/m/marketfailure.asp#ixzz3Wrp7sIzZ
When a market left to itself does not allocate resources efficiently. Interventionist politicians usually allege market failure to justify their interventions. Economists have identified four main sorts or causes of market failure.http://www.economist.com/economics-a-to-z/m#node-21529422

The interplay of technology and economic forces drives the social and economic system through firms and markets. Firms depend on the markets to justify its economic existence, and markets rely on firms to provide the concrete technological solutions that satisfy individual and collective needs. Firms and markets are, therefore, the unfolding consequence of an economic relation of technological complementarity. When different economic agents are connected in a semi-stable techno-economic relation, we have an industry.

2.2. Boundaries

Industrial organization arises from the techno-economic relation between two or more economic agents. While division of labor and specialization gives birth to producer and consumers, the interplay of technology and economics creates firms and markets. From this interplay, industrial organization can be found at the boundaries of two or more economic agents, where the sequence of activities of one is complementary to the sequence of activities of the other. Or as one set of capabilities ends and another begins. Defining these boundaries is a necessary condition for configuring the shape and scope of any industry. However, two features of boundaries must be highlighted.

First, a boundary is reached due to the impossibility of one individual or firm to master all the necessary knowledge to solve every problem. Hayek (1945) argued that all the necessary facts to be known in order to find a solution are never given to a single mind and, therefore, knowledge is necessarily dispersed among many people. Division of labor and specialization is the natural consequence of the division of knowledge.

At the firm level, problem solving is carried out within its routines[6] which operate as decision patterns based on the current repertoire of knowledge and skills of individuals (Nelson and Winter, 1982). Efficiency in routines is the result of how well individuals interpret internal and external signals and decides over the best operational course of action**.** Routines get better overtime and efficiency is improved with better knowledge, expertise and skills. Routines and capabilities reach their limit whenever individuals are not able to predict exactly what the signals will be, nor can they know the exact outcome of their decisions. In this cases, *uncertainty* is usually resolved through judgment[7] (Knight, 1921), and judgment

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[6] Nelson and Winter (1982) see "decision rules" as very close conceptual relatives of production "techniques," whereas orthodoxy sees these things as very different. “Routine” is their general term for all regular and predictable behavioral patterns of firms.

[7]Professor Frank Knight (1921), in the presence of uncertainty (a state of limited foreknowledge on the probabilities of every possible outcome) profit will be a reward to those who are able to make better inferences about future situations.

must be exercised because of *bounded rationality*[8] (Simon, 1969). Mistakes in judgment result in transaction costs.

While the first feature to boundaries relates to the capacity and ability of individuals and firms to master and apply the necessary knowledge to develop and produce specific solutions, the second facet to boundaries refers to the capacity a firm has to expand by being able to coordinate or manage internal resources efficiently (Penrose, 1959). In addition, the firm will grow not only because it is able to manage internal resources profitably, but because it can coordinate certain activities more efficiently than acquiring the same solution in the market (Coase, 1937, Williamson, 1985). After the point where the firm reaches this limit of coordination, the firm needs to interface with another to find complementarity and a transaction may take place.

Industrial organization, therefore, arises at the boundaries. As Richardson (1972) had observed, rather than ‘islands of planned co-ordination in a sea of market relations” (p.883), firms actually inter-relate in dense network of co-operation and affiliation with others that perform complementary activities. Therefore, the interplay of firms and markets are based on techno-economic interactions, transactions and technological interfaces between two or more economic agents. Techno-economic constraints are responsible for ultimately defining the limits to one firm’s capabilities and therefore the beginning of the market to this particular firm.

Technological constraints refer to the extent to which a firm possesses the necessary knowledge and assets to exercise a set of routines and capabilities in solving technical problems. *Economic constraints*, refers to the actual capacity of firms to deal with technological constraints more efficiently than the market.

Technological and economic constraints lead to the inevitable condition of boundedness, and are the ultimate source of transaction costs which prevent every economic activity to be carried on in one big firm as Coase’s (1937) predicted. Langlois (1992) has posed the same idea previously. Because firm’s capabilities are bounded, they must link up with other firms. According to transaction costs economics, this techno-economic gap between two or more economic agents will be bridged by an economic transaction.

Nonetheless, behind any economic transaction there is a transfer of some applied knowledge (technology) to solve a problem of a different economic agent. In other words,

[8]Bounded Rationality is the limited capacity of human mind to solve complex problems.

behind any economic transaction, there is the technological linkage of industrial organization which is a technological interface.

2.3. Technology and Economics, Stability and Dynamics

The way an industry is organized is a function of *technology* and *economics*. In fact, these two concepts are intimate related. By definition, economics[9] is a condition within which agents manage to allocate scarce resources in order to satisfy their needs. As resources are scarce and cannot be deployed solely by natural means, their allocation must be artificially (rationally)made, ideally reaching for optimization.

Mainstream economics assume rationality is perfect and the economic system always reaches equilibrium. They disregard the role technology in generating business, and how it continuously disrupts equilibrium creating uncertainty. As previously discussed, however, rationality is bounded (Simon, 1969) and firms can only profit due to uncertainty (Knight, 1921). Firms mitigate uncertainty by learning and developing a collection of routines (Nelson and Winter, 1982; Possas, 1989) techniques and tools to solve problems. Technology is the means through which firms create business and seek positive economic performance. In this sense, it seems unwise to speak about economics without considering the role of technology and *vice-versa*.

In a macro perspective, technology and economics enable the allocation of resources in the system. At the same time, in the micro perspective they define the boundaries of firms and markets. Economic agents will be bounded by the packets of technologies they are able to master, and economics will set the efficient boundary that will challenge their coordination capabilities. Firms, after all, are clusters of knowledge, routines and capabilities. When these technological clusters are linked in a semi-stable market-structure, we have and industry.

However, the nature of the linkages is only semi-stable because of the constant increments of new knowledge that flows from firm to markets and *vice-versa*. These knowledge increments keep shifting the boundary position of firms and markets. As new knowledge to solve problems enters the system and is validated by the market, the pattern of resource allocation changes and the clusters of capabilities get rearranged.

In this sense, equilibrium is never really reached because of the innate dynamics of techno-economic conditions. If, one the one hand, the organization of any industry presumes

[9]1530s, "household management," from Latin *oeconomia*, from Greek *oikonomia* "household management, thrift," from *oikonomos* "manager, steward," from *oikos* "house" (cognate with Latin vicus "district," vicinus "near;" Old English wic "dwelling, village;" see villa) + nomos "managing," from nemein "manage" (see numismatics). The sense of "wealth and resources of a country" (short for political economy) is from 1650s.

certain patterns of activities allowing a minimum level of predictability and coordination within and across firms. On the other, these internal patterns must be sustained by an equivalent transactional pattern in the market reflecting consumer behavior, contractual arrangements and institutional standards that stabilize the system. However, stable economic relations tend to have decreasing returns over time. Competitive forces eventually influence supply and demand for substitute solutions forcing agents to search for new ways or combinations (as Schumpeter would put) to solve the problem of allocation. Whenever certain economic agents are successful at figuring out new forms of allocation obtaining extraordinary profits, we have innovation.

Technology and Innovation disrupts the equilibrium state, forcing partial adaptation or entire renewal of industrial arrangements. While dynamics and innovation ultimately drive economic systems towards growth and wealth be it for the firm or for the industry (Schumpeter, 1911; Nelson and Winter, 1982, Rosenberg, 1982; Teece et al, 1997), stability is what guarantees the smooth flow of transactions among agents to payoff and give the appropriate return over the change effort. In this sense, economic systems cannot be uninterruptedly dynamic otherwise it would be chaos. Institutions arise providing the "rules of the game" that serve as ways of giving some stability to the system and reducing uncertainty (North, 1991).

The organization of any industry presumes certain patterns of activities allowing a minimum level of predictability and coordination within and across firms. Within the firm, this pattern is translated into capabilities, routines and decision rules. At the same time, these internal patterns must be sustained by an equivalent transactional pattern in the market reflecting consumer behavior, contractual arrangements, institutional and technical standards which stabilize the system. Even in the context of disruptive innovation, one can only realize innovation after the main concept of a new technology has been stabilized and new dominant designs appear.

In order to analyze the movements across stages of industrial development, we have to analyze how different economic agents organize packets of technologies and know-how and connect with others to find complementarities. If we can break-down to the very units of technologies and analyze the increments of knowledge that move the boundaries of firms and markets, we can better understand the dynamics of the way the economic activity is create and distributed, that is, the very definition of industrial organization.

Market exists only because it is composed of sellers and buyers that crystallize the resolution of economic problems through transactions. Industries exist only because sellers and buyers crystallize the necessary complementarity through technological interfaces.

3. Technological Interfaces as the Unit of Analysis

Identifying the appropriate unit of analysis is key for understanding the phenomena trying to be captured. Commons (1932) has noted that in hard sciences (physics, chemistry, biology) it was possible to find a common unit of activity. For physicians, as scientist dig deeper, the unity of activity can range from the very nature of the atom itself, to bigger and more complex biological systems. In applied social sciences such as economics, it is possible to find some correspondences, however the unit of activity is often diverse varying from *price* (neoclassical), *the firm* (Chandler, 1977; Penrose, 1959), *transaction* (Williamson, 1985), *routines* (Nelson and Winter, 1982), *resources* (Wernerfelt, 1984; Barney, 1991), *industry* (Bain, 1959), *knowledge* (Kogut and Zander, 1992), among others.

All of these concepts are important in offering different types of explanations on what are the key elements that influence the way the economic system as a whole works. Concerning research on industrial economics, however, a great deal of debate has taken place as to the appropriate unit of analysis – *the industry, the market or the firm* (Lee, 1985). In fact, industries and markets are often considered interchangeable terms (Jong and Shepherd, 2007). If we are trying to understand the dynamics of industrial organization, what the appropriate unit of analysis should be?

In order to address any conceptual ambiguity, one should decide what level of analysis is being considered. According Sawyer (1985), out of its many facets, industrial economics can be divided in those theories that group together o number of firms into sectors and industries, and others that treat firms as individual entities.

The industry as the main unity of analysis has led to definition of industrial boundaries and sectors such as *standard industrial classifications* (SIC)[10] which provides a useful framework within which several sectoral problems can be identified, data collected and analyzed. These analysis range from general quantitative data on production and prices to taxonomies of technological intensity and patterns of technical change[11]. These standard classifications have limitations of their own. As new industries emerge, they are slow in recognizing new sectors. Also they do not consider the full scope of technological domains or how sectors may overlap and interface.

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[10] Examples of such standards are: the North American Industry Classification System (NAICS), the Global Industry Classification Standard (GIC), International Standard Industrial Classification of All Economic Activities.

[11]Pavitt (1984) developed a taxonomy for describing sectoral patterns of technical change. See also OECD (2011) classification of sectors based on their technological intensity.

Conversely, firm level analysis find explanations based on to the firm's ability to develop and use applied knowledge, to generate economic "value" and to achieve performance. Firms are like 'economic molecules' (Coase, 1988a) constituted of some elementary properties and working respecting certain laws. To be able to transact in the market individual firms must develop the capacity of accessing, building, organizing and operating the necessary repertoire of knowledge, routines and capabilities to produce specific solutions with value to the market (be it another firm or the end consumer) in a cost efficient way. Depending on aspects such as size, scale and scope (Chandler, 1990) capacities, technological capabilities (Lall, 1994; Bell and Pavitt, 1995); and innovation capabilities (Zawislak et al 2012) and strategies (Freeman, 1987) these firms can have different impacts in the overall economic system influencing or being influenced by technological paradigms and trajectories (Dosi, 1982).

Nonetheless, neither the overall industry nor the firm alone provide a sufficient perspective on the mechanisms that determine the way the industry will be created and organized. To this end, there is a need to refine the proper unit of activity. Since the *sine qua non* condition of any industrial activities is the existence of at least two economic agents, the essence of industrial organization should be found at their techno-economic boundaries, in other words, at their technological interfaces. The capabilities of each firm are always bounded to some extent by technological or economic constraints which will call for complementarities found in other firms or in the market.

In this session, we try to enter into this marshy zone of industry and markets by specifying the technological interface as the unit of analysis to understand the sequential pattern of knowledge linkages that connect different economic agents, and therefore, the industry. Technological interfaces connect various locus of technical-knowledge, which are necessary to solve the economic problem. What mediates economic activities is the techno-economic matching between different stages of activities which can be internal or external to one specific firm, but are part of a whole we call industrial organization.

If by looking at a set of transactions we can understand the working of markets, by looking at technological interfaces we comprehend the organization of the industry and its dynamics. Therefore defining the properties and conditions that determine technological separability of economic activity is essential for any assessment on how the industry is created and organized.

3.1. The Unity of Analysis: Technological Interfaces

According to Langlois (2003), industrial structure is based on two interrelated but conceptually distinct systems: the technology of production and the organizational structure that directs production. These systems must solve the problem of economic *value*, that is: **how** to deliver the most utility at the lowest cost. If on the one hand, technology is understood as 'applied knowledge' used to provide a specific solution, on the other, this solution not only must fulfill a specific gap in the market but also should be justified economically.

According to Williamson (1985), the fact that technologies can be separable allows for the possibility of bridging two economic agents by means of a transaction. "A transactions occur when a good or service is transferred across technologically separable interfaces, in other words, where one stage of activity ends and another begins" (p.1).

Transactions costs economics makes the case the distribution of economic activity follows primarily an economizing rational (Williamson, 2009). However, technology underpins the 'core business' of any enterprise and technological imperatives drive efficient diversification (Teece, 1988). Firms are repositories of knowledge on how to produce things (Arrow and Hahn, 1971; Winter, 1991), and at the same time they are constrained by their ability to cope with the continuous increase in this stock of knowledge. In fact, the ability of firms to master certain technologies is as important as the transaction costs that derive from not mastering them. Learning is a key element when defining the boundaries of firms.

When firms increase their stock of knowledge, managers face the challenge of constantly making the coordination effort to reach the firm's expanding boundaries, as the organization increases in complexity and yield positive returns (Penrose, 1959). This idea is similar to Coasean[12] and transaction costs view, whenever the firm is unable to do so in a cost-effective manner, there arises the need for a transaction across firm borders. Before the economic transaction, nonetheless, there lies the technical matter that serves as basis for a complementarity relation between two stages. Hence, a transaction is a reflex of the technological interface bridging to poles of bounded capabilities. The technological interface is a *sine qua non* condition of the transaction. They constitute the technical-economic essence of the exchange between two agents.

In evolutionary economics, the firm is an agent constituted of routines and capabilities which are in the basis of the endogenous process of technological change. Nelson and

[12] Ronald Coase regarded Penrose's view as an addition to his own. Penrose's approach fulfills the lack of attention in economic theory to the role of the firm and management in actually "running a business" (Pitellis, 2009).

Winter's (1982) terms, "being capable means to meet the requirements necessary to perform routines". These requirements involve: 1) that the necessary knowledge regarding the repertoire of possible actions is provided to individuals in the organization, 2) the existence of specialized plants, equipment and technical-systems (whose handling ability is contained in the individual and collective repertoire), and 3) the existence of inputs that will be used and transformed during the processes. Routines are the building blocks of capabilities (Dosi et al, 2000; Alves et al, 2011; Felin et al, 2012)

If routines are the 'genes' of the economic organization, this internal thread of 'applied knowledge repertoire' and specialized technical systems to perform them are the genes' DNA. In complex economic system, however, these genes will only make sense as long as they establish a technological interface materialized in a transaction.

It could be argued that, a transaction takes place at the boundaries of the known and the unknown between two economic agents, however, firms usually "know more than they make" (Brusoni, Prencipe, and Pavitt, 2001) in order achieve efficient outsourcing. Therefore, as discussed previously, boundaries are always restricted by two '*laws'*.

First, there is the law of the technical boundary, that is, the knowledge, the technical systems and the capacity of performing a specific collection of specific routines. The second is the law of the economic *make* or *buy* dilemma, which constrains the decision around what and when to organize tasks and routines inside the firm or to transact them outside the firm. Of course these two aspects are correlated.

Firms need to choose the scope of activities that make economic sense to be carried out within its boundaries, and to do so, firms must be able to master necessary capabilities to achieve the desired performance. Whenever the firm reaches this capability limit, it will establish a technological interface with another.

To illustrate, let's take following example. In the individual level, the craftsman's 'know-how', its tools and the specific materials he needs to transform during the process of making, gives the sketch of his capabilities. However, where do his tools and materials come from? If this same craftsman does not master the knowledge needed to produce his own tools, nor he owns the sources of supply of materials needed to be transformed, he will necessarily rely on a technological interface. In order words, a technological interface is only established beyond the limits of one's own capabilities. At the same time, the craftsman's capabilities are on the limits of someone else's lack of capabilities which also justifies the emergence of another technological interface, thus a transaction.

A technological interface stands at the very boundaries of the firm and only exists in the possibility of techno-economic separability of productive activities among different agents. If these techno-economic units were inseparable, all production would necessarily have to be 'carried on in one big firm', recalling Coase's (1937) inquiry.

Technological interfaces are defined as the thread of knowledge and technology necessary for establishing a transaction between two or more agents at the boundaries of their capabilities (Figure 2). That is, the technological content of the system that bridge two or more economic agents from which a transaction may derive. In other words, the technological interfaces can be seen as the transactions' other side of the coin. In other words, technological interfaces form the sequence of systematically applied knowledge required to industrial relations with actors performing certain types of specific activities such as research & development, engineering, prototyping, testing, production, management, distribution, sales, and so on.

Figure 2. From bounded capabilities to technological interfaces

In a well working economic system, in order to develop, produce and distribute goods and services with economic value, there will exist necessarily a sequence of technical systems linked through transactions. What determine the technological interface are the bounded capabilities of each side of the transaction. The more or less parts of the sequence of applied knowledge the same techno-economic environment, the higher or lower its dynamic potential and wealth generation.

Industrial organization, therefore, can be understood as the result of the sum or nexus of technological interfaces linking modules or clusters of bounded capabilities. When economically linked by the transaction, technological interfaces form a thread of applied knowledge (technology) needed to create and put in place the set of operations which allows the smooth flow of a given mix of products (goods or services) across different economic agents.

If technology were stable in the long-term, transaction costs economics would probably suffice as the overall explanation to the way economic agents distribute different stages of activities across firms giving shape and scope to different sectors. However, the way the industry is organized is never stable in the long-term. Economic agents learn, new technologies emerge to solve new problems and the boundaries of capabilities keep expanding and retracting, recombined or completely reconfigured. This constantly evolving system defines the natural dynamics of industrial organization, that is, a continuous process of appearing and disappearing of technological interfaces.

3.2. Appearing and Disappearing of Technological Interfaces

In short, the movements of the boundaries of the firm determine industrial organization dynamics. The interplay of technology and economics constantly create incentives that inevitably change the nature of pre-established relations between economic agents.

Using the molecule analogy to the firm proposed by Coase (1972), the sum of various movements intermediated by technological interfaces (and thus transactions), will generate the dynamics of industrial organization. Some firms develop better capabilities than others and gain market-share, other firms innovate and create new markets. Some firms merge adding more or new capabilities and consequently may benefit from economies of scale or scope, other firms, diversify operations or outsource some stages of productive activity.

Since any of the economic activities described above presumes, necessarily, the existence of two or more economic agents, the dynamics of industrial organization follows a continuous process of appearing and disappearing of technological interfaces. Some are directly related to the process of vertical/horizontal integration or disintegration, others related to technological innovation.

3.2.1. Elimination of Technological Interfaces

Technological interfaces can be eliminated in two main ways. In the most fundamental level, a technological interface will be eliminated whenever a new technology replaces an old one. This is what happens when a ‘dominant design’ comes into existence. Standards, validated the new technological pattern. In fact, industrial organization can be seen as a constant battle of technological standards (Shapiro and Varian, 1999) which shapes and redefine the technical base of an industry. Innovative technologies come from new combinations of new or old technologies. One can say that highly recognized innovative products such as the iPhone, came as the result of old technologies integrated in new ways. Touch screen technologies, internal components such as processors and memory, wi-fi, digital camera, software technologies and so on had all been there before in stages of maturity, however, were re-designed, improved and re-combined within the phone creating a new market pattern.

New technological opportunities put firms facing two set of choices: firms can choose to incorporate (through learning) the new established standard or they can try to find other markets for its current set of capabilities. If firms decide to adopt the new standard, the previous technological content that linked two or more capability boundaries disappears. If firms do not adopt the new dominant design, they have to look elsewhere to re-establish their interfaces or fall into obsolescence.

The second way technological interfaces can be eliminated is through the firms' organizational capabilities. When firms learn how to deal with technologies *per se* and find new combination of internal and external capabilities, firms can find ways to 'bypass' certain stages of activity as part of new business models. New organizational forms can eliminate specific unnecessary interfaces. This is what happened with initial Dell business model which redefine its supply chain by eliminating the traditional retail interface and started delivering customized products directly to the end consumers.

Technological interfaces are eliminated when new technologies or new combinations of technologies emerge redefining the overall shape of industry. In this fundamental level, elimination means the process of replacement of an old technological base to a new one from which novel trajectories can emerge. Innovation is the key process in redefining interfaces. It is the creative destruction of previous industrial relations. Inevitably, when the old interface is eliminated, a new one must replace it.

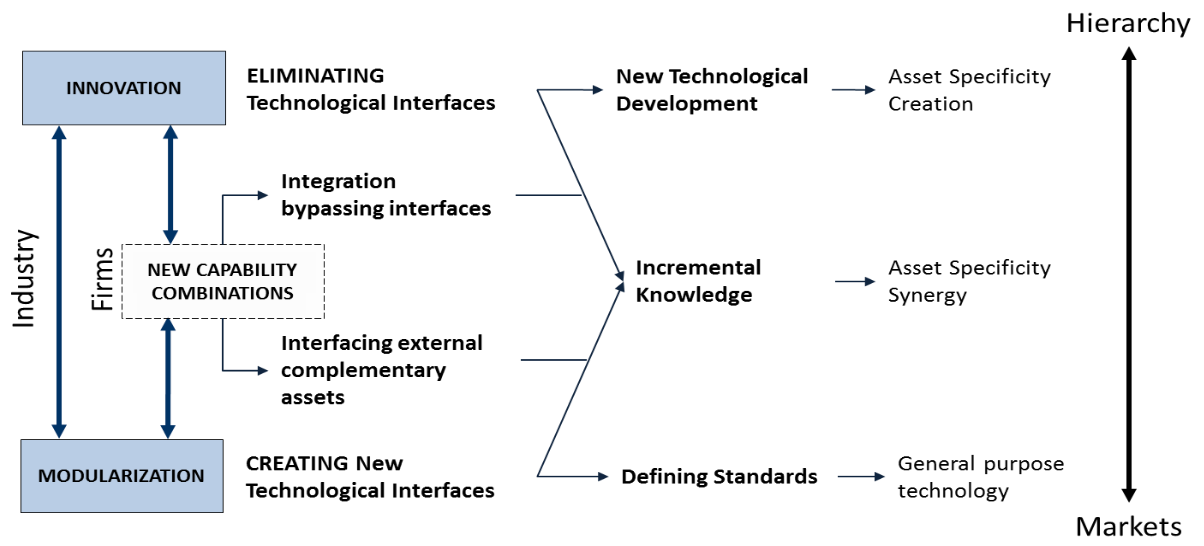
Whenever and old technology is replaced by a new one, a particular technological interface is eliminated and another emerges. The higher the complexity of technologies and the harder it is to master all the necessary knowledge, the higher the incentives for modularization of interfaces.

3.2.2. Creation of Technological Interfaces

Technological interfaces are *created* influencing the actual scope of the industry. Also, in a fundamental level, this can be a subsequent result from new technological endeavors. As in the example of the emergence of a dominant design, a natural consequence is the separation of the technological main frame into parts and modules that may be carried out by different firms with complementary capabilities allowing the economic functioning of the value chain as a whole. In this sense, technological interfaces can be created and established across various economic agents that will produce parts and products using the specific technology.

Standards play a key role in defining the actual interfaces between various components. Within defined standard interfaces, specialized firms can develop and improve internal components. In fact, specialization in different pieces of technologies or modules can also accelerate the pace of innovation (Langlois and Robertson, 1992), within the general dominant design. Nonetheless standards define the technical specifications and requirements for firms to operate. The choice of capabilities needed to develop, produce and sell the specific solutions of a firm (the scope of the firm) is dependent, besides technology, on economic constraints that will define the boundaries of each firm in the arrangement. Vertical disintegration can potentially happen in all levels, as long as it makes economic sense.

Figure 3. The general process of Appearing and Disappearing of Technological Interfaces



Source: Developed by author

Firms can establish technological interfaces as they find new partners with complementary capabilities to either create new products or enjoy new markets. Suppose a beverage company intends to enter a foreign market but does not have the necessary access to specific distribution channels. The beverage company might look for complementarity with a company that possesses the logistics and distribution channels to enter these markets. By establishing this particular interface, the beverage company opens up a new window of possibilities for commercializing its products and learning about other markets and the fit of its products in these markets. This is the essence of what Richardson (1972) called 'islands in a network of co-operation' that can take place for various reason such as: simple trading relationships, sub-contracting as well as, development, manufacturing and retailing agreements between different firms. New capabilities combinations are a way to achieve synergy among specific assets producing value from utility solutions of all sorts from specific technology to time and place (Figure 3).

The constant process of appearing and disappearing of technological interfaces are in the background of industries' design and configuration. Therefore, it is a key element for understanding the dynamics of industrial organization.

3.3. Technological Interfaces' Dimensions

Industrial organization is defined as the nexus of technological interfaces that connect various bounded capable economic agents into a coherent industrial arrangement. On the short-run, when justifying and economic transaction between two economic agents, technological interfaces provides stability to a system. However, industrial organization is a moving puzzle as new technologies and economic conditions change, they force the adaptation to the whole system, or it's completely disruption. What are the key dimensions influencing the existence of these technical-economic linkages?

3.3.1. Standards: Technological Requirements and Interfaces

Standardization has been at the core of historical technical developments in many industries. American railroads tracks, the oil industry (standard oil), and electricity current (AC/DC) in the beginning of the XIX century, and more recently the whole computer and mobile phone operational systems. All of which constitute true "wars" of standards (Shapiro and Varian; 1999)

Standards, therefore, have direct implications on industrial organization once they set common technological base and interfaces in a variety of significant areas allowing compatibility between products made by different manufacturers. As technology advances, SSOs and standard essential patents play a key role in setting the technological and institutional bases for industries to take shape.

According to Lemley (2002) a standard can be defined as "any set of technical specifications that either provides or is intended to provide a common design for a product or process". In fact, the very languages exist well as the different known measures (temperature, speed, length, currency, and so on) are types of standards developed to facilitate interaction and common understanding among individuals. In industrial organization, standards help to define specific features and interfaces allowing compatibility between products made by different manufacturers.

Four main sources of standards can be highlighted. Moreover, standards can arise from 1) the success of innovative firms developing products that the market value most or 2) governmental mandate; or 3) common agreement upon by different companies participating in the industry or a cluster and 4) set by standard setting organizations (Teece, 1986; Greenstein, 1993; Lemley, 2002; Langlois, 2007).

The first type is defined as ‘de facto standard’ which arise as a new technology is successfully selected by the market. When consumers drift towards that design or protocol, these standards can produce network effects (Katz and Shapiro, 1985, 1994) where adopters of the standard benefit from the fact that everyone else is doing so. This influences other producers to develop products that are compatible with the dominant standard.

Government defined standard sometimes are intended to compel all participants to comply with them in order to protect consumers from buying dangerous products or securing minimum safety requirements for products (Lemley, 2002). Both de facto or government standards influence industrial evolution by potentially opening up windows of opportunities for companies that are capable of fulfilling its requirements.

Nonetheless, while standards can be enabling by helping define the interoperability in a productive chain, reducing management and transaction costs and allowing gains of scale, they can also constraint future developments (Garud and Jain, 1996). Teece (2006) argues that, when design stabilizes there is a “regime switch” from a competition based on features to one based on price. Standards can also lead industries to be “locked-in” to a specific technology (Arthur, 1989, Liebowitz and Margolis, 1995) specially when commitment to licenses and standard-essential patents are enforced (Lemley and Shapiro, 2013).

Standards influences industry evolution and paths of innovations through the degree of compatibility and the strength of network effects (Teece and Coleman, 1998). Standards are also a key feature to technical separability and compatibility of interfaces. Standards along with interfaces and architectures are the fundamental dimensions for modularity (Baldwin and Clark, 1999). Standards set the technological base of the industry; however, technological developments that happen within firms belonging to the various industrial arrangements can directly destroy old linkages and create new ones, possibly creating new standards.

3.3.2. Modularity – Complexity Mitigation through Interface Separability

Once standards have been set, complexity can be broken down into smaller separable stages which can be carried out in different firms. This can happen through outsourcing or modularization. While highly concerned with the "strategy for organizing complex products and processes efficiently" (Baldwin and Clark , 1997, p.86), there have been attempts in the direction of developing modularity theory of the firm extending the view from pure technological to partitioning of rights among cooperating parties (Langlois, 2002). Modularity therefore is an important element in defining the scope of the firm.

Inspired by Simon (1962) work on *the architecture of complexity*, modularity is a general system concept that describes "the degree to which a system's components can be separated and re-combined, and it refers both to the tightness of coupling between components and the degree to which the "rules" of the system architecture en-able (or prohibit) the mixing and matching of components" (Shilling, 2000, p.312). Modularity, thus, presumes that any complex system can be broken up into discrete pieces (Baldwin and Clark, 1997). According to Langlois and Robertson (1992), the adoption of modular designs has dramatically increased the rate of innovation enabling companies to handle increasingly complex technologies. It can also give rise to different types of innovation as the ones noted by Henderson and Clark (1990) such as: incremental, modular, architectural and radical innovation.

Following Baldwin and Clark (1997), modular systems are design independently but function as an integrated whole which share some 'visible design rules' as well as 'hidden parameters'. The word 'interfaces' appears as the element of the visible design rules that describe how modules will interact. The link of modularity with the concept of technological interfaces is that, when brought to the organizational level, modularity can potentially create new technological interfaces between firms as new companies can emerge from the specialization of certain modules. However, modularity theories seem to be more concerned with a "microscopic" level analysis.

According to Baldwin (2007), the basic unit of analysis in modularity theory is not a "stage" in a sequential production process, nor is it "knowledge" that contributes to a routine, a competency, or a capability; rather, the primitive units of analysis are decisions, components, or tasks, and their dependencies which are more microscopic than stages, but more concrete and directly observable than knowledge. Baldwin (2007) assesses the origins of the transaction in the level of a network of tasks. The relation of modules and the boundaries of the firm is one of her core arguments. Modularization creates new module boundaries with (relatively) low transaction costs, making transactions feasible where they were previously impossible or very costly. Therefore, when modularization is taken to the level of the organization, a technological interface can be established as two firms can now be connected though specific transfers of know-how translated into their specific and complementary capabilities needed to produce specific products.

Industrial level analysis using modularity is found in Sturgeon, T.J. (2002) who discusses the economic performance benefits of vertical integration compared to value chain modularity in the context of globalization. Langlois (2003) also makes the case that, in an ever growing globalized economy modular organization is dispensing the highly hierarchical modes of organization. Moreover, studies on ‘business ecosystems’ have also included the problem of modularity concerning the different roles played by many firms from specialist component suppliers to system integrators which affects the extent to which firms can hold a leading position on technology (Adner and Kapoor, 2010).

According to Brusoni and Prencipe (2001) the literature on modularity provides some strong predictions regarding a positive correlation between product and organizational modularity. Nevertheless, this is not always true. Hoetcker (2006), shows that an increase in product modularity “enhances organization’s re-configurability more quickly than it allows firms to move activities out of hierarchy” (p.514).

For this study, the importance of modularity is related to fact that as technologies can be separable, they create the possibility of transactions between stages of activities and the definition of firm boundaries. The technical separability, however, must meet firms with the proper capabilities to deal with the technological requirements and deliver the required standards reliably if a successful transaction is expected. Reliability and trust on the capabilities of each firm are important aspects in bringing stability to technological interfaces and future industrial relations.

3.3.3. Innovation capabilities – Creative destruction of interfaces

If bounded capabilities define the limits where a technological interfaces will be necessary, innovation capabilities can re-define this relation. Technological interfaces, form the thread of systematically applied knowledge across different agents in order to develop, operate, manage and transact various products, are played by firms, their routines and capabilities. Technological change and innovation have key roles in modifying the structure of technological interfaces and hence the industry. By acquiring the capabilities needed to cope with technologies efficiently, firms incorporate technological interfaces or even substitute old ones. Nonetheless technological change and innovation is not an easy task, it involves learning, coordination and development of a specific set of skills and innovation capabilities (Zawislak, 2012).

Two important theoretical traditions can be highlighted in this direction: *technological capabilities* (Lall, 1992; Bell and Pavitt, 1995) and *dynamic capabilities* (Teece, Pisano and Schuen, 1997)[13]. While, technological capabilities are concerned with the "capabilities needed to generate and manage technical change" (Bell and Pavitt, 1995), dynamic capabilities is a more business oriented approach emphasizing also the role of management in orchestrating internal resources towards strategic change. Taken by its definition, dynamic capabilities is "the ability of firms to integrate, build and reconfigure internal and external competences to address changing environments" (Teece, Pisano and Shuen, 1997, p.516). In this sense, a dynamic capability seems a broader concept than technological capabilities.

The role of learning is key in both approaches (Dutrénit, 2000). However, dynamic capabilities highlight, besides technology, the coordination of efforts and strategic intentionality. According to Helfat et al (2007, p.4) dynamic capabilities express "the capacity of an organization to purposefully create, extend, or modify its resource base". Dynamic capabilities are discussed in the literature as a higher-order capability (Winter, 2003) or even as "the ultimate organizational capability that conduct performance in the long run" (Wang and Ahmed, 2007, p.35). There is no doubt that both approaches have enlightened our view of the role of the firm in promoting technological change and innovation. Nevertheless, while technological capabilities approach can be criticized by its narrowness in explicating innovation by focusing its attention on the technological side of the process and hence neglecting market and business ones, dynamic capabilities sometimes suffer from its broadness.

Ambrosini and Bowman (2009) identify a relative consensus in the literature on the role of dynamic capabilities as organizational processes to change the firm's resource base, however they also point some remaining open gaps in the literature regarding questions as such: how dynamic capabilities are created and operate, as well as, what is their full range which exist in practice? Recent conceptualizations on dynamic capabilities have started to draw a distinction between ordinary routine-based capabilities and dynamic and more strategic capabilities (Teece, 2012). Ordinary capabilities are less specific and therefore, can more easily be outsourced. On the other hand, dynamic capabilities cannot be bought in the

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[13] To find the boundaries and complementarities of technological and dynamic capabilities see Dutrénit (2000).

market, but are built within firms (Makadok, 2001). Therefore, there seems to be some room for studies that aim at exploring the different set of capabilities of the firm.

Some recent developments on *innovation capabilities* have also been made in an attempt to identify the different capabilities of the firm that contribute the firm's survival over time. Zawislak et al (2012) argue that, in order to understand 'why firms do what they do, and how they change what they do over time'*;* one should promote a "meeting" between Coase and Schumpeter. By joining respectively their coordination and entrepreneurial functions it is possible to describe the nature of the firm as it actually is.

The authors identify four types of complementary capabilities that can be found in any firm in different levels: *a) technology development, b) operations, c) management* and, *d) transaction capabilities*. All of which are necessary conditions in order to develop *innovation capabilities*.

In their view, technological development and operations capabilities embrace what Bell and Pavitt (1995) called the technological capabilities. Management and transaction capabilities express the coordination aspects highlighted by transaction costs and are more business driven. Innovation and dynamic capabilities are related in the sense all four capabilities proposed by Zawislak et (2012) have a level of ordinary (routine) activity as well as dynamic ones. Beyond the "technical change" (development and operations) and the "role of management will be crucial to transaction capability. More than that, our model deals at the same time, with static and dynamic.

As important as obtaining sustained competitive advantage is to the firm's long run survival and perpetuity, the significance of innovation and dynamic capabilities to technological interfaces lies in fact that, through technological learning and innovation, these capabilities can contribute to eliminate technological interfaces. Often new technologies vanish old ones. Recalling the Schumpeterian process of creative destruction new sources of supply, process, products, markets and industrial organization arise. Innovation is a way to reduce transaction costs. As changes in components and new technologies arise and become dominant designs, a whole change in the nature of technological interfaces also happens. When firms develop their internal capabilities to address change or to develop new technologies it is actually, eliminating and re-defining technological interfaces.

3.4. Why Explore Technological Interfaces

The problem of the organization of the industry can be traced back to the very idea of 'division of labor'. Economic agents have had to rely on each other's knowledge (the complementarity) on how to make certain things for a long time. Except in a context of a self-subsistent being, the distribution of specialized know-how in the capitalist economy has guaranteed the survival and the increase of supplies for various demands of civilization. As a society gets more complex so does the division of labor into new fields of knowledge and technology. Economics gives the outlines of this distribution.

Technological interfaces stand right at the technical-economic boundaries of the different economic agents' capabilities, "where one stage of activity ends and another begins". These technological interfaces appear due to the impossibility of one economic agent to both carry all of production by itself as well as continuously enhance its repertoire of routines and capabilities to deal with every new technology efficiently.

At the moment that the capabilities of an economic agent reach this technological limit, there arises the need for a technological interface with another. As science and technology advance, economic agents must establish technological interfaces beyond their capacity of connecting new technologies internally. Contrary to the transaction costs economics view, the unit of analysis in this case is not the transaction but the technological interface for the following reason. Before making economic sense, a transaction must make technological sense otherwise, a transaction would not exist.

Therefore a technological interface is a key element drawing the design, the coherence and the dynamics of industrial organization. New possible technological interfaces can be created as the state of the art in science and technology advance. However they can also be eliminated as the firm is able to follow up with the state of the art enhancing its capabilities. If firms are able to cope with new technologies in order to internalize certain activities instead of transacting them in the market, the firm is actually eliminating a technological interface and therefore changing the shape and scope of an industry. So, to answer "what determines the shape and scope of an industry and its dynamics?" it is necessary to understand the functioning of technological interfaces. How they are created and spread across economic agents and eliminated. Industrial *shape* is determined by technology, it's *scope* by the way activities are distributed and combined among several agents through economic transactions.

What implications do these re-combinations have for the economic organization and consequently for the organization of the industry? It has been argued in this essay that industrial organization emerges from the sum of technological interfaces. Therefore, technological interfaces do not simply describe the current display of industrial activity, but also addresses the design problem pointed out by Langlois (2003). Industrial organization is not only a matter of organizing production across several agents but an endless process of appearing and disappearing of technological interfaces. Identifying these mechanisms can help draw a roadmap for industrial organization, technological opportunities as well as guide for future policy making to foster economic dynamism and wealth creation.

Industrial Organization is a dynamic process that arises from the way economic agents deal with their techno-economic boundaries and how they build, destroy and create new technological interfaces. Through capabilities and organization, economic agents can modify their internal range of activities and redefine their external technological linkages possibly giving new shape or scope to the industry. In other to look at how industries evolve, there is a need to understand how economic agents build capabilities, define their boundaries and create the technological and economic linkages in order to form semi-stable and coherent system.

4. The Shape, Scope and Dynamics of Industrial Organization

Industrial organization is a moving puzzle where technology and economics interplay influencing the formation of economic activities and their distribution among various economic agents giving industries its *shape*, *scope* and influencing its *dynamics*.

This work argues that mainstream industrial organization studies have failed to explain this relation and how it changes overtime. Newer approaches have attempted to do bridge this gap. Under the heading of Industrial Dynamics, Carlsson (1987, 1989 and 1992) along with National Innovation Systems (NSI) (Freeman, 1987, 1992; Lundvall, 1991, and Nelson, 1993) approaches have added important insights on the dynamic and processual nature technical change and industrial evolution. However, we argue that there is a need to narrow the focus of analysis to what happens at the boundaries of economic agents in order to understand how industries or systems will be created, evolve by the techno-economic interactions of various economic agents.

While technology and economics have long been considered within economic theory, their implications in the way the industry is organized and evolves seem to have been treated in separate ways, respectively through neoclassical economics, transaction cost economics and evolutionary based approaches. If one is looking for a more comprehensive understanding on the organization of economic activity these different dimensions should jointly be considered (Madhok, 1996; Foss, 1999; Langlois, 2003; Zawislak et al, 2012).

4.1. Industrial SHAPE

Technology underpins industrial shape and it is on the basis of any economic relation. Technology enters economic theory under the heading of production duality or the technology possibility set (Hicks, 1947; McFadden, 1978). The general neoclassical view in economics takes the firm as a 'black box' that transforms factors of production into outputs (Teece and Winter, 1984). The technology set is a list of different combinations of inputs and outputs that are available to the firm (Panzar, 1989). However, in classical theory of cost and production, the firm is assumed to face fixed technological possibilities determined by technological knowledge and physical laws (McFadden, 1978). The most common example of these technological possibilities is the Cobb-Douglas production function based on the combination of capital (K) and labor (L).

According to Arrow and Hahn (1971, p. 53), "the production possibility set is a description of the state of the firm's knowledge about the possibilities of transforming commodities". To the extent that the technology to produce something is mastered in different levels across firms, it defines the technical sequence of production of each particular firm. Technology stand as one of the basic conditions to the structure of the industry (Mason, 1939; Bain, 1965) and technological features will determine (in some extent) the way the industry will be organized.

Neoclassical economic theory follows a static rationale, based on the assumption of equilibrium and perfect rationality. It has been criticized for neglecting the role of change and technology in bringing development and creating wealth (Nelson and Winter, 1982, Dosi et al, 1982) or even leading to lack of realism and wrong assumptions about real life business (Teece & Winter, 1984). Although the assumptions are regarded as misleading in the real word, it seems to depart from the principle that technology is exogenous and predetermines the shape of the industry.

This is not to imply that technological determinism is right, but that technology influences economic and social conditions and is also influenced by these conditions.

However, when we think of established industries and their current state, the shape the industry assumes is strongly defined in terms of its technological domain, standards and modularity.

Technological domain encompasses the set of knowledge and technology to produce specific solution. Standards set common communication grounds and technical parameters that will be used by firms to deal with technologies. The combination of these different technological domains and parameters translated into a succession of stages of production (or set of activities) with different degrees of technical separability and modularization.

Whatever the technological paradigm is at a particular point in time at some industry, sector or firm, that technological core, in the short run, gives shape to the current possibilities of the industry. The technological core serves as the backbone of the industry to which all other elements will connect.

For instance, if the current known merchantable technology for producing cars only allows for the assembly of cars with wheels, at some point of the production sequence or chain, wheels will necessarily have to be placed on the body of the car. This cannot be avoided unless a new technology replaces wheeled cars for other types of personal vehicles, which have their own technical sequence to be produced. In this sense, technology determines the shape of the industry at a specific point in time.

This does not mean that incremental innovations do not happened along the way on techniques and components. Abernathy and Utterback (1978) show that after any significant product innovation, changes shift from product to process. Modularity also allows for some level of innovation in components, however, the technological core remains outlining the general technical sequence until a new development disrupts the technical sequence.

The technological core of any industry results from the current frontier of technological domain and standards. It can emerge as a 'dominant technological design' produced by leading companies or it can also be agreed upon by different companies participating in the industry or a cluster (Teece, 1986; Langlois, 2007). Once, a dominant technology comes into existence, it sets the technological basis of the entire industry which tends to follow a more stable behavior pattern.

While technology defines industrial shape, it is not the main determinant of economic organization (Williamson, 1985). However, it seems reasonable to state that, before any economic transaction, the evaluation the firm's own problem solving capabilities relatively to its production stage and surroundings should happen before any attempt to look for transacting counterparts. In this sense, technology comes before the transaction, and the possibility of establishing a technological interface with another economic agent is what justifies the economic transaction.

Taking the above example, while particular technology in place defines *what* the technical sequence is to obtain the desired outcome, it does not determined *when* nor *where* the specific sequence will take place in the production chain. This issue of distribution of economic activity across different economic agents is a matter of scope. In other words, while technology defines the technical shape of an industry, it does not define its scope.

Industrial Shape is defined by the technology in a given point in time, in other words, by the technical sequence of activities necessary to produce a desired outcome. *Standards* play a key role in defining this sequence. *Modularity* defines the degree of separability of the process. The more complex the technology, the higher the number of separable technological interfaces. Complexity, however, has two dimensions. The first is related to the number of parts and pieces that interact in multiple ways. The second is related to the "complicatedness" of the type of problem to be solved. This can be measured in the amount of time to reach the appropriate learning or training to developed the necessary skills. Complexity "as number of different parts interacting in multiple ways" defines the technological SHAPE of the industry. Complexity as "complicatedness" will influence the economic SCOPE of the industry as different firms will present different levels of capabilities to coordinate clusters of technologies more efficiently than others.

4.2. Industrial SCOPE

Scope is not solely an issue of technology, but of economic adaptation. Economic features drive the decisions of firms towards investments and positions. According to Williamson (1999) transaction cost framework follows the premise of Barnard (1938) and Hayek (1945) that 'adaptation' is a key purpose of the economic organization. Game-theoretical models also recognize this feature of economic activity. Tirole (1988) argues that game theoretical models advance over 'structure conduct performance' once it captures the dynamics behind the choices of firms based on asymmetric information and expectations regarding the possible moves of competing agents. However, in both approaches what is being referred to as dynamic, is an assessment on the adaptive nature of decisions giving a set of known available possibilities. Innovation is at most, organizational (Williamson,1977, 1985).

Transaction costs economics poses that the main strategy of firms is to reduce transaction costs (Williamson, 1991) and it aims at explaining the different forms, features and alternative modes of the economic organization (Williamson, 1985).

Transaction costs economics best fits the idea of industrial scope as to how economic activity will be distributed across different agents. "Transactions occur when a good or service is transferred across technologically separable interfaces" (p.1), in other words, where a stage of activity ends and another begins. These transactions underlie the make or buy decision of "*when* and *why* should a firm acquire a technologically separable component by outsourcing rather than producing to its own needs – where outsourcing entails contracting out and own-production to contracting within" (Williamson, 1999. p.686). The fact that specific technical sequences are separable, creates the possibility of a transaction to occur by means of outsourcing depending on various economic conditions.

We define this as the Scope of the industry. Industrial Scope depends on aspects such as firms' position concerning technology mastering, capabilities and asset specificity[14] to produce a specific outcome more efficiently relative to competition. It is influenced by the economics of scope and the scope of the firm (Teece, 1980). While technology specifies the technical sequence, scope defines the economic sequence of industrial activities based on the boundaries of firms and markets.

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[14] Williamson (1996, p.60) defines six types of asset specificity: "(1) site specificity, as where successive stations are located in a cheek-by-jowl relation to each other so as to economize on inventory and transportation expenses; (2) physical asset specificity, such as specialized dies that are required to produce a component; (3) human asset specificity that arises in a learning-by-doing fashion; (4) dedicated assets, which are discrete investments in general purpose plant that are made at the behest of a particular customer; to which (5) brand name capital and (6) temporal specificity have been added."

According to TCE, the 'make or buy' decision follows an economic reasoning and depends on key dimensions of the transactions. These dimensions are *frequency, uncertainty* and the condition of *asset specificity* (Williamson, 1985). Organizations, consequently, will adapt its modes of governance among *hierarchy* (internal coordination), *hybrid* (co-operation through contract)and *market* transactions, as the dimensions of the transaction change. Uncertainty has two sources: *bounded rationality* and *opportunism* and they prevent agents from knowing *ex ante* the exact outcomes of organizational arrangements that are influenced by the *self-interest* behavior of the parties involved. This will encourage them to engage in contracts in an attempt to safe-guard the organization from opportunistic behavior. Williamson (1985) argues that out of the three transaction dimensions, asset specificity is the most important one.

In the absence of technological change, these explanations would suffice for a good understanding of how the industry is organized. However, it is not the primary concern of transaction costs economics to explain the process through which these specific assets come into existence in the first place. According to Lazonick (1991), economic organization, nonetheless, does not take asset specificity as a given, and thus, transaction cost economics is not suited to provide explanations on the sources of change in this specific parameter and consequently the origins of the innovative organization. In fact, when vertical integration happens, it is not the 'transaction' *per se* that is incorporated, but the set of assets, knowledge and routines needed to execute a certain stage of activity, in other words, the capabilities need for a particular technological interface.

Given a certain Shape, that is, given a specific technological sequence of activities that follows pre-defined standards and separable interfaces, industrial organization will define its Scope as firms take part and integrate certain stages of production. Beyond the boundaries of what firms can actually coordinate, they will necessarily establish a technological interface with another.

When scope is defined within the possibilities of organizing the industry under a pre-established technological shape, we have simple form of economic adaptation as TCE suggests. This process involves the decision of firms around what they will make and what they will buy (forming a technological interface with another firm). Of course this is dependent on the availability and costs of acquiring specific capabilities elsewhere. Complexity in terms of "complicatedness" also influence the availability certain capabilities across different economic agents.

The higher the complicatedness of a technology the harder it is to build the capabilities needed to deal with the technology and the lesser the availability of these capabilities in the market. This will favor vertical integration. Modularization can mitigate the technological complexity and complicatedness through specialization, however, greater effort on coordination may arise when stages of activities are highly interdependent. Issues such as delivery time and standards have to be well planned in order to bring stability to interfaces avoiding transactions costs.

Scope also changes overtime as technologies are learned and firms catch-up on the necessary capabilities. This process has been described by both Stigler (1951) and Langlois (1989, 2003).Technologies tend to lose their complicatedness other firms may become more efficient at clustering certain capabilities which will influence vertical disintegration of previous dominant firms shifting their boundary positions regarding the "make or buy" decision.

In short, the technological base (knowledge frontier and state of the art) defines industrial shape. Industrial scope, is determined by the ability of each economic agent (firms and consumers) to master the specific technological base. The SHAPE determines WHAT problem has to be solved, the SCOPE will determine HOW the problem will can actually be solved.

However, when new knowledge is incorporated through learning and innovation (dynamic) capabilities, not only the economic boundaries of firms change, but the actual content of the technological shape of the industry. We have dynamics.

4.3. Industrial Organization DYNAMICS

Industrial organization has a continuous *design problem* (Langlois, 2003). Evolutionary perspectives show that industrial structure and technical change/advancements are related. To Nelson (1995, p.171) "it is reasonable to say that technology and industrial structure co-evolve". However the challenge seems to be on understanding the nature of this process which is not solely technological nor solely economic but a combination of both.

While to transaction costs economics tradition the nature of the firm and its boundaries derive from the process of internalizing new transactions, to the Neoschumpeterian evolutionary perspective, the explanation comes in the ability of firms to develop internal routines and capabilities, which are highly based on intangible knowledge and skills. Whether transaction costs seeks to explain '*when*' and '*why*' a new transaction will be internalized or contracted out (Williamson, 2009), evolutionary approaches are concerned with the process of '*how'* firms differ and evolve over time (Nelson, 1991). The firm's trade-off seems to get a third type of choice. It is no longer between make or buy, but among *make, buy or develop*? The fundamental question, then, is how economic agents create their specificities that will turn, later, in various economic arrangements.

In fact, all views are intertwined telling us a part of the story of how industries are formed and evolve. Evolutionary approaches and TCE both attempt to explore what goes on inside the neoclassical "black box" and are complementary to each other (Williamson, 1999; Foss, 1999; Langlois, 2007; Pitelis and Teece, 2009; Zawislak et al 2012; Tello-Gamarra and Zawislak, 2013). According to Loasby (1999), instead of considering transaction costs and capabilities (evolutionary) as alternative explanations to the organization of economic activities, we may do better by combining them into an institutional and evolutionary economics of incomplete but augmentable knowledge.

After all, industrial organization is like a moving puzzle (Alves and Zawislak, 2013) as technologies evolve and change the technical shape and the economic scope of the fitting parts. Within this line of argument, evolution is a continuous process that results as firms search and change its internal routines and capabilities over time in the process of problem solving (Nelson and Winter, 1982; Freeman, 1982; Dosi, 1982, Rosenberg, 1983, Winter, 1991; Teece, Pisano and Shuen, 1997). While routines are expressions of the repertoire of alternatives based on knowledge and skills to produce a desired outcome (products or services), change in these routines is at the origin of the innovation process.

As moving system, industrial organization is continuously dealing with stability and dynamics. Industrial organization's *shape* and *scope,* can be respectively summarized as the result of technology and transaction costs economizing forces. Technology defines the technical sequence of industrial activity given the current state of technological domain, standards and degree of modularity. Transaction costs economics explain the adaptive fitness of industrial organization outlining how the different industrial activities will be distributed across firms give their position on asset specificity, and behavioral orientation vis-à-vis opportunism[15] and bounded rationality.

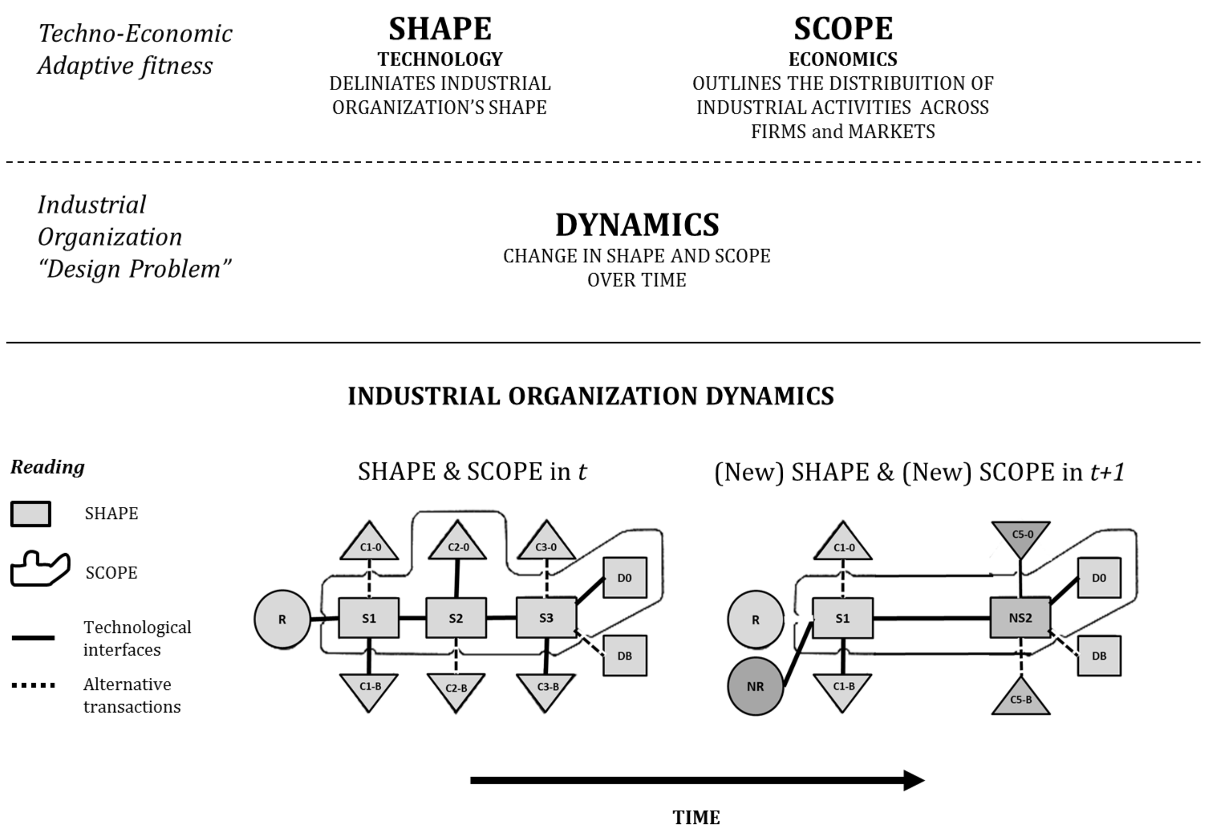
However, the industrial organization's 'design problem' is explained by industrial dynamics. This can only be addressed by adding to the analysis how industrial firms actually introduce new solutions to the market through innovation. While industrial scope distribution

[15]Within general agency theory and transaction costs, opportunism is generally considered as a potential source of moral hazards from the very nature of principal-agent conflict. However, according to Zawislak (2004), opportunism is an essential part of innovation and competitiveness whenever an individual firm seizes an opportunity naturally looking for profits.

result from the condition of asset specificity of firms and their behavioral orientation towards opportunism and bounded rationality, innovation provides the means through which these conditions change.

The key aspect about *Innovation*[16] is that it alters the condition of asset specificity in the level of the firm and it mitigates bounded rationality opening up new possibilities for the firm to be opportunistic going after profits. However, to be successful in any opportunistic endeavor, the firm must be able to capture value by developing the necessary capabilities in order to provide new solutions to the market and consequently establish new transactions. In fact, innovation is the main way through which firms can economize in transactions costs. Figure 4, adapted from Williamson (1985) illustrates the problem of industrial organization.

Figure 4. Determinants of Industrial Organization's Shape, Scope and Dynamics



Source: Developed by the author, adapted from Williamson (1985)

[16]Innovation has many facets. Following Schumpeter's approach, it can be any novelty introduced by firms that produces extraordinary profits. The classical Schumpeterian classification to sources of innovation is: new products, new production methods, new markets, new sources of supply or new forms of organization. Also, innovation can be considered according the degree of novelty as in the current convention of the Oslo Manual: ***new to the world, new to the country, new to the firm.***

The grey sequence represents the industrial shape based on the specific technological requirements, types of resources and components. To each stage of activity presume a set of routines and capabilities to deal with their respective technological specifications. *R* drew as circle represents the raw materials. Draw as triangles, *C1* to C5arecomponents. As a square, *D* represents the alternatives for distribution. The letters *a* and *b* represents alternative suppliers to the same component. Draw as a closed curve, we have the SCOPE of the industry based on the efficient frontier. The solid line represents the technological interfaces connecting to stages of activities. On the left hand side, we have Shape & Scope of the industry is a particular point in time ($S\&S_t$). The firm decides to internalize the technological interface corresponding to *C2a*, but outsources *C1b* and *C3* interfaces. Of course, in the short-term, changes on prices of resources and components or the appearance of more efficient firms in to carry the different stages of production could lead to a movement on firms' boundaries, shifting the scope of the industry. The firm could choose to switch suppliers of components from *C1b* to *C1a* or to outsource C2 by transacting with supplier C2b. Nonetheless, this type of decision does not change the fundamental *shape* of the technology. Deciding whether to make or buy (giving a specific technological core) follows what Williamson called "*adaptive fitness"* of economic organization in search of efficiency.

However, when the search of efficiency involvers changing specific technical requirements, standards and technologies we have change in Shape and DYNAMICS. Dynamics necessarily depends on time and learning. On the right-hand side, we have new shape and scope ($S\&S_{t+1}$). As technologies are developed and new combinations of resources and components arise, new technological core and ways of organizing economic activity appear. Firms learn and incorporate new routines to their repertoire and must continuously decide over what activities to integrate and what others to outsource. *NR* is a new source of resource that substitutes the previous *R*. Stage 2 and 3 merged giving birth to a new stage 2 (*NS2*). The new stage also requires a new interface with a new component *C5-0. C3b*became obsolete due to the *NS2* technology. Time and learning are the underlying processes behind the appearing and disappearing of technological interfaces.

Figure 4 serves only as a simple illustration based on a previous exercise made by Williamson (1985). However, the number of stages and the degree of integration or disintegration will depend on the degree to which capabilities and technologies are mastered by different economic agents.

When technologies are not mastered and capabilities are not sufficient, there is a need for more technological interfaces with other firms. However problems of coordination may arise which will increase transactions costs.

Based on the discussion up until now, Figure 5 summarizes some of the propositions and elements to be taken into consideration when analyzing the dynamics of industrial organization.

Figure 5. Dimensions and Propositions concerning Industrial Organization Dynamics

Dimensions	Propositions		Elements
Industrial Organization	P1.	Industrial Organization is based on an economic relation of technological complementarity	✓ Firms ✓ Markets ✓ Boundaries ✓ Interfaces
	P2.	Capabilities are bounded by technological and economic constrains	
	P3.	Bounded Capabilities need a technological interface	
SHAPE	P4.	The more complex the technology the higher the number of separable modules and interfaces (and the higher the number of players).	✓ Nº of parts (modularity) ✓ Complicatedness ✓ Standards
	P5.	Standards set the technological base and mitigate complicatedness	
	P6.	The higher the complicatedness of a technology the lower will be the availability of proper knowledge and capabilities in the market.	
SCOPE	P7.	The boundaries of capabilities are a function of the repertoire of routines that firms are able to operate given its mastered pool of knowledge and assets.	✓ Knowledge ✓ Assets ✓ Routines
	P8.	The higher the Boundedness of Capabilities, the higher will be the number of technological interfaces needed (and the higher the number of players).	
	P9.	The higher the number of technological interfaces, the higher the need for coordination mechanisms across firm boundaries	
DYNAMICS	P10.	Dynamics is always a feature of time.	✓ Time ✓ Learning ✓ Development
	P11.	Complicatedness diminishes overtime as firms and markets absorb technologies though learning, which changes their boundary positions.	
	P12.	Within a particular technological shape, only the economic scope of the industry varies.	
	P13.	Learning always changes industrial *scope* by changing the efficient boundary of firms, however it only changes *shape* when it leads to technological development and innovation	
	P14.	Movements on industrial *Scope* are a short run phenomenon whereas movements on *Shape* is a long run one.	

In the previous section it has been argued that industrial organization should be defined at the technical-economic boundaries of two different economic agents. Economic agents are limitedly capable because of techno-economic constraints. This leads, necessarily, to the division of industrial activities, which are connected by an economic relation of technological complementarity. While the transaction is often the chosen unit of analysis to understand this relation, it will be argued, that the concrete matter of industrial organization is the technological interface.

5. Research Design

In order to address the question of w*hat determines shape and scope of an industry and it dynamics*, this study investigated the recent developments of the Shipbuilding and Offshore industry in Brazil. Shipbuilding and Offshore is a mature industry worldwide, nonetheless it is relatively new in Brazil even though it has been present in the country for in previous decades. Moreover, besides its mature technological base, it has a high degree of complexity for local players where the full range of capabilities have not been developed. The scenario where capabilities are clearly bounded from engineering to construction requires firms to select specific stages of productive activity and to linkup with others to complete the necessary sequence and produce the desired outcomes.

The unit of analysis to the dynamics of industrial shape and scope is the nexus of technological interfaces found in the industry. By looking at the technological interface, it is possible to infer about the boundedness of capabilities of firms in this specific sector and the implications for the future. In this sense, the recent state of this industry in Brazil provides the genuine "experiment" for this study once it opens the possibility to analyze the evolution and dynamics of industrial shape and scope in the making.

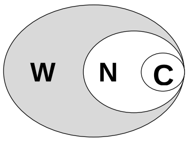
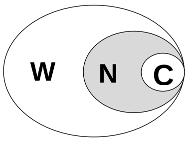
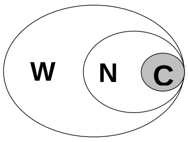
The most suited method is the case study approach (Yin, 2009). Case studies are flexible allowing multiple sources of data. For this research, most importantly is the fact that case studies can be used in the effort of building theory, testability and empirical validity from the intimate connection with empirical evidence (Eisenhardt, 1989).

This research was divided into three levels of analysis as Figure 6. It begins by broadly discussing the shipbuilding industry worldwide based on a literature review of the evolution and main players. It then, narrows down to a narrative on the evolution of the Brazilian Shipbuilding sector and its recent developments. Finally, the study explores more deeply the dynamics of shape and scope of one shipyard yard by describing the technological interfaces that could be observed during the research.

All these steps were necessary in order to enrich the analysis of the specific case putting Brazil in perspective in this complex and competitive sector.

The next sub-sections present the different phases of this research in more detail.

Figure 6. Levels of Analysis, Research, Method, and Data Sources

LEVELS		Research conducted	Sources of data
World (W)	REVIEW on Shipbuilding and Offshore Industry Worldwide 	• Description of the shipbuilding and offshore industry; • Overview on the historical developments of six shipbuilding nations; • Analyzes of the contributing technological and economic factors that enable the consolidation of this industries	• Previous Literature • Data sets produced by specialized sources in the industry
National (N)	REVIEW and FIELD STUDY of Brazilian Shipbuilding and Offshore 	• Overview on the evolution of shipbuilding in Brazil from its early emergence to the later decline; • A description and analysis of the recent institutional and industrial configuration set to allow the re-emergence of shipbuilding and offshore sector in Brazil.	• Previous Literature • Interviews and documents provided firms and institutions. • Information obtain in sectoral conferences and symposiums.
	CASE STUDY (C) on Shipyard 	• Description of the general interface plan of the Shipbuilding Project • Description of industrial *shape* as the sequence of development and productive activities • Description of the industrial *scope* based on bounded capabilities and technological interfaces • Description and analysis of the *dynamics* of the interplay of bounded capabilities and technological interfaces.	• Data set and documents provided by the firm; • Interviews and • Observations on site

5.1. Review on the Shipbuilding and Offshore Industry Worldwide

The first phase of this study sought to draw an overview on shipbuilding worldwide presented in the Chapter 6. This step involved a literature review on the technological path and the economic shifts in competitiveness in leading nations over the years. The section begins by introducing the shipbuilding industry, the types of markets and the main players worldwide. Then, six emblematic cases of national shipbuilding industries are presented: United Sates, Japan, South Korea, China, Norway and Singapore. This cases were organized chronologically according to their importance to the Shipbuilding (in the first four cases) and Offshore Sector (in the latter two). This chapter ends with the analysis of the general patterns to industrial evolution. Besides providing a general overview on this complex sector, this section allows to put the Brazilian industry into perspective. The overall process of setting institutions to foster capabilities in shipbuilding is not a new phenomenon reserved to Brazil. In fact, as it will be seen, this type of industry relies heavily on governmental incentives many of which were re-produced in Brazil recently.

The literature review involved, research papers on the shipbuilding industry of each country, specialized studies alongside secondary data from specialized sources, such as Clarkson Research, and other specialized reports such as the *International Benchmarking Performance Indicators for the Shipbuilding* by Alberto Luiz Coimbra Institute for Graduate School and Research in Engineering (COPPE).

5.2. Review on the Brazilian Shipbuilding and Offshore sector

A second review was conducted on the national level presented in Chapter 7 to describe the origins and evolution of the shipbuilding and offshore sector in Brazil. The chapter begins with a literature review that presents a brief history on the earlier years of the sector, technologies and market growth trajectories until its decay in the late 1980s.

Then, the chapter describes in further detail the recent developments beginning with a new institutional framework and the role of Petrobras as the leading firm in the sector. This step was based on a review of specialized literature, institutional secondary date from sources such as: the Institute for Applied Economic Research (IPEA), publications by PETROBRAS, National Shipbuilding and Offshore Association (SINAVAL) and the National Organization for the Oil Industry (ONIP). Interviews and technical visits to shipyards and Petrobras were also conducted to describe the national scenario from institutions set-up to industrial organization.

5.3. Technological Interfaces and Industrial Organization Dynamics Analysis

Finally, the study entered in its empirical phase: a case study was conducted on one Brazilian Shipyard. This is presented in Chapter 8. In order to understand the dynamics of industrial organization, the research involved e detailed description of the boundaries and interfaces of one shipyard. The shipyard was codenamed SHIPYARD A. As it was discussed in the theoretical sections of this study, industrial organization is viewed as the sum of technological interfaces that connect bounded capabilities of firms. In a Complex Product System such as Shipbuilding these relations can be observed on site.

In total, this part of the research involved three weeks of visits, interviews and data collection on SHIPYARD A. One week for preparation and two weeks were spent on the site. The data collection for this phase of the research happen in October of 2014. The shipyard in analysis was producing a hull that was going to be integrated in SHIPYARD B in Rio de Janeiro. This research also involved visits to the headquarters of Petrobras and the Research and Development Center (CENPES) and interviews with managers involved in the same construction project.

Figure 7 presents the set of companies visited and the main interviews that were conducted.

Figure 7. List of Organizations and Interviews conducted.

Company	Interface	Title of the interviewee
PETROBRAS (Main Client) *Rio de Janeiro*	Planning (Head Quarters) Engineering (CENPES) Construction Management (SHIPYARD B)	1. Local Content President Assessor 2. E&P R&D 3. Interface Manager
SHIPYARD A *Rio Grande*	Engineering • Detailed Engineering • 3D	4. Engineering Director 5. Chief of Detailing Engineering 6. 3D Manager
	Planning	7. Strategic Planning Manager
	Procurement	8. Procurement Director
	Structure Construction • Structure • Block Assembly	9. Chief of Construction 10. Chief of Structure Division 11. Block Assembly Manager
	Advanced Finishing • Outfitting • Piping • Paint • Architecture	12. Chief of Advanced Finishing Division 13. Outfitting Manager 14. Piping Manufacturing Planning and Control Manager 15. Paint Manager 16. Architecture Manager
ULTRABLAST *Rio Grande*	Paint	17. Production Planning and Control Manager
ABS *Rio Grande*	Certifier	18. Surveyor

From these different interviews and observations, it was possible to describe the main production sequence from engineering to construction, as well as the different participating firms in each interface.

5.3.1. Technological SHAPE and Industrial SCOPE

Following the discussion on theoretical chapters, industrial organization can be seen as the sum of technological interfaces connecting bounded capabilities of different economic agents. This theoretical statement was empirically observed by looking at the construction process and the firms involved forming different industrial relations. Industrial organization is about the way economic activity is divided-up and undertaken by different firms. In order to capture this relations and describe their specificities, two types of information have to be gathered through instrument, protocols and data available.

a) The Shape of the industry is defined by the technological sequence of activities that have to be put together in order to produce the desired outcome.
b) The Scope of the industry is defined by the different Firms and their capabilities to take part in specific stages of production.

By using the different sources of data described above, it was possible to create a descriptive map of the technological interfaces present in the yard and how the unfold into different industrial relations and specificities.

5.3.2. Dynamics

During the two weeks spent in the site in October 2014, interviews and observations, it was possible to capture the dynamics of bounded capabilities and how the shipyard was looking for solutions through linking up with others firms or by integrating specific interfaces that were not working. In other words, in the constant process of appearing and disappearing of technological interfaces as the learning curve in both ends of technological interfaces steepens. One year later, in October 2015, the site was revisited to check for changes in its industrial scope and the reasons that led to those changes. The updated number of firms and employees was informed (see. Appendixes F, G and E). The changes in productivity levels were also informed. By combining these two sets of information, it is possible to infer about the gains in learning from one year to the other.

5.3.3. Instruments, Protocols and Data Sources

As a source of primary data, this study will use semi-structure interviews. Semi-structure interviews best suited this research once it required the use of script but with autonomy to allocate the issues as the dialogue goes on and to formulate new questions that were not contained in the original script (Hair et al. 2005). Moreover, during the two weeks on site, interviews were set randomly accordingly to the availability of managers and directors. The research protocols (found in Appendix A) include open-ended questions that were divided into the dimensions that wanted to be observed regarding the shape, scope and dynamics.

Secondary data provided by SHIPYARD A added to the analysis quantitative characteristics of the shipyard regarding the number of firms and labor that were present across different stages of productive activity. This made possible a complete map of the organization of industrial activity of the yard.

The shipyard also provided materials such as organograms and flow-charts to exemplify how processes happen. Other visual materials related to the project descriptive overview documented and made available by PETROBRAS on the internet.

Because of the complexity of the activities of the shipyard and the number of parts involved in building such type of ships, it is almost impossible to capture, in a snapshot, every-single industrial relation for every single type of supplier.

5.4. Precautions and possible limitations from this approach

Yin (2009) points to the problem of non-generalizability of the findings from case-study. However, because of the complexity of the sector which involves many firms, and its re-emerging condition, many of the findings and challenges that were observed are similar to other national cases.

Another pre-caution relates to the use of case study in building theory. Eisenhardt (1989) argues that, intense use of empirical evidence in to an overly complex theory and the hallmark of good theory is parsimony.

For confidentiality reasons, this thesis did not have access to more detailed information on financial costs other than the estimated percentage cost per group of productive activity presented in Table 2. Neither the research had more access on the types and terms of contracts involved with the different firms.

The next section will present the organization of the shipbuilding and the key technological and economic determinants of its distribution worldwide.

6. The Shipbuilding and Offshore Industry

The Shipbuilding and Offshore industry can be classified under the definition of Complex Product Systems (CoPS), that is, "high cost, engineering-intensive products, systems, networks and constructs that involve a number of customized components (Hobday, 1998). These systems arise to produce high-value capital goods and which makes this business essentially a project-based industry (Davies and Hobday, 2005).

Shipbuilding involves an array of technologies to address specific markets which linkup various firms into industrial relations. Shipbuilding industry is a complex array of institutions and firms that develop and construct ships, underwater equipment and naval architectures for various purposes and markets such as: shipping industry, fishing industry, naval defense and extraction of ocean resources. According to Sohn, Chang and Song (2009) the shipbuilding industry is composed of three major products classes: commercial vessels (bulk carriers, Very Large Crude Oil Carriers a.k.a VLCC, general cargo ships, container carriers, LNG carriers); naval architectures (Floating Production Storage and Offloading a.k.a FPSO, Drillships); and special-purpose carriers (navy ships, cruise ships, platform supply vessles a.k.a PSV) (Figure 8). Naval architectures and drillships used to oil exploration and production are also referred to as Offshore Industry.

Figure 8. Classes of Vessels

As far as the general construction process, it involves converting materials into basic inputs or components, components into parts, and parts into an integrated complex systems following specific engineering projects. Unlike light industries, that usually involves the continuous processing of large quantities of products, construction projects entails the erection on site of single or small number of large units (Masten et al, 1991). As each project is unique and vary, assets are less likely to be specific to one particular transaction. Coordination and timing is a critical component as different stages of production are necessarily interdependent and there is no possibility of producing intermediate buffer inventories in between stages.

Figure 9 illustrates the complexity just described. As “Lego-like” structures, pieces of different technological domains must be somehow integrated into the various types of vessels. Complexity can be described in terms of:

a) number and types of parts that must be integrated (eg. basic inputs, components, integrated systems;

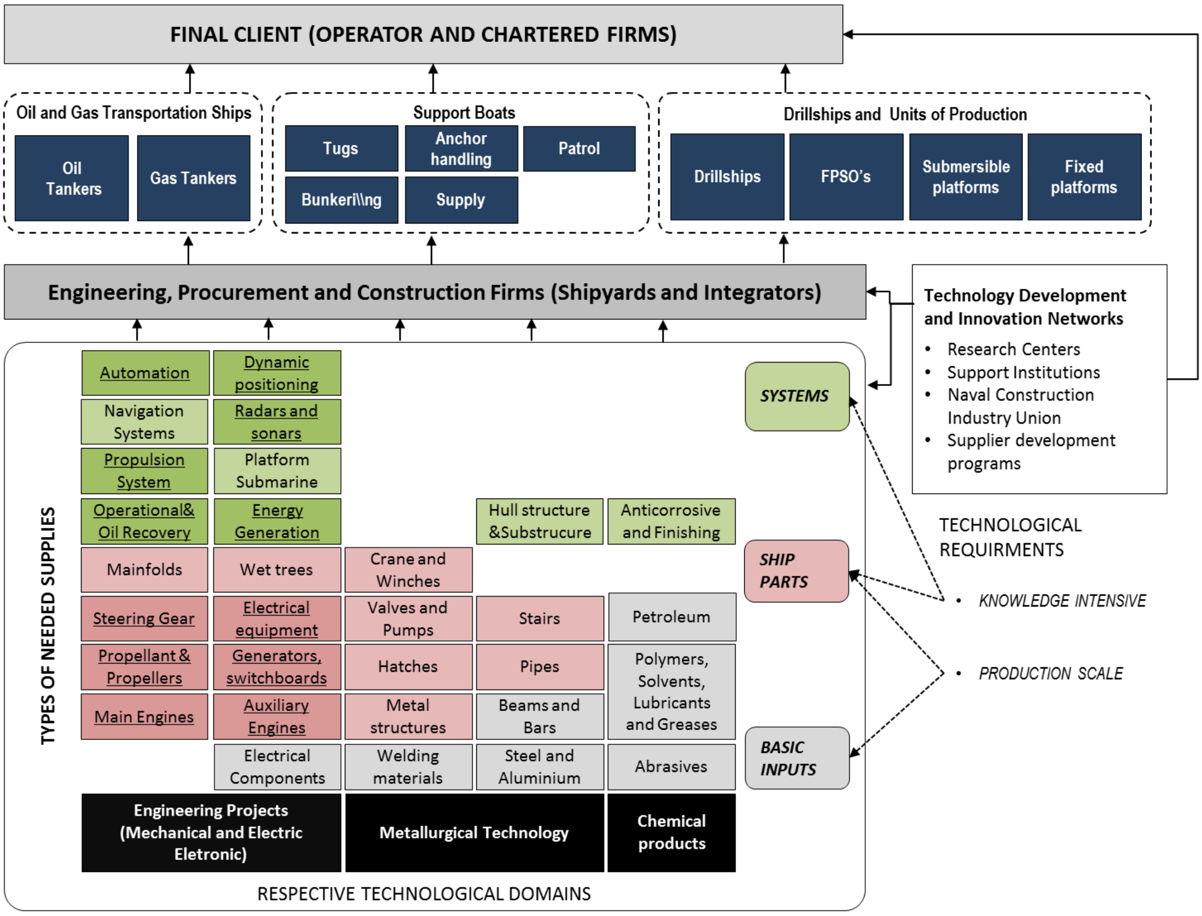
b) the technological domains of each part(e.g: metallurgy, chemical, mechanical, electro-electronic and systems);

c) the type of transformation (eg. *physical* – like bending, heating and welding; *chemical* – like painting, galvanizing, coating; and *integrative* – like manufacturing, connecting, mounting and testing;

d) the “complicatedness” to both master the technological base, and the ability to coordinate the necessary activities. This last item will influence the number of firms involved in the process.

To deal with this complexity, construction projects usually involve temporary coalitions of organizations (Hobday, 1998), which are based on a set of stable relationships between a general contractor and special trade subcontractors. These temporary coalition or relations have been characterized as ‘quasifirms’ (Eccles, 1981) as they integrate and dissolve following the emergence and finalization of projects.

Figure 9. From inputs to final client: Unbundling Shipbuilding



Source: Developed by author

Sohn et al (2009) puts forward a couple of specific characteristics of the shipbuilding industry. First, as a complex product system, it involves a *complex chain of suppliers* and labor which is usually analyzed in terms national industry once firms belonging to the same country are subjected to the same input and output environment. Second, while this is a labor-intensive industry, there is also a *high need for skilled workers and cutting edge technology* in both engineering and operations management. In fact, cutting edge technology in Design and Production are key requirements for an industry to become a world leader. Third, while *advancements in the shipbuilding technology are not easily captured in easy-to-compare figures*, this should not be mistaken for lack of sophistication. Building a highly sophisticated LNG carrier or FPSO, requires utmost precision in both design and production comparable to what is required to the aeronautics industry. Forth, the main determinants of competitiveness can be summarized in *technological sophistication and low cost*. This influence buyers selection criteria that are essentially based on quality, price and delivery time (Cho & Porter, 1986).Fifth, the key technological capabilities of the shipbuilding follows the dimensions proposed by Kim (2001) where TC are divided into *production capabilities* (design, construction, operations management and process) and *innovation capabilities* (development of new process and product-related technology).

While technological factors are a key element in creating sustained advantage and leadership position in the long-term, the shipbuilding industry is affected by two main group of factors (Mickeviciene, 2011): *macro factors* (world seaborne trade, oil prices, economic stability, and political stability) and *market factors* (subsidies by the government, scrapping of old vessels, charter rates, vessels on order). Technological and market/economic factors will determine the shape and scope of the industry worldwide.

6.1. Shipbuilding Firms and Markets

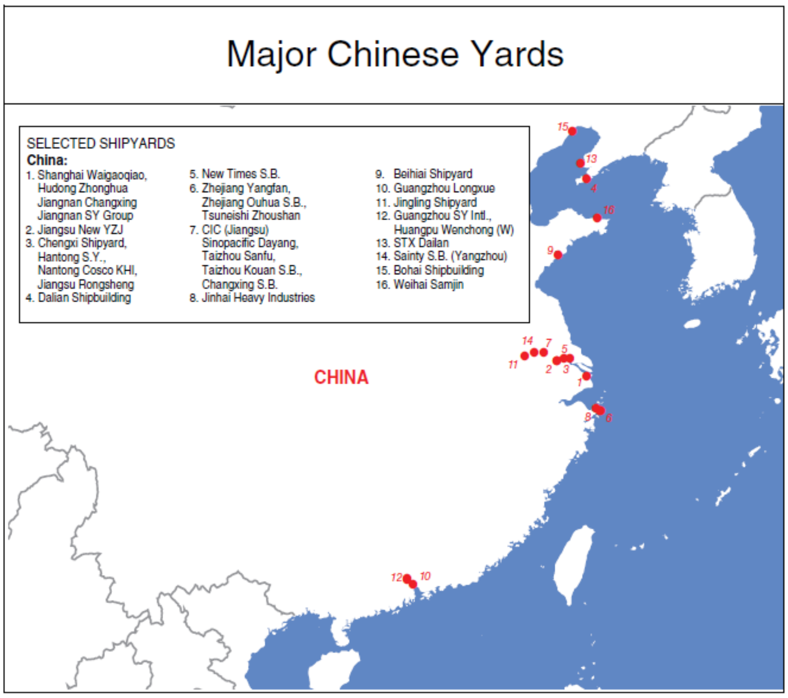
Shipbuilding is a dynamic industry that follows world's economic cycles (Pires et al, 2007). Expanding economic cycles drive increasing international commerce, which in turn create demands for more maritime transportation. According to Pires et al (2007), the productions cycles can be explained in four different periods. From 1960 to 1975, the world's production of ships increased due to the growth of developed economies, easiness of financing and a boom demand for Oil Tankers. From 1975 to 1980, oil crisis led to a chain effect and overall collapse of merchant ships and tankers. The sudden collapse resulted in a rapid drop of prices due to an over-capacity built in previous years. This led to a regime of subsidies, rationalization and supply control. From 1980 to 1990, the second oil crisis in 1979 and the World's economic recession in the beginning of the 80s kept production low hitting the lowest level in 1988. Several shipyards in Japan and Europe (the biggest producers at the time) were shut down due to the crisis.

From 1990 up to date, the shipbuilding industry moved to the east as South Korea and China entered and alongside Japan are now responsible for 2/3 of the words book-orders According to Pires (2007), these three countries along with other shipbuilders from Asian are responsible for 85% of the world's production of merchant ships.

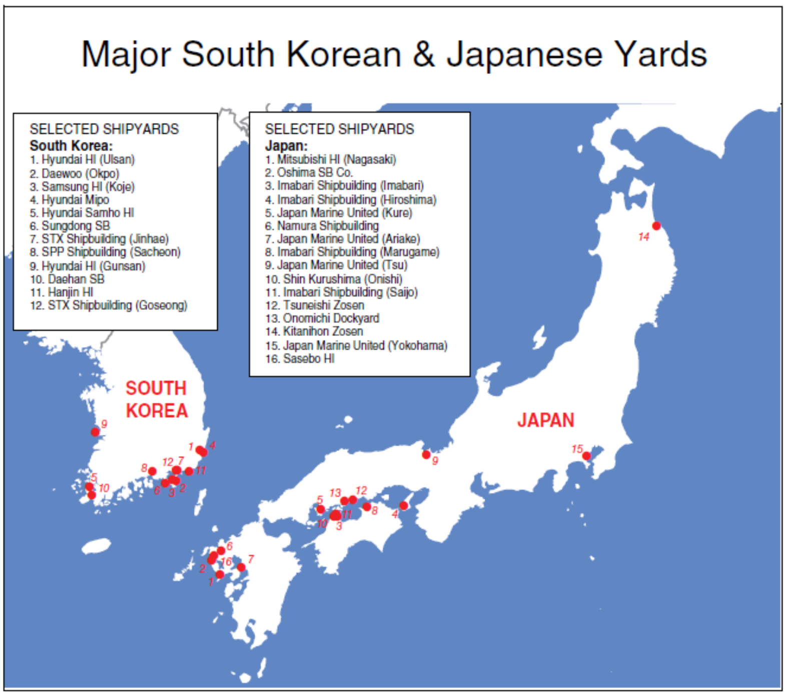
Figure 10 presents the major shipbuilding nations based on the order books status in 2014. 81,6% is dominated by China, South Korea and Japan. Brazil figures in the 4th position with 3%.However, by summing the European producing countries together, Europe appears as the 4th shipbuilding zone in the globe (Figure 10).

Figure 10. Leading shipbuilding companies worldwide as of June 2014, based on compensated gross tonnage (in millions)

Orderbook by Builder Country			
Rank	Country	No.	m. CGT
1	China P.R.	2,429	45.6
2	South Korea	868	33.3
3	Japan	986	19.7
4	Brazil	162	3.0
5	Philippines	73	2.1
6	Italy	20	1.5
7	Germany	19	1.4
8	United States	100	1.1
9	Taiwan	35	1.0
10	Romania	30	0.9
11	Vietnam	65	0.7
12	France	7	0.7
13	Netherlands	76	0.6
14	Norway	55	0.5
15	Finland	10	0.4
16	Croatia	20	0.4
	Other	290	2.2
GLOBAL TOTAL		5,245	115.1



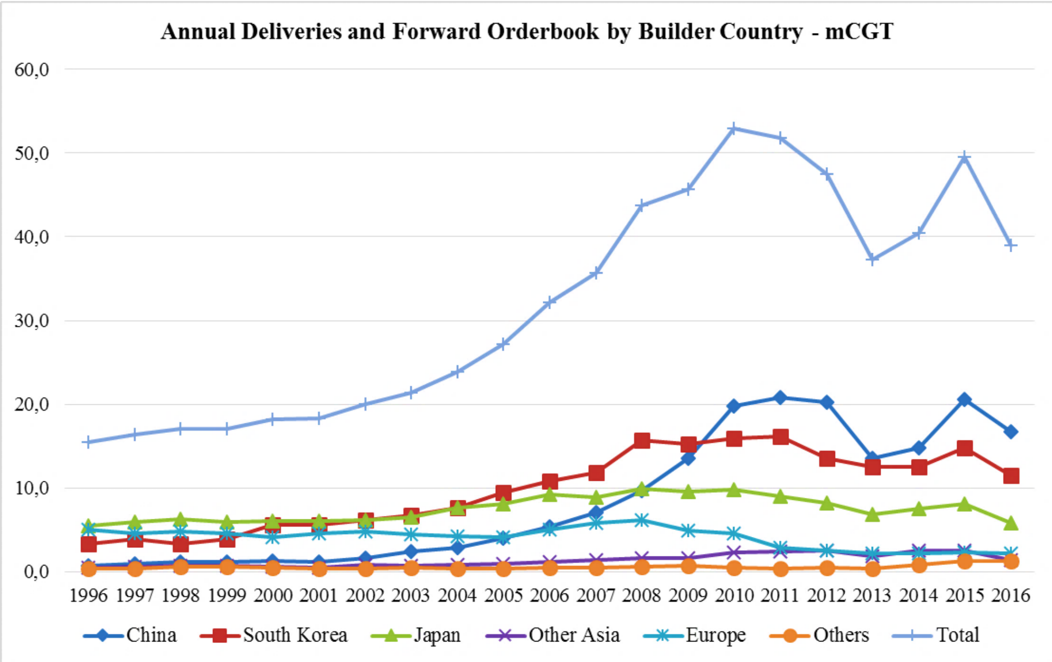
Orderbook by Shipyard			
Rank	Company	No.	m. CGT
1	Daewoo	121	7.5
2	Hyundai HI	103	5.1
3	Samsung HI	86	5.0
4	Hyundai Mipo	164	3.7
5	Hyundai Samho HI	83	3.7
6	Hudong Zhonghua	53	2.5
7	Shanghai Waigaoqiao	75	2.5
8	Jiangsu New YZJ	98	2.4
9	Sungdong SB	74	2.0
10	STX SB (Jinhae)	71	1.8
11	Dalian Shipbuilding	44	1.7
12	New Times SB	58	1.6
13	Chengxi Shipyard	92	1.6
14	HHIC-Phil. Inc.	36	1.4
15	Oshima SB Co	82	1.4
16	Imabari Shipbuilding	86	1.3
	Other	3,919	69.8
GLOBAL TOTAL		5,245	115.1



Source: Clarkson Research Services (2015)

Figure 11 shows the evolution of leading companies on annual deliveries and their respective forward orderbook.

Figure 11. Leading shipbuilding companies worldwide as of June 2014, based on compensated gross tonnage (in millions)*

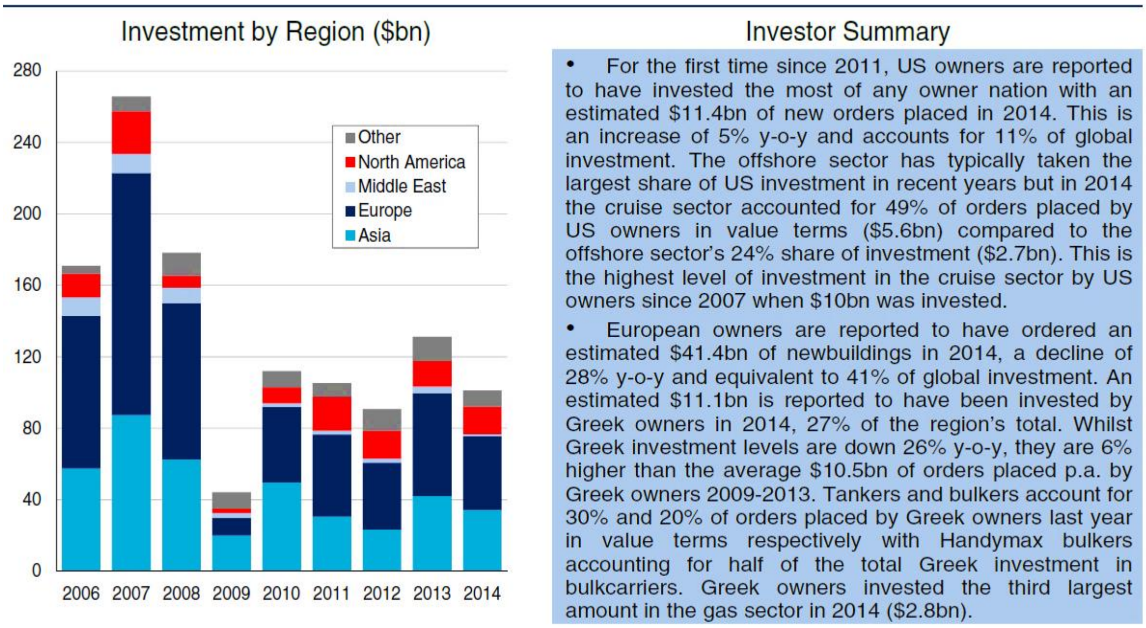


Source: Clarkson (2014)

While China appears as the world leader in the overall production in terms of forward order book in 2016.

Markets for this class of Ships are manly found in Europe and Asian Countries, Figure 12. North America appears in the third position.

Figure 12. Major Buyers - Investment by Owner Country/Region



Source: Clarkson Research Services (2015)

The next section will discuss the technological and economics behind the shift of competitive positions of leading nations.

6.2. The Technological Path to Leadership in Shipbuilding and Offshore

On the other side of markets are the technologies and the shift in Shipbuilding competitiveness over time. Like every other technological endeavor, it has progressed with the advancements of methods, techniques and tools. These techniques evolved from tradition-bound craft techniques to rational scientific technologies (McGee, 1999). Since wood was replaced by iron and steel, leadership in the global shipbuilding (in GT, CGT[17]) went from G. Britain to Japan, then to S. Korea, and finally to China (Mickeviciene, 2011). More importantly, the use of technology has immensely driven production output of different competing nations shifting their competitive position every time technology advances.

Until the middle of the last century, world production was dominated by European shipyards. Britain became the leader since 1860 until 1950. This was mainly due to the invention of naval architecture. According to McGee (1999), naval architecture was the first early modern technology to make use of measured plans after architecture itself. These measured plans in shipbuilding originated in Britain around 1586 and thereafter, the British naval dockyards became the single largest industrial organization in the world. However the industry failed to modernize and was slow in increasing productivity and implementing new technologies and production management. By 1950, Japan took over the first position after the World War II.

What is important to note is that, technology is not the sole determinant of industrial competitiveness. Institutional (macro) and market factors impacted the entry level of countries into the global arena (Mickeviciene, 2011). A common feature of the leading nations is the strong governmental support of local industrial firms to initiate and expand operations. Market reserves, subsidies as well as strong national goals fostered and directed the efforts of building capabilities and establishing the necessary technological interfaces of the industry. However, the ability of nations to gain the leading position has much to do with the ability to learn and develop technological capabilities to both produce and innovate. As newcomer nations find ways to both master different technological interfaces they were able to exploit

[17]Compensated Gross Tonnage. The ship's volume adjusted by a factor to render the amount of work at the yard equivalent for different types and sizes of ship

market opportunities combined with exploring new technological endeavors. This is the main factor creating their leadership position (Figure 13)

Figure 13. Shift in Leadership position of Countries in Shipbuilding

Duration of the leadership	**Country**	**Rise**	**Decline**	**Stage of Business cycle**
1860's – 1950's	G. Britain	Introduction of Naval architecture and iron made ships	Failure to modernize the industry	Lost leadership
1940's – 1945.	USA*	Shipbuilding "miracle" Introduction of mass production on military ships Development of Welding	Slowdown of internal market after WWII.	Lower productivity and competitiveness.
Mid 1950's – mid 1990's	Japan	Lower labor costs Introduction of high-performance welding	Ageing and higher cost human resources. Reduced R&D budget to less than 1%. Increased price of steel	Post-Maturity, weakening of competitive power
From mid1990's	S. Korea	Lower labor costs Technology absorption and development of the Membrane LNG carriers	Higher cost of human resources. High steel prices. Currency depreciation	Post-growth, maintenance of competitive power
Since 2010, earlier than it was planned	China	Lowest labor cost. Ambitious State programs for the development, growing shipyards capacity and subsidies.	S. Korea has replaced topped China in 2015	Reduced growth. Competitiveness based on low labor cost.

* The USA did not reach a market leadership position during this period, however it did introduce important innovations.

Source: Adapted from Mickeviciene (2011), Sohn, Chang and Song (2009), Pires et al (2007)

The following subsections discuss the shift in leadership position based on technological and economic factors that have led to the current scenario dominated by Asian countries.

6.2.1. United States – From Standard Design to Process Technology Development and Mass Production

The United States used to lead shipbuilding until the second half of the nineteenth century. The advent of steel structured ships and steam engine shift that position to Great Britain who by 1882 had dominated 80% of the world's market (Cho and Porter, 1986).However, the United States were responsible for important ship construction innovations during World War II. These innovations were later adopted in the Japanese catch-up process that led to their subsequent leadership (Sohn et al, 2009). The shipbuilding industry in the US during 1941-45is regarded as an 'economic miracle' (Lucas, 1993).

The United States Maritime Commission (USMC) was created in 1930 in order to replace the countries aging commercial ships. Nevertheless, it was only when the United States got involved in the Second World War, that President Franklin D. Roosevelt authorized the expansion of the quota of cargo carrying merchant ships (Blazek and Sickles, 2010). A rapid increase in demand for cargo ships was a result from the Emergency Shipbuilding Program of the US Navy. It pushed the search for new ways to fast produce cargo ships to supply troops in the war fields. Because time was the most relevant criteria, the USMC opted for existing designs used in producing war cargo ships to Britain in previous years. American shipyards adopted this existing standard design, all-welded, steel-hulled and traditional diesel burning engine technology. While ships by then were already using steam turbines, the old-fashioned piston engines were easier to make, operate and repair. Simplicity in the choice of key components and equipment, led to radical changes on every level such as cost, time, modularity and commonality of systems and parts (Keefe, 2014).

Standard design in both the vessel and components, simple construction methods (specially welding) and radical new approach in the organization of production using prefabrication and assembly lines, were the underlying principles of the Liberty Shipbuilding Program which created a shipbuilding revolution. These changes reduced man-hour by a third, cutting ship costs from 2 million to 1.7 million. Over four-year period, 16 U.S shipyards delivered 2,699 Liberty ships of 7000 tons each (Thompson, 2001).

According to Blazek and Sickles (2010) the major defining characteristic of Liberty ship manufacturing was the speed of production. While in the beginning, at typical construction of one ship took six months to complete, by 1943 U.S. shipyards were producing the vessels from start to finish in one month. The record was set as part of a publicity campaign, the Robert E. Peary Liberty ship was launched in 4 days after the laying of the keel. For Thompson (2001) the revolutionary aspect of the liberty shipbuilding program was related to the organization of production as most of the ship construction took place off the ways "(the berth in which the keel is laid and from which the ship is eventually launched)" (p.105).

Rapid training was necessary as population boomed in the cities where shipyards were located. Onsite schools were set to train unskilled labor on the several tasks, specially welding which was the bulk of the work accounting for a one third of the direct labor employed in construction (Thompson, 2001).Labor requirements measured in man-hours for each vessel fell by over 50% from 1941 to 1945.

Despite of the production speed, Thompson (2001) finds evidence that part of the measured productivity increases were secured at the expense of quality. This explains some welding issues that resulted from the low resistance of welded ships to low temperatures. Problems went from cracks to full broken ships. According to Motora (1997) one of the cases a Liberty ship broke in half due to low temperature. Nonetheless, improvements in metal engineering and welding methods have increase the resistance of steel against cold temperatures. The development of the welding technology will explain the Japanese rise in the industry in the following years.

6.2.2. Japan – Improving Welding and Production Techniques

The shipbuilding industry in Japan has over a hundred years beginning in the Meiji era (1868-1912), rapidly growing in the Taisho era (1912-1926) where Japan's modern shipping industry was formed and some original technologies were developed (e.g. fin stabilizer), through the Showa era (1925-1989) where, after WWII, the shipbuilding in industry in Japan took off in a "golden age" becoming the world leader by mid 50's (Motora, 1997).

According to Sohn et al (2009) the key aspect to this shift was the adoption of welding and block assembly method to shipbuilding. These technique was invented and put to use by the US to the mass production of ships in 1940 in order to reduce shipbuilding time and supply warships quickly during the war. While American shipbuilding focus on special purpose carriers, Japanese shipyards adopted the welding machine from the U.S in 1951. The European shipyards, on the other hand, were resistant and did not adopt the new technology because of safety concerns. Welded ships were fragile to low temperatures and there were several accident cases with some American welded ships.

The technological transfer of welding techniques was important for *Japanese* shipyards in the process of catching-up in order to get export orders. In addition to technological transfer, Japanese shipyards also developed and adopt a series of process innovation such as: block construction method in the 50's; advanced assembly system in the 60's; quality control technologies since 1962; and rationalization of work. Technologies were also developed which increased productivity. Kawasaki Heavy Industries developed the numerical automatic gas-cutting machine in 1967. Mitsui Shipbuilding Co developed the "Lotus System" which allows more efficient downward welding (Motora, 1997)

According to Al-Timmi (1975), Japanese shipbuilding had a cost advantage over English ships. However this was not due to lower labor costs, but primarily because of several processes innovations which helped increase productivity by reducing re-work, delivery time and at the same time improve quality.

The dominance of Shipbuilding in Japan was overcome by *South Korea* in the 1990's. Mickenviciene (2011) lists a couple of reasons: 1) increased in the Japanese labor costs and difficulty in recruiting young engineers; 2) resistance in looking for new markets that demanded bigger vessels; 3) 60% of ship production was focused in domestic market which didn't keep pushing for technological development and better methods. Additionally, a gap between the demand and supply for materials and strong currency against the USA dollar, reduced the competitiveness of the industry in both cost and delivery time. Technological, institutional and market factors prevented Japan from leading and opened-up an entry door to South Korea.

6.2.3. South Korea – From Imitation to Innovation and jumping ahead

South Korea, entered the modern shipbuilding in the 1960's. According to Shin (2010), the path to the top followed five major steps. 1) Preparation stage for modernization (1960's), 2) Takeoff stage (1970's), 3) High-speed growth (1980's), 4) Maturity stage (1990's) and 5) world number 1 shipbuilding nation in 2000.The rapid absorption of foreign technology and the ability to develop own technologies was a key factor behind Korean Competitiveness in Shipbuilding. This industry fallowed the path described by Kim (1997) from imitation to innovation.

According to Sohn et al (2009), during the preparation stage, strong governmental incentives and nationalization of shipyards alongside a five-year strong economic plan were the basis of the industry. Korean begins the construction of steel ships with local technology after the re-structuring of the Korean Shipbuilding Corporation in 1962. With the slow progress in terms of technology, in the 1970's the government established a plan to promote the Heavy Industries and induced major companies such as Hyundai Heavy Industries, Daweoo Shipbuilding & Marine Engineering and Samsung Heavy Industries to enter the industry. These companies adopted European and Japanese technologies with technological transfer taking place by acquisition of equipment, machinery and technical assistance from foreign engineers as well as short-term training overseas. Additionally, Computerized systems for shipbuilding design and production such as SEAKING, FORAN, PRELIKON, VIKING and AUTOKON were adopted during the takeoff phase and growth phases in the 70's and

80's. These technologies had to be transferred from advanced countries such as Germany (Howaldtswerke-Deutsche Werft - HDW) and from Britain (Appledore Shipbuilders and Scott Lithgow).

However, while imitation played an important role in acquiring know-how, technological development was sought to prevent Korean becoming dependent on foreign technology. Governmental action was taken in the late 70's to promoted local companies' R&D to explore new technologies in ship design, ship production, welding, engine and machineries. Besides, companies such as Hyundai, Daweoo and Samsung also invested in their own R&D facilities in the 1980's to develop not only process technology but also to compete in other sub-segments of the shipbuilding industry such as engine manufacturing. According to Sohn et al (2009), Hyundai initially started producing engines based on a licensed design from the German company MAN B&W. Hyundai enters the production of these engines after signing alliances with MAN B&W and Swiss Sulzer. As its European counterparts refused to provide the company with their engine designs, Hyundai decided to invest in their own design.

A similar process happen as South Korean enters the market for LNG carriers. As the leader in the production of this type of ship was Japan which used Moss type of technology, Korean shipyards were willing to initiate a technology transfer with Japan and production of this type of vessel. With the increase in Korean competitiveness, however, Japanese shipyards become reluctant in transferring technology and started to charge high prices for technology leases to Koreans. Korean shipyards were forced to consider building LNG carriers using a less common technology (Membrane). Because membrane was consider less safe, Moss technology has been the preferred choice for a long time. However, Membrane type of vessels had a higher capacity. Since the 1990's Korean shipyards started to move to this type of vessel and improve the Membrane technology. With the increase of LNG carriers in 2000 and the shift of demand from Moss type to Membrane, Korean Shipyards took the leading position in the LNG carrier market.

South Korean leadership lasted until it was passed by China. Only in 2014, South Korea recuperated its lost position, but competition with China is tight.

6.2.4. China – Reform, Low-Labor Costs and Lessons Learned from the Past

The case of China can be divided into two different moments. According to Sohn et al (2009), China enter the world market for shipbuilding in the 1980's, however, the Chinese shipbuilding industry has become competitive only in the past 10 years after the economic reform, when China entered the World Trade Organization in 2001. During the previous years, the Chinese strategy was very much closed to external possibilities of technological transfer and the industry invested highly in developing own technologies. The industry struggled to reach competitiveness. After the reform and a more open setting to allow both the transfer of technology and external commerce, the production of Chinese shipyards rapidly caught up jumping from 1.9 billion CGT to 62 billion CGT in 2008. Some compare the Chinese development with the Korean, however conditions differ significantly. While the South Korean shipbuilding Industry focused on the external market, the Chinese strategy focused on developing shipyard capacity to sustain economic development. According to Tsai (2011), the main goal in the Chinese strategy has been primarily to enable China to become self-sufficient in sea transport.

China is the cost leader in shipbuilding which has allowed the country to gain competitiveness specially in standard and less value-added ships (Jiang and Strandenes, 2011) such as bulk tankers. While the industry has been diversifying to more complex and technological advanced ships, it still relies heavily in the bulk vessels (Tsai, 2011). After the reform, the rise in the China shipbuilding industry has followed intense governmental incentives towards the formation of joint-ventures with international firms. According to Pires (2007), Chinese legislation allowed the formation of joint-ventures with international firms that could have up to 49% of invested capital in the new shipyards with mandatory provisions to make sure foreign technology transfer into Chinese Shipyards. This same rule applied to machinery factories. The idea behind this policy is to create the incentives for international firms to engage in technological transfer while still maintaining the control of the shipyards and factories with the Chinese State.

According to Mickeviciene (2011), governmental support, massive investments and cooperation with MAN B&W, Wärtsilä, and other equipment manufacturers have incredibly improved the Chinese position in shipbuilding. Moreover, Chinese policy also sought, not only international technology but new trade principles with more open competition and business practices. According to Collins and Grubb (2008), virtually all Singaporean shipbuilding and repair firms established joint ventures or installed subsidiaries in China, as well as major Shipbuilders from South Korea (Samsung Heavy Industries, Daewoo Shipbuilding) and Japan (Tsuji Heavy Industries and Tsuneishi Group).

The Chinese Shipbuilding Industry is divided into two conglomerates: The China Shipbuilding Industry Corporation (CSSC) and the China State Shipbuilding Corporation (CSIC). CSSC has shipyards around Shanghai while CSIC, concentrates shipyards in the region of Bo-hai golf. The biggest shipyards in China are Dalian Shipbuilding Industrial, Jiangnan Changxing and Kiangsu Rongsheng (Mickeviciene, 2011).

The accelerated growth brought change in the type of constructions that took place within Chinese shipyards. According to Pires (2007), production went from bulk carriers and tankers of small and medium sizes to VLCC, container ships as well as complex architectures such as FPSOs. The available production capacity in China made possible a change in the direction of orders. While Japan and South Korea had tight schedules and overloaded portfolio of orders, demand started to gradually shift towards the Chinese shipyards. The intense use of labor in China in contrast with the use of automation in Japan and South Korea brings higher levels of flexibility to projects executed in China and eases project adaption. With lower costs and excess capacity, Chinese order-books expanded rapidly in the last few years. However, Pires (2007) also point that there are still concerns regarding productivity, quality and timing of production.

6.2.5. Norway: From Offshore to Special Purpose Vessels and Technologies

While shipbuilding in Norway may be traced back to the Vikings, Norway has been a strong player in the shipbuilding sector. According to Holte and Moen (2010), the expansion of the Norwegian maritime industry came with the abolition of the British restrictions to foreign shipping. Norwegian ship owners and shipbuilders were fast to adapt to the new context. By 1880, Norway held the 3rd largest shipping fleet. Though not a world leader in term of volume of production, Norway deserves some attention once it has been a technological pioneer in Offshore technologies.

During the 70’s and 80’s, the maritime industry went through rough times due to the Oil embargo and the closing of the Suez Canal, which led to a boom on orders for large vessels to go around South Africa. European shipbuilders were faced with a heavy competition from Asian shipbuilders (Holte and Moen, 2010). Even with slowdown of the shipping industry, shipbuilding in Norway received a second boost by a new rising Offshore sector that lasted from the 60s to the 70s (Eugen, 2009). The oil crisis of the 70’s pushed the pursuit of oil extraction in the North Sea. The Norwegian shipbuilding industry which was formerly supported by fisheries and shipping sectors diversified into production of equipment for oil and gas exploration and production (Wicken, 2009). The industries’ design and construction techniques went through a significant transformation by emphasizing sectional construction instead of building the complete unit from the keel up (Engen, 2009). This implied greater specialization of different yards and the creation of governance mechanisms that strengthen cooperation, integration and the formation of several specialized clusters. A significant investment in drilling technology, specialized vessels and naval architectures were possible (Andersen, 1997).

The development of the Condeep[18] platforms put Norway at the center of the petroleum innovation system. According to Engen (2009), the petroleum innovation system in Norway went through five phases of development: 1) entrepreneurial (1970-76); 2) consolidation (1977-1980); 3) maturation (1981-1988); 4) reorganization (1989-1996) and; 5) second consolidation (1997-now). It is important to note that, during the first two phases, institutions and regulatory regimes were placed and firms such as Statoil, NPD, Aker and Kvaerner were establish as main drivers for the consolidation of the industry. While in the 60s, oil and gas was characterized by absorptive capacity limited to receiving technologies, in the 70s, public policy sought to expand Norwegian participation in technology development and supply. The Condeep construction was a milestone in this direction.

The following phases witnessed and increase in R&D spending and international "goodwill agreements" intended to incentivize international petroleum companies to contract with Norwegian firms and research institutes to develop national research institutions and capacity building. The forth phase was highly influenced by the high decline on oil prices which led to a shock on the innovation system. However this crisis encouraged actors within in the system to cooperate in order to develop new cost-savings technologies. A national program called NORSOK was created to develop new technologies, standards, contractual relations, regulations and negotiate with oil companies. In the last phase represent the continuous internationalization of Norwegian petroleum industry.

As the main sector in Norway, the oil industry reflects on the shipbuilding industry. The Norwegian maritime cluster involves construction activities from cranes to vessels to maritime services. Norway has around 30 small-scale shipyards to produce technologically advanced vessels such as: support vessels, fishing boats, research ships, specialized oil tankers, high-speed catamarans and ferries (Pires, 2007).

According to Holte and Moen (2010), the Norwegian martime cluster developed into a market leader in several sectors related to the maritime as well as offshore sector. Activities vary from advanced ship equipment found in the Kongsberg Cluster; drilling and (un)loading equipment for marine operation in the South Norway Cluster; Technological development for oil exploration under extreme conditions in the North Norway Cluster, among others.

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[18]Condeeps were large gravity concreet platforms places on the sea bead.For more information see: https://en.wikipedia.org/wiki/Condeep

6.2.6. Singapore – Leading the Offshore Industrial Clusters

With regards to the Offshore sector, Singapore also deserves some attention as it specialized in Naval Architectures such as FPSOs, Platmorms and Drilling Rigs. The shipbuilding activity in Singapore has strong ties to the port activities. Despite the high completion against other ports in Asia, high investment in automation and ICT to increase productivity has led the Port of Singapore to reach the position as the biggest container port in the world and second in terms of total cargo throughput (Wong, 2009). Parallel to this, the marine engineering industry involving offshore and shipbuilding and repair, had been emerging. Initially, shipbuilding and repair were directed to the Port of Singapore, but started to diversify into the offshore Oil & Gas sector.

The State has also played a key role in promoting the industry. Wong (2009) details some of the key factors:

a) Promotion of the International Maritime Center with the goal of becoming the leading comprehensive integrate IMC in Asia. The institutional framework involves several ministries, government agencies and industry representatives to generate integrated development.

b) Governmental programs for R&D and Innovation. In 2002, Singapore and Norway signed a Memorandum of Understanding which provides a framework for technological collaboration among research institutes, academics and industry representatives of both countries. Also, a Maritime Innovation and Technology Fund was created to support the Maritime Technological Cluster Development Roadmap.

c) Offshore & Marine Engineering Cluster. Singaporean firms specialized in the construction of Offshore rigs and platforms reaching 70% of the worlds' market-share in this segment.

d) Development of Public R&D Institutions and Innovation Collaboration with Offshore Industry. Several agencies were created to integrate research and education institutions and the industry such as: Centre for Offshore Research & Engineering; Agency for Science, Technology and Research; Marine & Offshore Technology Centre of Innovation.

Singapore has two of the major companies in the offshore segment. Keppel FELS and Sembcorp.

6.3. Some Remarks on the Patterns of Industrial Development in Shipbuilding and Offshore

As a complex industry in both the number of the necessary integrating parts and technological domains, the entry barrier for any new comer is very high which requires not only capable firms, but also proper macro and market conditions to allow new entrants to have a minimum level of comparative advantage. The different leading countries, chose different strategies to build their shipbuilding industry. This development required the existence of previously related capabilities and/or effective technological transfer. Unless the country is the pioneer in some specific technology, the reliance on some type of technological transfer seems inevitable. The American path of shipbuilding industry has obvious ties with the British industry as far as using iron as the main input, however, the "miraculous" growth of the American shipbuilding was possible because of previously developed industrial capabilities of US firms, especially in mass production. The development of assembly lines, standard interchangeable components, to facilitate reaching scale of complex systems is a genuine American innovation. Moreover, welding technology was developed to speed up the process in comparison to riveting.

Once a technological path has been open by a pioneering firm, it seems to be less costly and faster for newcomers to imitate in a first stage by engaging in technological transfer to expand industrial capabilities. Nonetheless, the long-term success of this cases show that firms had to move past the copy strategy, to develop their own technologies.

Usually, this process follows, as Kim (2001) argues, the building of production capabilities first and innovation capabilities later. Literature on catching up of firms from developing nations classifies the paths from imitation to innovation as follows. First firms enter the market as Original Equipment Manufacturers (OEM) by licensing the production of foreign technology. Overtime, firms develop engineering capabilities and can may become Original Design Manufacturers (ODM). As firms develop enter markets with their own products, than they become Original Brand Manufacturers (OBM) (Hobday, 2000).

Sohn et al (2009) argue that Japan and South Korea are two examples where the success can be attributed to the effective transfer of technologies with external firms. The open strategy towards technological transfer helped both industries to catch-up and competition stimulated the development of national technologies (e.g. welding and process technologies in Japan, and engines and Membrane LNG carriers in Korea). South Korea started by exploiting production capabilities and was able to move up and build innovation capabilities.

A different path, they argue, was chosen by Taiwan. While Taiwan has been successful in the electronics industry based on an OEM/ODM/OBM strategy (Hobday, 2000), the same cannot be said about the shipbuilding industry. Even though, the shipbuilding industry achieved high levels of quality in production of unsophisticated vessels, Taiwanese shipbuilding relied heavily in technological transfer and imitation and the industry never was able to raised up the bar in terms of R&D investment, own design engineering and equipment manufacturing. The reliance in external transfers and the lack of engineering technological capabilities compromised the industry's possibilities in the first market shock it faced. Figure 14 presents a summary of the different strategies by different leading companies.

Before the Reform, Chinese shipbuilding remained closed to technological transfer, and the industry struggled to gain competitiveness. According to Sohn et al (2009) China was the first to promote the shipbuilding industry under national incentive in the mid of the 20th century. Since then, China had invested in national R&D with the establishment of the National Institute of Shipbuilding and Ocean Engineering in the 50s. The Great Proletarian Cultural Revolution in 66 prohibited all sorts of technological transfer from foreign nations. The Chinese independent development without having any influx of advanced technology led to lost decades and lack of absorptive capacity.

The recovery of the Chinese shipbuilding industry is highly explained by the adoption of an open policy for technological transfer and cooperation combined with the low labor and currency devaluation which creates enormous comparative advantage. However, while these conditions of lowest prices combined with an excess capacity discussed previously allowed China to both enter the market and figure as the leader in the mid 2000s, China may experience the same problem faced by Taiwan in the 1990. With the production of unsophisticated vessels and lack of R&D capabilities in advanced shipbuilding technologies, China may not be able to sustain a leading position for long. However, Chinese success in the long run can be expected as long as the country moves from imitation to developing its own technological solutions and products.

As long as the country is at the technological edge either in product or in process, it is not reasonable to stay closed to technological transfers. The latecomer leading shipbuilding nations of today, have engaged high efforts in absorbing technologies from advanced economies before entering on a path for development.The lower-right quadrant is empty once being closed necessarily requires development capabilities within that context.

Figure 14. Technological transfer and Capability Building in different shipbuilding nations

	Technological Transfer	
	Open to External Sources	**Closed**
Building Innovation Capabilities	***Japan*** • Welding Technologies • Block Construction • Advanced Assembly Methods ***South Korea*** • Engines • Self-developed cutting, welding and assembly techniques • Own product design carrier and container vessels • Building cutting-edge Membrane LNG vessels Technologies ***Norway*** • Development of the Condeeps Platforms • Specialized Vessels Technologies ***Singapore*** • Became Specialized and lead the Engineering and Production of Offshore Platforms	***USA*** (pioneering) • Modularization • Pre-fabrication and assembly line • Mass production process • Welding ***China*** (before the reform) • Unsuccessful • Didn't achieve performance
Exploiting Production Capabilities	***Taiwan*** • Production of sophisticated ships with international technology ***China* (**After the Reform**)** • Catching-up based on technological transfer and low labor costs	*None existing*

Source: Based on the discussion above

The stories behind the emergence and path to leadership the cases presented above show some patterns. First, in all cases presented, *governments played a key role* providing the necessary institutional support for national industry. For instance, the WWII triggered the US government to concentrate industrial activity on war equipment and technologies, among them, shipbuilding. According to Motora (1997), in the first years after the war, Japanese policy initially intended to reduce the shipbuilding capabilities as the industry could barely survive by repairing existing ships. However, policy changed during US-Soviet confrontations and the shipbuilding industry received governmental support with the purpose of improving the shipping industry and ensures domestic food supply in Japan. With financial support from the government recovery fund, US funds and from the Japan Development Bank alongside the fixation of the Japanese currency (360 yen to a dollar) in 1949 put the shipbuilding industry in a favorable condition to receive international orders. In a similar fashion, South Korea and later China also received intense governmental support to promote the shipbuilding industry begging by taking advantage of the available cheaper skillful labor and latter getting momentum developing technological capabilities.

This means that, shipbuilding and offshore sector are a type of industry that will not likely develop without proper institutions. Governments had to publically set shipbuilding as a strategic priority to the national interest. Institutions played a key role in several instances: a) by setting an institutional framework that address short and long term expectations; b) by providing subsidies allowing national firms to enter into the factor markets with lower costs (labor and materials);c) by stimulating linkages between education/training systems and industrial actors; d) by stimulating international technological transfer; e) by stimulating Research and Development and the development of technological capabilities.

Second, technological transfer from international firms was necessary to the process of catching-up and capability building. Unless a country is the pioneer in technology, capabilities will not likely 'grow' competitively (neither in quality nor in cost) out of thin air. This may mean that it may not be prudent for countries that are not on the leading edge to count solely on the endogenous development of industrial capabilities. Japan benefited from transfers from the USA. South Korea benefited from technological transfers from Japan and Germany. China more recently received transfers South Korea among other. Norway received support from international oil companies and foreign firms who agreed to help building national capacity. Singapore, signed agreements with Norway for cooperation.

Nonetheless, as the third point, capabilities cannot be transferred in the vacuum. Technological transfer needs not only transferors, but transferees with capacity to absorb technologies (Teece, 1977). All cases showed some level of previous existing capabilities in related industries. Japan was a traditional shipbuilder. South Korea had also been in the shipbuilding business in the past and had built industrial capacity based on the *chaebols* policies. Norway used its local competences on construction and engineering. Singapore initiated with the port activities and ship repair and moved on to the shipbuilding.

Fourth, besides already possessing some level of capabilities present, the ability to learn fast was an important feature of firms in all the described cases. Norway was said to have developed national absorptive capacities (Engen, 2009). South Korea was very intense on their path from imitation to innovation by reverse engineering foreign technologies until Japan became reluctant in licensing its technologies to Korea. Singapore, and now China are following the same path. Education was a pre-condition to this development.

Fifth, in all cases national firms were created or used to be the anchors of industrial development. This may be a coincidence, but building national champions was a common feature. Finally, it is important to note that, while companies from catching-up countries used technological transfer and imitation at the start, their long-term success was reached by overcoming the knowledge barrier and becoming owners of particular technologies and markets (Sohn et al 2009).

The description of the Shipbuilding Industry as a complex system, show that, entering the market requires planning, coordination, previous levels of capabilities present and it happens gradually (faster or slower) depending on both the intensity of technological transfer and the ability of national firms to learn and master different parts of the building process.

Given the natural complexity of the sector and the need to build a thick and integrated supplier base, Brazil has several challenges to overcome beginning by mastering the technological base within competitive costs.

The next session will describe the Brazilian Shipbuilding and Offshore industry from its origins to its re-emergence.

7. The Brazilian Shipbuilding and Offshore Industry

The shipbuilding industry in Brazil began more than a century ago. However, the sector has undergone through growth and rapid decline cycles. Since the 2000, it is has been facing a new opportunity to reemerge backed by the opportunities in the Offshore Oil Exploration and Production activities and institutional incentives. This section reviews this historical process of the Brazilian shipbuilding industry and it analysis the recent reemergence.

7.1. A Brief History

Brazilian Shipbuilding initiated in XVI century to produce small vessels and in XVIII with the foundation of marine arsenals in different Brazilian regions. However, private investment in the Brazilian shipbuilding started in 1846 in Niteroi (RJ). Influenced by the English Industrial Revolution, entrepreneur Barão de Mauá transformed a little foundry into the biggest shipyard in the country at the time. Brazilian shipbuilding received a first boost in the 1950s during the presidency of Jucelino Kubitsheck and its “Plano de Metas” which intended to accelerate progress and economic growth of “50 years in 5”. During this period, as the Goal 28, the Merchant Marine Fund (FMM) was created alongside the National Development Bank (BNDE). The goal was to promote the renewal and increase of the national fleet, reduce international imports of ships as well as charter costs with foreign ships and to stimulate ships exports (Foster, 2013).

In 1959, two foreign shipbuilder, Ishibras from Japan, and Verolme from Holand established themselves in Rio de Janeiro alongside national shipyards Caneco, Mauá and Emaq. Another shipyard, called Só, was implanted in Porto Alegre during the same period. These were the six main shipyards responsible for pushing the national supply chain of ship-parts from steel frames to electrical components and power generation. Some technologies such as propellers and engines were licensed international firms (Sulzer, Burmeister& Wein, Man Diesel, Daihatsu Diesel Manufacturing, SEMT-Pielstick and Wartsilla). Moreover, the supply of ships was mainly directed to internal market. In 1964, Brazil entered the international market by selling cargo ships to Mexico (Foster, 2013).

In 1967, another round of infrastructure investments were made under the administration of president Costa e Silva. Governmental programs also guaranteed orders to national shipyards. From 1967 to 79, three programs were launched to fullfill demands from Merchant and Naval feet (Foster, 2013).In 1968, the first Jackup Rig was built in Brazil for

Petrobras. In 1969, ship-owners were provided with access to subsidies and financing to build ships in the country.

By 1975 Brazil had reached the second position in shipbuilding orders worldwide, behind only Japan. According to Cho and Porter (1986) Brazil was recognized as a major force owning 7% of the world's market-share. Export subsidies (up to 30% of the ship price) and low labor costs created market competitiveness and incentives for orders, specially from Honk Kong who purchased the ships from Brazilian shipyards and leased them back to Petrobras. Nonetheless, tight monetary policy to the industry and the large local content requirement eliminated the generous terms it had offered to foreign customers and the Brazilian shipbuilding industry eroded by 1990s.

The beginning of the crisis may be attributed to inflationary economic system which made the financial game more attractive to investors than the industry. Disinvestment led to delays on deliveries, costs overruns and technological downgrade. The Brazilian fiscal crisis and the inability to compete neither in quality nor costs of vessels, put the industry in check. The Brazilian shipbuilding industry did not accompanied the technological revolution that happen in the maritime industry with the emergence of *full-container* and *roll-on-roll-off* ships used to carry wheeled cargo such as automobiles, trucks, trailers, among others (Barat, Neto and Paula, 2013). On top of that, when market reserve policies were taken away with the opening of the market in the 90s, it became impossible for national shipbuilders to keep operating.

However, the industry would eventually re-emerge in the 2000s as Brazil was able to balance its fiscal deficit and manage inflation successfully. The re-emergence of the Brazilian Shipbuilding took institutional efforts, Petrobras as the main engine, and new Off-shore Oil discoveries. This will be discussed in more detail in the next subsections.

Figure 15 presents the evolution of the Brazilian Shipbuilding Industry, Technology and Markets served. While shipbuilding had grown until the 70s, the industry never fully developed without some type of governmental incentive or subsidies. Its main market was national ship-owners or foreign ones that would operate in the cost line of Brazil.

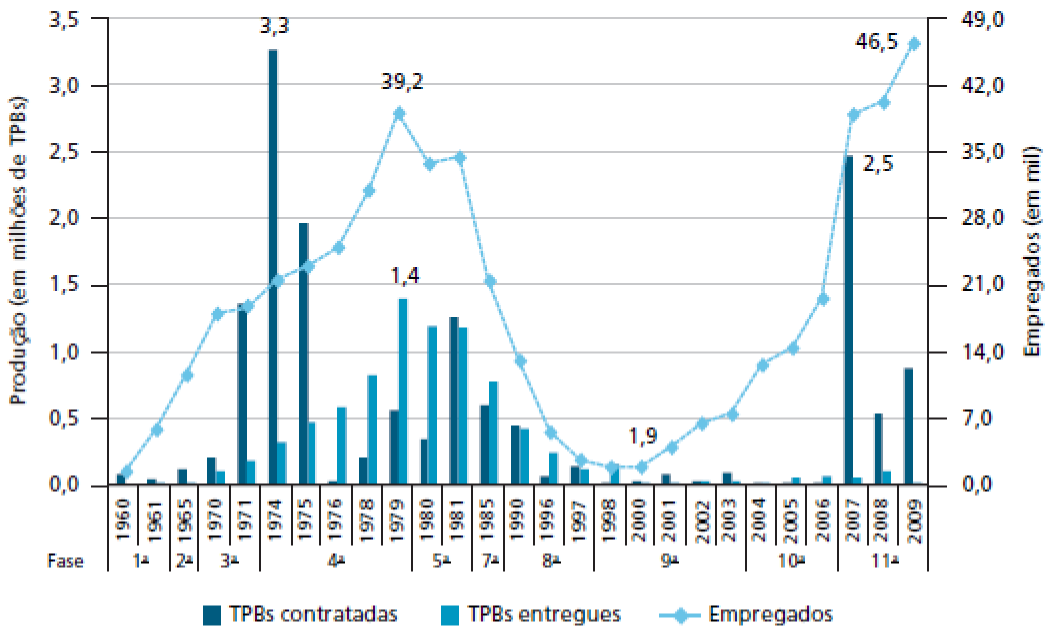
Figure 15. Phases of Shipbuilding Industrial Development in Brazil

Phases	Technology	Market	Industry Organization
1st: 1961-1965	• Small vessels	• Orders for internal market.	• Low level of local content requirement. National and International Shipyards were established
2nd: 1966-1969	• Cargo Ships • Tankers • 1stJackup Oil Rig (1968) • Higher levels of automation in production	• Demand driven to strengthen national merchant and marine fleets. • Petrobras and Vale do Rio Doce • 1st Ships sold to Mexico • Brazil reached 2nd place in shipbuilding worldwide	• National and Foreign Shipyards. • National supply chain for basic inputs • National production of licensed foreign technologies
3rd: 1970-1973	• Cargo ships • Tankers	• Launch of the 1st Governmental Program of Shipbuilding Construction • Cia Vale do Rio Doce	• Increase in shipyards capacities and capabilities
4th: 1974-1979	• Vessels for High Seas (oil tankers, cargo, ore-oil) • Vessels for river navigation • Support Boats • Floating Dock	• 2nd Government Shipbuilding Plan. • 47 vessels were exported. • 2nd bigger Orderbook in the world. • Oil crisis	• Delays marked this period • Costs overruns • Incapacity to meet de demand • Inability to technologically upgraded
5th: 1980-1982 6th: 1983-1984	• Tankers, Cargo, Tugs, bulk carriers	• Market slow down • Fiscal Crisis in the Country • Entrance of Asian Shipbuilders • Government created the Permanent Plan for Shipbuilding	• Reduction in the volumes of production
7th: 1985 - 1989	No recorded change	• Paralyzation of construction contracts	Reduction in the volumes of production
8th: 1990-1997	No recorded change	• Opening up of the market • Exposure to international competitiveness • Obsolescence of the national merchant fleet	• Collapse of the Shipbuilding Industry in Brazil. • Bankruptcy of Shipyards
9th: 1998-2003	• Oil rigs • Oil tankers • Support vessels • Line handlings • Anchor Handling Tug Supply • Tugs	• Change in the market • New players in the Oil E&P in the coastline of Brazil • Demands from Petrobras. • Creation of the National Oil Agency	• Reliance on Imports
10th:2004-2006	• Support Vessels • Oil Tankers • Platforms and modules	• Petrobras initiated programs for fleet renovation • Pre-salt oil discoveries • Local Content Requirements Demand boom!	• Reactivation of the shipbuilding industry • Reactivation of some Paralyzed Shipyards • National Training Programs (PROMINP)
11th: 2007-2013	• Platforms • Drillships • Support Vessels • Tankers • LNG carriers • Bunkers	• Intensification of demands • Intensification of local content requirements • Creation of SeteBrasil • Demand mainly done by Petrobras, SeteBrasil and Charter Firms.	• Emergence of several new shipyards and Shipbuilding Clusters.
12th: 2014-Now	• Platforms • Drillships • Support Vessels • Tankers • LNG carriers • Bunkers	• Cancelation of some contracts • Corruptions investigations	• Inability to meet deadlines and quality • Retraction and adjustment

Source: based on Barat, Neto and Paula (2013) and Foster (2013)

Figure 15 above presents the evolution of technology, markets and industrial organization over the years in Brazil. The industry started with the construction of small vessels during the 60s to attend local market. National and international (from Japan and Holand) shipyards were established in Rio. Based on new round of investments, institutional incentives and governmental programs, the industry increased its capabilities and scale during the second half of the 60s producing bigger vessels and oilrigs. For the first time, Brazil started to export. The peak in orders were in 1975, however, macro factors such as inflation, external shocks and the entrance of new shipbuilding players in Asia led to a rapid disinvestment in Brazil.

Figure 16. Labor and Production Evolution



Source: Barat, Neto and Paula (2013)

Figure 16 shows the evolution of shipbuilding in Brazil in numbers contrasting tonnage produced, delivered and the labor change over the years since 1960. It is possible to note that industry received a big number of orders in the first years of the 70s while the capacity to deliver increased gradually over the next few years reaching a delivery peak in 1979. From 81 to the 2000, the industry slows down and vanishes in the year of 2000. Another important aspect to observe is that this industry is great job generator. It employed 39,2 thousand people in 1978. From 2001 and on, job creating in the shipbuilding also increased rapidly. In 2007, the order book increased based on Petrobras demands. Job creation reached 46,5 thousand in 2009. In 2014, it was reported that the industry was creating 82.4 thousand jobs in 2014 (SINAVAL). In December of 2015 the number went down to 57 thousand.

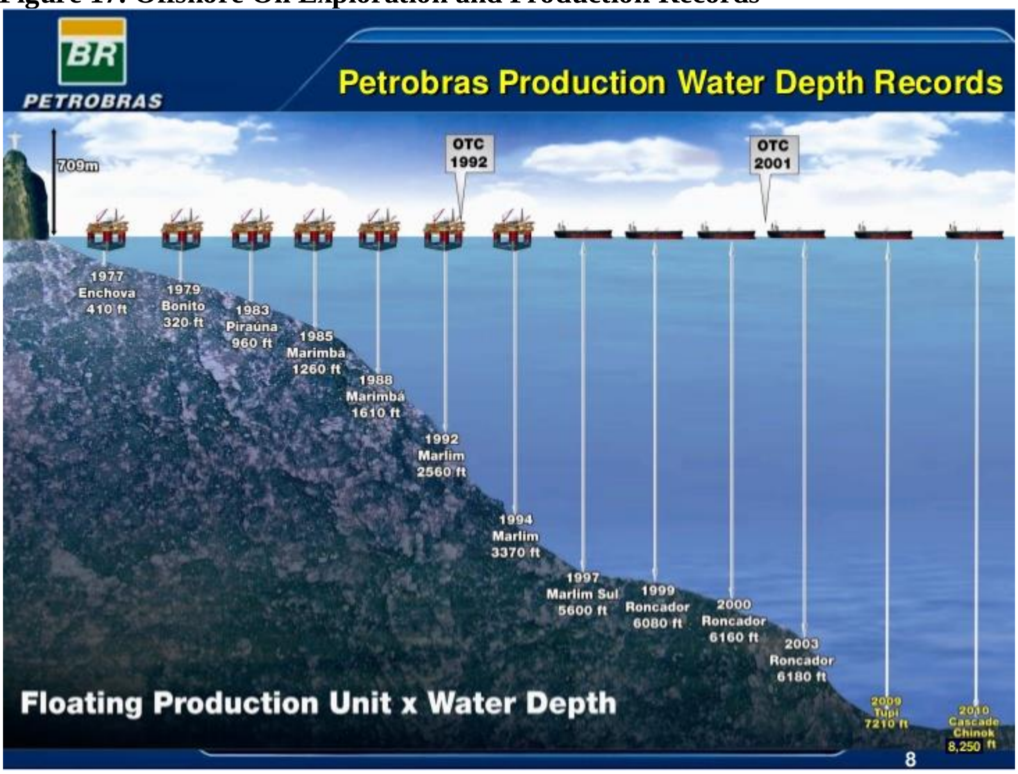
The next section will present briefly the issues behind the oil and gas industry which are the main source of funding for the shipbuilding and offshore construction projects.

7.2. New Opportunity from Offshore: The Pre-Salt “Black-Gold” Reserves

The prospects of oil found in the pre-salt layer, is the big offshore area along the sea cost of Rio and São Paulo. It is also the main source of financing for the shipbuilding industry in Brazil. There are estimated 15 billion of barrels of oil equivalent (BOE) which puts Brazil among the top 10 oil producers in the world. The pre-salt layer is also the deepest oil fields found up until now, which will require important technological development to reach over seven thousand meters. These developments involve production, drill rigs, drill ships, support vessels. Sub-sea technologies which require the work of specialized professionals in different domains of engineering, geology and geophysics.

It is important to highlight that, Petrobras has steadily been breaking records in oil Exploration and Production in deep waters (Figure 17).

Figure 17. Offshore Oil Exploration and Production Records



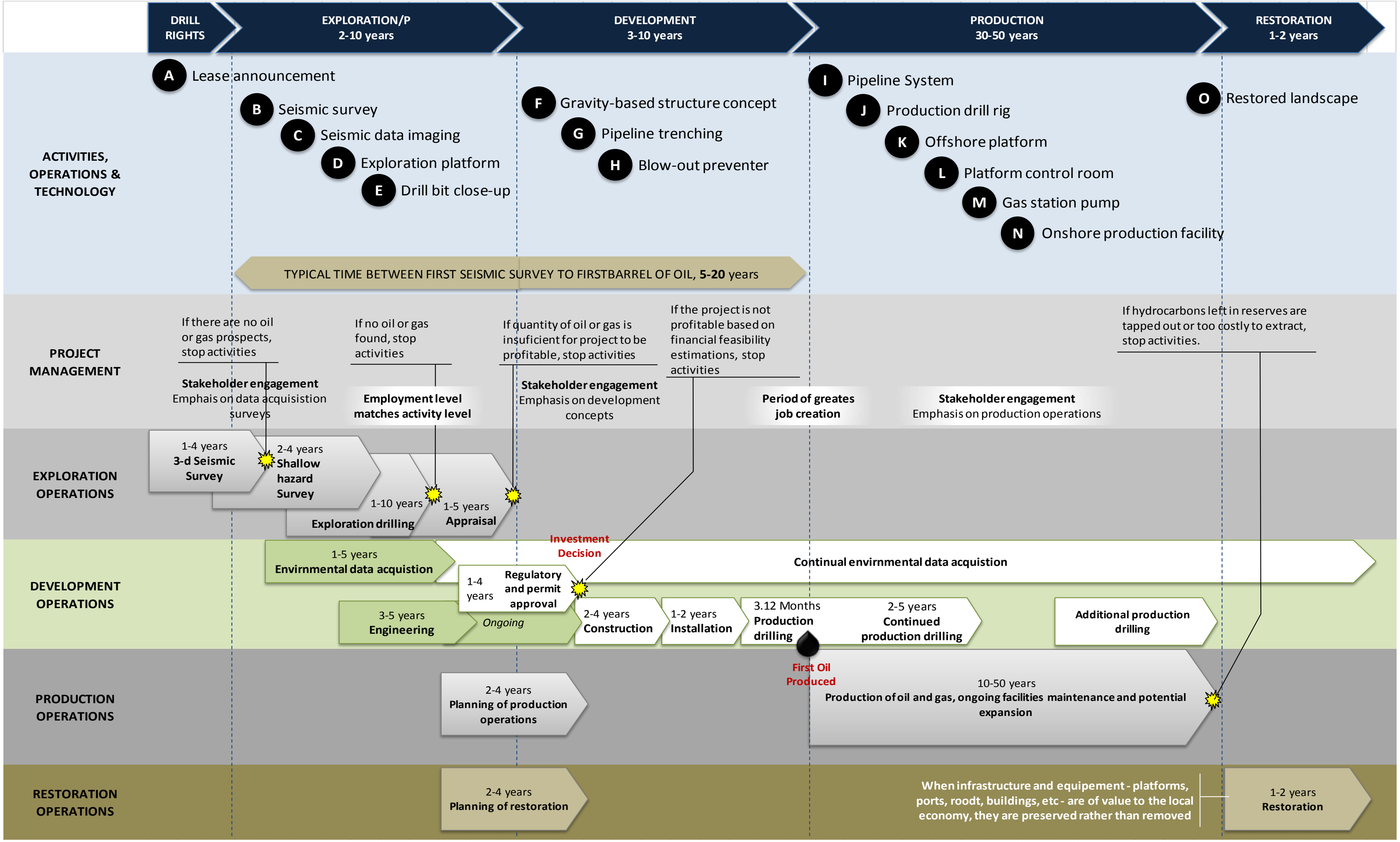
Source: Presentation by Petrobras 2009

The challenges that arise with the Pre-Salt also brings opportunities for advancing the technological frontier into ultra-deep waters. In fact, the importance and complexity of these challenges have been compared by specialists as the Brazilian "space-race" in analogy to the American-USRR real space race the 60´s.

The general notion of the oil industry is commonly dived into what are call upstream (Exploration and Production – E&P), midstream (transportation, pipelines, storage and wholesale) and downstream (refining, distribution and marketing – R&M).The upstream process to explore oil in deep and ultra-deep waters follows a complex operations that requires high-technology and safety standards in order to reduce risk and cause minimum environmental harm. The exploration of oil offshore is a long operation that can take up to 50 yeas (or more) depending on the quantities available. The upstream process goes form the obtainment of drilling rights by a company.

The *exploration* phase involves the mapping of seismic conditions through seismic surveys, data imaging and the search of the oil fields using drill-ships. If the field is considered economic feasible, the *development* phase begins in order to prepare the wells to be producing. The development phase may take from 3 to 10 years and only after it, the first oil may be produced. *Production* starts and continues until the wells are tapped out or too costly to extract. Production activities then give place to restoration. Figure 18 illustrates in detail the complexity and sequential activities in the Offshore Exploration & Production. The overall E&P operation may take several years from drill rights through exploration, development, production and restoration of the field.

Figure 18. Offshore Oil Exploration and Production Processes



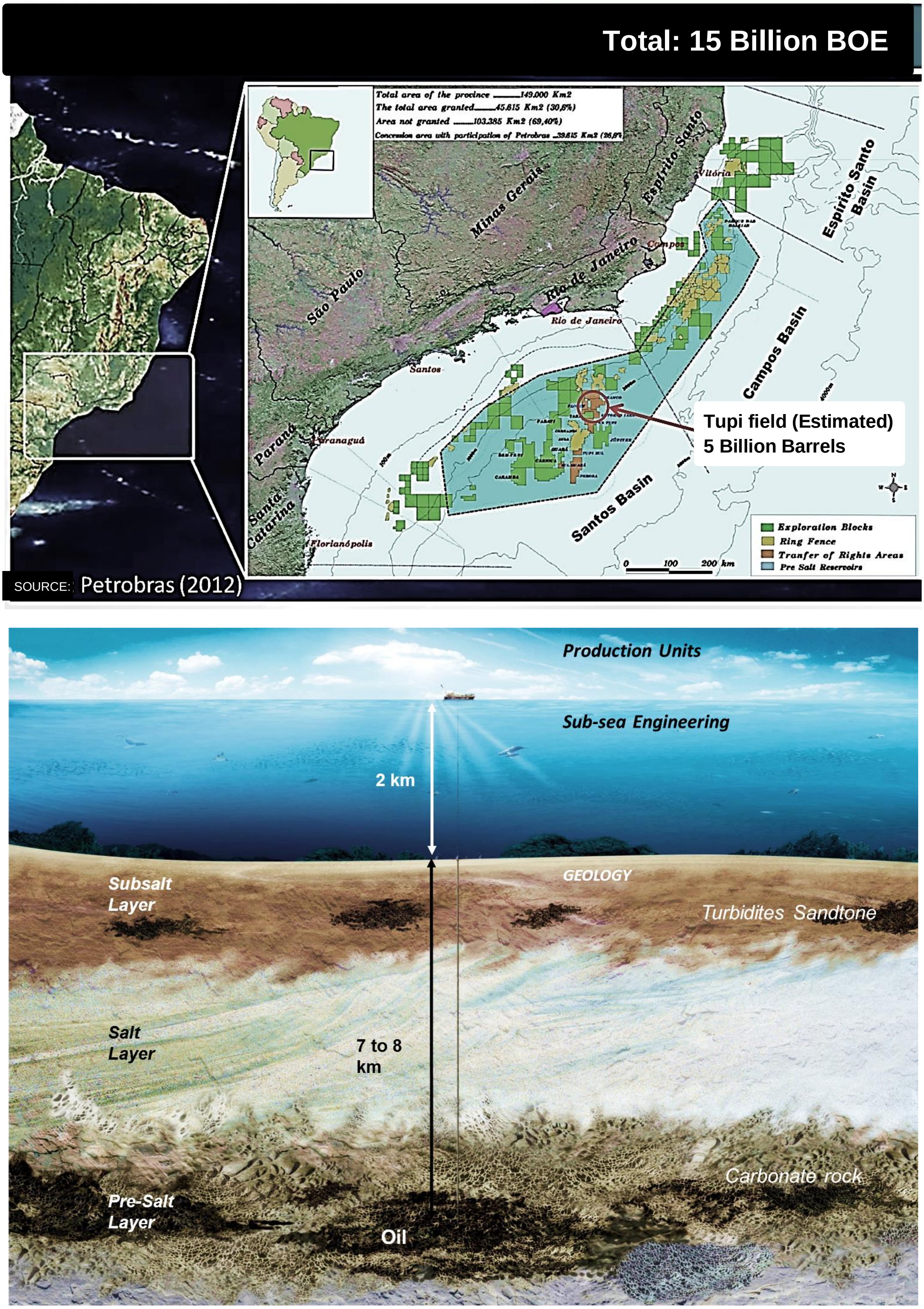
Source: adapted from Shell 2012

While there is a global effort to reduce the emissions of CO_2 in the atmosphere and that has direct impact on the consumption and production of oil and gas, estimates on Oil & Gas trends still account for an overall increase in consumption worldwide. The Global Marine Trends 2030 (2013), showed that while the USA and Japan are reducing their oil consumption slightly, developing countries will still increase their consumption by 2030. Similar estimates are shown by World Oil Outlook 2014. Oil demand in the medium-term in all OECD regions falls with the OECD's aggregate demand having peaked in 2005. However, developing countries are leading increasing their demand with their expected consumption exceeding the OECD in 2015 for the first time. Figure 19 illustrates the prospects on the Pre-Salt Oil fields.

It is widely discussed that the cost of reaching for new fields of oil have increased alongside with the increase in the difficulties to reach for them. However, this brings technological challenges that may unleash the development of new capabilities and innovation.

In this sense, despite the general accepted idea that there is a trend and an expectation that there will be a shift in the sources of energy consumed, its seems unlikely that the oil industry will seize to exist in the short and medium term. Some companies may not be able to compete depending on their relative costs of exploring oil in deep fields as this is a highly complex operation. The real threat to some Oil companies is not alternative sources but the apparent excess supply, which is driving oil prices down. However, the break-even point in the pre-salt fields are estimated to be between US$ 40 to 50 dollars per barrel (Petrobras, 2014).

Figure 19. The Pre-Salt Prospects



Source: Petrobras (2012)

Following the international examples discussed in the previous sections, a fundamental aspect for the establishment of shipbuilding industries worldwide have been institutions. This was not different in the recent Brazilian Shipbuilding and Offshore industrial Renascence. The next subsections details the setting-up of institutions the shipbuilding industry possible.

7.3. Setting-up INSTITUTIONS

The development of the institutional framework that would support the shipbuilding and offshore industry initiated even before the discoveries of the Pre-Salt Oil reserves. In 2002, the State-Owned Company Petrobras announced it was going to buy two offshore oilrigs (P-51 and P-52) from overseas as part of the companies' *Program for Offshore and Support Vessel Fleet Renovation* initiated in 2000. However, this generated a big reaction from labor unions against the external purchase of these two platforms. The unions required them to be constructed in Brazil giving jobs to local labor. President Luiz Inácio Lula da Silva, at the time, received a letter from the union, which led to the change in course to allow the platforms to be produced in Brazil.

From this event and on, a series of acts and policy changes were passed (Figure 20). A new public bid was called later that year, requiring the two platforms to be built in Brazil (Foster, 2013). An legislative Act[19] created the National Program for Mobilizing the Oil & Gas Industry (PROMINP) which aims at maximizing the participation of national suppliers of goods and services to the Oil & Gas industry. This organization, whose slogan states "*everything that can be made in Brazil, should be made in Brazil*", maps the national capabilities and provides training in several related fields of shipbuilding to the oil industry.

In 2005, Petrobras found the first field in the pre-salt layer and launched a program to expand and modernize its fleet of vessels. In 2007, the Brazilian government instituted the Program for Growth Acceleration and placed the shipbuilding industry as one of the key national strategic sector to generate wealth and create jobs (Negri, 2014). In the same year, the National Oil Regulatory Agency created the resolution[20] for minimum local content requirements. The same year, Petrobras kept discovering new oil fields in the Pre-Salt layer

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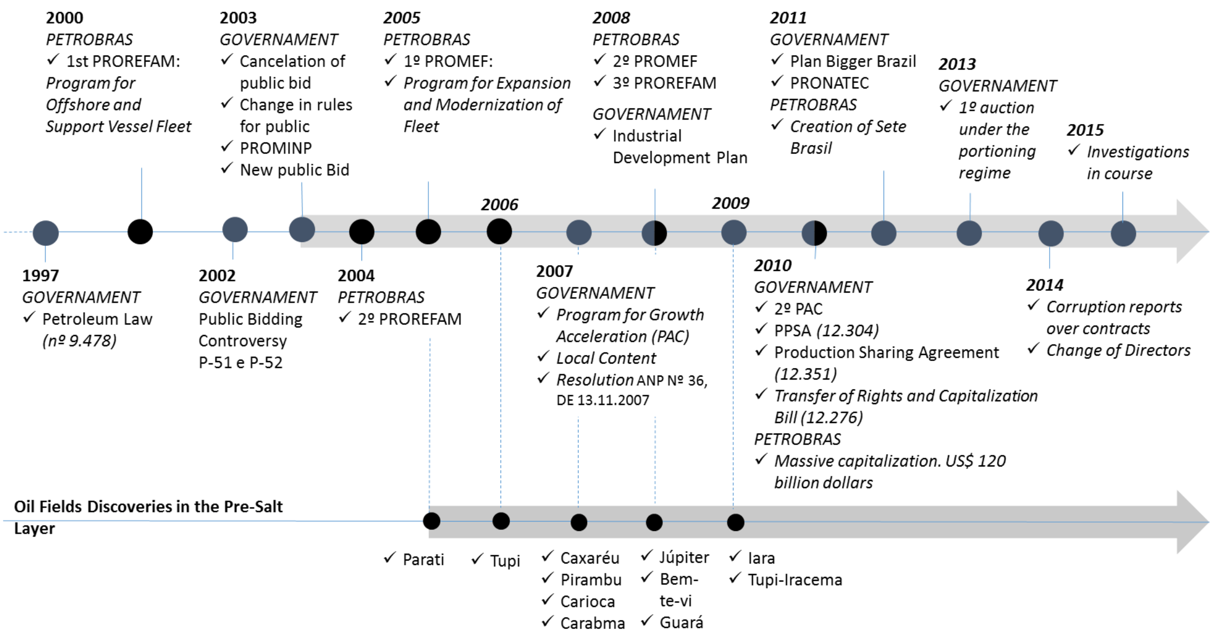
[19]Decreto Nº 4.925 de 19 de Dezembro de 2003. http://www.planalto.gov.br/ccivil_03/decreto/2003/d4925.htm
[20]Resolução ANP Nº 36, de 13.11.2007. http://www.anp.gov.br/brasil-rounds/round9/round9/Diario_oficial/Resolucao36.pdf

that were classified as giant and supergiant[21]. In 2008 the government launched another plan for Industrial Development and Petrobras launched other two major programs to renew its vessel fleet with expectancy of major orders to be directed to the Brazilian Shipbuilding industry. In 2010 the president passed a law modified the 1997 petroleum act which had broken the monopoly of Petrobras in the E&P operations in Brazil. With the new law passed by Lula in 2010, Petrobras re-established (to some degree) its monopoly power over the pre-salt fields. This law declares the Oil from the Pre-Salt fields as property of the State. In addition, it requires Petrobras to participated and have a share in all oil exploration and production activities to take place in the pre-salt fields.

Figure 20. Chronology of the Renascence of the Brazilian Shipbuilding and Offshore Industry



In 2010 Petrobras announced the biggest capitalization in the world's history. Around 120 billion dollars were borrowed to fund the exploration, development and production of the Pre-Salt fields. The purchase power o Petrobras has been directed to national shipyards in order to stimulate the national industry to develop a supplier base to meet the demands for renewal of their fleet of platforms, tankers and support boats. In 2011, Petrobras alongside other major construction companies created the Sete Brasil SA, a company that would be responsible for the drilling operations of the Pre-Salt fields. The company placed several orders of drillships to various shipyards.

[21] Giant oil reserves are considered from 500 million barrels of recoverable oil equivalent (boe). Supergiantoil reserves go from 5 billionor more boe.

Figure 21, presents the institutions and agencies that participate or support the Brazilian Shipbuilding Industry.

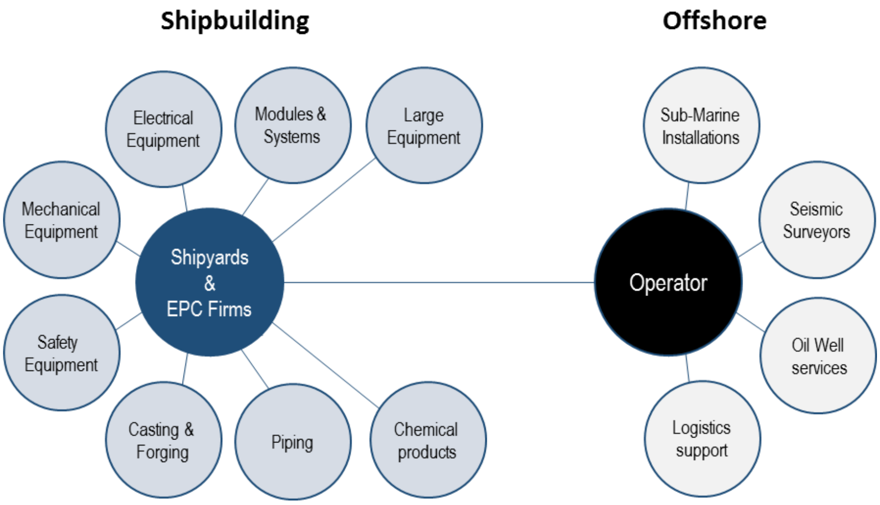
Figure 21. Main Institutions of the Brazilian Shipbuilding and Offshore Industry

Government and State	Ministry of Mines and Energy Ministry of Science and Technology Ministry of Industry and International Commerce Ministry of Transportation State Secretaries Brazilian Navy National Oil Agency (ANP)
Science and Technology	CNPq – S&T Research Fund Universities Institute of Technological Research - IPT Center of Excellence in Maritime Engineering (CEENO)
Funding Agencies	Merchant Maritime Fund (FMM) National Development Bank (BNDES) Financial Agency for Studies and Projects (FINEP) State Funding Agencies Caixa Econômica Federal
Professional and Industrial Associations	SINAVAL – Shipbuilding and Offshore Industry Union SYNDARMA – Ship-owners Firms Union SOBENA–Brazilian Society for Naval Engineering ABENAV – Brazilian Association of the Shipbuilding Firms ABIMAQ – Machinery Industry Association RICINO – Innovation Network ONIP – National Organization of Oil and Gas
Classification Societies	Lloyd Register American Bureau Shipping Bureau Vertias Noëk Veritas Germanischer Lloyd Noble Danton INMETRO ABNT

7.3.1. MARKET Structuring

The recent Brazilian Shipbuilding story is tightly linked with Oil and Offshore Industry. The demand for oilrigs, tankers and support vessels among other types, comes from companies that will be involved in the Offshore Oil E&P activities (Figure 22). The Oil Discoveries in the Pre-Salt and government strategy placed Petrobras at the center of this endeavor. However, other companies may enter based on public bids.

Figure 22. The structure of the shipbuilding and offshore industry



Source: Based on ONIP 2012.

The current Brazilian legislation defines three exploration regimes: *production sharing; concession and; transfer of rights regime*[22]. The *production sharing agreement* states that all oil from the pre-salt fields are the property the state. The state-owned oil company is guaranteed to participate in the exploration while it may not be the main operating firm in the exploration. The operating firm to be contracted in a public bid is the responsible for exploring and extracting the oil paying for all operational expenses, in exchange for a part of the value from the oil fields. The operating firm absorbs all costs and risks from exploring the specific field and does not have any right of restitution or compensation in case the oil field is not tradable.

In the *concession regime*, the oil extracted is property of the operating firm during the time frame stipulated in the contract in exchange for financial compensation to the state. This compensation comes in the form of taxes and royalties. Finally, the *transfer of rights agreement* states that the state may give to Petrobras the rights over the activities of exploration and production in certain areas of the pre-salt fields with up to 5 billion barrels and Natural Gas at the company's own expenses and risk. It is a way to compensate for the companies capitalization effort to promote the supporting industry.

The institutional environment behind the re-emergence of the shipbuilding industry in Brazil covers, on the one hand, the Oil Exploration contracts, that is, defining what oil fields

[22] Lei 9.478/97 (Lei do Petróleo), Lei 12.351/10 (Lei da Partilha de Produção), Lei 12.304/10 (Lei da criação da PPSA), Lei 12.276/10 (Lei da Cessão Onerosa)

are going to be leased to different firms and the respective role Petrobras takes in each type of contract. On the other hand, institutions mandate the percentage of vessels and related equipment to be built within the Brazilian national boundaries.

On the other side of the contract there are the Shipyards and the Engineering, Procurement and Construction firms that are responsible for the actual construction of the ships. This firms also have their own set of contracts with suppliers of the equipment, materials, components and special services.

The National Oil Agency (ANP) created the Local Content resolution in 2007. This resolution requires that every concessionaire that will be producing oil in the Brazilian offshore fields must acquire a minimum of 70% of goods and services from national suppliers. Suppliers, nonetheless, must be certified by the National Organization of the Oil Industry (ONIP) in order to participate. On the one hand, local content policy attempts to a local market reserve for national suppliers. On the other, it creates incentives for local suppliers to gradually build capabilities and gain capacity.

7.3.2. INDUSTRY promotion

With the demand side institutionally guaranteed, there was a need to also promote the supply side. This was done by creating incentives such as tax cuts, local content requirements and finance. This set of laws and resolutions intended, on the one hand, to reduce the comparative costs disadvantages of Brazilian Suppliers compared to the external competition. On the other, stimulate the entrance of new national players into the chain of suppliers. By facilitating credit, firms are able to obtain lower rates on loans to invest in activities related to the shipbuilding industry.

Besides, fiscal, local content requirements and financial benefits, the promotion of a national training program involving universities and technical schools intended to map national suppliers and provide the necessary training to labor in different fields.

Figure 23 presents a summary of the main laws and resolutions created in the last decade to promote the shipbuilding and offshore sector in Brazil.

Figure 23. Institutional Incentives to Stimulate the Supply Side

Incentives	Description	Legislation
Local Content	Local content requirements for vessels used in the activities of exploration and production of oil and gas in the Brazilian offshore oil fields.	ANP Resolutions 36 a 39/2007
Fiscal	Exemption of tax (IPI) for industrial production on parts and materials for the construction of ships in domestic shipyards. Zeroing of PIS/PASEP and COFINS taxes on equipment for the marine industry.	Act 6.704/2008 and Law 11.774/2008
Finance	Facilitating financing conditions to the sector through the Navigate Brazil Program, which introduced changes in access to credit for ship owners and yards, increasing the participation of the Merchant Maritime Fund (FMM) from 85% to 90% in the operations of the shipbuilding industry and increase in the maximum loan term from 15 to 20 years.	Re-edition Provisory Act 1.969/67
	Establishment of differential interest rates and participation in financing with FMM resources for those contracts that ensure local content rates of over 60% or 65%.	Resolution CMN 3.828/2009
	Creation of the Shipbuilding Guarantee Fund (FGCN) with the purpose to ensure risk credit to financing operations for construction and production of vessels and the risk of performance of Brazilian shipyards.	Law 11.786/2008
Training	The institution of the Program for Mobilization of the National Oil and Natural Gas - PROMINP, which aims to enhance the participation of national goods and services industry, competitive and sustainable manner , the implementation of oil and gas projects in Brazil and abroad.	Act Nº 4.925/ 2003.

7.4. PETROBRAS: Balancing Demand and Supply

The exploration of the Pre-Salt layer, involves a complex requiring a number of technologies and vessels. Since the creation of the *production sharing agreement*, Petrobras was set as the main engine directing the demands to the Brazilian shipbuilding industry. It is the main buyer of different vessels.

7.4.1. Securing Demand

On the demand side, there are four entities and sub-firms connected to Petrobras. Petrobras is responsible for the operational activities in oil production and for the acquisition of Platforms and support vessels. Transpetro is a subsidiary of Petrobras responsible for the transportation and storage activities of the oil products. It is the main owner of large crude carriers fleet such as Tankers and LNG carriers. A third company was created in 2011 to become specialized in the exploration and drilling activities. SeteBrasil is responsible for placing the orders for the drill ships. Table 1 presents the number and values of order books as they were by 2012.

Table 1. Order books and Investment by type of Vessels

Vessels Type by Program	Number	Investment	Average cost/vessel	Investor
Support Vessels PROREFAM 1, 2 and 3	223	R$ 16.7 billion	R$ 75 million	PETROBRAS
Platforms FPSO's	22	R$ 53.9 billions	R$ 2.45 billion	PETROBRAS
Large Crude Carriers PROMEF 1 and 2	49	R$ 6.8 billion	R$ 139 million	TRANSPETRO
Drill ships	29	R$ 54 billion	R$ 1.8 billion	SETE BRASIL
Total		R$ 131.4 billion		

Source: Neto (2014). Data from 2012 reports of contracted orders.

7.4.2. Managing Local Content and Suppliers

The National Oil Agency instituted a resolution defining the minimum local content requirements for different vessels. In their resolutions, these requirements vary from 45% up to 70% of local sourcing depending on the technological complexity, availability and time to master the necessary technologies by local suppliers. The national suppliers have to be audited and registered at the National Organization for the Oil Industry (ONIP). Petrobras manages these requirements closely. The company has mapped all potential suppliers in Brazil from every single piece of technology, equipment, ship parts and materials that are detailed the engineering projects.

According to president's assessor for local content, the company has a pretty good understanding of the gaps in the national industry. The company has documented in several books the different pieces of technologies which describes the technology and informs what can be done in Brazil as well as what cannot, including the reason why not. The company continuously surveys potential suppliers through its inspectors adding to the additional studies ran by other institutions such as the Development Bank that ran a study in the Competitiveness of the Brazilian Industry.

> *"When the agent says we must have 65% of local content, we have to analyze every screw that goes into the project as to what extent they can be made in Brazil. If it can't be made in Brazil, what are the reasons? So we have this book with more than a thousand attachments analyzing each little item, equipment and parts. What are the suppliers that can be found in Brazil? Here are a few examples: Example: "drilling package .... (X)" - there is no national manufacturing of this technology that owns the drilling package vendor X. - The same only guarantees the performance using their conventional suppliers." Then for each system or item of the project there is a qualitative description of this kind. To make a thorough study of these is necessary to know what the domestic industry may or may not offer. And that we know well. We have several studies with the. BNDES and Petrobras itself which is the study of competitiveness of Brazilian industry*

> *published in 2008 and updated in 2011, where we analyzed the 25 segments the domestic industry ... so we know what each segment can provide in terms of local content. In addition, we have our manufacturing inspectors who reside or visit frequently our suppliers, so we constantly monitor the industry." (Interviewee – presidential assessor for local content at PETROBRAS)*

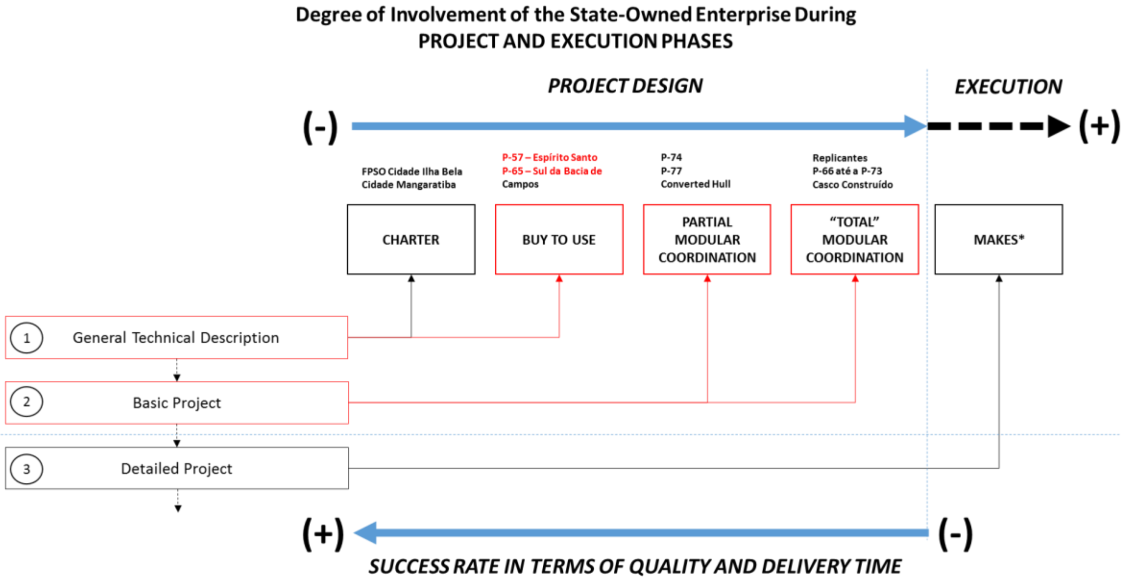
7.4.3. Research and Development

As the state-owned company, Petrobras is the main firm demanding the production vessels being ordered in Brazilian shipyards. The firm gets involved in different parts of the production process. Shipbuilding follows *Engineering, Procurement, Construction and Commissioning* (EPCC) activities. Petrobras participates in all of these process with different degrees of involvement. Generally, the company has to provide the general technical description (GTD) to the shipyards or to the operating firms. This general description explains the requirements for each platform or vessel to be built and it is produced at the company's Research Center (CENPES). At CENPES there are two main groups that exchange information to create the technical descriptions and later turn them into an engineering project.

The *Research and Development in Engineering and Production* group gathers the geological and geophysical surveys as well as materials and technology developments or improvement. The other group corresponds to the *Basic Engineering in Exploration and Production*. This second group is responsible for the basic engineering and architecture of surface productive units, that is, platforms and rigs. It generates the basic requirements for platforms and rigs and, in some cases, produces also the basic engineering project to be designed.

When the company will Charter the oil fields to an operating firm, this is all Petrobras informs the concessionaire who will manage to find the national suppliers. Petrobras only inspects from time to time the vessels being constructed and also participates in the commissioning and testing. When Petrobras is the main operating firm, it can choose between other three approaches depending on the complexity of the project. It can simply provided a GTD to an EPCC firm who will manage to build the vessel (buy to use). Or the company may also decide to define the basic project whenever it wants to use internal technologies and specific developments done by its own R&D. It can engage in a partial coordination of modules integration where it participates in the basic project of the topside modules (Figure 24).

Figure 24. Different contractual approaches to construction



Source: Developed by author

7.5. (Virtual) Shipyards and Suppliers

The prospects and ambitious construction plans from Petrobras unleashed the interest of various states to benefit from the construction of shipyards. The previous history of the Brazilian shipbuilding had left yards infrastructure. However, a series of new shipyards projects were announced in different states different Stated bargained to guarantee a part in the production chain (Figure 25). These new shipyards came to be called "virtual shipyards" once they were based on projects and were going through the process of obtaining licenses to begin construction and finely operate.

Shipyards are classified into Large and Medium-Scale depending on the type and size of vessel to be worked on and they have been divided into three main types: Construction, Module Integrator and Repair and Maintenance. Medium-Scale construction country. Besides that, there are also three "module integrators" where the hoofs are coupled with the modules. In the map bellow it is visible the locations of which one of these yards. The initial requirement is that, the company operating the shipyard has to either be an experienced firm or show proof of an international partnership with recognized experienced in the industry. Technological partners come from Japan, South Korea, China, and Singapore with different purposes but all of them carrying special technological know-how. Brazilian shipbuilding companies are almost all being built from scratch combining local capabilities on industrial construction or building construction.

Figure 25. (Virtual) Shipyards

Shipyards in operation – Large-scale

Shipyard	State	Order book
ATLÂNTICO SUL	PE	Large oil tankers, production platforms and drilling rigs
BrasFELS	RJ	Production platforms and drilling rigs
RG	RS	Production platforms and drilling rigs
EISA	RJ	Bulk carriers, container ships, maritime support vessels and patrol ships for the Navy
MAUÁ	RJ	Oil and product tankers for Transpetro
VARD PROMAR	PE	Gas tankers for Transpetro
QGI	RS	Platform module Integration
RENAVE	RJ	Ship repairs
BRASA	RJ	Platform module integration

Shipyards in operation – medium-scale

Shipyard	State	Order book
ALIANÇA	RJ	Offshore support vessels
VARD NITERÓI	RJ	Offshore support vessels
WILSON, SONS	SP	Offshore support vessels and port tugs
SÃO MIGUEL	RJ	Offshore support vessels
ARPOADOR	RJ and SP	Offshore support vessels
DETROIT	SC	Offshore support vessels and port tugs
DSN EQUIPEMAR	RJ	Offshore support vessels
ENAVAL	RJ	Offshore support vessels and construction of platform modules
NAVSHIP	SC	Offshore support vessels
OCEANA	SC	Offshore support vessels
ETP	RJ	Offshore support vessels
INTECNIAL	RS and SC	Offshore support vessels, pusher craft and river barges
KEPPEL SINGMARINE	SC	Offshore support vessels
NAPROSERVICE	RJ	Ship and offshore equipment maintenance and repairs
RIO NAVE	RJ	Product and gas tankers
SERMETAL	RJ	Repairs and maintenance
UTC	RJ	Integration of modules for platforms
INACE	CE	Patrol ships for the Navy and offshore support vessels
EASA	PA	River barges and pusher craft
BIBI	AM	River barges and pusher craft
RIO MAGUARI	PA	River barges and pusher craft
RIO TIETÊ	SP	River barges and pusher craft

Shipyards under construction

Shipyard	State	Order book
EJA – Estaleiro JURONG Aracruz	ES	Drilling rigs
ENSEADA Indústria Naval	BA	Drilling rigs
Estaleiros do Brasil – EBR	RS	Integration of modules for platforms
OSX	RJ	Integration of modules for platforms
CMO Offshore	PE	Integration of modules for platforms

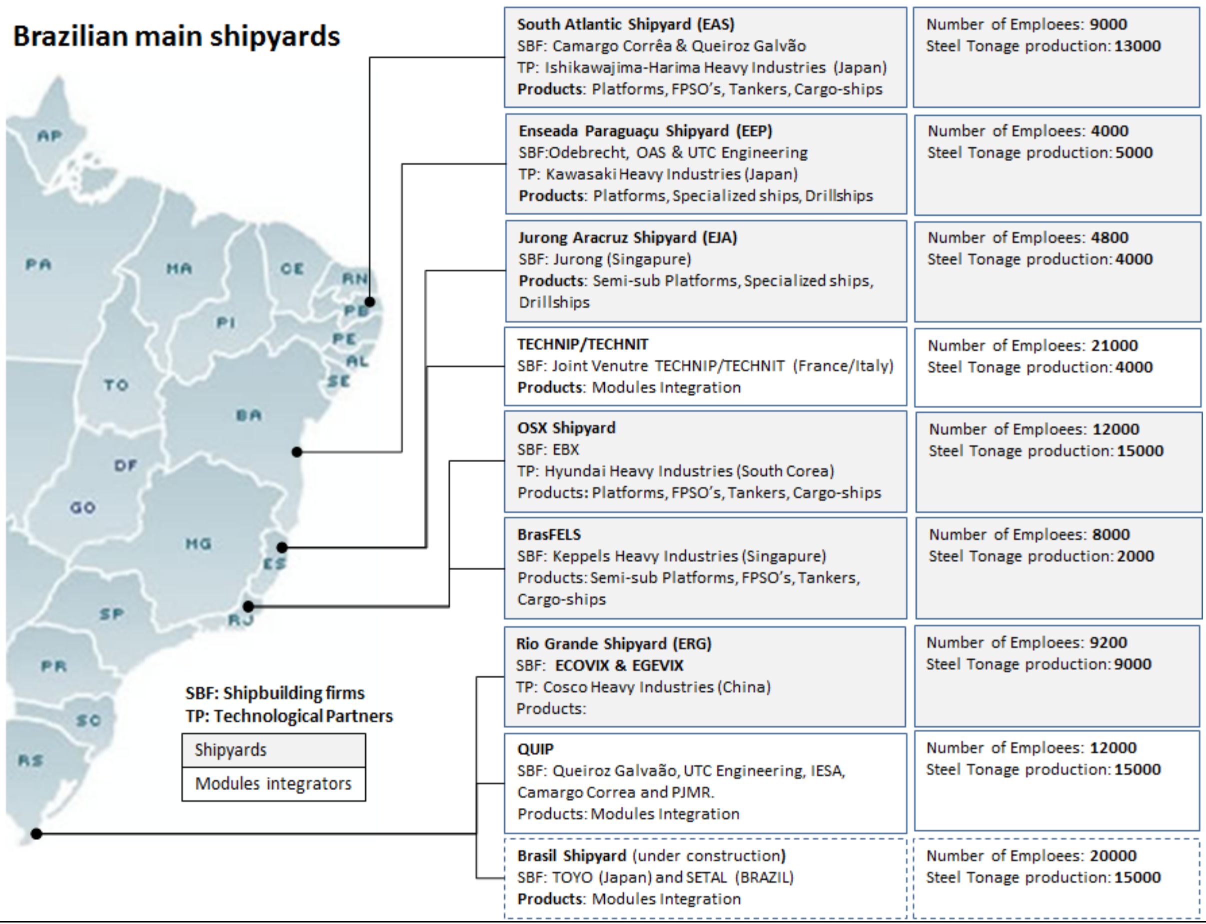
Military shipyards

Shipyard	State	Order book
Arsenal da Marinha	RJ	Maintenance and construction of military vessels
ITAGUAÍ Construções Navais	RJ	Under construction to build five submarines, one of which will be nuclear propelled

Source: Sinaval, 2014

Figure 26 shows the spacial distribution of the shipyards in Brazil as they were planned. Each shipyard was planned to specialized in different types of products and establish their technological partners for technological transfer. The shipyards are classified in three different types: i) “large scale shipyards” which builds vessels larger than 500.000m²; ii) “medium scale shipyards” which builds smaller vessels like cargo ships, gas tankers and oil tanker; iii) “small scale shipyards” that builds boats and support vessels.

Figure 26. Distribution of Brazilian Main Shipyards



(Source: Alves & Zawislak, 2014)

7.6. Summary and Concluding Remarks on the Brazilian Shipbuilding Renascence

The Renaissance of the Brazilian Shipbuilding in Industry has two fundamental aspects. The first related to technological opportunities and challenges that have arisen with the discoveries of high volumes of oil reserves in the coastline of Brazil. The 15 billion proven reserves of barrels of oil equivalent (BOE) opened up the possibility for leveraging expectations and generating an enormous investment plan in the Offshore sector led by the Brazilian State-Owned Oil Company Petrobras.

The whole operation of oil exploration and production created demands for several types of vessels oil rigs, drillships, tankers, support boats (among many others) almost overnight. This demand could have been fulfilled by international shipbuilding firms around the world. However, governmental intentions decided to use this sudden demand to re-structure the Brazilian Shipbuilding sector.

However, this takes the analysis to the second key aspect for the re-emergence of the Brazilian Shipbuilding and Offshore sector: institutions. With a potential market demand under Brazilian control, and pressures by labor and industry unions, governmental authorities initiated a process of setting the institutions to emulate Brazilian firms into acquiring shipbuilding capabilities and creating jobs within the Brazilian borders. Moreover, these discoveries are argued by the current president to be the Brazilian's "passport to the future", meaning the expected increase in investment capacity to boost economic dynamics through infrastructure and engineering projects, technological developments and innovation in both exploration and production activities.

Similar to what had happen in other world cases (USA, Norway, Japan, Korea, China and Singapore) described above, in order to allow such complex operations to happen within national boundaries, institutions were set, on the one hand, to create and temporarily maintain a situation of 'market failure', in other words, a situation where a market is workable (in the economic sense) but none or few firms are present to fulfill the gap (Figure 1). On the other, regulations such as tax cuts and local content were created to stimulate the supply side of domestic industrial firms and S&T institutions to both engage in technological development as well as production of several types of vessels and equipment used in the process of oil exploration.

Besides local content policies, the wiliness of the state-owned oil company Petrobras to pay (in the begging) higher prices for more expensive national products and services, such as equipment, parts, materials and the construction itself, were intended to provide national firms the sufficient time to develop their capabilities and gain efficiency and competitiveness. In 2012 it was estimated that 180 billion dollars were going to be spent in this industry until the year of 2020. This generated a wave of investment in the sector with several new shipyards being announced.

It is worth mentioning that, the re-emergence of the shipbuilding industry in Brazil was based on the National market for ships. The majority of the international cases focused on export markets since the beginning.

Additionally, likewise the international cases, most Brazilian shipyards involved National firms. However, the successful implementation of the shipbuilding industry in Brazil will require industrial firms to learn fast and expand their boundaries. This will probably involve the need for technological transfers with advanced firms in order to first catch-up with production capabilities and later develop new technologies. Technological partners were planned to be a part of the process of building national capabilities and transfer engineering and production know-how.

Therefore, the recent shipbuilding industrial development had some similarities in terms of the way the market was created by public policy incentives and planning. Nonetheless, as national capabilities are not complete nor mature, this will influence the dynamics of industrial organization from its initial phase to its future development.

This thesis argues that, industrial organization dynamics is the result of a constant interplay of technology and economics that will determine industrial shape and scope. Under specific technological shape, industrial scope will be configure as firms deal with their capability boundaries and establish technological interfaces with other firms.

The next section will describe the actual Shape, Scope and Dynamics of Brazilian Shipbuilding as the result of how technological interfaces are configured across the various firms' boundaries.

8. The SHAPE, SCOPE and DYNAMICS of the Brazilian Shipbuilding and Offshore Industry: the case of Hull Construction

This section analyses the dynamics of shape and scope industrial organization in the SHIPYARD A. The shipyard is one of the biggest in Brazil and has been prepared to build eight hulls of FPSO's and other three drillships.

The shipyard is relatively new and the firm responsible for building the vessels had now previous tradition in shipbuilding. As other national shipyards that were installed in Brazil, the original industry of SHIPYARD A was civil engineering of complex infrastructures projects such as roads, bridges, damns, industrial complexes (e.g. refineries, petrochemicals, etc). These companies had capabilities to mobilize large contingents or resources like labor and materials, however the technological base is completely different from that of shipbuilding. This poses some challenges to the capability building process from engineering, construction and labor skills in welding. To surpass this issue, companies were required to establish technological partnerships with recognized shipbuilding firms in order to engage in technological transfer. SHIPYARD A engage in partnership with a Chinese company and more recently sold 30% of its shares to a Japanese firm. These issues will be further discussed in the analysis of the scope of the shipyard.

The construction projects done in this site are one of the most challenging and of this new re-emerging scenario of the Brazilian shipbuilding. Eight identical FPSO were contracted to be produced in series. Constructing the entire hull for FPSOs is not a common choice among shipbuilders. These types of vessels usually result from existing hulls of old tankers that are renovated and later converted into FPSOs. The project aimed at combining complexity with scale by building eight exact FPSO's (*floating, production, storage and offloading*) units. The project is an attempt to plan and organize the majority of the construction chain from hull to modules within Brazil respecting the 70% local content that was determined by the Brazilian National Oil Agency (ANP).

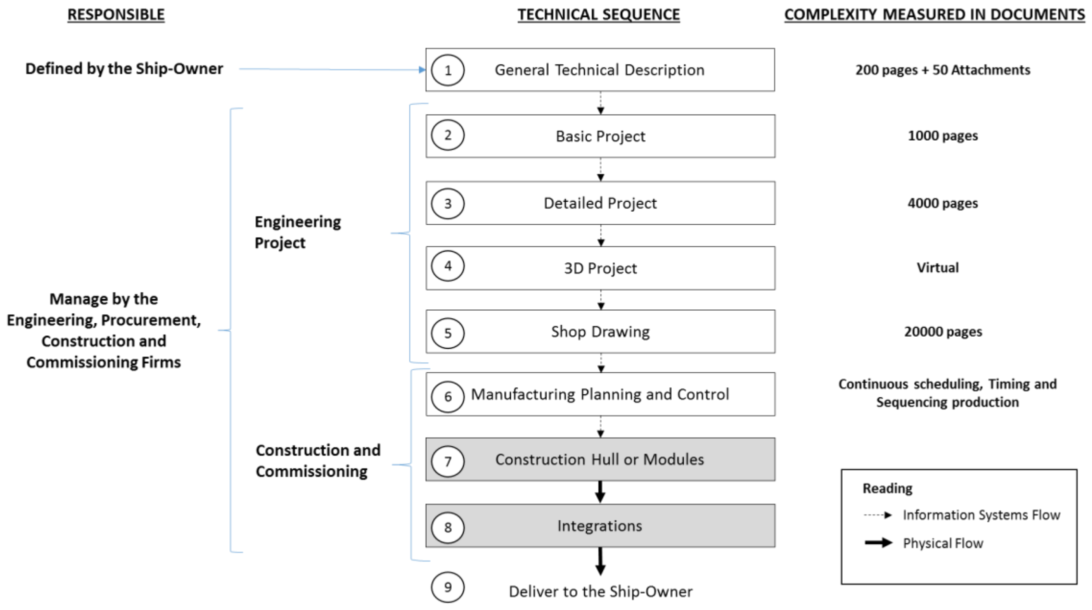
8.1. General Interface Plan, Modes of Contract and Coordination.

As a naturally complex process, shipbuilding construction project is generally divided into *Engineering, Procurement, Construction and Commissioning* (EPCC). Engineering involve the activities from developing the project requirements, its design as well as the projects detailing, 3D modeling and final drafts for production. Engineering alongside

Procurement involves the decision around what to make inside the yard and what to get from external suppliers. Procurement, involves all activities related to finding the various suppliers, selecting them, contracting or purchasing their materials, equipment or services. Construction takes places and production plan integrates engineering and procurement to organize and schedule the productive sequence. Finally, commissioning involves the testing every system of the vessel.

Figure 27 shows the flow of engineering activities pro project requirements to production.

Figure 27. From Engineering to Production (Simplified Overview)

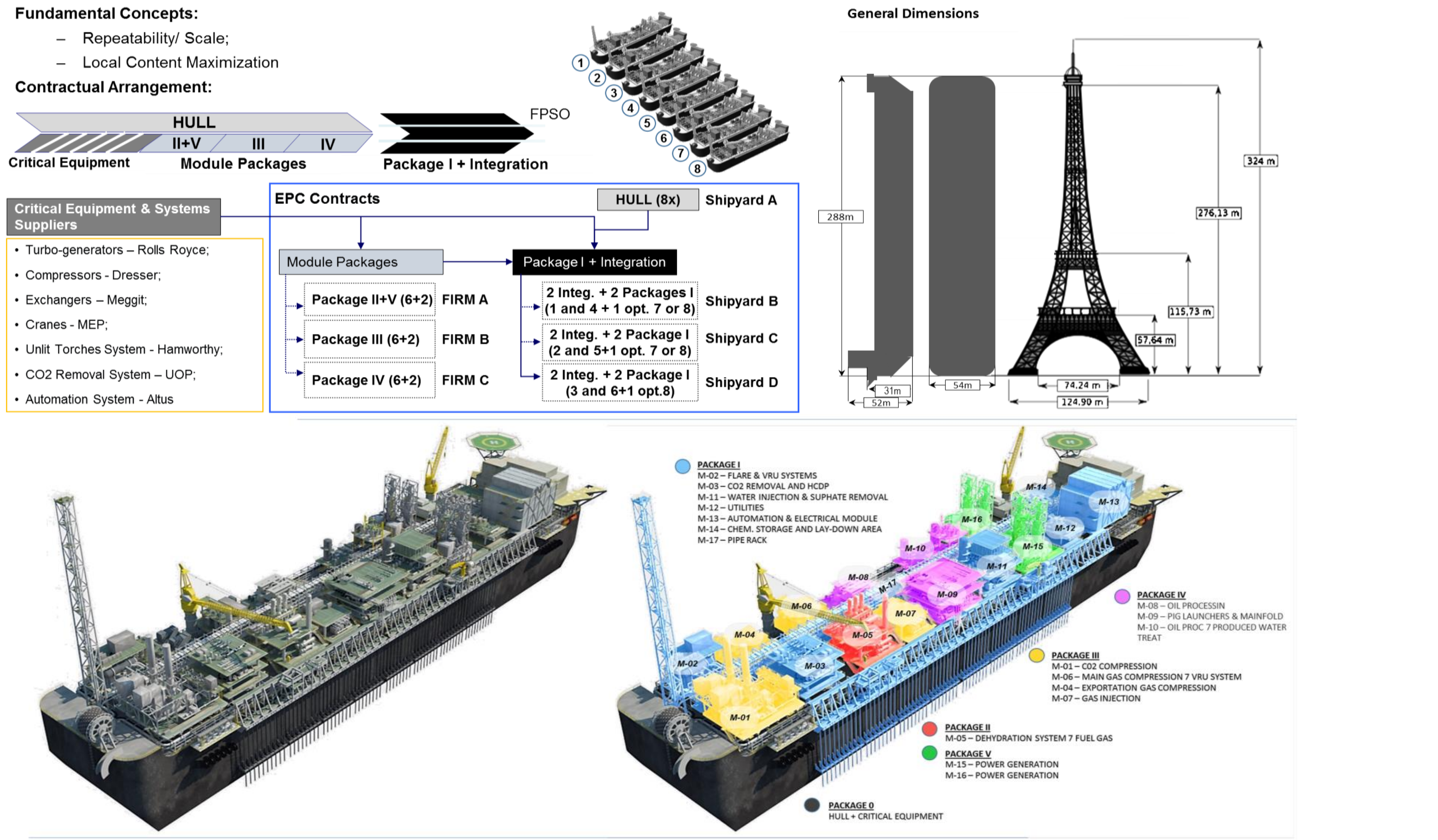


Source: Developed by author

These platforms have the capacity of producing 140 thousand barrels of oil per day for approximately 25 years. The set of production events were planned to reach economies of repetition as well as scale favoring suppliers.

The construction process was then divided into 'packages' of modules distributed across different firms as it is described in Figure 28.

Figure 28. General view of the Shipbuilding and Offshore Industrial Organization



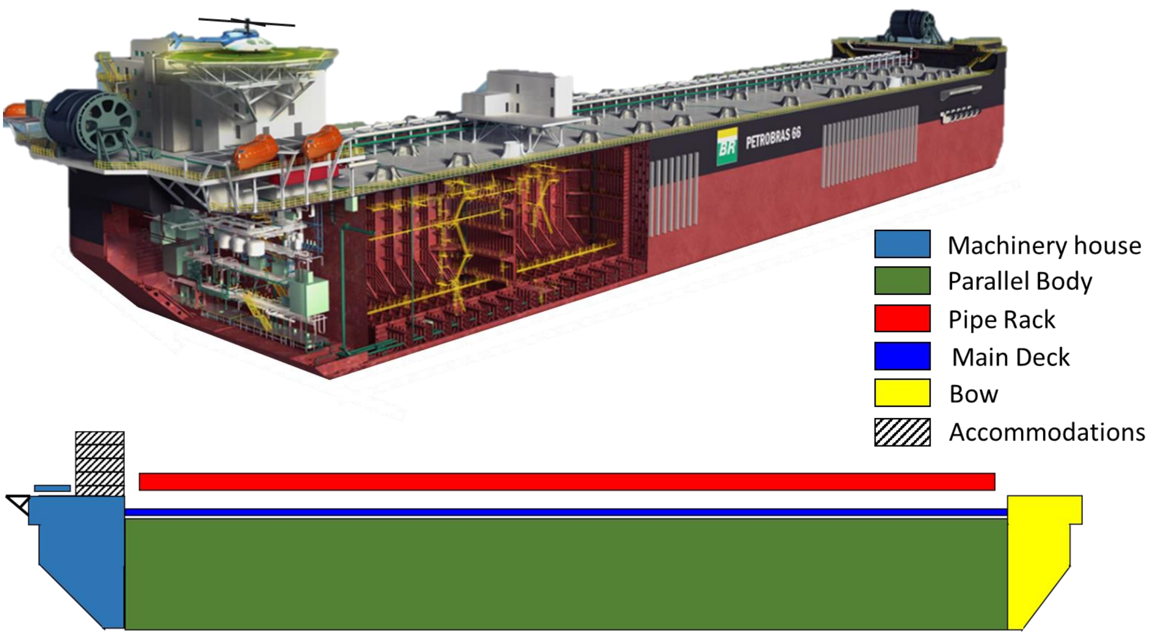
(Source:Based on Petrobras (2014)

Shipyard Co A was responsible for building eight exact hulls, other three firms (A, B and C) have the responsibility to specialize in different packages of modules that are to be integrated in three other Shipyards (B, C and D). The contractual arrangement predicts that firms A, B and C are responsible to build six exact modules of each package and may be eligible to make other two depending on their performance in producing the first six. The same logic applies to the shipyards that will be doing the integration. Each will be responsible for the integration of two platforms and may be eligible of integrating another one depending on their performance in both quality and time schedule.

The overall management of contractual interfaces was planned to be done by PETROBRAS which has offices in every location where modules are being produced and integrated. Around 150 people from Petrobras are located in the hull construction and integration shipyards to inspect and make sure that contracts are being respected as well as managing schedules and problems solving.

Figure 29 presents the overview of the Hull project conducted at SHIPYARD A.

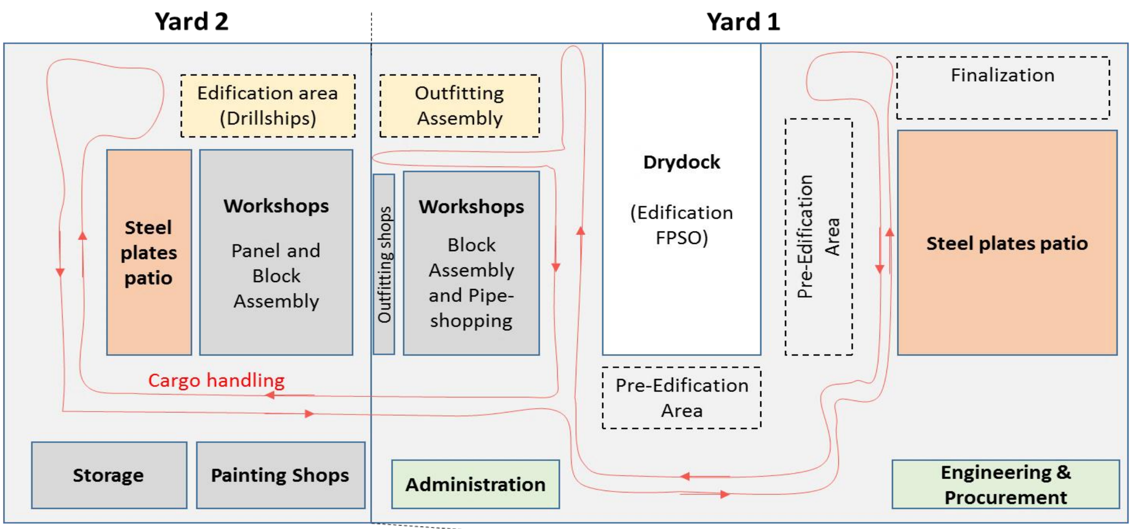
Figure 29. General Overview of the Hull Project



Source: Adapted by author based on information provided by shipyard A.

Figure 30 presents the overall layout of the Yard. Buy the time of the research, they shipyard was divided in to two: yards 1 and 2. Yard 1 was previously owned by an independent investor who leased the use of yard 1 (where the drydock is located) to Petrobras (PETROBRAS). Petrobras than, contracted through a public bid a construction firm who later expanded to yard 2 eventually bought Yard 1. Yard 1 is directed to the construction of the platform hulls. Yard 2 focuses on the construction of drill ships, however it carries the painting activities that serve both products. Workshops in Yard 2 are also used interchangeably with drill ships construction whenever Yard 1 is at full capacity.

Figure 30. Overall Layout and Contractual Arrangements at SHIPYARD A



	Yard 2		Yard 1	
	SHIPYARD "A"	SHIP-OWNER	SHIPYARD "A"	SHIP-OWNER
OWNERSHIP	X		X	
OPERATION:	X		X	
USE-RIGHTS:	X			X
ADMINISTRATION:	X			X
CLIENT:		X		X

Source: Developed by author

A significant investment was made in building the construction yards and facilities. These investments have been shared among different participants. At Yard 1, while it is owned by SHIPYARD A, the rights to administer what goes on in the yard remains with the PETROBRAS who has invested in building a large 2000 tonnage capacity porch.

The construction site was entirely owned by a SHIPYARD A, however it sold 30% of its shares to a Japanese firm in order to engage in technological transfer as well as organizational and management advising.

In October of 2014, there were a total of 11.4 thousand people working at the shipyard in various areas. Around 64% of the employees are direct construction labor, while 36% are distributed across engineering, management, procurement and support activities, 67% of all employees where from SHIPYARD A. The remaining 33% were distributed across 91 other firms in different areas. The details will be shown in the following sections.

8.2. Industrial SHAPE defined by the technological sequence of the EPCC project

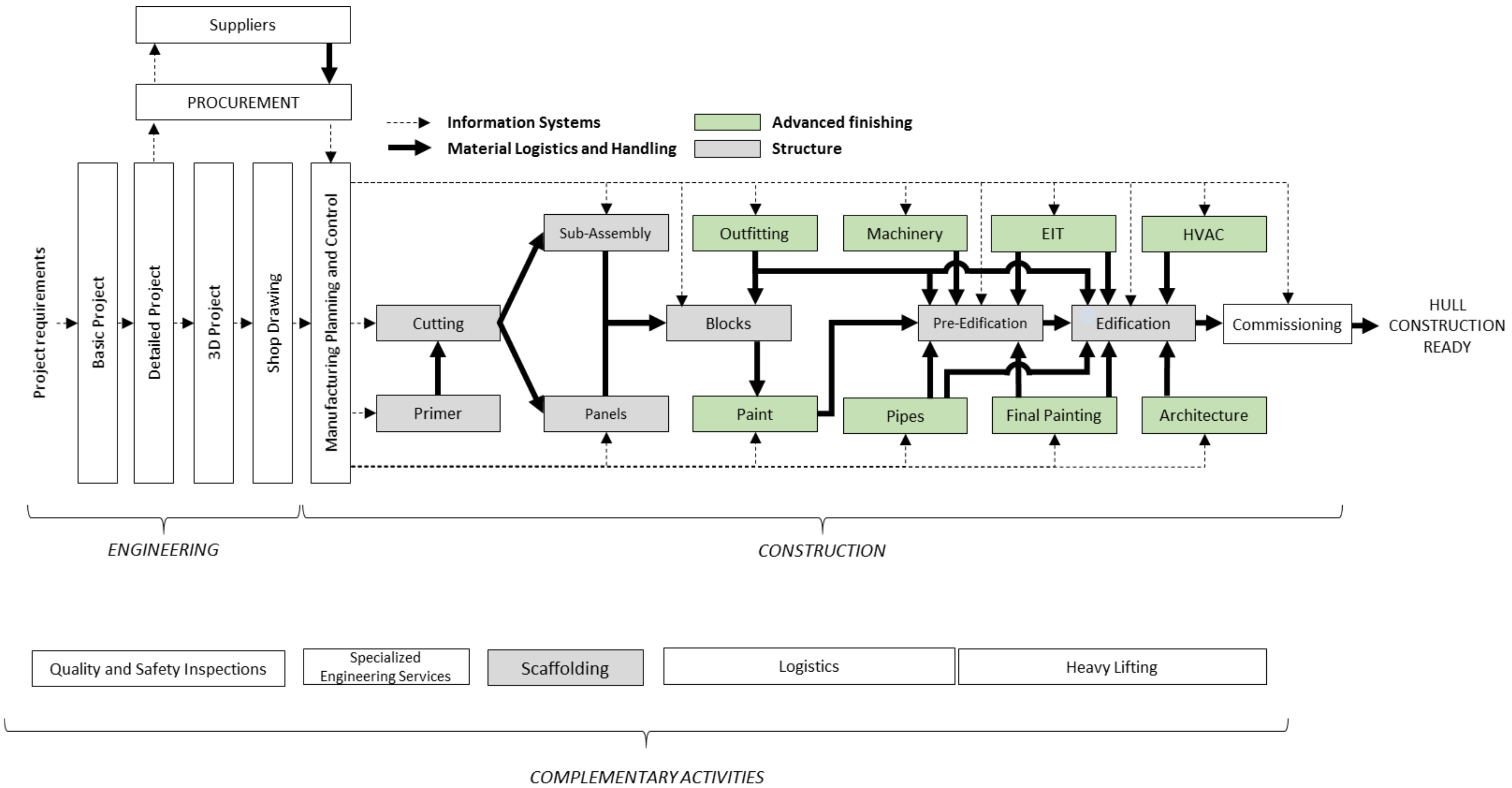
EPCC projects start with the general performance requirements or general technical description defined by the PETROBRAS. These general technical descriptions are based on a set of characteristics of the oil fields geology, oil type and environmental conditions that the platform or a rig will be under. The General Technical Description will foresee these aspects and define what technologies will have to be put together in order to reach the expected performance.

The General Technical Description is passed on to be used in the next step: the Engineering Basic Project. The construction of a FPSO (*Floating, Production, Storage and Offloading*) ship is a complex process which involves many industrial activities, technologies and interfaces and systems such as: engineering and project design and detailing, metallurgy for structure and outfitting, metallurgy for piping, chemical treatments and paint, mechanics and equipment, electric, instruments and telecommunications systems, heating, ventilation and air-conditioning systems, architecture and accommodation. All of which must be integrated and erected using cranes and porches. Due to its complexity, such use a general division called Engineering, Procurement, Construction and Commissioning (EPCC).

The general view of the technological interfaces involved in the EPCC project are illustrated in Figure 31 and explained in detailed in the subsequent sections.

The project begins with the list of performance requirements of the vessel giving the characteristics of the oil field to be explored such as: seismic aspects of the field, quantities to be produced, type of oil, densities, etc. From this ‘project requirements’, an engineering ‘basic project’ must be developed defining types of, materials, ship parts, equipment needed, interfaces, and overall layout of the various parts. Once the basic project has been defined and approved, a ‘detailed project’ is developed involving the description and particulars of each material, ship part, equipment and systems.

Figure 31. General view of the technical sequence involved in the EPCC project



Source: Developed by author

During the project detailing, a set of decisions are also made regarding what will be produced inside SHIPYARD A alongside who will be supplying specific parts or services. At this moment, a list of materials and other resources are sent to the 'procurement' department which will look for qualified suppliers. The shipyard does not manufacture any type of specific equipment, nor materials, therefore these items are beyond the technological scope and capabilities and must be procured. It only assembles. Other specific services or parts that are produced inside the shipyard can also be acquired outside depending on the needs and internal demands.

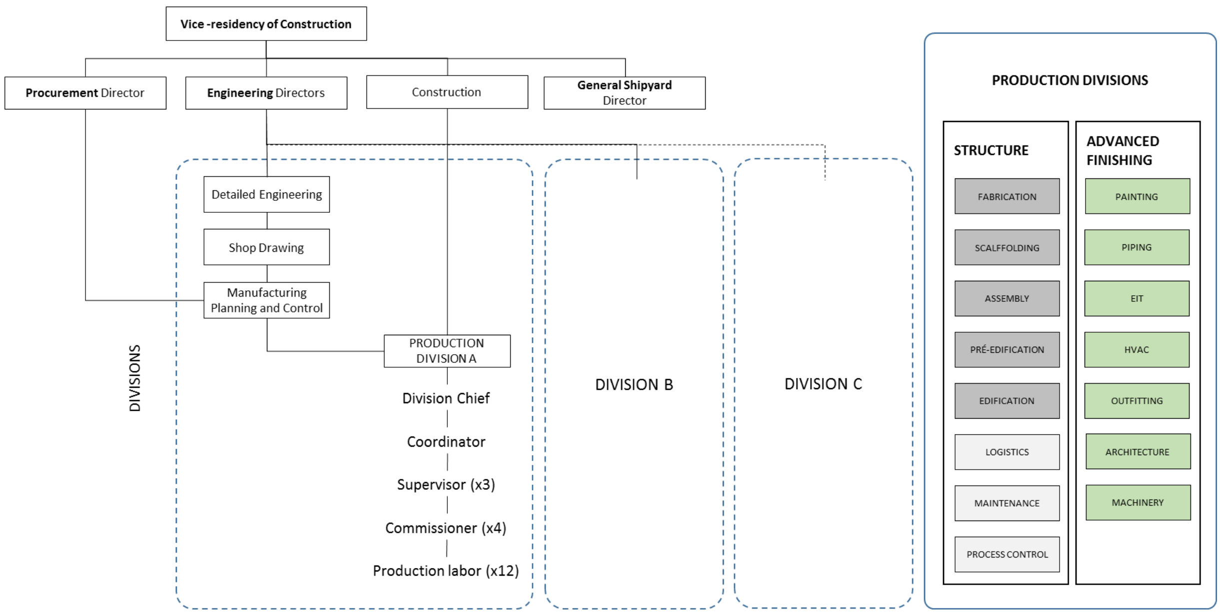
With the detailed project ready, the 3D project can begin and subsequently, the 'shop drawing' documents can be prepared to be sent to the shop floor for manufacturing and assembly inside and outside. As the list of documents are finely ready and approved, they are sent to 'Manufacturing Planning and Control' (MPC) who will distribute documents and specifications such as production schedule across the various manufacturing shops accordingly to a specific sequence which takes into account the various timings of production.

Technological interfaces require managerial and organizational interfaces in order to give efficient flow to the production process. As documents and shop drawings leave the engineering department and materials are available and are ready to be used in production, manufacturing planning and control can define the sequence of production. Managerial interfaces follows the logic of the technological interfaces involved. From engineering to final assembly, the organization is dived by disciplines.

Figure 32 presents the main interfaces under the heading of the production divisions (on the right). And the general organizational hierarchy of activities (on the left). The main process is the construction of the main structure. The structure building follows mainly metallurgy processes. Structure building is sub-divided into fabrication (treating steel plates against corrosion, cutting pieces and edges to form panels and sub-structure) assembly of blocks. Blocks are then put together in pre-edification phase forming mega-blocks, which will finely be built into one full structure.

Alongside the main structure construction process, other divisions interface with the main process. These disciplines are under the organizational hierarchy called 'advanced finishing'. They include machinery, pipes, outfitting supports, electric equipment, instruments, telecommunication systems (EIT), heating, ventilation and air-conditioning (HVAC), well as architecture and accommodation. For every division, follows a similar organizational logic. Detailed engineering, shop drawing, Manufacturing Planning and Control, and Production.

Figure 32. General organizational interfaces



Source: Developed by author

The next sub-session will analyze how the industrial shape described above is translated into different firms' boundaries and interfaces.

8.3. Industrial SCOPE from Bounded Capabilities to Technological Interfaces

The scope of industrial organization is a result of firms' boundaries, which are defined in technological and economic terms. Table 2 presents an estimate of the percentage cost involved in the different phases of construction. The costs distribution serves to infer, to some extent, about the scope of the firm.

As it can be seen, a larger portion of the budget (40%) goes to procurement of items and services. This gives some idea on the extent of boundaries and interfaces that may be present. These procurement costs are relative to a variety of items or services that have to either be outsourced or sub-contract. Any purchase of equipment, materials, and services goes under procurement, including engineering (such as the Basic Project), complex accessories (e.g. accommodation building) or painting (which is subcontracted).

Table 2. Estimated distribution of Costs in the Hull Construction as percentages

Interface	% Production Cost
1 - EPC MANAGEMENT AND MOBILIZATION	**10%**
2 – ENGINEERING	**12%**
2.1 Detailed Engineering Design	9,0%
2.2 3D Model and Project Automation (Intools and PDS)	1,2%
2.3 Conditioning/Commissioning Engineering Data-books	0,6%
2.4 Construction and Assembly Technical Support	0,6%
2.5 Issuing of "as-Built" Documents, stamped by Classification Society	0,6%
3 – PROCUREMENT	**40%**
4 - HULL CONSTRUCTION AND ASSEMBLY	**36%**
4.1 General, Quality and HSE Requirements	1,1%
4.2 Fabrication, Construction & Assembly Drawings	0,4%
4.3 Hull Structure Fabrication, Assembly and Erection	29,9%
4.4 Piping Fabrication and Assembly	2,5%
4.5 Equipment	0,7%
4.6 Electric, Instrumentation and Telecom Equipment	0,4%
4.7 Hull Outfitting	1,1%
5 - COMMISSIONING AND SYSTEMS TRANSFERENCE	**1,50%**
6 – CERTIFICATES	**0,50%**

Source: Based on estimates provided by Shipyard A relative to October of 2015.

EPC Management and Mobilization takes 10% of the budget. These are activities involved in preparing, selecting and planning for the future allocation of resources during the project. Engineering takes 12% of the budget. Detailing engineering is responsible for 9%. As it can be seen, a large portion of the construction process involved procured items. 36% of the cost is on the construction, assembly and erection of the hull. Piping takes 2,5% of the construction budget. Then commissioning and certificates represent around 2% of the total cost.

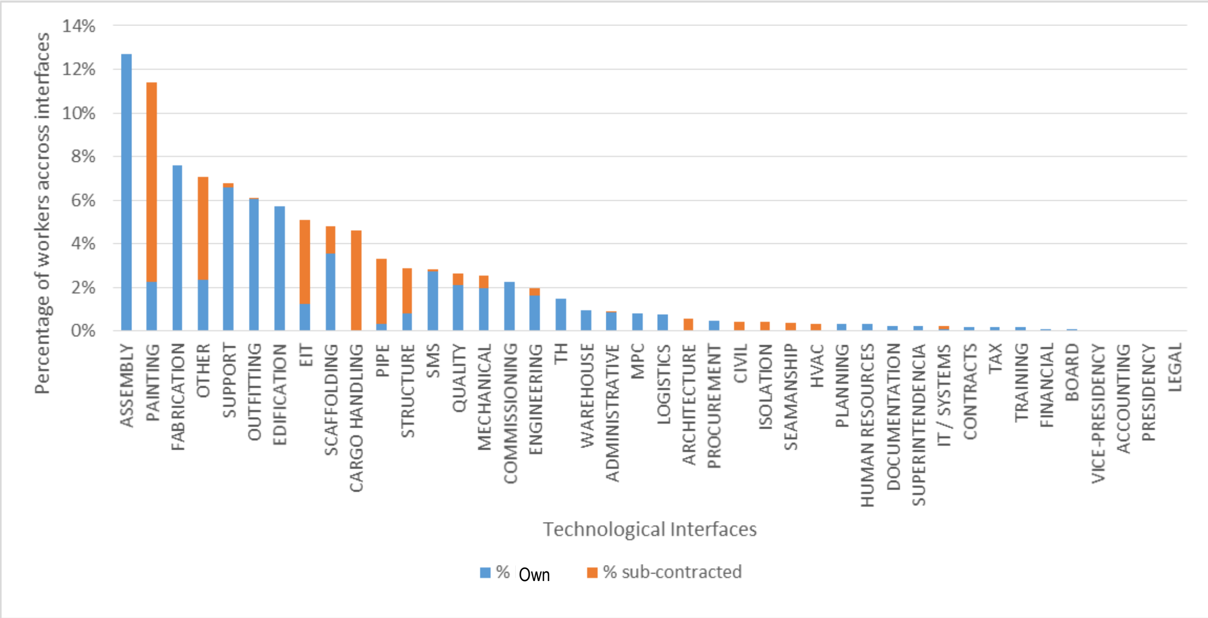
Nonetheless, put this way, it is not very clear where the boundaries and interfaces are. In fact, procurement so far is the “black-box” in this case. This section will analyze in further detail the nature of the boundaries and interfaces present in the case.

In October of 2014, 67,14% of its employees were from the company. The other 32,86% were sub-contracted. The technological complexity that goes along several construction interfaces depends on knowledge, assets and the ability to apply them into efficient routines. Whenever one of these elements is missing, there arises the need for further cooperation with external firms.

The overall distribution of vertically integrated interfaces vs subcontracted can be seen in

Figure 33.

Figure 33. Own vs Subcontracted firms as % of Workers

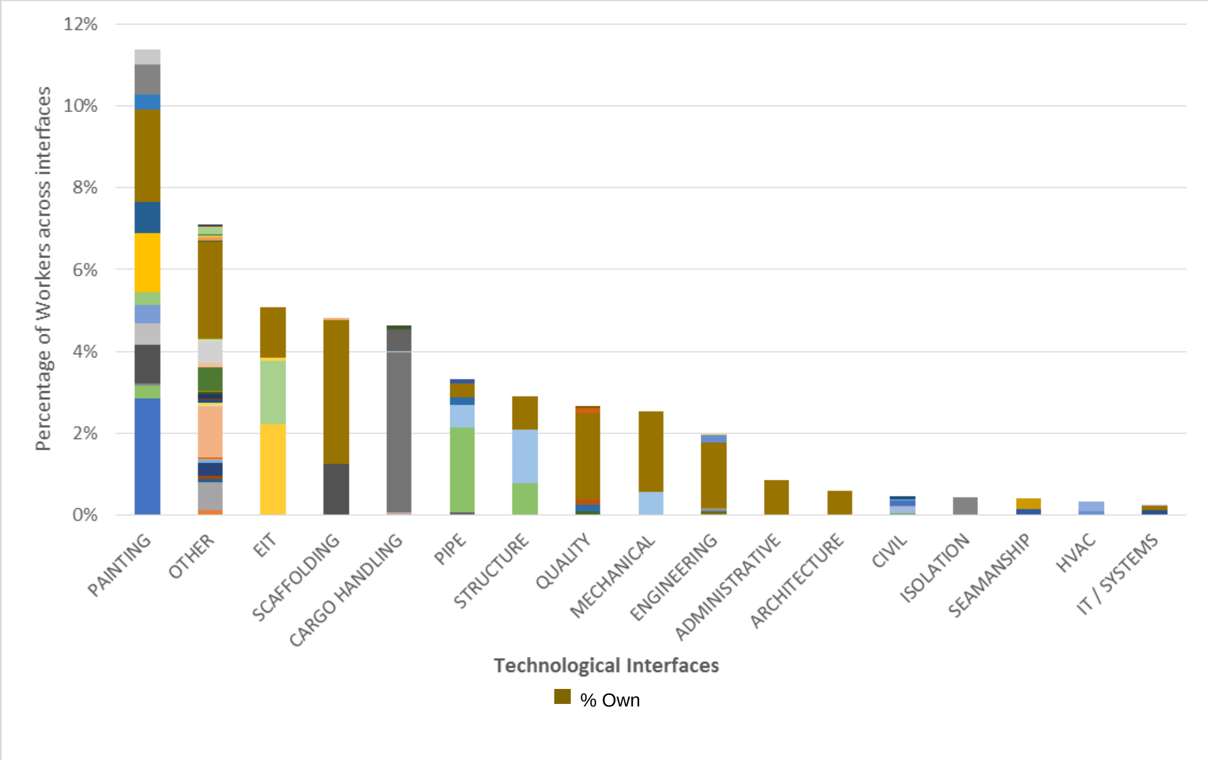


Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

It is possible to see that from almost 42 different disciplines that the firm classifies, at least 18 have some degree of sub-contracting involved. Six (6) are completely subcontracted, and a few show a significant degree of sub-contracting. 80% of the painting activity is subcontracted. What the company calls as “other” correspond to support activities such as health and restaurants which are not part of the firms core activities. Electrical, Instrumentals and Telecommunication activities are also significantly subcontracted (76%), as piping and the structure building. Cargo moving and handling is 100% subcontracted both in labor and equipment such as tractors and cranes. Nonetheless “logistics” which corresponds the coordination of the cargo movement and handling remains internal. With a minor representation but also fully subcontracted we find specialized services such as architecture, isolation and HVAC.

Figure 34 presents the structure of sub-contracting by discipline or departments of the firm. The colors represent the different firms involved in the process. Taking the areas of the firm that uses some kind of sub-contracting, the field called “Other” corresponds to the most diverse once it is related to some organizational activities and independent services that do not have any direct relation to production. From production-related activities, painting is the more diverse with 12 different firms involved in the process. The internal painting is completely undertaken by one firm (25%).

Figure 34. Distribution of firms across interfaces: Own vs Subcontracted firms as % of Workers



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Piping, EIT and structure building also rely on sub-contracting which in these cases are basically focused on hiring labor. Some of the subcontracted firms in these cases are, participate in different disciplines providing labor where there is shortage. One of these firms is present by providing workers to painting, piping and structure building.

Other types of subcontracting relations can be seen in cargo handling and lifting where 2 main firms provide not only labor force but also equipment such as tractors, cranes and trucks. Other than these major subcontracting relations, other minor ones refer to specialized services such as seamanship or IT systems. Or it can be related to less frequent or final activities in shipbuilding such as HVAC, Architecture and Isolation. These services enter at the end of construction in the finishing of specific areas of the ship.

Complexity is also shown as the construction process involves suppliers, direct and indirect labor from various countries. During the research at least firms from nine countries (China, Japan, England, South Korea, Spain, Italy, United States, France, Sweden) were involved in supplying special materials, equipment or know-how.

Besides operational and construction activities that are distributed along local and international firms, the construction of ships is subjected to various regulations, safety and quality inspections. The American Bureau of Shipping is an international classification society responsible for inspecting the whole construction of the ship as well as suppliers of components and parts. The full construction is monitored and the ship can only leave the dock once it had been fully approved. These are regulatory boundaries.

From the need to coordinate different technological interfaces, arise from a complex set of industrial relations. These relations respect the nature of knowledge and skills required; specific technological assets, and routine orchestration. The next subsections will analyze each of these interfaces in detail.

8.3.1. Engineering

Engineering is where the where the construction process actually starts. After the project requirements have been defined, engineering is responsible for using these requirements as performance goals and must figure out the necessary dimensions of facilities, equipment and technologies to be assembled. In the case analyzed, the project requirements are defined by the PETROBRAS. A 200 page document is issued to the shipyard from which a 1000 page basic project will be designed. Then, a detailed project (4000 pages), 3D modeling and Shop-drawing (20.000 pages) follow. Only after this, the construction process can actually begin. Figure 35 presents interfaces and industrial relations.

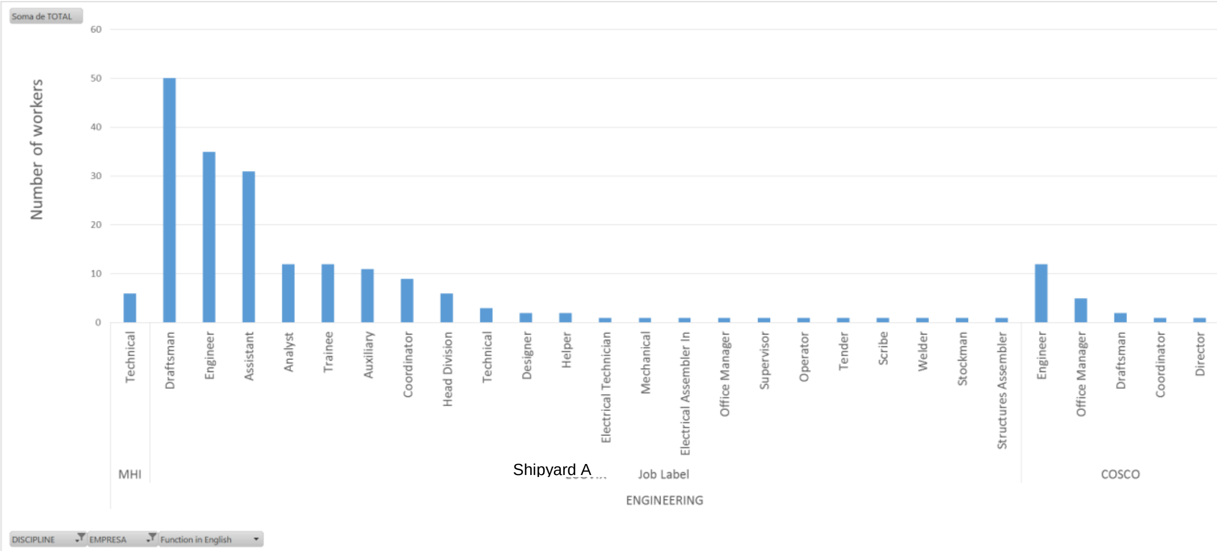
Figure 35. Engineering Technological Interfaces and Industrial Relations

		What it consists on	In-house	Sub-contract	Outsourcing
Engineering Activities	***Project requirements***	• 200 pages document describing the general characteristics and operational requirements of the platform.	• None	• None	• Provided by the PETROBRAS
	Basic Project	• 1,000 page documents, describing the general functional aspects of the platform to be built.	• None	• None	• Outsource Specialized Service
	Detailed Project	• 4,000 page documents describing in detailed how the platform will be built containing: equipment location and connections, pipes, connections, curvature, flexibility, electrical, instruments and telecommunication systems, outfitting, painting, etc.	• Partially done in-house	• Partially done by international partner	• None
	3D	• Electronic System used to integrate Basic, Detailing and Shop Drawings	• In-House	• None	• None
	Shop Drawings	• 20,000 documents, explaining how the platform will be built for the shop floor. Isometric, Lego-Like instructions of each piece and system to be built	• Partially done in-house	• Partially done by international partner	• None

Source: Developed by author

The engineering department corresponds to only 2% of the total number of people working at the shipyard. When we look at the structure of the engineering department. The engineering department itself has 50 engineers and 53 draftsman working on the shop drawing turning detailed engineering into the production instructions (Figure 36). From the total engineering knowledge from the engineering department, 12 of these engineers come from the Chinese partner.

Figure 36. Engineering Department, Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

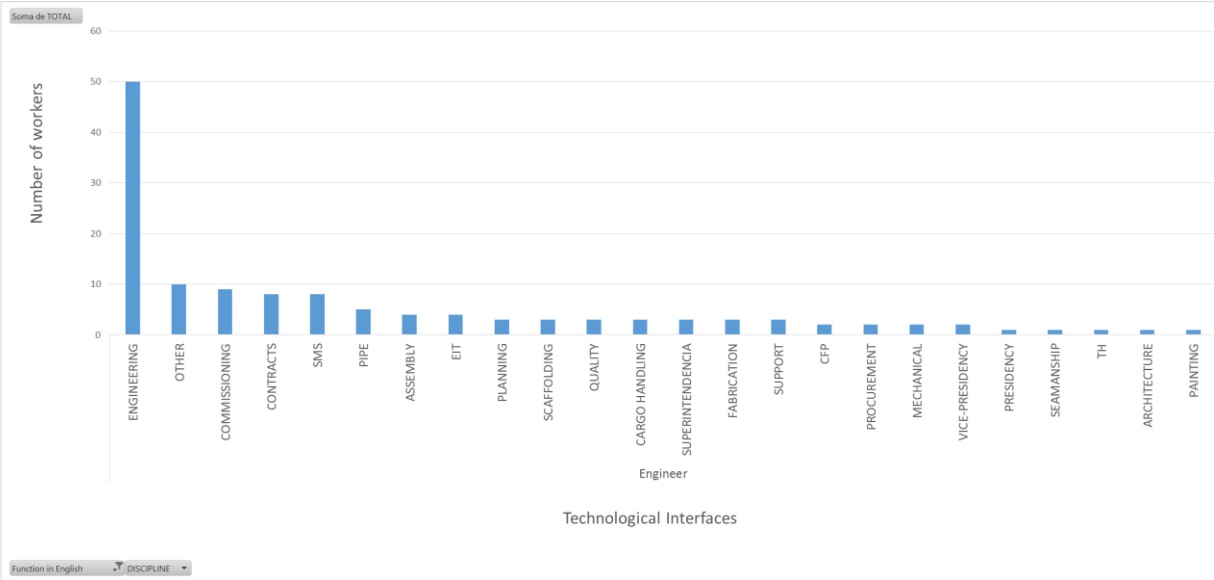
Co-investor and Partner	**Capabilities**
MHI Japan	Passenger Ships, LNG Carriers, Commercial Ships, Special Purpose Ship, Marine Development Equipment, Automated Systems, Marine Machinery and High Speed Engines, Marine Structures, Shipbuilding Engineering
COSCO China	Founded in 1960. Today, the company is the leading in heavy ship construction in China. The main types: Container lines, Bulk Shipping, Tankers, Specialized Carriers, Passenger ships.
Outsource	**Capabilities**
GVA Sweden	GVA is a world-leading designer and provider of licensed technology for semisubmersible and monohull-type marine platforms and vessels to the offshore oil and gas and renewable power markets.

However, the majority of the engineering knowledge (99 of them) distributed across different firms within the shipyard belongs to the Shipyard operating firm (

Figure 37

Figure 37). These engineers are distributed across interfaces and organizational departments such as Contracts, Commissioning and Other specialized services.

Figure 37. Distribution of Engineering knowledge across Interfaces



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Engineering capabilities in the firm analyzed were bounded in almost all levels. The Basic Project in the case studied was outsourced to a specialized firm from Sweden. According to the Engineering Director. It is hard to find in Brazil enough specialized engineering firms with the necessary capabilities and experience in this type of project. In this sense, a technological interface with the Swedish firm was necessary. The detailed engineering, 3D modeling and Shop drawings capabilities are also not complete. These activities were done in partnership with a Chinese firm.

> *"We contracted a Swedish company to draw the basic project of the FPSO. Today we do not have the experience to do a Basic Project. We need to get more experience. In Brazil, the Marine is the only one capable, but other than them it's hard to find any other firms with basic project capabilities. Moreover, PETROBRAS requires the Basic Project to be done by a company with proved experience in designing this type of project with proved construction success. The detailing and shop drawings are done by SHIPYARD A with help of COSCO from China."(Engineering Director – SHIPYARD A)*

The process of transfer of know-how in engineering starts at the detailing engineering and shop drawings which are more directly related to the concrete construction at the shop floor. Although detailing engineering and shop drawings are more complex in terms of the number of documents that have to be produced, the basic project seems to be more complicated to master. And this capabilities are rarer in Brazil. However the company set the goal to also gain this types of engineering capabilities in order to become more autonomous in project development.

> *"One of our goals at the Institute of Technology and Innovation is to obtain the knowledge to one day be able to design a Basic Project." (Engineering Director – SHIPYARD A)*

Among the contributing factors to "boundeness" of capabilities is the "newness" of the project to all participants. According to the Engineering Director:

> *"One important thing is that this FPSO project is being done for the first time this way (in series)." (Engineering Director – SHIPYARD A)*

Therefore, besides the newness of the project's technology *per se*, the organization of production also is new for this type of vessel.

It is important to realize that, as construction capabilities are not fully ready, there may be an increase in the occurrence of errors to be dealt with by the engineering team. Another aspect to boundaries of capabilities in engineering is set by the tools used.

For example, at least three types of different tools were accounted for in the engineering detailing process (see Figure 39). Two 3D softwares (ShipConstructor and SmartMarine) and other two for project detailing in 2D (Autocad) and for piping (Caeser II). It seems that, the lack of a standard platform for detailing and communication increases the risk for errors across interfaces.

> *"Everyone would like to use 3D modeling as the main platform, however it takes a little more time to finalize the project because it has more details including materials and processes. Not to mention that this type of software requires people training and discipline so everyone can work together. However trained people on this type of technology are rarer while it is relatively easier to find trained people on 2D tools such as AutoCad" (3D Project Engineering – SHIPYARD A).*

While the 3D tool would be desirable once it makes it possible to integrate engineering and construction interfaces through drawings under one platform which can deal with changes and corrections in real-time, not enough personnel with the appropriate training were available. This generates the need of another interface with a second best solution in 2D. While a standard platform requires enough personal with the appropriate training on the necessary tools, lack of integrating mechanisms requires more organization, planning and management.

The engineering capability of the shipyard analyzed is an operational one, focused on project detailing and shop-drawings that will be used in production. This type of engineering has to be close to the operations in order to respond quickly to problems that may arise during the construction process. However, the Basic project, which is more oriented towards development is totally outsourced. With the entrance of the Japanese firm, the Basic Project and detailing engineering may now be undertaken and coordinated by Mitsubishi engineers and those two interfaces with Cosco and GVA will no longer be needed.

8.3.2. Procurement

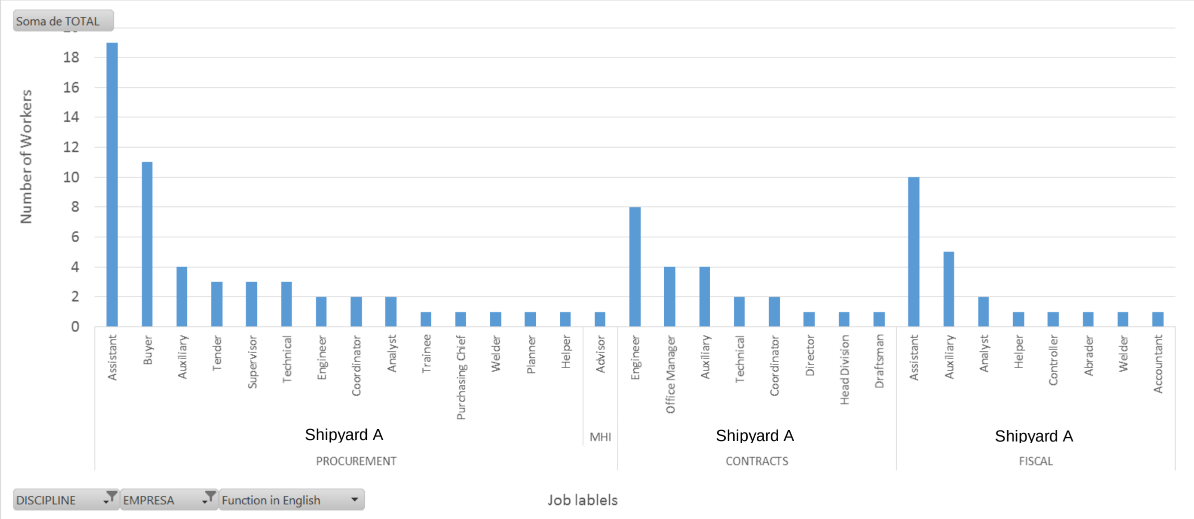
Procurement is responsible to fill the gaps of capabilities boundaries of the firm and identify the suppliers establish the respective technological interfaces. This department also deals with the contractual issues that arise as well as the fiscal duties.

According to the procurement director, the main processes of the department consist on: *acquisition, diligence, international commerce* and *warehouse.* The *acquisition* process starts as soon as the engineering detailing project defines the necessary materials or services and create a Material Request (MR). With the MR ready, the procurement department goes to the market. To check for national suppliers, there is a list called Vendor List which comprises a list of suppliers who are defined by Petrobras. These suppliers that appear in the Vendor List have been approved respecting local content requirements and quality standards. When specific suppliers are not in the list, the firm goes after international suppliers. With the request of materials in hand and a list of potential suppliers, the firm starts the procurement process *per se*. Request for Quotations from various suppliers. Once the best quotations have been received and selected, a process of negotiating and approval with the board of directors initiates. With the quotation's approval, the company places a purchase order.

Diligence is the process of monitoring new or current suppliers in search for attending local content requirements, quality control, improvement and supplier development. *International commerce* deals with the process of international purchases, import tariffs, taxes and fees as well as the management of the material logistics from arrival to the warehouse. The *warehouse* and inventory control is another major process of the procurement department (see

Figure 38).

Figure 38. Procurement functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Procurement is the department responsible filling the gaps at the firm's boundaries by finding and selecting suppliers. Nonetheless, in Brazil, given the local content requirements, the firm also acts upon the boundedness of its supplier base by providing the requirements and setting some production goals. However there are challenges. According to the procurement director, the main difficulty in the process is finding the necessary suppliers within Brazil.

> *"The major difficulty is when we need to identify suppliers that are not international. Brazil still lacks a supplier base. So we usually have to stick with the few big companies there are around. Specially here in Rio Grande, it is very limited" (Procurement Director – SHIPYARD A)*

The complicating aspects mentioned by the procurement director can be divided into four. First, there is a lack of a sufficient supplier base in numbers. Second, within the available supplier base, there is the lack of specific technical capabilities to deliver what is required by the shipbuilding industry. Third, besides the lack of capabilities, whenever they are present, there is also the difficulty in competing in economic terms, which makes the costs of producing anything in Brazil less attractive than imports. Forth, the comparative costs are influenced by externalities beyond the capabilities of firms, such as, logistics and national infrastructure. When we look at the enabling factors for nurturing capabilities, they go well beyond the scope of the mere scope of the firms.

> *"For example, in Brazil there is only one steel company (Usiminas) that process the type of steel plate we need. And Usiminas is a problem because it is still not competitive on price. We have to bring the plates via highway to here and this is very expensive. At the time we bought the steel plates from an international supplier, Usiminas had no technical condition (it was missing*

> *some equipment to make the size of the plate that the we wanted with the thickness we needed) and on top of that they didn't have the price" (Procurement Director – SHIPYARD A)*

Moreover, even when suppliers reach the technical capabilities, there must be an effort fitting their technical performance within economic ones. In this sense there is an apparent paradoxical relation with factors that increase the costs of building up capabilities, and the need to reach economic competitiveness.

> *"It seems now that they have reached the technical condition and the price it is all coming together, but it still is very difficult to get the price we can buy from China. However, they intend catch-up and we will support them. But no one will pay more for it." (Procurement Director – SHIPYARD A)*

Therefore, if the intention is to build capabilities, there seems to be a need and effort to find mechanisms to reduce these costs.

8.3.3. Planning, Integrating Systems and Organization of Production

As previously exposed, technological interfaces require managerial and organizational interfaces in order to give flow to the production process (Figure 32Figure 32 above). Engineering and Procurement set the basis of construction and have to be aligned in order to provide the construction process with the necessary tools, information and materials to start production. This network of organizational activities and information sharing is done by different departments through formal and informal ways. IT systems, provide the formal means of information transfer across interfaces as well as some the tools for design and plan of production. Figure 39 presents some of these systems that formalized the exchange of information across interfaces. At least 11 types of systems were mapped over the interviews.

Figure 39. Pathways of information from EPC systems

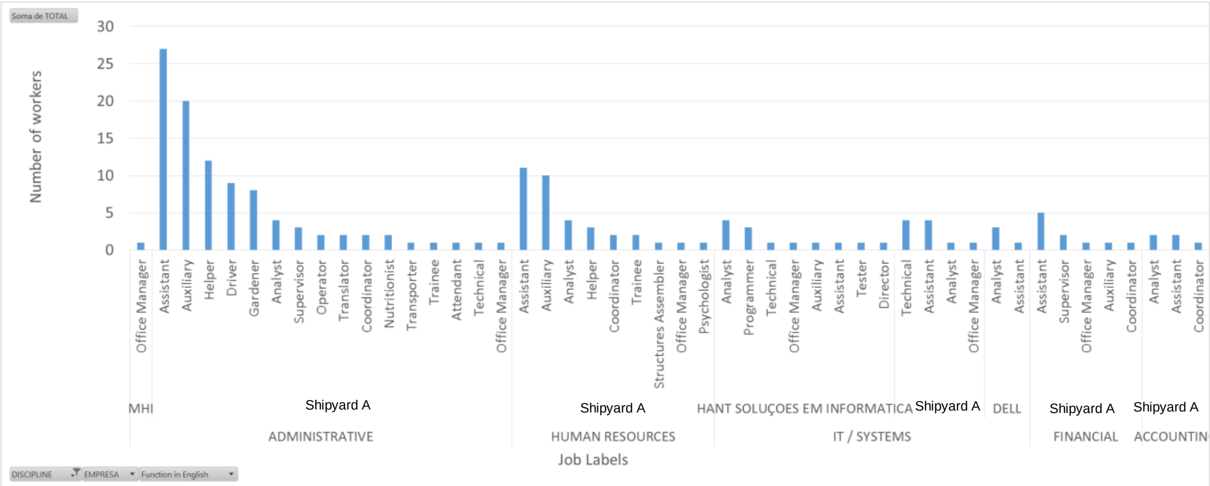
		Department				
		Engineering	***Procurement***	***Construction***		
System Used	**Description**			***MPC***	***Structure***	***Adv. Fin***
ShipConstructor	3D construction modeling	x				
Smartmarine	3D construction modeling	x				
Caeser II	Pipe stress analysis simulation	x				
AutoCAD	Shopdrawings	x		x	x	x
Sincomat	Steel cutting pathways	x		x	x	
Project Wise	Work Sharing tools	x	x	x	x	x
Spider	Project management			x	x	
SCM	Piping, Structure, Fabrication, Commissioning Control System			x	x	x
HANT	Request of Materials, Purchase Orders and & Inventory Management		x	x		
Oracle	Fiscal control of HANT		x			
Vendor List	Supplier Database		x			

Source: Developed by author

The link between engineering and procurement to the Construction is done through the Manufacturing Planning and Control. Different departments use a set of different IT tools and systems. The engineering detailing design uses 3D modeling software, simulators as well as CAD. Procurement uses a set of systems of its own to request materials, place purchase orders and control inventory. In order to get to construction, this information are passed through a working sharing system, put in order by Manufacturing Plan and Control who schedules and distribute the work out.

The management of internal organizational boundaries is done by internal management. However the information technologies used in this process are sub-contracted which justifies the number of subcontracted personnel in the IT-Systems compared to the ones by SHIPYARD A (17 of 27) (Figure 40).

Figure 40. Organizational and support functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Support organizational activities are routine base. Planning, coordination and decisions take place at the directory board, construction superintendence and vice-presidency. The planning department gathers relevant information from the different division, procurement and support activities and monitors the shipyards capacity and overall performance which generates feedback for the directory board to decide on the courses of actions.

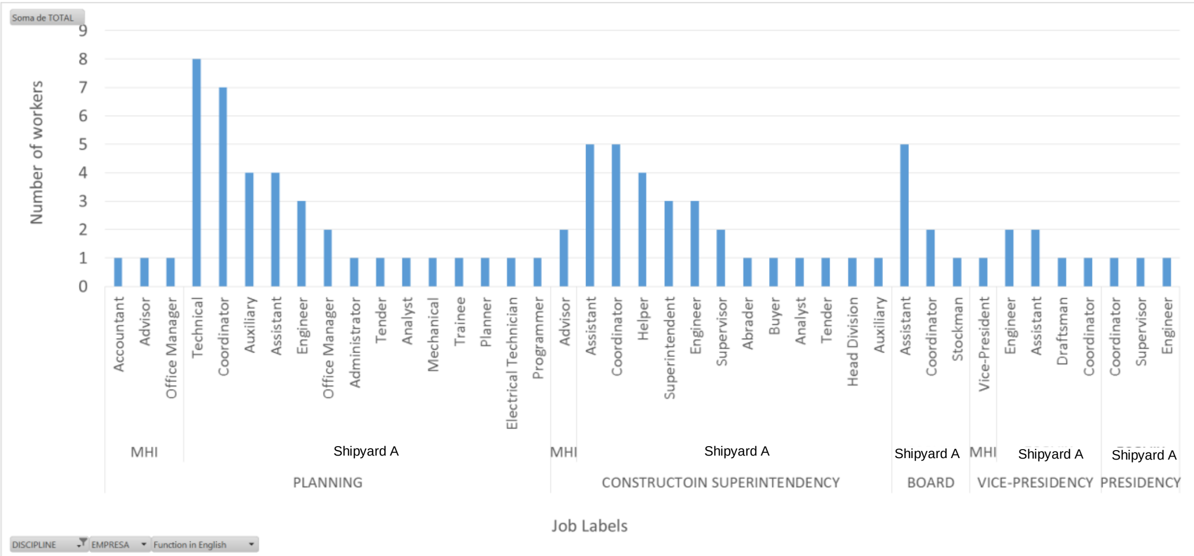
> *"Behind all the engineering and construction activities, we have planning. At our department, we look at the contractual requirements for the orders and the budget division being proposed by the client. During the construction phase, we'll divide the documentation according to our different divisions: construction, assembly, structure, manufacturing, painting, etc. Our strategic planning department helps in the macro planning looking at the capacity of workshops*

> *compared to our demand and requirements. I look at the demand for the various divisions, how the production in workshops are scheduled, how we are performing compared to the contractual requirements. Sometimes we have a demand curve that goes well above capacity which means capacity is insufficient. Then this will generate a re-planning. We generate information and run simulations that can help the board to decide whether to produce inside or to buy from external suppliers." (Interview – Strategic Planning manager – SHIPYARD A)*

From the description above, the planning department manages the information on the balance between demand (technical requirements and quantities) and supply (internal capabilities and capacity) to attend demand. Whenever the firms shows signs that is reaching its limits or incompatibility to attend demand, it may decide to establish interfaces or outsource. The sources of these limits are mainly two: technical capabilities and capacity that generates delays on schedule.

The planning and coordination is entirely internal, nonetheless, as a key department, the company has an advisor from the Japanese company, including the vice-president of Offshore Construction (Figure 34). According to the Strategic Planning Manager, this interaction has been slowly improving the efficiency of operations. The planning and coordination is done mainly by SHIPYARD A personnel. Mitsubishi added a number of advisers in the process in order to slowly transfer organizational and technological know-how to give internal coherence to internal and external managerial and technological interfaces firm.

Figure 41. Planning and Coordination Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

8.3.4. Construction – Main Structure

Construction results in the concrete product of engineering, planning and production. As previously explained, it is divided into two main groups of activities: 1) the construction of the Main Structure of the Hull; and 2) the fabrication, assembly and integration of finishing components, machinery and systems. This accounts for 29,9% of the cost of the construction process.

The main structure follows nine steps: primer treatment, steel cutting, panels welding, sub-assembly (fabrication), block assembly, internal painting, pre-edification and edification. Scaffolding is a support activity. The scenario for subcontracting is changing. Initially, the shipyard was intended to have the majority of the interfaces subcontracted, however the lack in control and the inability to meet the contract's terms from the client forced, the company to internalize the most of the production interfaces, including coordination of logistics.

> *"Originally the yard was designed to make it all away. To outsource almost everything. Only the structure was planned to be here. Then we were convinced that this was not a good choice. At first, even the structure would be outsourced. The shipyard owner created a separate company to make the structure. As the project went on, we realized that the company, which had other partners, were more concerned with earnings but without the commitment to meet the schedules. The company wasn't able to deliver what it was supposed to, in the order that we wanted. When they got to the measurement stage, the company focused a lot of people on measuring the block, and stopped doing other things as the schedule was programmed for. Then we decided to cancel the contract and do everything. Initially subcontractors would work as an industrial condominium. And the company would be like a holding commanding all these other companies, like in the automotive industry. Now everything is made by us using our internal structures." (Interview – Chief of Structure Division – SHIPYARD A)*

The only company that works under the concept of industrial condominium was the painting cabins for blocks where the investment on the infrastructure and equipment was made by a single firm. Therefore, a large part of subcontracting takes place to fulfill periods of labor shortage. Similarly to the choice of outsourcing certain pieces of production when there are capacity lacks, the firm engages in subcontracts for labor to increase capacity.

> *"We weren't supposed to have this many subcontracted labor, but we had a peak of demand and we had to hire more people to meet the schedules. However, lots of people already have gone out. PETROBRAS made a strong request to speed up the process, and the only alternative was to increase the labor force." (Interview – Chief of Structure Division – SHIPYARD A)*

Nonetheless, there are shortcomings for this strategy as the simple increase in the size of labor force does not automatically increase production capacity nor quality. In fact, it may even generate more problems such as inefficiencies, less productivity and difficulties in coordination, and most importantly, stagnation in the learning curves. This will require a reconfiguration of internal scope the shipyard.

Another source of subcontracting happen in the pre-edification and edification process where there is a need for specific heavy lifting equipment and skills to use them. All cranes, tractor and trucks are sub-contracted as well as the respective labor to maneuver them. However the internal logistics and coordination is done by SHIPYARD A.

Figure 42 analyzes the types of industrial relations that may take place across the different stages of production.

Figure 42. Technological Interfaces and Industrial Relations in the Main Structure Construction

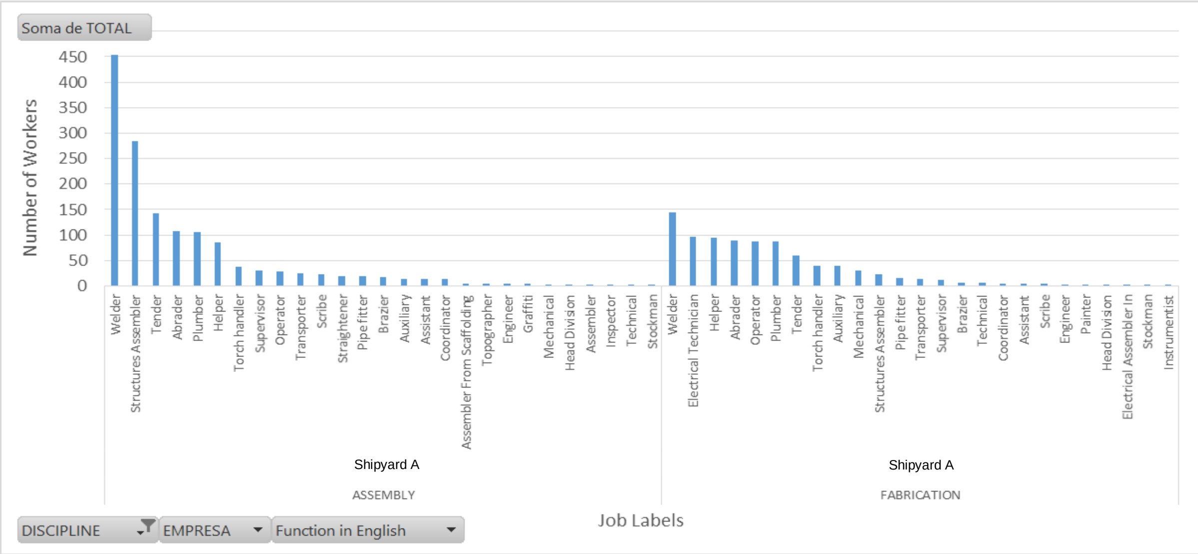
		What it consists on	In-house	Sub-contract	Outsourcing
Structure Construction Activities	***Primer***	• Shot-Blasting application for protection of steel plates	• Application	• None	• Chemical products
	Cutting	• Cutting edges of steel plates to form panels; or • Cutting of steel plates into specific pieces to be assembled	• Processing and Cutting	• None	• Steel plates
	Panels	• Welding of steel plates to form panels	• Connecting and welding	• None	• Steel plates
	Sub-Assembly	• Welding of pieces to form the substructure of blocks	• Connecting and welding	• None	• Steel plates and sections
	Scaffolding	• Scaffolding assembly and disassembly alongside construction	• Assembly	• Labor due shortage	• Scaffold pieces
	Blocks	• Welding for panels and sub-structure into caves and blocks	• Connecting and welding	• Labor due shortage	• Basic inputs such as welds.
	Pre-Edification	• Welding of blocks into mega-blocks • Preparing internal systems, connections of pipes and electrical systems • External painting	• All	• Heavy-lifting and handling	• None
	Edification	• Building the final structure inside the dry-dock.	• All	• Heavy-lifting and handling labor	• None

Source: Developed by author

Fabrication, Assembly and Edification

The composition of the subcontracting across activities can be seen in the following figures. Figure 43 shows that in Assembly and Fabrication of the Blocks, the company chose to vertically integrate these two interfaces.

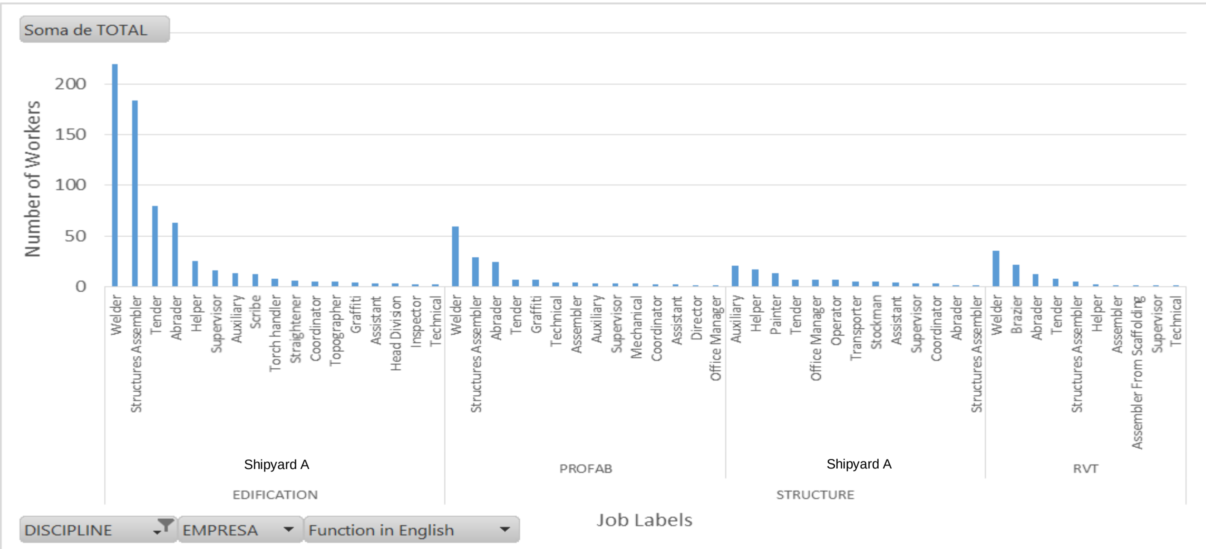
Figure 43. Fabrication and Assembly functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Subcontracting in edification and structure is mainly done by two firms who basically lands its labor force composed of welders and structure assemblers (Figure 44)

Figure 44. Edification and Structure, Firms and Functions



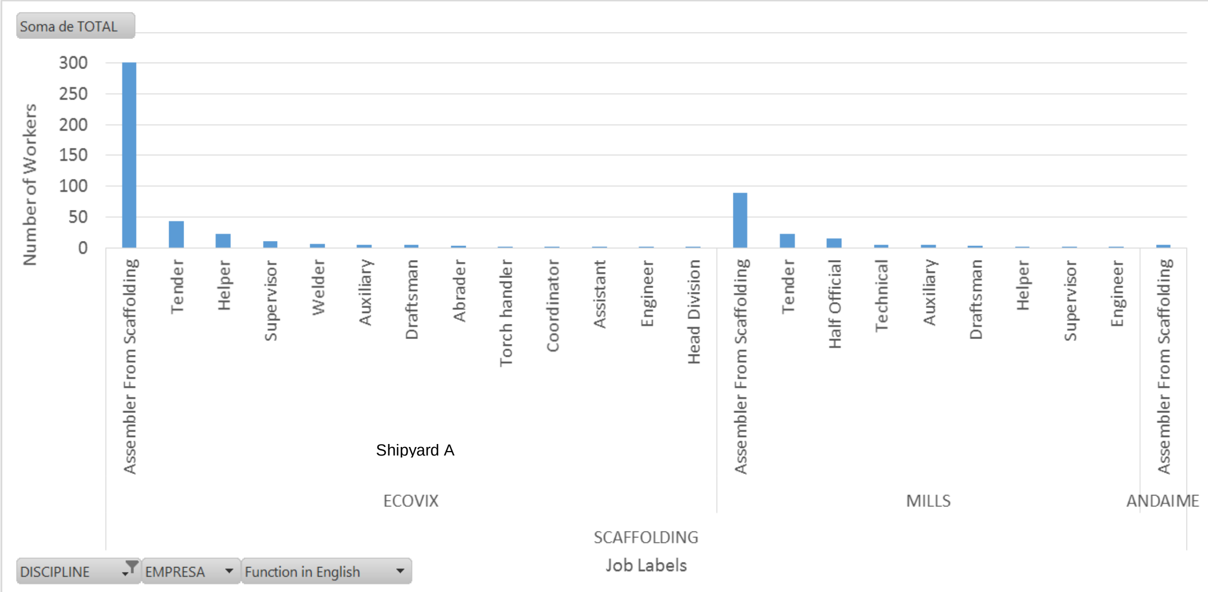
Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	Capabilities
RVT Brazil	Founded in 1992 to meet strong demand recovery of industrial valves services. In 2000, the company formally amending its field in the market, establishing itself as a service provider in the maintenance business and industrial assembly, changing its name-RVT. Capabilities: Steel Structures, Pipe Manufacturing and Assembly, Sandblasting, Industrial Painting and Inspections.
PROFAB Brazil	Established near the Shipyard, the company provides a team of workers for Pipe Manufacturing and Assembly of spools, manufacturing and assembly of metal structures, pipe hydrostatic tests, Painting of pipes and metal structures; and industrial maintenance.

Scaffolding

Scaffolding is a support activity highly labor intensive. It involves around 400 people just to mount and dismount scaffolding. The shipyard subcontracts one firm to help in this support activity (Figure 45)

Figure 45.Scaffolding Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	Capabilities
MILLS Brazil	Founded in 1952. Participated in several major construction projects from stadiums, historical cathedrals, bridges, industrial plants. It providesshoring and access equipment to perform large construction projects.

The main resource provided by these firms is the labor force to fulfill eventual gaps or shortages, specially welders and scaffolding assemblers.

8.3.5. Construction – Advanced Finishing Activities

The advanced finishing is a concept of shipbuilding imported from Japan. The activities that fall under this heading are: outfitting, piping, EIT, Machinery, Painting, HVAC and Architecture (Figure 46). The idea behind the organization of production following advanced finishing is to allow the construction of blocks to happen in continuous flow. Each of the 280 blocks that compose the ship's hull has a specific architecture of its own. The advanced finishing activities intend to optimize the planning and process of adding the necessary features to each one of the 280 blocks. Therefore, the advanced finishing activities have to plan, pre-fabricate and prepare all items to be built in each block in synchrony with the production of the block.

Figure 46. Operations, Technological Interfaces and Industrial Relations

		What it consists on	In-house	Sub-contract	Outsourcing
Advanced Finishing Activities	***Outfitting***	• Fabrication and assembly of various supports, • Fabrication and assembly of bases for electric systems and pipelines. • Installation of protections, contentions, manholes, hats, pathways, stairs, fenders.	• Fabrication , Assembly and Installation	• No	• Raw materials • Specific Components and parts
	Pipes	• Assembly and installation of stools and pipes.	• Assembly and Installation	• Labor shortage	• Fabrication • Testing • Galvanization • Painting
	EIT	• Installation of Electric-electronic, instruments and telecommunication systems	• Installation	• Specialized labor	• Equipment • Components • Lines
	Machinery	• Positioning and installation of machinery and equipment	• Installation	• Labor shortage	• Equipment • Machinery
	HVAC	• Installation of heating, ventilation and air-conditioning systems	• Installation	• Full labor and equipment	• Equipment • Machinery
	Internal Painting	• Painting of internal caves inside blocks for protection	• Application	• Full labor, equipment and facilities	• Marine coating and finishing
	External Painting	• Finishing external and internal painting	• Labor and tools	• Distributed	• Ink • Tools
	Architecture	• Installation of acoustic isolation and finishing of rooms and accommodation.	• Installation	• Full labor and accessories	• Materials • Parts
	Commissioning	• Final testing of systems and inspections	• All inspection	• Special services	• None

These different interfaces are clustered into activities that happen before and after the blocks go into the painting cabins for cleaning and painting. Before painting, most of the necessary outfitting must be built in the blocks. Outfitting requires welding and abrading which literally burn the block. This burning must be done before painting otherwise it will generate re-work to re-paint damaged areas.

> *"When we talk about advanced finishing we mean a decision on the organization a production. This means that the Structure Division will assembled the blocks, then, we will enter on the block to add every little accessory that is in the project of that block, such as: supports, ducts, rails, walking platform, rampart, and so on, all that is possible to fill in the block, so we don't need to build these things after the blocks are united into the ship. But before putting the ducts and panels, we have to send this block for painting. So we divide this advanced finishing in two stages. The First, everything that BURNS the block, everything that has to be welded in position. So if I have a passage for a pipe or some structure that has to be welded into the wall, I have to do this welding before it goes into the painting cabins. When most of the outfitting is in place, we send the block to painting. After painting, we get the block back and then start second stage to add pipes, electrical systems, machinery to be mounted, etc" (Interview – Chief of the Advanced Finishing Division – SHIPYARD A)*

Differently than the structure construction where activities follow a similar set of skills (e.g. welding and abrading), the advanced finishing is more diverse (electrical, machinery, systems, HVAC, etc). In this cases, the shipyard uses a higher level of sub-contracting firms. Except for 'outfitting' where subcontracting is close to zero, all other production processes involve subcontracting In piping two firms account for the majority of the production.

In EIT, other two firms add labor to the building process of electric equipment. In the HVAC division, other two specialized firms provide not only labor, but also the equipment to be installed.

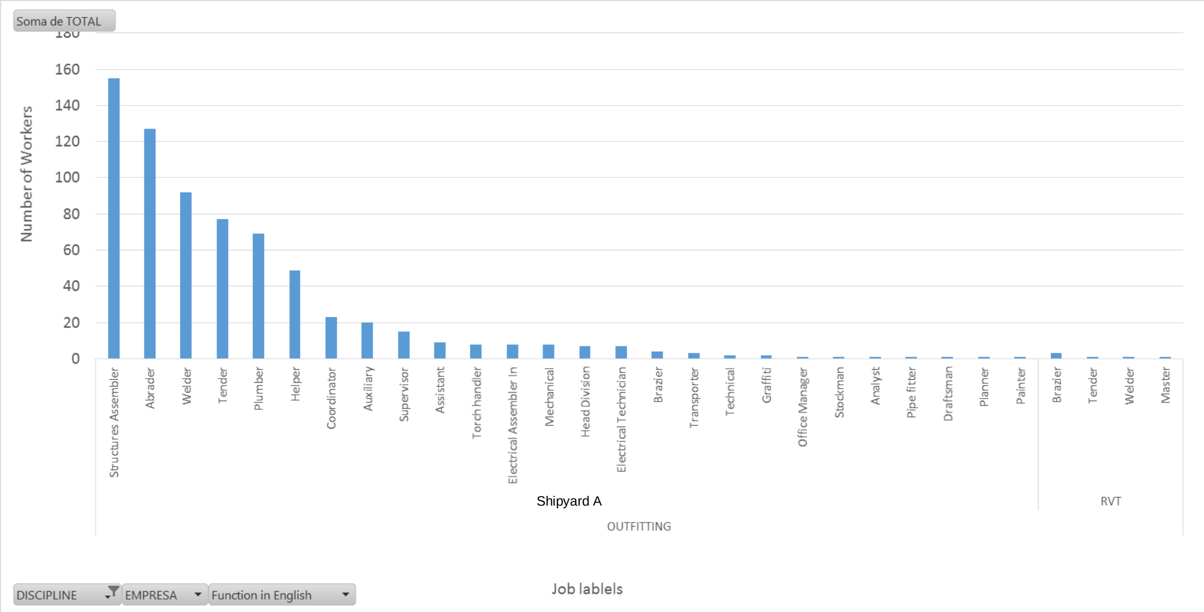
Outfitting fabrication and assembly

Outfitting corresponds to the set of support, rails, walking platforms, ladders, ramparts and other additional accessories that either serve as the base for other equipment such as machinery, electrical network and piping or to build the safety protections around walking accesses, platforms, stairways, ladders and handrails. The company does not use any subcontracted labor to fabricate these items (Figure 47). In fact, outfitting involves a similar set of activities with the core of the structure building. However, it does outsource a part of the items that it installs into the ship. The outfitting department divides these items into three groups according to its sourcing complexity and proximity.

> *"We have items fabricated in the shipyard: bases, elliptical protections, coaming, supports, elevated floors, monorails. All of which add 300 tons to the ship. Then we have items that are manufactured within the state's region: ladders, platforms and walkways). Which add 800 tons. Finally, we have purchased items (in Brazil or imported): Fenders, hats, manhole, hat stiffeners, zinc anodes, ship guard fenders, etc.(500 tons).Here, we just send the guy a project, and we purchase the material. In some situations, we provide the material for the subcontractor that had no capital. Usually the more complex the item, the greater the likelihood of being outsourced. When the item is simple, we make it here on the site, or, send to the somewhere around the state's region. It is a matter of strategy. Whatever generates impact in the production, we try to make here. The right is to have all outfitting done before painting, then all items are made here, in this case, 95% stays between here or the region" (Interview – Outfitting Manager – SHIPYARD A)*

The fact a large portion of the outfitting process happen inside each constructed block and requires welding which burns the metal walls of the block, it has been agreed with PETROBRAS that blocks can only be sent to the internal painting as long as they have completed at least 75% of the Outfitting to avoid rework and waste.

Figure 47. Outfitting Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Outsourced Companies	**Capabilities**
Thor Brazil	Founded in 1985. The company started as manufacturer and assembly of equipment to the agriculture and food industry, and moved to mining, pulp and paper equipment.
Hilti Liechtenstein	Founded in 1941. The company develops, manufactures, and markets products for the construction, building maintenance, and mining industries, primarily to the professional end-user. Hilti concentrates on anchoring systems, hammer drills, firestops, and installation systems, but manufactures and markets an array of tools (including cordless electric drills, heavy angle drills, laser levels, power saws, and fasteners).
Other Spain, Italy	Fenders, hats, manholes, hat stiffeners, zinc anodes, ship guard fenders Mooring system, among others

Pipe manufacturing and assembly

The manufacturing of pipes that will go on the platform are done partially inside the shipyard, and partially outsourced. There is a lack of capacity inside pipe shops and on top of that, pipes require specific treatments and special paintings that are not possible to be done within the shipyard once it does not have the necessary facilities. So the scope of the piping production is very much constraint by these possibilities. The general process of pipe fabrication and assembly involves: the Manufacturing of Spools, Hydraulic Test, Galvanization, Coating, Painting, Mounting and a Second Hydraulic test. Some of these stages require that all spools fabricated at the shipyard have to leave to other locations to be galvanized, painted and tested. So the company diversifies its demands by outsourcing part its production to different companies. There only a few companies in Brazil that does these procedures.

Piping manufacturing and assembly is complex beginning at engineering.

> *"Pipe is not only a problem of this shipyard, but a general problem of Brazil […] First, the project is complicated. Few people really know pipe building. There are many people doing but few people really know. Piping has specific problems of flexibility analysis that we have to be very rigorous about in the engineering phase. Pipes are "alive" in an sense that they vary in size*

depending on temperature and pressure conditions. It moves with the ship's movement. So it is highly rich in this type of detail and few people really know how to do this with excellence. The assembly process is not simple either, it is complicated. Our pipe shopping is well automated, but during assembly we can have problems. It is a process that requires high precision. If you assemble a little crooked, it will leak when placing enormous pressure at it. So we have to get it precisely aligned." (Interview - Engineering Director – SHIPYARD A)

The complicatedness of piping involves the precision necessary in both the engineering and the construction once there are several safety issues that should be address and prevented. Accordingly, both engineering and construction capabilities are limited in Brazil with only a few firms specialized in it.

A second limitation is related to coating treatment, which requires special facilities as it involves the use of chemicals in coating and galvanization.

"In the case of galvanizing it is a local problem. We do not have in the state a specialized company to galvanize or to give the coating. We have a company that does the painting, but not in the speed we need or the quantities we need". (Interview - Engineering Director – SHIPYARD A)

The lack of internal capabilities to deal with this stage of pipe treatment leads to the outsourcing to firms outside of the state. The pipes constructed within the shipyard have to travel to receive the treatment and get back for testing and assembly. Testing is done in the shipyard.

"There is a part of the scope that we manufacture here. Another part of the scope that is manufactured outside. We have pipes that are galvanized and coated, others that are manufactured, galvanized and coated. There is an external company in the state that does the coating. Some pipes we buy from Jambeiro, in São Paulo. They make the pipe, then send to Metalcoating for painting, and they sent to us. Jambeiro fabricates the spools and also does the hydrostatic test. This test takes the spool and put pressure on it. To date, we tested all the lines before galvanizing and painting. Now we will be doing this only with the coated and galvanized lines. All others can be tested after mounted in the ship. (Interview – Pipe Manufacturing Planning and Control Manager –SHIPYARD A)."

As it can be expected, there are costs incurred in logistic and potential delays that can impact the overall construction process. This would justify the internalization of these interfaces or, at least, position it nearby the shipyard. However, the difficulties of investments in pipe treatment technologies involve (besides de investment in capability building) dealing with institutional constraints.

"We have companies interested in investing in business here, but they are discouraged once they have to get permits from Fepam (Local environmental agency) which, in some cases, takes 2 years to get the approval. Some of the environmental inspectors are very rigorous, especially here in the municipal area where we are. This environmental issue is very complicated. We are very

> *interested in having a piping firm close by. In galvanizing there are many people thinking about coming, but no one actually came. Now we have a cost of sending the spools to Sao Paulo and bringing it back."(Interview - Engineering Director – SHIPYARD A)*

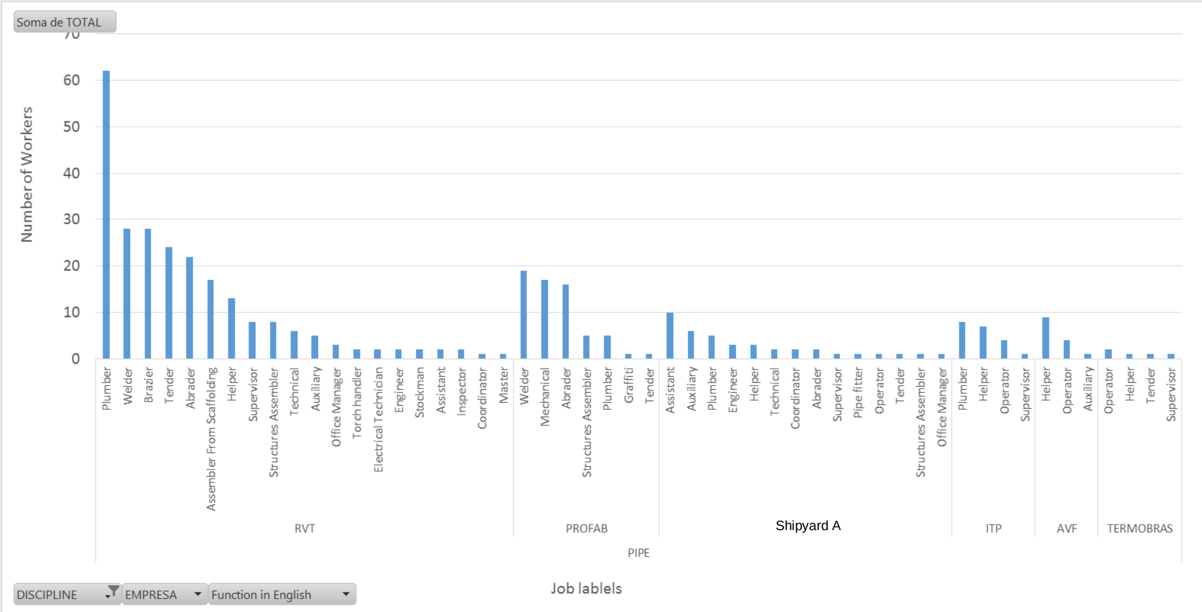
If the company would choose to integrate piping treatment processes, according to one interview, it would only be worth it by achieving economies of scope by using it for multiple purposes.

> *"My personal opinion, I think it would be worth it to invest in a chemical bath deposition because you can use it for multiple purposes (no only piping). I can treat also the steel plates and frames that arrive. I can use it to give a Primer to protect from corrosion problems in the future. Other technologies such as Jet equipment to do this process, I think we would be losing money."(Interview – Chief of Structure Division – SHIPYARD A)*

When we look at the number of employees within the shipyard, the great majority was subcontracted. Two of the main sub-contracted firms also provide labor force for the structure construction. However they are most present in the piping with plumbers and welders in the pip construction (Figure 48).

Following table 2, piping accounts for about 2,5% of the estimate budget cost, however, the complexity involved in construction process, the precision required and the types of treatment dependent on specific facilities that are not available nearby increases the costs, delays and is a potential source of re-work and production paralyzations. Moreover, adding to the analysis of the costs increase that is not totally dependent on the capabilities of the firm (section 8.3.1), institutional regulations such as environmental ones can generate disincentives to investment on capabilities.

Figure 48. Piping Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

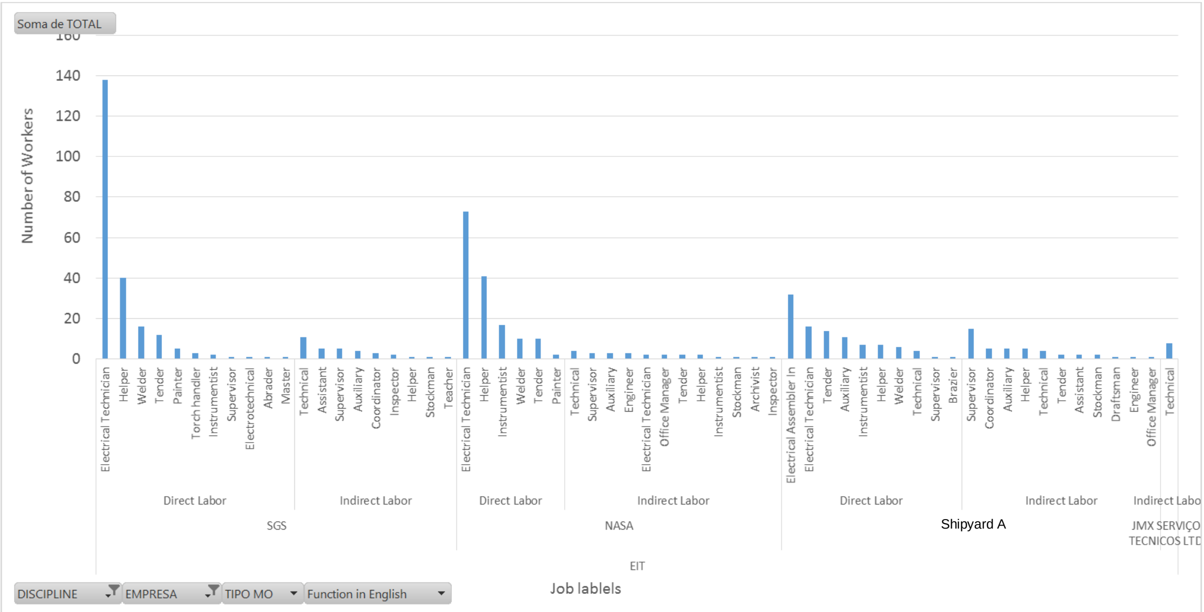
Sub-Contracted firm	**Capabilities**
ITP Spain	In Brazil, the firm was founded in 2007 from the Spanish ITP with more than 35 years of experience. Capabilities: Hydrostatic Testing Services, Leak Test with Pressurized Nitrogen, Chemical Cleaning, Flushing with Oil on Tubbings, pipes and vessels and Purification and Oil Transfer Lube, Oil Diesel Fuel Transfer, Industrial and Borescope Inspection.
RVT Brazil	Founded in 1992 to meet strong demand recovery of industrial valves services. In 2000, the company formally amending its field in the market, establishing itself as a service provider in the maintenance business and industrial assembly, changing its name-RVT. Capabilities: Steel Structures, Pipe Manufacturing and Assembly, Sandblasting, Industrial Painting and Inspections.
PROFAB Brazil	Established near the Shipyard, the company provides a team of workers for Pipe Manufacturing and Assembly of spools, manufacturing and assembly of metal structures, pipe hydrostatic tests, Painting of pipes and metal structures; and industrial maintenance.
Outsourced Companies	**Capabilities**
Jambeiro Brazil	Manufactures metal structures and pipes: spools, pressure vessels, storage tanks, skids, gates, suction tubes, etc. Provides Services of metal cutting, various welding, industrial painting against corrosion,
Metal Coating Brazil	Operating since 2000, is a company specialized in Technologies of organic coating applications for anti-corrosion protection. Application of Polyamide 11/12; Fusion-Bonded Epoxy, Polyethylene, Epoxy, Fluorpolymer, Polyester Resins
Tecnoar Brazil	Metal surface preparation (abrasive blasting) and industrial painting.
Purchase	**Capabilities**
Tenaris Italy (HQ Luxemburg)	Founded in 1909. Various types of piping solutions: pipe fors Exploration and Production, Distribution pipelines, connections, pipes for Sanitation, Mining, industrial applications, sucker rods, tiling, distributors

It is reasonable to consider, however, that if any company would be able to overcome the institutional barriers, there would be a potential for creating a piping firm that could achieve sufficient scale to serve different shipyards in the region.

Electrical, Instruments and Telecommunications

By looking at the numbers from the Electrical, Instrumentation and Telecom activities, it is possible to notice that this is a major sub-contracted activity. The installation of electrical panels, electric cables and connections are mostly done by two companies (Figure 49). The shipyard own personnel playing a bigger role in the management and supervision of these activities. These activities are estimated to account for 0,4% of the construction budget and this enters closer to the end the construction process.

Figure 49. Electrical, Instruments and Telecommunications (EIT), Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	Capabilities
SGS Swiss/Brazil	Founded in 1878, it is a multinational company headquartered in Geneva, Switzerland which provides inspection, verification, testing and certification services.
NASA Engenharia Brazil	Detailed engineering projects, procedures and operation manuals, Inspection, Electromechanical Assembly, Tests on Mechanical and Electrical Equipment, Instrument Calibration, Commissioning, Start-up and Assisted Operation in Process Unit. Calibration and Repair in safety valves.

Internal and Final Painting

The painting department at SHIPYARD A, is responsible for the management of all the process of treating the steel plates, cleaning and decontamination and painting. The first step begins even before construction of the blocks. It initiates by treating the steel plates by passing them through shot blasting machine which will apply a protective primer to all plates.

> *"In order for the ship to last 25 years at sea, there must be a good painting, because it is what will slow the hull corrosion process. We work in various stages of ship. The first step is the blasting and painting plates with low thickness SHOP-PRIMER. This is a primary protection from corrosion during the waiting process before taking the plate for cutting, assembly, and manufacturing of the blocks. The shop-primer protects it until the plate goes to the paint cabin". (Interview – Paint Manager* **-** *SHIPYARD A)*

The process is highly intense in knowledge, especially in chemistry. Moreover, this discipline is mainly related to cleaning and requires a rigorous processes and steps to guarantee the attendance of safety and quality requirements.

> *"I need to control water hardness. Chlorine, iron, manganese, the Phosphorus, silica, pH, and conductivity. The latter is a problem for me. If I have conductive salts, it is bad. It's not about accidents. It can happen what we call osmosis, blistering on the wall. We have salts, and these salts in its plaster, they will turn into liquid and will form a bubble between the plaster and the ink film. If you drill this bubble, it will leak. I, cannot have more than 3 micrograms per square-meter. If you have more, this block is faulted and I need to make all the decontamination." (Interview – Paint Manager - SHIPYARD A)*

Generally, painting is responsible for the process the rigorous of cleaning, decontamination and protection that will conserve the ships' structure over the years.

> *"Everyone understands that the painting is not a discipline like. Everyone understands that the painting is a cleaning discipline. All other disciplines leave residues. The plate gets exposed to dirty place and has to be clean. I have to do the cleaning. After cleaning, I have to do the decontamination of the area (which is desalination, 3 micrograms). After we do this decontamination, we apply the first demon, than we apply a stripe coat, and repeat the application of a demon and stripe coat other two times". (Interview – Paint Manager – SHIPYARD A)*

After the first treatment is done, steel plates may go to the construction process to become the structures and blocks. After cleaning, it goes to the paint cabins for cleaning, decontamination and painting. This process is done by on major subcontracted firm which has invested in the necessary infrastructure.

> *"After the shot-blast, I send this plate for assembly and construction of the blocks. The staff, structuring and advanced finishing will perform all construction than they must. After everything is finished, and they give me the OK, the block is handed back to me. Then I send it to ULTRABLAST, or CIMEC to do the hydroblasting or the abrasive blasting. Then I make a further step, which is the barrier for protection step. Which is what we were hired to do. Only I do it in 90% of the block. I do not paint 100% of the block. Why? Because I have a lot coupling welds that will be done. The block will fit in the other. Then I'll have the burning process. If I do all the painting on a 100%, I'll have to re-work after welding (paint removal to make the weld). So we left about 200 mm on each side and all the welding unpainted coupling."(Interview – Paint Manager – SHIPAYRD A)*

The Sub-contracted firm that performs this stage or production is ULTRABLAST. The company invested in facilities and specialized equipment. These activities are somehow outside of the realm of the shipyard construction capabilities. The sub-constructed firm brings technology from France.

> *"The Company was formed in Rio de Janeiro that it is part of Lassarrat group. The Lassarat group is a group that has 60 years in France. So it was a partnership of Brazil-France staff to build this company. It is a new company, (only two years). It comes with the latest technology, ie. We make the painting of the blocks through the water jetting process. Previously*

> *people used abrasive techniques such as sand blasting, but this is worse for the health of people that will be applying it. In addition, we have a problem at this location. Because of the proximity with the ocean, the salinity of the air is very high. Then, the abrasive jet it will push the salt inside the piece, depending on the conditions. So we use the waterjet. We use the waterjet to wash and clean the block. The water itself of waterjet it is treated in here in our wastewater treatment plant and reused" (Interview – Production Planning and Control Manager - ULTRABLAST).*

The company has around 400 employees. The equipment used must is very dangerous and must be carefully handled by well-trained personnel.

> *"Learning to use the application equipment is easy. However, the great danger of the waterjet is safety. If I spend the waterjet on you, I'll pour you from side to side. It is a gun. 40,000 Psi, is a lot of water pressure. So it's a very dangerous and requires training and safety personal equipment. For that, we have an outfit that has no equal in the yard. It is an outfit that is special to endure. If spending the jet on the clothing, it marks the clothes, but not enough to cut the skin. It is an extremely expensive material." (Interview – Production Planning and Control Manager - ULTRBLAST).*

Besides, the technology present in the facilities international. It requires constant monitoring and maintenance. The specialized services for this matter come from Europe from time to time.

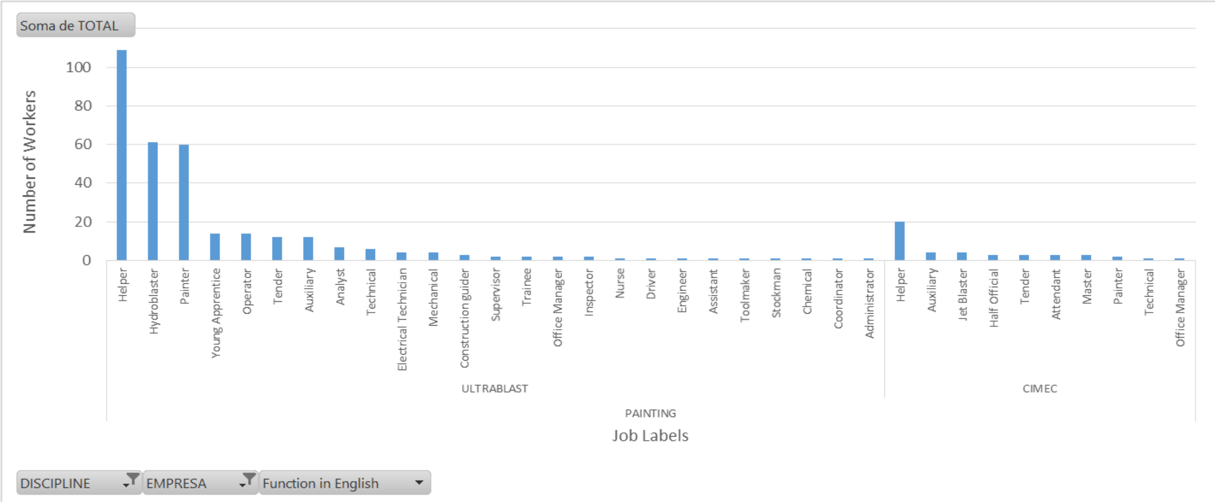
> *"We have approximately 400 people at ULTRABLAST. However, we have professionals that come as Lassarat to provide support. These are not the direct labor, but indirect. This staff comes as Lassarat and they are specialized people. For example, we have Joaquim who is the director of ULTRABLAST at the shipyard. He is the construction and assembly manager and he has the most knowledge of the process. He brings staff from Lassarat that are specialized people in the particular technologies and machineries we use. For example, we have a solvent treatment unit, which prevents solvent from being wasted so we can reuse much of it. We need to bring specialized people to deal with this technology, and they come from overseas"(Interview – Production Planning and Control Manager - ULTRABLAST).*

Besides the internal painting given inside the cabins by the subcontracted firms, there is a subset of painting goes on at the dry dock during the pre-edification, edification and commissioning. This painting gives the final finishing and protections to structures.

> *"After the block leaves the cabins it goes to pre-construction at the dry-dock. Pre-construction will do their job, all the tests, and will return the area to do the final painting. Now, the block comes back not as block, but as compartment. Then I'll work down at the dry-dock to do the rest of the finish painting or to repair any possible damage that has happened in the process."(Interview – Paint Manager – SHIPYARD A)*

Painting overall uses the most diverse set of subcontracting as shown in Figure 50 and Figure 51. These subcontracted firms engage in different set of activities such as: surface treatment, painting application, waste removal and cleaning using hydroblasting applications and other techniques.

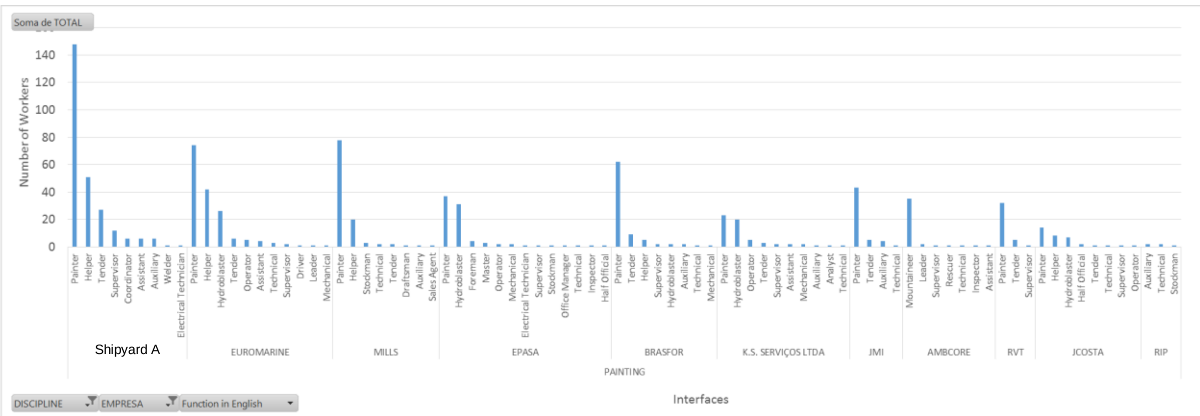
Figure 50. Internal Painting Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	**Capabilities**
ULTRABLAST Colombia-France	The company was officially founded in 1997, but it is history is tight back to 1978 form a firm specializing in the agriculture land treatment and machinery imports, later expanding negotiation capabilities, entered in the market in other sectors (pharmaceutical, petrochemical, Pulp and Paper, Food, among others. The company is owned by a French group. Capabilities: Water Jetting using Hydroblasting technology to clean metal surfaces.
CIMEC	[No public information] Works with abrasive jet technology.

Figure 51. Final painting Firms and Functions



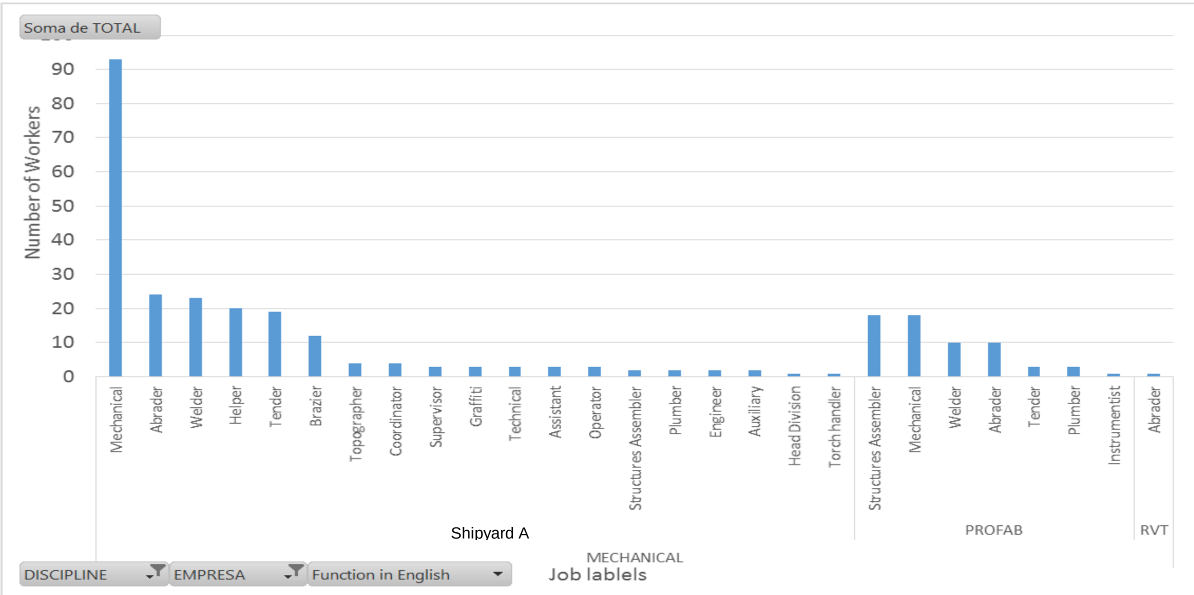
Source: Based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	**Capabilities**
EUROMARINE Brazil	Surface treatment and preparation for painting, Passive protection painting, Maintenance painting, wastewater treatment
EPASA (no info)	Painting application
BRASFOR	Cleaning bilges and tanks with waste removal / sewage tanks with air and electric pumps, mechanical treatment services ST3 with priming application, painting services with high pressure pumps (airless) Hydrojet washing. Labor supply: Painting Services / Abraders / General Cleaning Scraping manual tanks, boat hulls Treatment ST3 (Use of professional climbers)
K.S. Serviços (no info)	Painting and Hydroblasting application
AMBCORE (no info)	Alpinists
JMI Brazil	Consolidated in the aircraft market, JMI provides Paintings Painting services, Polishing, Cleaning Aircraft, Prefix exchange, and removal.
JCOSTA Brazil	Painting and Hydroblasting application
Simple Purchase	**Capabilities**
Sherwin-Williams	Founded in 1866. It is one of the largest producer of paints and coatings in the world.

Machinery

The machinery interface is responsible for mounting all equipment into the ship. Most of the labor involved into the mounting process is form the shipyard with a few subcontractors. All equipment however, is purchased from different suppliers. Only one subcontracted firm in the assembly of structures to receive the machinery, but the installation is done by the shipyard (
Figure 52). These two subcontracted firms, and their capabilities were presented previously as they participate in other interfaces of the construction process.

Figure 52. Mechanical Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

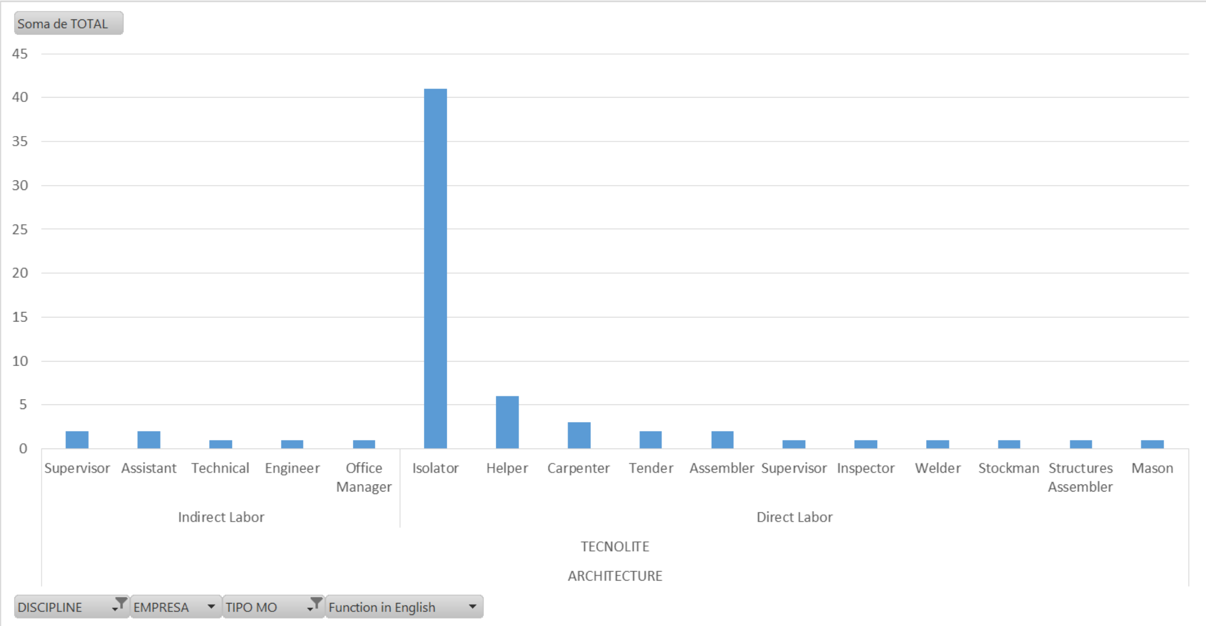
Architecture

Architecture is one of the final construction processes. It is mainly concerned with the acoustic isolation of areas and rooms where there will be people circulating or staying. Architecture also manages the installation of the accommodation structure which is completely built in China.

> *"The architecture is the last even after all other important items are ready. In other words, after all other disciplines and compartments have been finished. The architecture involves: pinning, crating, soundproofing, depending on the room gets a certain thickness. We work in the areas where there will be people circulating or staying like: accommodations, laundry rooms, bathrooms, next to ventilation machinery or engines. All of which is subcontracted." (Interview – architecture manager – SHIPYARD A)*

The engineering depart sends the projects to the architecture department which is responsible for managing the preparation and assembly of the building process. However none of the materials are produced in the yard. Everything comes from external suppliers. In terms of mounting the structure, the yard uses a subcontracting firm specialized in this type of construction. The company is also the supplier of the materials it puts in place (Figure 53)

Figure 53. Architecture Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

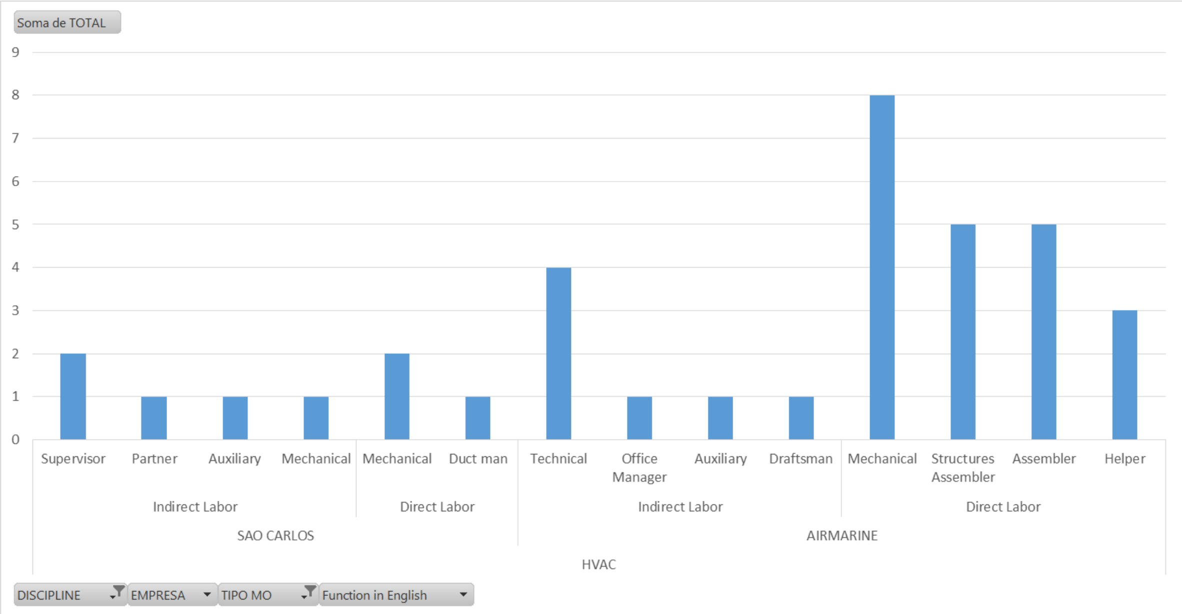
Sub-Contracted firm	**Capabilities**
TECNOLITE Brazil/Italian	Founded in 1964 as Termolite / Asberit with Italian capital. In national and international ship construction environment, the company provides in addition to isolation, all materials and services for design, construction and reform of accommodation areas and support life on ships and platforms, including complete modules plug and play type. For the industrial sector, provides and constantly develops thermal insulating materials in plates or workable for many different applications.
Outsourced	**Capabilities**
COSCO China	Shipbuilder. Builder of all accommodation structure.

Heating, Ventilation and Air-Conditioning

HVAC services enter at the end of the construction process and involve specific equipment, installation know-how and maintenance services. This is completely sub-contracted using two firms. Figure 54 present these firms and their specific capabilities.

This process initiates close to the end of production and uses technology provided by the suppliers, which take care of the full installation process.

Figure 54. Heating, Ventilation and Air-Conditioning Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

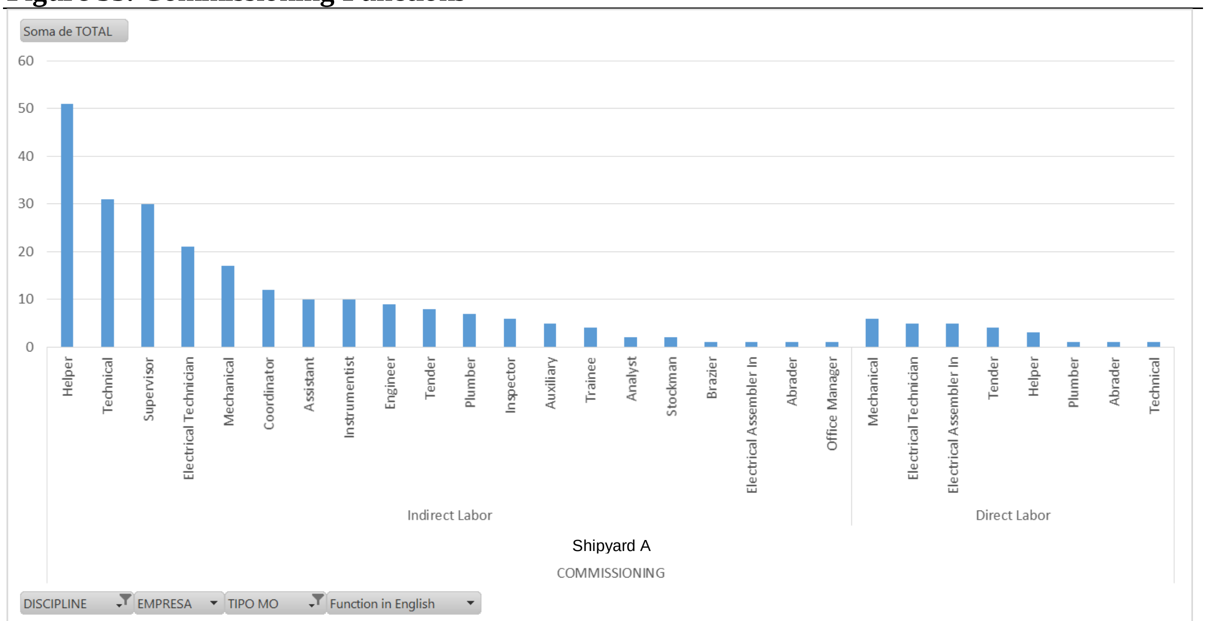
Sub-Contracted firm	Capabilities
SÃO CARLOS Brazil	Founded in 1958. Headquartered in Esteio (RS), in the metropolitan area of Porto Alegre, the company has consolidated its operations in engineering services in the design, execution and maintenance of works in the segment of air conditioning, refrigeration and ventilation industry, commerce and services
AIRMARINE Brazil/Sweden	Founded in 1991 by former staff members of FläktTécnica de Ar Ltda (Brazilian branch of Fläkt Marine AB of Gothenburg, Sweden). Capabilities: design, assembly, and commissioning of marine and offshore HVAC and refrigeration systems. Large-scale designs and/or installations were supplied, however, in a partnership with Semco. Over the past 14 years Airmarine has been operating in the marine and offshore sector together with ABB AS (Norway), a company it represents which recently became part of the Swedish group Cailenberg under the new name "AC Marine AS".

Source: Based on data provided by Shipyard A relative to October of 2015.

Commissioning

Commissioning involves the final testing of every single equipment and system installed on the ship. This is done by internal personnel (Figure 55)

Figure 55. Commissioning Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

8.3.6. Logistics and Heavy Lifting

Moving materials and giant ship parts such as blocks and mega blocks around the yard and positioning them with precision in the right places requires heavy specialized equipment such as: trucks, cranes, forklifts, heavy-lifting tractors and high capacity porches. This area all specialized equipment. Figure 56 describes the main technologies involved in this field and the characteristics of sub-contracting and coordination.

Figure 56. Logistics and Heavy Lifting

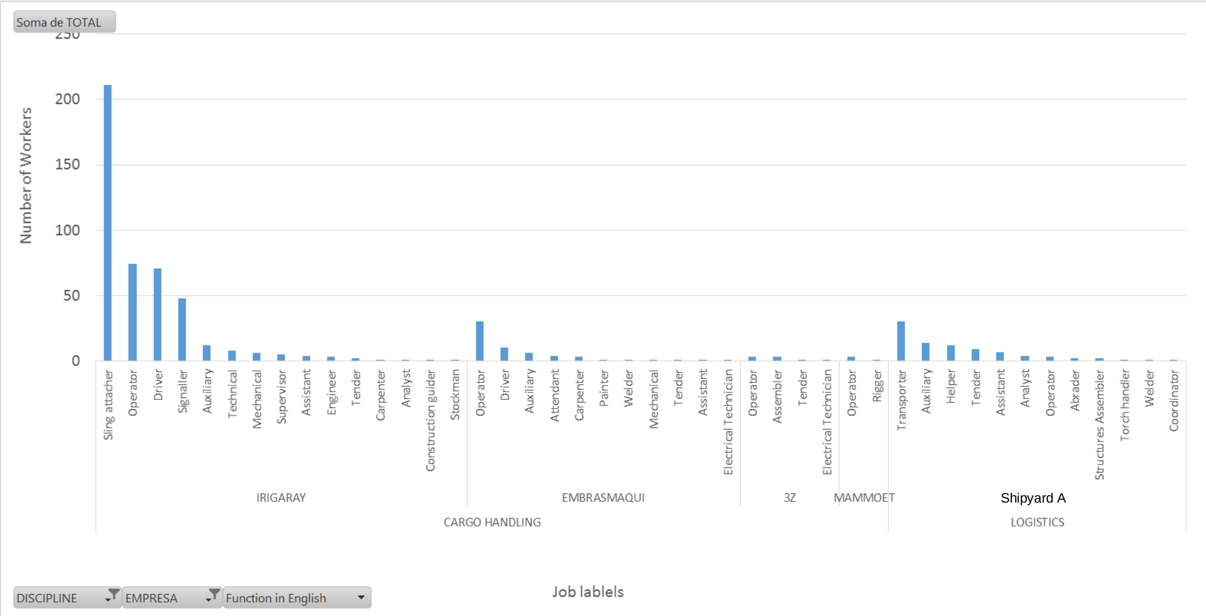
		What it consists on	In-house	Sub-contract	Outsourcing
Logistics and Heavy Lifting	***Heavy-lifting tractors (KAMAG)***	• Movement of heavy cargos around the yards	• Coordination	• Equipment and labor	• None
	Derrick trucks	• Lifting of heavy cargos in construction areas and Drydock	• Coordination	• Equipment and labor	• None
	Shipyard Crane	• Lifting of Super-Structures, blocks and mega-blocks inside of the Drydock.	• Coordination	• Specialized labor	• None

Source: Developed by author

At SHIPYARD A, these services are subcontracted by different firms. While the coordination of the internal logistics is done by the shipyard itself, all of the transportation equipment as well as the corresponding specific personnel to operate and maneuver the equipment are subcontracted.

National firms provide cranes, trucks, tractors and personnel. The shipyard large crane was an investment done by SHIPYARD A and PETROBRAS, however, the operation of these heavy lifting cranes requires specific skills that are subcontracted from an American firm.

Figure 57. Logistics and Heavy Lifting Firms and Functions



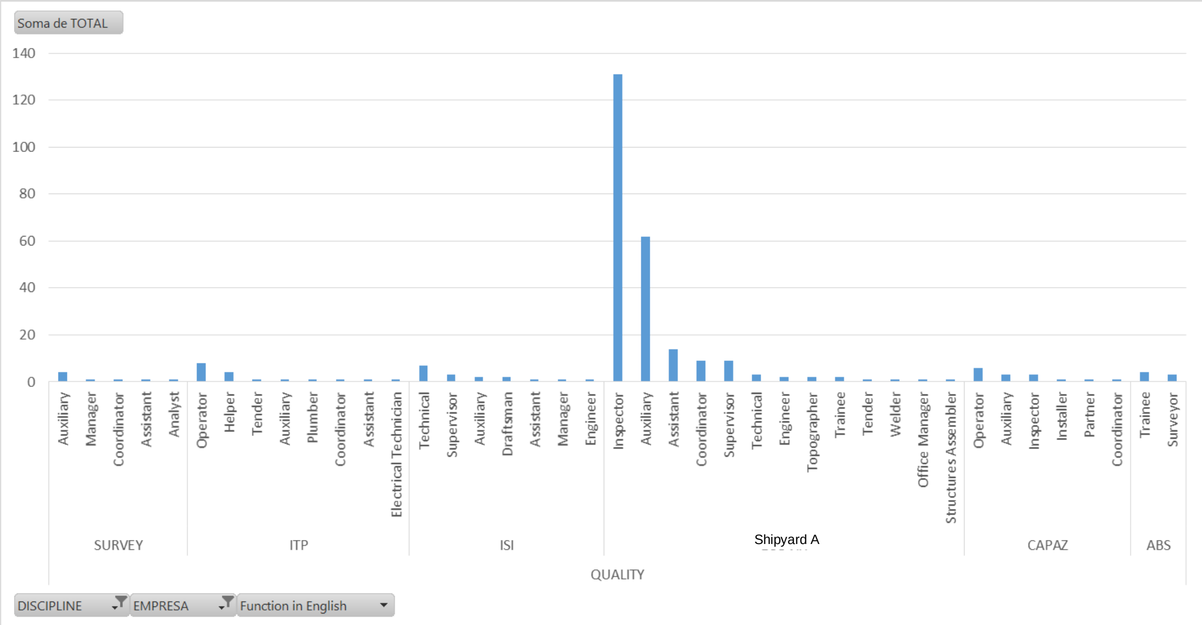
Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	Capabilities
MAMMOET United States	American company with expertise in Heavy Lifting, Heavy Transport, Industrial shutdown management, Sitewide construction, Modular construction, Onshore and Offshore decommissioning, heavy logistics. At the shipyard, the company provides the porch operator.
IRIGARAY Brazil	Founded more than 40 years ago, the company provides services for cargo handling and transportation using up-to-date and reliable equipment. The company owns forklifts and cranes, Riggers, trucks and trailers, as well as ferries and tugs for maritime transportation.
EMBRASMAQUI Brazil	Forklifts and equipment
3Z Brazil	Tower cranes, cranes, platforms and tele handlers,

8.3.7. Quality and Safety Inspections

Quality and safety inspections are very strict in the naval and offshore industry which is similar to the aviation industry. The complexity and danger of dealing with explosive chemicals offshore creates requires high carefulness and precision in every built-in technology. Moreover, quality measures are institutional imposition by national and international standards. SHIPYARD A had a large number of works doing inspections. Besides its own personnel in charge for quality control, has additional four firms specialized in testing and quality measure. Figure 58 shows the sub-contracted firms and their capabilities.

Figure 58. Quality and Safety Inspections Firms and Functions



Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

Sub-Contracted firm	Capabilities
SURVEY Brazil	Founded in 2009. Provides Dimensional Control and 3D Laser Scanning services.
ISI Brazil	System for quality inspections and control of structure building, piping, fabrication and commissioning.
CAPAZ Brazil	Non-destructive testing, Fabrication, Assembly Inspections (painting, dimensions, strength, borescope testing, weld inspection, maintenance inspection, mechanic testing.
ABS United States	Technical inspections and verification, Safety Risk and Compliance, Asset performance Optimization.
External Co-ordination	**Capabilities**
PETROBRAS Brazil	Biggest oil company in Brazil. The company is present in each construction site in Brazil where it has construction projects.

The American Bureau of Shipping (ABS) is the classification society within the shipyard entitled to survey and guarantee that international safety standards and requirements are met. ABS verifies the standards for the design, construction and operational maintenance of marine-related facilities. It is concerned with safety standards for the crew and environment as well as quality and integrity of the ship. The American Bureau of Shipping verifies and certifies for every ship that leaves the yard.

> *"One of the most important aspects in the maritime industry is that working condition on boar is safe. International standards in shipbuilding are formalized by classification societies and is regulated by the International Maritime Organization (IMO). The IMO belongs to the United Nations and Brazil is a signatory of that entity. Therefore, to any standard and norms or laws that are passed and signed by the United Nations, Brazil has to follow. As a classification society, we see the whole piece of equipment protection, personnel protection. Once this is set, comes our turn in dealing with everything related to the compliance shipbuilding worldwide to these rules. That is, the client can ask for anything, but if it does not comply with the rule, it cannot be done. And the yard has to follow exactly all of which has been agreed, disseminated and approved by the classification society. And*

we are here to verify this. As surveyors we usually treat these rules as statutory. Brazil accepts certain types of vessels to enter its territorial waters as long as they follow the standards. Some of these standards are: SOLAS. Signature of Live at Sea which is basically the safety and safeguard of life at sea. There are others for prevention of oil spills, sewage, air, chemical, we have some other ranging from against terrorism, ship hijacking. Many of those conventions had some historical event for which they were created. The Solas, for example, happen after the Titanic. When the Titanic sank, the ship had a stability problem, and this problem was generated because, at the time, the ship had a steel construction methodology that believed the harder the steel, the stronger the vessel. This was proved not to be true. Today, for example, the steel has to be double tier. It has also to meet some deformation properties that had not been used before then. Steel was tougher, but was not able to deform. Also, as the ship went down it had no lifeboats for everyone, etc."(Interview – ABS Surveyor)

ABS certifies the ship to be able to navigate in national or international waters depending on the type of certification. Its surveyors look at every single aspect that can pose some kind of threat to the ship such as: Conditions for classification, Materials and Welding, Hull construction and equipment, Ship System, machinery, motor, piping and electrical machinery.

In the case of the shipyard analyzed, where capabilities are not mature and the levels of knowledge are not widely diffused, ABS has another role, that is of transmitting and sharing information, experience and sometimes, even training. According to the interviewed surveyor acknowledgments comparing his experience in the Brazilian shipyard vs others his role is much more of teaching than learning.

"I've worked for Shell, Chevron, ExxonMobil out there and I think I learned a lot. I know there is a specialist Pipe at Chevron who knows a lot pipe. I learned a lot with them. I often sat with the responsible for the structure construction to learn. Here I go into one recently built block and, although I´m relatively young, I have a load of things to teach the guys here, whereas, on the other places I worked I just learned. In fact, these other international shipyards were already much ahead of the required standards improvements. Their construction process is much more advanced. Things I honestly do not see how we can get there quickly. (Interview – ABS Surveyor)

One of the reasons has to do with organization and labor turnover.

"The labor turnover is very high. At times a see improvements, other times I see production making the same mistakes and will have a meeting to talk about the same things on welding. Supervision sometimes is absent, there are too many people…and what I think there is lack of commitment of each workman in doing their best. We have discipline problems (there have been cases of marihuana use on the ship). Moreover, the yard is running straight, after a while (all of a sudden) "boom" there is a contractor with 3000 new employees! No company can handle this type of sudden change. (Interview – ABS Surveyor)

This seems a challenge for the scope of capabilities of the firm. If one of the premises is that there is a need to gain capacity by building capabilities, and capabilities are built upon learning, management should be concerned on the mechanisms that guarantee progress of the learning curves on routines. In this sense, organizational effort should also be put on the factors that prevent learning to take place. Nonetheless, these factors may be, not only internal, but also external such as pressures from the main client.

Petrobras also enforces several standards which go well beyond the ones required by ABS. While the ABS inspections are concerned to safety, there is a whole set of norms and rules that PETROBRAS has also to comply with, which are related to the Brazilian standards organization.

> *"The requirements that the ABS see are others. The ABS has a focus over safety and health requirements of the vessel. For example. Our list of documents has 3000 documents. The ABS sees 500 documents. Then they sees 1/6 of the project. Petrobras, however, are in all other technical and operational requirements. We always seek to observe equipment criteria, best engineering practices and international standards." (Interview – Interface manger – PETROBRAS)*

In this sense, there are several challenges for the fixation of knowledge within the shipyard and expansion and stabilization of a set of necessary capabilities. First, the project is complex in both the number of parts and the complicatedness of mastering the different technologies. Second, this requires, on the one hand, a high level of organization to guarantee the efficient flow of production, but also, on the other hand, a general commitment to learning and improvement from engineering, management and the construction labor force. In both processes, the key behavior required is discipline.

8.3.8. External Coordination and Interface Management – The view of the PETROBRAS

As shown in Figure 28 (above), besides being the sole purchaser of the construction outputs from SHIPYARD A, PETROBRAS plays also the role of the overall construction manager. It manages all of the contractual interfaces among the different main EPCC companies. It is responsible for managing the schedules and assuring that the contracts are being respected. The complexity of the project and the type of decisions being made on the daily basis required a dedicated team at each yard.

> *"We are present at each of the construction fields on the daily basis. We coordinators for each of the contracts here (at the integrator).One for module A, one for B and one for C. This structure repeats itself for each of*

> *the Integration firms. So my day to day is to stay with the Project Detailing Firm located in Rio where I follow the project's progress. And once a week or when there is a special demand I come to the yard to see the physical progress. And I do the part of the interface between engineering and supplies." (Interview – Interface Manager from PETROBRAS)*

The complexity of this project also required a change in the organization structure of PETROBRAS in order to deal with the demands from managing several interfaces.

> *"Before this project, we were a venture connected only to a general management and inside there were several managerial departments. There were project management and the supply department, which was my original department. Now, the managerial departments of construction and assembly have become focused on specific projects. As soon as we walked in the previous structure, it was clear that it was an undersized structure. Today, even with the "boom" of projects we are still undersized. Each contract has an enterprise management. The Hull has its own, each one of the modules and each of the integrators have a well defined manager." (Interview – Interface Manager - PETROBRAS)*

The management process of the several projects is integrated through a system called Interface Query Management (IQM) where all information exchanges are formalized. Besides the system, meetings also constantly take place whenever it is necessary.

> *"In these projects, we have a system called Interface Query Management (IQS SYSTEM). Since the beginning of the project, this is where all official exchanges of information between contracted firms are made. We started this at the level of engineering project and now, we have also created at the level of construction and assembly.*

> *"Each contracted firm is responsible for updating the system using filters. We have a person at Petrobras who is the interface manager and the contracted firm has another person who is the interface manager at the other side. They are in touch all the time. When the Engineering firm needs an information from (say) a module builder, they open the IQS selecting the discipline's code number and request the information or inform some problem. This information passes through the filter of the Petrobras, which requests the information from the module builder. Then, at the module builder, the responsible interface manager transmits the information." (Interview – Interface Manager from PETROBRAS)*

> *"These exchanges are made official by this system and we also have meetings whenever an issue is more complex than what can be handled in the IQS. Each contractor has access to all documents from others. We have a database that is called IDR where the contractor can select or request particular documents from each contractor. The integrator firms are responsible for integrating modules and the hull. They have to disclosing these information, especially related to the Electrical Part which generates the most interfaces". (Interview – Interface Manager from PETROBRAS)*

> *"The types of documents in the IDR, for example, include hull's documentation, 3D models of the hull, etc. These are published on weekly*

> *basis in an FTP which is an area at PETROBRAS where each contractor publishes a 3D review. Then the integrator is responsible for entering the database of each contract and run the interference system to identify 'clashes' and responsibilities in order to determine who must solve the problem."(Interview – Interface Manager from PETROBRAS)*

8.3.9. Summarizing Industrial Scope

In October of 2014, there were 91 companies inside the shipyard (Appendix D). Some 34 firms were involved directly in production and were distributed across the various divisions and disciplines. The analysis of bounded capabilities and technological interfaces concentrate on those. However, other 36 firms accounting for 541 workers (Appendix E) were of non-core activities providing medical, food services, cleaning and other need services that support the shipyards core-activities.

As far as the dynamic on the core activities, the different firms translated the boundaries and interfaces present from project engineering, procurement and construction, operational services such as logistics and heavy lifting as well as quality inspections and testing. The source of these boundaries, nonetheless, varies.

Figure 59 presents a summary of the observed patterns. This was a non-exclusive list of companies as many other procurement relations exist. In the column where it says "internal coordination" are all the interfaces where SHIPYARD A had allocated labor either directly involved in the productive activity or indirectly in the coordination of the activity.

By analyzing the types of industrial relations that arise from the need to organized bounded capabilities and technological interfaces, 11 different patterns appeared divided into three main groups**:** External Coordination, Internal Coordination and Outsourcing.

The external coordination is done by PETROBRAS who is the ultimate manager of contracts. As the interface manager, is present in all shipyards and construction areas to inspect and make sure schedule is being followed. Once a state-owned company has also to comply with regulations of its own and has legal responsibilities in terms of quality and technical inspections.

Internal Coordination involves all activities that must be done *in loco* in order to make the product. It assumes a couple of different forms: Full-Coordination or Execution by the main company; Partnership Development and Subcontracts (labor, specialized services, equipment and/or facilities). *Full-coordination*, the firm executes the entire sequence of activities relative to a particular interface. *Partnership development* was used specially for knowledge transfer and information exchange in the process of engineering detailing of the project and the shop drawings. *Subcontracts* are used due to one of the following reasons from simple to more complex: a) labor shortage in production; b) specialized services requiring specific labor and tools; c) specialized services requiring specific labor and equipment; d) specialized services associated with labor and tools, equipment and facilities.

Figure 59. Firms, Technological Interfaces and types of Industrial Relations

	Firms	Country	Interface	Internal Co-ordination	Sub-Contracted	Outsourced	External Co-ordination
1	MHI	Japan	Coordination	x			
2	Cosco	China	Detailed engineering	x	x		
3	GVA	Sweden	Basic Engineering			x	
4	RVT	Brazil	Structure & Piping & Machinery	x	x		
5	Profab	Brazil	Structure & Piping & Machinery		x		
6	Sermetal	Brazil	Structure			x	
7	Mills	Brazil	Scaffolding	x	x		
8	Thor	Brazil	Outfitting			x	
9	Hilti	Liechtenstein	Outfitting	x		x	
10	Others	Spain and Italy	Outfitting			x	
11	ITP	Brazil	Piping		x		
12	Jambeiro	Brazil	Piping			x	
13	Metal coating	Brazil	Piping	x		x	
14	Tecnoar - bra	Brazil	Piping			x	
15	Tenaris	Italy	Piping			x	
16	Sgs	Swiss/Brazil	EIT	x	x		
17	Nasa	Brazil	EIT		x		
18	Euromarine	Brazil	Painting		x		
19	Epasa	Brazil	Painting		x		
20	Brasfor	Brazil	Painting	x	x		
21	JMI	Brazil	Painting		x		
22	Sherwing-Williams	USA	Painting			x	
23	Tecnolite	Brazil/Italy	Architecture		x		
24	Cosco	China	Architecture			x	
25	São carlos	Brazil	HVAC		x	x	
26	Airmarine	Brazil/Sweden	HVAC		x	x	
27	Mammoet	USA	Logistics and Heavy-Lifting		x		
28	Irigaray	Brazil	Logistics and Heavy-Lifting	x	x		
29	Embrasmaqui	Brazil	Logistics and Heavy-Lifting		x		
30	3z	Brazil	Logistics and Heavy-Lifting		x		
31	Survey	Brazil	Quality and Safety Inspections		x		
32	Isis	Brazil	Quality and Safety Inspections		x		
33	Capaz	Brazil	Quality and Safety Inspections		x		
34	ABS	USA	Quality and Safety Inspections		x		

35	Petrobras	Brazil	Quality and Safety Inspections			x

Source: Developed by author, based on data provided by Shipyard A relative to October of 2015.

The first three types of subcontracts involve general purpose technologies that can be allocated from project to project elsewhere. The last type of subcontract resembles the notion of complementary assets (Teece, 1986) and it has a higher degree of locational specificity requiring facilities to be inside the yard. Nonetheless this facilities are outside of the core-capabilities of the leading firm at the shipyard.

The third group of relations involves Outsourcing**.** These interfaces involve all activities that are literally contracted-out. They do not necessarily happen inside the yard, although some of them would be considered desirable. The nature of outsourcing deserves some considerations. It is possible to imagine that, it would be technically possible to outsource any piece of production that happens before the edification process. In this sense, the edification process, which is a process of integration, have to be done in the shipyard (along with all the respective services related to this process). However, while technically possible, outsourcing every piece of production before edification is likely harder to coordinate and possibly involves higher inefficiencies.

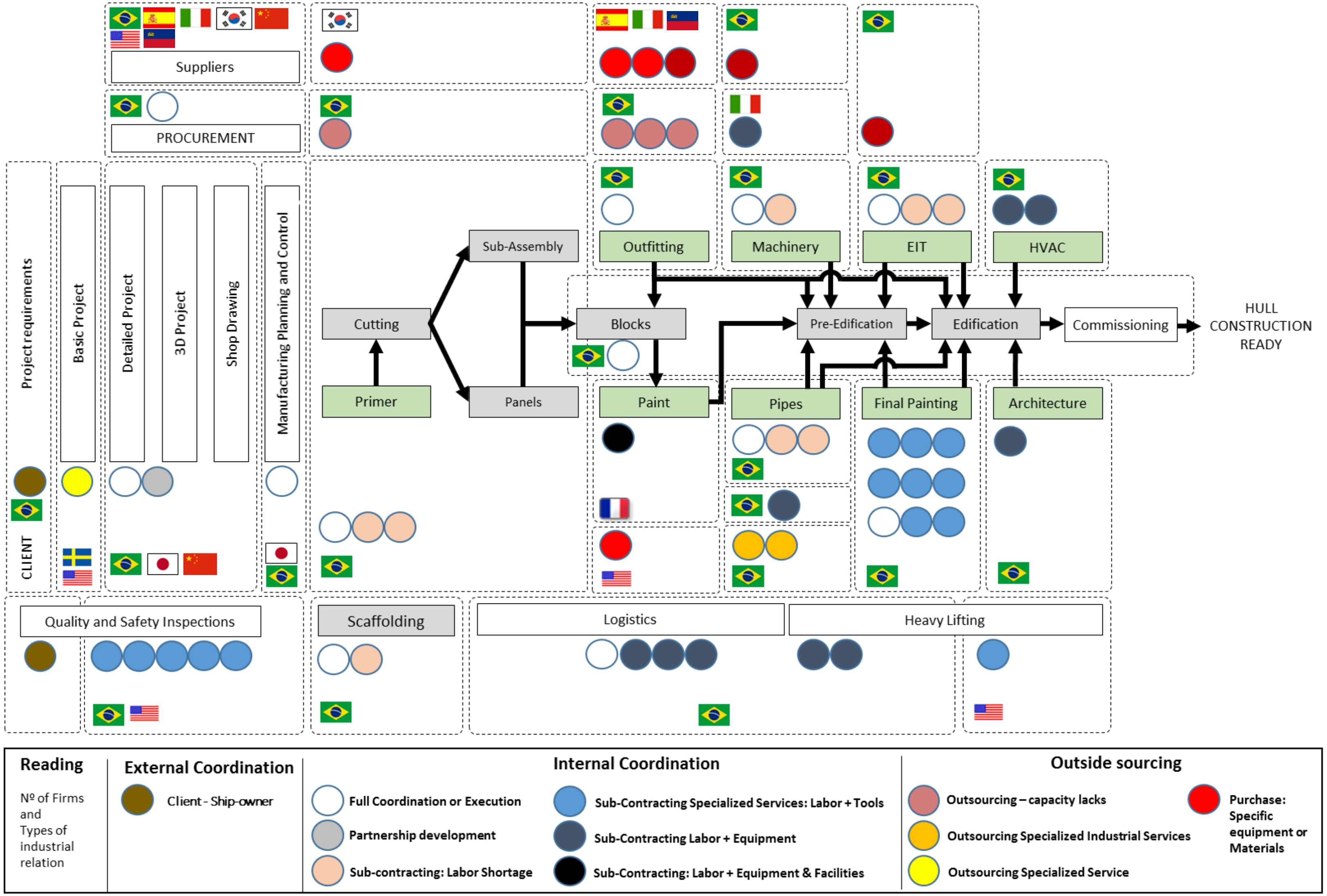
Outsourcing takes place in four situations. The first is the simple *Purchase of inputs* (materials, components or specific equipment) which are clearly outside the shipyards core capabilities. The second is the outsourcing of *specific services* (usually knowledge intensive) that the firm does not qualify for and don't require *in loco* activity. The engineering of the Basic project was totally outsourced to a Swedish firm. This was a requirement by PETROBRAS and according to the interview in section 8.3.1, it is hard to find this type of know-how in Brazil. The third outsourcing observed was *industrial services* that require specific facilities that the firm do not have (like galvanization). This is dependent on specific assets that the shipyard is not capable of investing (some of which are external to the firm, like environmental licenses). The forth Outsourcing situation was due to *Capacity Lacks* whenever the firm foresees that it will not be able to meet deadlines and honor contracts.

For example, the yard may opt to contract out any ship-part as long as they have a clear standard and are perfectly modularized. SHIPYARD A has its own pipe shop, however, it does not produce 100% of the pipes it needs. Similarly, shipyard, outsourced of the entire construction of certain blocks of the structure. This can happen as long as the project the project is clear and outsourcing firms are able to comply with the proper specifications of the original project. As it can be seen in Appendixes D and F, construction follows a modular sequence resembling a Lego structure. With a sufficient stable project, entire modules can be outsourced to other shipyards with similar capabilities. In this case, the outsourcing is not happening because of the shipyard does not have the necessary assets or knowledge, but because it lacked efficiency in its internal organizational routines. They are “capacity spillovers”. Moreover, this type of choice of outsourcing requires other technological interfaces such as, specialized logistics to transport giant structures. All of these additional interfaces are transactions costs. At the several relations, there are some potential “sweet spots” that could be used to be created by swapping some make-or-by decisions. For example: capacity lacks can be solved by increasing efficiency in operations. Some Outsourced Industrial Services such as galvanization, would probably work best and causing less delays if this interface were sub-contracted or internalized with the necessary equipment and facilities installed within the yard. However, this would probably also be justified if the piping construction also increased productivity and capacity.

At the same time certain internal coordination activities that may not necessarily happen *in loco*, such as the engineering *partnership development* could be fully outsourced under specialized services. Nonetheless, this is a choice on the types of capabilities to be developed over time. The intention of the partnership was engage in transfers of engineering know-how.

Based on general view of the technical sequence involved in the EPCC project (Figure 31), Figure 60 illustrates the set of industrial relations that were observed in October of 2015. The circles indicate the number of firms involved in each activity. The colors represent the different types of industrial relations chosen with each interface.

Figure 60. Bounded Capabilities, Technological Interfaces and Industrial Relations



Source: Developed by author

Several issues were observed as the capabilities of the shipyard and even suppliers are under the process of development. The complexity of the project requires a high level of coordination across interfaces, which, in turn, are dependent on internal and external factors that can be enablers or constrainer to the dynamics of capability building process. These factors are very costly. The next section explores some of the issues observed.

8.4. DYNAMICS of Bounded Capabilities and Technological Interfaces

This thesis has been arguing that the interplay of technology and economics are the key determinants of firms boundaries and interfaces giving the industry its shape and scope. Dynamics emerge from firms learn to deal with new problems and expand or redefine their boundary positions.

Throughout the project, these boundaries were changing as SHIPYARD A was gaining experience in shipbuilding. However, this process of gaining capabilities has not happened without costs. National companies selected to the shipbuilding projects, had little previous experience in the sector. To win the public bids to show proof of their EPCC capabilities based on their record in similar projects. However, similar is not ‘the same’. The capabilities of firms were related to complex civil construction projects such as infrastructure projects and industrial complexes. While they may share some similarities in terms of the amount of resources that are mobilized and the number of interfaces that have to be coordinated, shipbuilding has a completely different technological base.

The lack of knowledge in the specific industry resulted in the need for a larger number of technological interfaces with other firms. The higher the number of interfaces the harder it is to orchestrate the necessary capabilities and achieve the desired results. Moreover, the harder to orchestrate the organization of interfaces, the harder it becomes to obtain the gains from learning curves. In fact, these frictions play against learning.

8.4.1. Interfaces and Frictions

In order to reduce boundedness, companies were required to establish technological partnerships with highly regarded international firms interested in transferring know-how and experience in shipbuilding and offshore construction. In this case SHIPYARD A was contracted to organize and orchestrate the construction of eight hulls for the FPSO oil rigs. SHIPYARD A established a technological partnership with a shipyard in China to help with the engineering detailing of the project. The other part of the engineering detailing, 3D modeling and shop drawings would stay initially in the companies' headquarters in Rio de Janeiro while construction would take place in Rio Grande.

A high investment in facilities, automated welding technologies, infrastructure, dry-dock and in two porches (600 tons and 2000 tons of lifting capacity) puts this shipyard (specialists say) with the state of the art shipyard technologies to achieve 8000 tons of steel processing capacity per month. However, at the moment of the research was done, SHIPYARD A had achieved 3.600 tons/month. The gap between the estimate capacity and what was really happening is the result of lacking capabilities. While the necessary assets to produce have been constructed, the ability to operate them involves a high level of knowledge and skills, as well as organizational capabilities. The boundedness of capabilities will necessarily require technological interfaces with other firms.

While the firm had little previously experience in shipbuilding, it had a very good experience in dealing with complex construction projects especially in resource allocation such as mobilizing large labor forces around the country, selecting and managing supply from national and international suppliers. This led to the initial planning of the shipbuilding construction project to be mainly coordinated using of contracts. As one of the Chief of the Construction Division said.

> *"Initially, the shipyard was conceived to be organized using mainly sub-contracts in every process. The company even hired another firm to build the ship's structure, however, as time went by, the co-created company was not able to meet the terms with the planned schedule"(Chief of Construction).*

SHIPYARD A canceled this contract and vertically integrated the construction process of the Structure. Nonetheless, balancing the organization of the industry, using a "brand new" project involves at least two types of learning costs: the learning of shipbuilding production technologies on the one hand, and the learning a brand new project that was being done for the first time. He said:

> *"it is different when you are producing something that has already been made, the project is stable, any corrections have already been made and approved and production can just follow the instructions" (Chief of Construction).*

This was different than other cases where the choice for technologies at the start of the industry was simpler ones (eg. USA standard liberty ships). As the first project of this sort in Brazil, the cost of learning had already been predicted and planned. It was estimated that the cost of the first Hull would be higher than the later ones due to the necessary time to obtain gains in the learning curve. However, accordingly, these costs were higher than expected.

When interviewees were asked about what prevents the project to finely achieve its full capacity internal and external reasons are mentioned. Figure 61 summarizes some of the issues.

Figure 61. What prevents the mastering of technological interfaces

Sources of frictions	Reason	Internal response	Results
External interference of the PETROBRAS in the process	Need to comply with regulations and specifications	Extra task force efforts to guarantee compliance	Higher Costs and re-work
Pressure from the PETROBRAS for time schedules and deadlines	Need to capitalized over oil production	Speeds up, starts process with incomplete projects	Eventual mismatching of parts, rework and need to update original project
Insufficient engineering teams with the right tools and skills.	Re-building of engineering team in the shipyard.	Use of different systems to produce drawings	Slow project updates and risk of mismatching project and construction.
Lack of key suppliers nearby	Difficulty in obtaining all required environmental licenses. High bureaucracy.	Outsource	Delays and higher costs
Lack of an industrial ecosystem of key materials and suppliers	Lack accessible logistics, infrastructure, economic incentives, regional disputes for resources.	Need to plan in advance, organized cash flows and make inventory	Higher costs, risk of material waste, delays, and quality
Project specs not fully defined by the PETROBRAS	Oil Field characteristics still being studied	Find standard parts to be produce, and adapts later. Continuous meetings with the PETROBRAS	“Alive project” subjected to frequent changes, re-work, higher costs
Low labor productivity	Underdeveloped skills and managerial disorientation	Frequented meetings, training and supervision	Delays and re-work

Source: Developed by author

The internal dynamics of the orchestration of various interfaces and the need to acquire technological and organizational capabilities have been preventing the shipyard to achieve its fool production capacity.

The reason why is, in the case of SHIPYARD A, from the beginning of the construction project and on, it has been not able fully stabilize the system. For one reason, the project is complex from the start and it necessarily happened “too big, too fast” lacking the necessary organizational and learning rapidity. As it has been shown in Figure 28 in section 8.1, the overall concept of the project, modules and distribution of activities where planned to provide the necessary standards to allow the construction process to have the appropriate flow. However, as the industry as a whole is ‘learning’, the lack of operational and organizational capabilities have been increasing the overall cost of the project.

From the beginning, the whole project has been subjected to several frictions that caused delays and higher costs. All of these frictions turn the process of acquiring capabilities master the needed technological interfaces and to orchestrate them harder.

As previously mentioned, at first the company thought it would be in a better position by outsourcing and subcontracting almost everything, but frictions with the sub-contracted firm appeared. These frictions led the firm to incorporate and vertically integrate some technological interfaces in order to have better control of schedules and output. The structure construction and internal logistics are two examples where this has happened. However, vertical integration is reliant on technical and organizational capabilities. Only by finding the right balance of capabilities, it is possible to incorporate different technological interfaces.

Nonetheless, frictions still appear on the supply side as some key operations are still not possible, such as some piping treatments which require more investment in facilities. As a result, the shipyard outsources this operation. As this part of the operation has no physical interdependence, only process interdependence, it can be fully outsourced. The downturn to this is only timing and delays caused by long distance travels.

Frictions also appear on the demand side as the client's pressure to speed up the process and its continuous interference either as another inspector or by requesting project changes due to changes in requirements not necessarily ease the process of creating capabilities and stabilizing the system.

In the words of the construction coordinator, the project is 'alive'. Changes in the project account for a big portion of the problem. However, internal logistics and organization also contribute to delays and rework.

The inability to meet the demands and schedules forced the company to look for further technological transfer, 30% of the company and the overall control of the construction process was handed over to Mitsubishi Heavy Industries in order to initiate a process of technological transfer.

8.4.2. Boundedness and Learning

The dynamics of organization follow the existential need of the firm to remain active in face of natural selection. Vertical integration of technological interfaces, even if not the most efficient way to organize this specific industry, came as a solution to deal with the impossibility of stabilizing the system. However, this lack of well-defined interfaces, had created a vicious and costly cycle from which the company is struggling to resolve.

Nonetheless, after vertically integrating and adding the international know-how on operations management and engineering that were brought by the Japanese, organizational knowledge started to be incorporated, routines started to be settled and the capability boundaries of the firm expanded. The learning curve and labor productivity was increasing. At the same time, the PETROBRAS seem to also understand that it had some responsibility due to some project decisions made in the past that resulted in re-work and delays. However this didn't alleviate the need to cancel one of the orders from the SHIPYARD A and send it to be constructed in China in order to remain on schedule.

After one year, the shipyard has reduce its workforce in about 40%, it vertically integrated some of the interfaces. The change in the total labor structure and the increase of knowledge transfer with the international partner begin to stabilize interfaces from engineering to production. Figure 62 shows the basic differences. While in October of 2014 the number of employees was 11.413, in the same month in 2015 it was employing 6.973 (a reduction of 38,9%).

Productivity, suffered a little reduction due to financial problems. Productivity decrease from 3.600 tons of processed steel per month in October of 2014 to 3.014 tons per month in October 2015. This represented a reduction of 25,6%. However, the average productivity per labor increased by 37% which shows an increase in the learning curve.

In July of 2014 was reported a peak in production of 4.800 tons. The company had around 7.173 which represented 0,67 tonnage per worker. This had been an improvement in productivity per labor from October 2014 to July 2015 of 112,1%.

Figure 62. Variation in productivity after one year of technological transfer

Indicator	October 2014	October 2015	Variation
Total Number of Employees	11.413	6.973	-38,9%
Direct Labor	7.516	4.727	-37,1%
Indirect Labor	3.897	2.246	-42,4%
Number of Total Sub-Contracted Firms	92	57	-36,0%
New Sub-Contracted Firms		16	
Number of Sub-contracted workers	3.743	980	-73,8%
Production in Steel Process Tonnage Month	3600	3014	-25,6%
Average productivity per employee (tonnage per worker)	0,32	0,43	37,0%

Source: Based on data provided by Shipyard A relative to October of 2015.

Another contrasting factor from one year to the other is related to the number of subcontracted firms and labor. In October of 2014 there were 92 firms that accounted for 3.743 workers. The overall number of subcontracted firms was reduced by 36% to 57. 16 were firms, so the total reduction of previous firms were 41. Due to financial difficulties, the company reduced its capacity in the later months.

The firms is slowly improving as the technological transfer with the Japanese firm intensifies. SHIPYARD A originated in the civil construction industry. Its owners had mostly a business and negotiation background and their experience was on the mobilization of large amounts of resources in different infrastructure construction projects. In this sense, the firm did not entirely master the technological base of shipbuilding. Moreover, this technological base is not easily absorbable as the, apparent simple task of welding has its own specificities even for the workers that do not have the experience. This issues tend to improve also as stability is achieved in the process and workers can perfect their dexterity. However, this also requires that managers and engineers get their own tasks right.

9. Discussion: Industrial Organization Dynamics

This thesis is an assessment on industrial organization dynamics. It parts from one simple premise largely discussed and agreed in the literature, which affirms that: economic development and prosperity results from the dynamics of economic activity and innovation (Fagerberg and Srholec, 2009). Behind this dynamic are the activities of economic agents with different set of knowledge, skills and capabilities engaging in economic exchange becoming industries and markets.

Industrial organization, as the field that should provide an understanding on “how economic activity is undertaken and distributed across different firms” (Coase, 1972) is incomplete unless we look deeper into the boundaries of capabilities and the technological interfaces that form the thread of any economic system. The way economic agents deal with their boundedness in capabilities will determine their dynamic potential.

This process depends on the levels of knowledge available within specific economic settings, which will determine the *shape* and *scope* of different industrial arrangements. The unit of analysis of this process, is neither the firm nor the transaction, but the technological interface that connect bounded capabilities of different economic agents. The nature of industrial organization is based on economic relations of technological complementarities. The level of knowledge available and mastered by different firms and the interconnections established between them will determine the possibilities for new dynamics, innovation, value creation and development.

So, what lessons can be learned from the Brazilian Shipbuilding Industry renascence?

9.1. Institutions in the Short and Long-Run

Firms and markets rely on each other to exist. Any attempt to understand the organization of the industry and its dynamics must consider how both firms’ capabilities and markets intertwined. There are basically two ways to foster capabilities and create markets simultaneously. The first is the result of the very activities of firms through innovation. The extent to which some firms will actually be able to innovate technologically is highly path dependent and requires capacity to pull the necessary investment.

However, technological innovation in established industries is less likely to be expected in latecomer firms or economies. These economies have to combine their own set of capabilities to develop other market opportunities, or rely on the creation of favorable institutions.

Governmental institutions play a central a role in creating the conditions to economic activity to take place (Coase, 1992). Institution set-up can foster innovation, technological change and the underlying production systems within an economic structure (Edquist, 1997). The challenge, however, is to find the right match of institutions with the actual capacity of economic agents to absorb technologies to meet expectations.

By defining specific institutional settings such as market reserves using local content policies, tax cuts, trade barriers and special funding, governmental policy making is able to create conditions for a potential market to emerge. By doing so, it can consequently also create the necessary stimuli to economic agents to climb their way up and build the necessary capabilities to fulfill the market gap.

Market reserves created first, a situation of temporary ‘market failure’ to stimulate the industry to develop capabilities and find solutions to fulfill them. By creating market reserves through local content requirement and tax reduction for suppliers, government creates a condition where it guarantees that there will be transactions for those that claim to be capable of delivering the desired outcome. While companies can win the public bids, the question that remains is whereas industries will eventually sustain similar transactions in the future with external markets. This is only possible if companies acquire the right set of capabilities. When firms reach their capability boundaries, they must link-up with others through a technological interface.

Governmental institutions, therefore, can create an environment that guarantee beforehand, that transactions will happen which reduces the uncertainty and create incentives for investment. However, when building industry nearly ‘from scratch’ such as the shipbuilding industry in Brazil, the focus has to be on what capabilities and technological interfaces that should be established within national boundaries. If the focus is to be put on the transaction, than it is less risky and costly to follow TCE advice and contract everything out.

Nonetheless, there is a trade-off. By contracting solutions out (and in the case of Brazil it means, to import) it is hard to expect that capabilities will be ever built to generate economic development. At the same time, it is unlikely that any economic system could be made of a nation of consumers alone. Wealth must be generated by some kind of productive activity which reflects the state of available knowledge that can be produced and exchanged within an economic system. The question is on the choice of capabilities and technological interfaces to be internalized and on what are the most effective mechanisms to achieve this goal.

The problem is that planning this process requires an intense effort (Kim, 1998) and commitment of various interconnected firms. By generating an institutional market reserve, governments "play with" transaction costs dimensions by reducing the comparative costs of transactions allowing national economies to internalize certain technological interfaces. However, this is not enough. Even with all the incentives, the costs of producing ships in Brazil still exceed the costs of importing them from other shipbuilding nations.

This initial governmental institutions and industrial policy are short-run ways to create demand. In order to really take advantage of market entry incentives created by governmental institutions, latecomer economies have to figure out faster ways to develop capabilities at the lowest possible cost. The inability to master and orchestrate technological interfaces will undermine the possibility of conducting economic transactions in the future.

9.2. The Primacy of Technological Interfaces over Transactions in Defining Industrial SCOPE

Transactions costs economics famously poses that “in the beginning, there were markets” (Williamson, 1985, p.87), and firms are alternative ways of coordinating economic activities (Coase, 1937). The extent to which activities will be conducted inside the firm or outside, in the market, will depend on the comparative costs advantages of one over the other. However, in practice this may not be so straightforward. Internalizing a particular interface requires capabilities of mastering specific skills and technologies, and the ability to organize these capabilities into efficient routines. These are two efforts that may not be easily incorporated into the firm, but are essential for building competence and later development.

As previously argued, firms and markets are complementary constructs bounded by different levels of capabilities found in an economic setting. If the supply of capabilities is low in a particular setting and require high investments on assets, knowledge and routines that are already available in markets elsewhere, transaction costs rational would suggest decision-makers to buy rather than make once, the costs of organizing these activities internally would be prohibitive. Therefore, building capabilities would be only possible if there is some type of economic incentive to alter the relative costs of organizing this activities internally.

Taking this notion to the National level, these economic incentives can be provided by institutions. Tax cuts, local content policies and credit, for example, can reduce the estimated comparative costs and change the course of investment decision favoring the internalization of transactions (make) rather that contracting all solutions out in the market (buy). When we look at the Brazilian Shipbuilding case, this was the first initiative in order to promote the industry. There was a series of incentives to reduce the comparative costs through tax cuts and local content policies. The second initiative attempted to secure a market for the industry by using the State-Owned Oil Company as the main buyer of locally produced vessels. In other words, government intended to guarantee that the "in the beginning there were markets" so transactions could happen.

While the firm relies on the market for finding complementarities by means of transactions (downstream as purchase or hybrid modes of coordination and upstream in the form of sales) it can only be a part of the system buy developing specific capabilities around specific technologically separable interfaces. In this sense, whereas the link can be in the form of an economic transaction, the concrete side of the transaction is what was defined as a *technological interface* between *bounded capable* agents.

The focus on the technological interface rather than the transaction has some important implications. If a market can be institutionally created "overnight", the same cannot be said about capabilities. In fact, by using a transaction costs rational to decision-making on the interfaces to be carried in Brazilian firms, would lead us to the conclusion that (given the current set of firms in the market) Petrobras would be better off by outsourcing the construction of this ships elsewhere. Nonetheless, these capabilities would never be developed in Brazil. The "window of opportunity" brought about by the discoveries of the Pre-Salt oil reserves, coupled with the availability of a "national deep water technology", created the possibility of choosing to develop national capabilities in this sector. However, successfully implementing this strategy will require a closer focus on the technological content and requirements that gives the shape to the industry, and gradually plan national scope based on the capabilities found within national firms.

Institutions created a potential market and national firms with support agencies should figure out how to catch-up on capabilities and select the sequential logic of technological interfaces that can be technically and economically done within the country. The long term sustainable development of an industry is dependent on capabilities. As a matter of fact, it would be much easier to create markets based on capabilities, than the contrary. Capabilities create their own demand.

When we look at shipbuilding, market reserves work when there is a sufficient level of capabilities present or, at least, readily available. In fact, markets function much more as "mechanisms for selection" of the best capabilities of firms in the industry (Nelson and Winter, 1982), not as mechanisms for enabling catch-up.

The Brazilian case in shipbuilding shows that institutions created a national internal market, and an ambitious industrialization plan with the announcement of several virtual-shipyards. Out of these, only a few really started to operate. The Brazilian case share some similarities, but also some differences when compared to the international cases analyzed in chapter 6 as far as the approach to markets and industries.

Japan built upon previous historical shipbuilding capabilities to address national and international markets. South Korean nationalized shipyards that had been operating in the country and also directed its supply to exports. The US put together a shipbuilding industry to address national market during war times, but it had previous industrial base technology and the industry was dismantled afterwards. China maintained a shipbuilding industry for years, but had only become competitive after entering international markets in the 2000. Nonetheless, all of these cases presented previous levels of capabilities.

Brazil shares (to some extent) certain conditions. Brazil had reached the second place in global production in shipbuilding during the 60's, but the industry virtually disappeared in the 90's. Nonetheless, although Brazilian capabilities in shipbuilding may be more bounded when compared to the international players, they do exist. The question is how fast they can develop in order to really compete in the external market and what are the possible strategies to do so?

9.3. Determinants of Capability Boundaries of the Firm

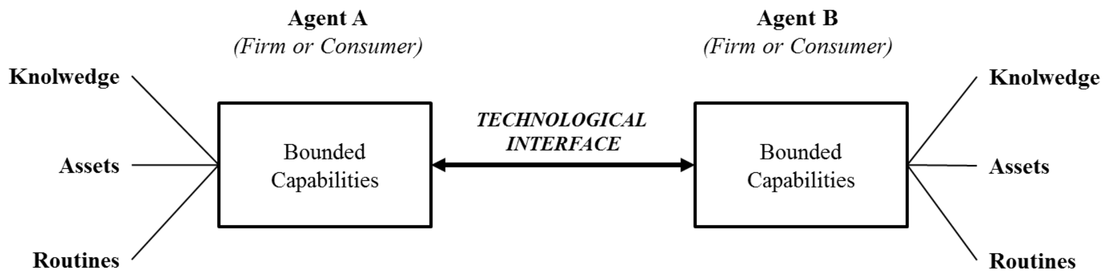
Capability boundaries of the firm require technological interfaces that can result in economic transactions of different sorts. In order to understand the dynamic potential of an economic system, it is necessary to analyze what determines these boundaries. The case of the re-emerging shipbuilding industry in Brazil illustrates some of these determinants.

Capabilities are the sum of a collection of routines (Dosi, Nelson and Winter, 2000, Alves, 2012). Routines, in turn, are reliant on knowledge and assets. In this sense, to be capable of doing something requires the information about what has to be done, the necessary assets (technologies, equipment and tools) and the know-how and skills to operate efficiently. Capability Boundaries are, therefore, determined by three elements *1) Knowledge and Skills, 2) Assets,* and *3) Routines.*

Knowledge and Skills, refers to the sum of individual repertoire of information, awareness, experiences and capacity to perform different tasks using tools to produce a certain desired outcome. *Assets* refer to the technical apparatus, technologies and tools available such as equipment, tools, land and IT systems. *Routines* referred to the skills and the orchestration of applied knowledge to achieve the desired results efficiently. It encompasses the ability to find the efficient relation between internal resources and output.

Capabilities, therefore are bounded when any of this elements is missing, which affects directly the firms' operational performance. Missing element may create sources of frictions that destabilize the system and generates transaction costs. At the same time, accesses to these three elements are also the pre-requisites of capabilities. Firms are defined, therefore, as clusters of knowledge, assets and routines that build their capabilities.

Figure 63. Knowledge, Assets and Routines



In this sense, building up capabilities to fulfill the market gap requires that economic agents figure out ways to cluster specific individuals and assets, knowledge and how to orchestrate them into efficient routines.

In this sense, there seems to be three levels of difficulties in building capabilities. First solving the choice on production *assets* (site, technology, equipment and tools). Assets are the easiest of the elements to obtain. It is only dependent upon the access to the sufficient amount of investment. However, operating different assets, require information about what has to be done and knowledge (often tacit) on how to operate specific assets.

Another aspect to assets is that they do not necessarily have to be owned by the main firm. The shipyard only needs to have the access to their services. For instance, heavy logistics and heavy lifting equipment and labor were sub-contracted. These can be seen as what Teece (1986) calls complementary assets. In the case analyzed, these types of equipment are general-purpose technologies that have a more efficient use by being allocated leased by other firms. However, the internal coordination of their activities within the shipyard was done by the shipyards internal management.

Another case of sub-contract is the internal painting. In this case, the full operation including facilities and equipment was done by a French firm located inside the shipyard. Painting is a requirement for other processes to move forward, however it requires investment in specific assets such as cabins and hydroblasting and water treatment technologies that are outside of the realm of the core capabilities of the shipyard. However painting is dependent on the process and timing of other stages of production which often causes delays.

Assets, nonetheless, do not seem to be the problem. According to specialists, the facilities present in the shipyard belong to the state of the art in technologies. However capability boundaries need, besides assets, knowledge and skills applied to the right routines.

Knowledge and Skill are the second level of difficulty and requires training and experience. The shipyard in analysis has made an enormous investment into the necessary assets, nonetheless, it was still facing the challenge to overcome some knowledge barriers of certain steps of operations and the use of internal tools available from project to production.

On the operational level, knowledge and skill of labor was improving slowly. For example, the majority of the labor force in shipbuilding is used in activities of welding and abrading. Although welding may seem a simple task, the type of weld used in shipbuilding is very different from regular home plumbing and electric tasks. Even though there is a part of this process that is automated, especially in the construction of panels, block construction is very much done manually. This type of welding is very much dependent on the dexterity of labor. Productivity in welding, for example, is measured in the number of weld wire spools that are burned per day. While Chinese were known to burn 6 rolls per day, the Brazilian labor force was burning on average around 1 or 2 spools of weld.

Knowledge and skills on the use of tools is also an issue at the engineer detailing and shopdrawing. The mastering of knowledge and tools for project design and 3D modeling were still not fully diffused across engineering detailing and the shop drawings which resulted in the use of complementary tools to address the production demands. CAD/CAM technologies were complemented with AutoCad for shop drawings. Although this process could speed up the lead time of final drawings to arrive at production, it also slowed down the process of integrating engineering to production effectively, and increased the risk of operational errors and re-work.

Finally, putting in place a complex operation and fully mastering different technological interfaces depend on the efficient orchestration of several interconnected routines. The boundedness in knowledge and skills in different levels from engineering to production interfaces can only be balanced out by organizational capabilities in the orchestration of routines. Setting up routines requires managerial capabilities and leadership.

The lack of the necessary skill has created internal frictions, which result in some inability to stabilize internal routines to operate in the most efficient manner. The more frictions are created, the more managerial effort is required to correct directions and this comes with a high cost. The more 'alive' (as one of the interviewees had put) the project is, the more frictions it creates which puts the firm's existence is at risk. The more stable the routines are, the less supervision is needed and management can focus on improvements and innovation. Balancing out assets, knowledge and routines is a necessary step to the evolution of capabilities. Discipline is a prerequisite to learning and innovation.

9.4. Stability and Dynamics at Technological Interfaces Mastering

The case demonstrated that firms belonging to the industrial arrangement must find mechanisms to deal with frequent frictions that arise from the boundedness of capabilities. Constant frictions generate transactions costs and undermine the potential future of the project and the industry. Firms must find mechanisms for stabilizing the project. In fact, it was seen that, stability eases the process of competence building. Only by stabilizing interfaces it is possible to further build and improve capabilities.

By keeping projects simple and standardized, the American shipbuilding industry in the 1940s was able to achieve scale and produce an average rate of almost 2 ships per day. However, the Brazilian case has two complicating factors. First, the industry can be considered in its infant stages where capabilities are more bounded than it would be need. This requires a large number of interfaces which can be sources of frictions. Second, the projects are substantially more complex than the American case of the 40s. In this sense, reaching scale is also more challenging. The complexity (in terms of number of parts and in terms of "complicatedness") increase the costs of building capabilities.

The sector must find ways to achieve some level of stability. In the process of developing capabilities, commitment of all parties involved and simplicity is key. In order for transactions to flow smoothly, technological interfaces must be stable. Standardizing economizes on capabilities, and interfaces can be used to distribute the workout. The more complex the project and the higher the probability that technological interfaces will be necessary by means of transaction. If the firm lacks the ability of vertically integrating complex projects, interfaces must be well defined.

On building an industry from a mature sector, 'living projects' can 'kill' the industry. Projects must be 'dead', in the sense that standards must be well defined and change does not interfere on the process achieving efficiency. Stability speeds the process of capability building and reduces the cost of learning productive tasks. Even though the shipbuilding technology used in the Brazilian case is relatively mature worldwide, the process of building capabilities in this location resembles the development of new technologies with projects in in the state of flux and drawings constantly changing. When technologies are new and projects change, this often frustrates technological transfer (Teece, 1977). From the evidence collected, on the one hand, Petrobras frequently required changes, and on the other, the lack of engineering and managerial capabilities also makes the cost of building capabilities much higher than expected both in terms of investment and time in form of delays.

Only after stabilizing interfaces, it is possible to 'spread the work out' through effective modularization. Standards are a key feature to modularity (Baldwin & Clark, 1997; Baldwin, 2007). With effective modularization and specialization of capabilities, it is possible to create a healthy business ecosystem (Adner & Kapoor, 2010) to generate incremental changes and innovation at the interfaces.

In the case above, vertical integration happened due to the impossibility of bringing stability at technological interfaces. Various sources of friction appear which challenge the capability building process. The lack of enough stability at technological interfaces generates transaction costs. The consequence to that may lead to disinvestment.

This has important implications for the organization of the industry. Only by stabilizing interfaces a transaction can occur smoothly across economic agents and an industry can flourish. The lack of stability at technological interfaces in the case studied, had led to vertical integration and organizational costs. This change came alongside the knowledge on organization of production brought by the Japanese. Stability across interfaces was slowly being reached and the learning curve started to increase.

Therefore, the boundedness of capabilities should be matched with the right amount of complexity (technological and organizational) that they are able to handle. On the contrary, economic agents must be able to speed up learning in order to expand their boundaries to deal with more complexity. In the case studied, the expansion of firms boundaries came with the knowledge that started to be transferred by the Japanese.

The boundedness of capabilities comes with higher transaction costs. In order to surpass these challenges, and expand capability boundaries, it seems necessary to analyze closely not only the costs of production versus transaction, but actually, the costs of learning and building capabilities. These costs will actually determine the technical possibilities of building capabilities and the dynamics that can be generated afterwards.

9.5. From Transaction and Organization to Capability Building Costs

The problem of industrial organization has often been defined as an issue of finding the optimal allocation of activities considering transaction versus production and organization costs. Whenever the transaction costs are higher than the internal organization of a particular interface, the choice should be of vertically integrating that particular interface. However, when the gap between a particular technology and the relative capabilities found within an economic arrangement is also high, the dependence on transactions seems insurmountable unless some other measures are taken to reduce this gap.

Ideally, any “healthy” economic arrangement should be able to nurture the capabilities of firms and, at the same time, allow for markets to be created in order to sustain economic development. This process is not trivial as the nature and distribution of economic activity (its shape and scope) will be constrained by technological and economic conditions found, not only within a specific economic system, but also elsewhere worldwide. This understanding has important implications to national economies and policy-making once the definition of the scope and boundaries of firms within a specific national location competes with the scope and boundaries of firms found in other economies.

In fact, it seems import to mention that, managers from multinational firms have learned to identify these conditions and “fine-slice” their activities selecting the best optimal location for each stage becoming "global factories" (Buckley, 2009). In this sense, locational factors and institutions (formal and informal) play a significant role in this dynamic by creating conditions to attract and foster certain types of activities.

Institutions create incentives and restrictions that must be taken into account when economic agents decide whether to expand internal boundaries through capability development or to establish technological interfaces through a transaction with other economic agents. Moreover, while multinational corporations may be able to choose optimal places for its different stages of activities, capabilities don’t travel. They must be built somehow either by being created from scratch or through transfer of specific know-how. All of these processes, however, involve different costs.

Generating dynamics by changing the shape and scope of industries, involve reducing the boundedness of capabilities of firms through learning. This process always involves costs beyond the mere transaction or production costs. They are dynamic learning costs. Some of these costs have been defined by Teece (1977) as technological transfer costs (the costs of transmitting and absorbing the relevant firm specific knowledge).

Other costs are related to the constant change in scope of specific industrial arrangements. As capabilities are bounded and part of complex development and production chains, changing the distribution of economic activity, and consequently the scope of industrial organization may also involve supplier switching costs (Monteverde and Teece, 1982). Some other costs may be relative to institutions such as tariffs, bureaucracy, infrastructure that may create barriers to the development of capabilities.

Therefore, local institutions have an important role in reducing a part of the relative costs of building capabilities. In fact this costs may be in large, dynamic transaction costs related to “the costs of persuading, negotiating, coordinating and teaching suppliers” (Langlois, 1992). All these costs will influence industrial scope and the dynamics that can be generated.

The question of reducing the boundedness condition of firms and creating internal dynamics is dependent on the ability of certain economies to reduce the cost of building capabilities and at the same time build the respective market presence. However, it seems that, in a world of well established firms, the cost of building capabilities will almost always be higher than the respective transaction costs at the start.

9.6. Novelty and Inexperience Costs

The main source of capability building cost mitigation is learning. The faster firms are able to absorb specific technologies, the faster they are able to move their boundary position and gain specificity. By looking at the struggles faced by the case study, two sources of boundedness can be observed: novelty and inexperience. Novelty can be considered the “best kind”, because requires the development of new ways to solve new problems. Inexperience, however, may be the “worst” kind in a sense that the knowledge is already available and firms must learn it in order to catch-up.

The lack of experience results in the need for more overhead and supervision to get the job done. This can be explained with the following example. A Chinese welder can be 6 times more efficient than a Brazilian welder. The same Brazilian welding process would require 6 workers to get the same efficiency in terms of time. This causes the Brazilian process to be inherently more costly in terms of unit cost as well as in terms of risk increase of errors, re-work and bad process flows.

Both processes of reducing boundedness involve costs. While the first is the cost of innovation which can be transferred to the product, since no one (or very few) know; the second is the "cost of inexperience". This second type of costs generates, production costs (low productivity which may not necessarily be passed on to prices) and transaction costs (mostly procurement, for establishing unnecessary technological interfaces when compared to the standard industrial organization a particular type of sector).

The Brazilian case is combining both types of costs which makes the challenge of building capabilities even harder. Not only the engineering projects of that type of hull were novel, but also the organization of production to achieve scale were specially new to the SHIPYARD A, that came from a sector of a different technological base (Civil Engineering)..

To mitigate these costs of building capabilities, institutional incentives as local content policies and tax cuts are not enough once they do not have any direct influence the costs of inexperience, unless, there are institutions that clearly establish mechanisms of effective technological transfer.

It is reasonable to think that, the wider the knowledge gap between capability boundaries present within an economic setting and the minimum level of capabilities necessary to compete in the market, the higher the probability that the acquisition and absorption of knowledge will require more intense knowledge transfers to speed up learning.

It is important to mention that international technological transfer is an important mechanism. Teece (1977) explains that international technological transfer involves the cost of transmitting and absorbing all the relevant embodied knowledge, in other words, the cost of the various activities related to ensure a successful transfer of the necessary know-how. This strategy requires, on the one hand, that some firm with the specific technology is willing to transfer the know-how, and on the other, that national firms have the necessary technical and managerial skills to absorb the technology. The purchase of 30% of SHIPYARD A by Japanese firms was a recent fact and the technological transfer is slowly starting to happen focused on the re-definition of internal and external interfaces.

When knowledge lacks in complex sectors, the only possible alternative is to have partnerships. One of the reasons of this eternal movement in shape and scope are the boundedness of capabilities. Capabilities are bounded because of technical and economic reasons. The mastering of the technological base, and the ability to organizer routines efficiently. If the size of this limit cripples the activity, the only alternative would be to exist the business. However, if the investment in asset specificity is high to a point where it makes this exist even more costly, there is a need to seek knowledge as fast as possible. The easiest way to complement knowledge gaps is through knowledge acquisition by third party, such as partnerships, joint-ventures, mergers and acquisitions.

While institutions allow the formation of market to carry transactions, economic agents must be sufficiently astute in successful acquiring and absorbing knowledge that will sustain and create the basis for industrial dynamics.

9.7. Summary of the Main Findings

When we look at the world examples on the shipbuilding industry it becomes clear that, the sector relies heavily on governmental policies. Institutions are not the single unit of analysis of this study, but they any economic arrangement is embedded in institutions. Moreover, they affect the development of capabilities and technological interfaces. The key role of institutions in the world cases, and also in Brazil, is to serve as a magnet for investment in a specific sector. Institutions, however, do so by lowering the comparative transactions costs in the national levels, helping the productive output of the sector reach competitive prices. The challenge, however, is how to set institutions to attract direct investment into sectors in a way that does not leads to a “race to the bottom” based solely on cost reduction (Kaplinsky, 2015).

Industrial policies are short-run, or run as long as the market sustains it, in order words, as long as there are firms with acceptable capabilities and a purchaser accepting to for the output of this capabilities. Industrial policies require constant monitoring and management once, after all, countries compete in institutions to attract investment. However, the success of this governmental policies, relies on the responsiveness of national markets for capabilities and resources.

The lower the level of capabilities, the higher the number of technological interfaces that will have to be stablished and the higher the coordination costs involved. Not only it becomes costly to orchestrate several external bounded capabilities, but they also influence the rate of learning. Because of constant frictions created of not having the right capabilities at the time a price the firm needs, errors, re-work and internal stress lead to constant make or buy decisions that create instability and negative learning curves. In such scenario, the choice of buying will always prevail.

Reducing boundedness and strengthening capabilities requires stability of interfaces of some sort. While learning is never stable, routines require repetition to build up skill and dexterity, especially when dealing with a mature technological base such as shipbuilding. There are two types of boundedness or “ignorance” in capabilities. One related to novelty as the knowledge frontier to deal with a particular problem has not yet been revealed. And the other, related to inexperience of dealing with problems that are dominated elsewhere. The

Brazilian shipbuilding case combined the two. Not only that specific type of project were never produced in series, but the technological base of shipbuilding was also new to the firm.

This requires even more planning before execution. When capabilities are not present, the catching-up process may involve the choice simpler, but dominated technologies rather than the state of the art ones to create momentum and speed up learning. The newness of projects may bring much higher costs and prove to be impossible to reach to that particular firm. The Brazilian case showed that it was hard to bring stability to project due to bounded capabilities from engineering to production. The choices over the interfaces to be established is fundamental to bring stability and breed competence. Bringing stability to reduce boundedness in capabilities requires experience. This gap started to be bridged by the inflow of external know-how into the firm.

The choice of firms, will influence the types and number of technological interfaces that will have to be established. All of which will also involve higher costs to build capabilities. It is important to recognized that, the shipbuilding sector in Brazil re-emerge from the technological opportunity brought about the discoveries of Oil in ultra-deep waters called the Pre-Salt. The technology to explore and produce oil in such types of fields is dominated by Petrobras. Shipbuilding is not a core activity of this process and it lies outside the capabilities of Petrobras. However, the political discourse around shipbuilding and the motivating factor (see chapter 7) for policy making, primarily, the opportunities for job creation that this sector could bring as it involves a large contingent of workers.

The choice over firms and technological interfaces are that may be questioned. Since shipbuilding has a different technological base of the main national construction firms that were selected to participate in the process, the only way to speedup learning is to engage in an intense process of technological transfer, which also involves costs (Teece, 1977) and dynamic transaction costs (Lanlgois, 1992) of negotiating and teaching suppliers.

At the limit, the fastest and possibility less costly way to build capabilities within national borders could have been to create the conditions and attract foreign companies to produce in Brazil. Nonetheless, this requires a relative safe environment for business with clear institutions and rules of the game. It is seems the Brazilian institutional setting may still be a black box for foreign direct investment. It also requires a more open view by politic-makers to the role of foreign firms in diffusing productive capabilities and slowly increase the use of local content from national suppliers as well as, develop partnerships with national universities for knowledge exchange.

Finally, it is important to note that, capabilities boundaries were dependent on knowledge, assets and routines. In this industry, assets are highly specific and are usually sunk costs. This investment has already been made and it highly costly to move it from there. Some, are even immobile (e.g. dry-dock). In this sense, what may lack (at the moment) are other capability ingredients: knowledge and routines to effectively use those assets. Although capabilities don't travel and they must be built, knowledge may be more mobile and less costly than the complex assets. In this sense, if policies do not completely scare away investment, the industry may likely continue.

10. Final remarks and Future Research Opportunities

The question of "what drives economic development" is one of the oldest inquires in economic theory attracting the attention not only of scholars but also of policy makers trying to tackle the various challenges for sustaining growth and wealth in national economies. Economic development is a direct result of the internal dynamics found within an economic system composed of multiple bounded capable agents (firms and markets) that connect through different technological interfaces. From the way these various economic agents are able to deal with their capability boundedness, arises the essence of how industries will be organized and the type of innovation that can be nurtured.

In this sense, identifying the specific features that define the boundedness condition of different firms within and across industries is key when looking for a comprehensive theory on industrial organization dynamics. There are, however, four important consideration regarding 1) the field of research, 2) the unit of analysis, 3) the object of study and 4) the methodological approach to it.

First, it seems necessary to re-conceptualize what is commonly understood as industrial organization. Advancing over an earlier suggestion by Coase (1973), industrial organization should describe the way in which economic activity both created and undertaken by different firms. The fact that technology can be partitioned, creates the possibility of specialization and distribution across many actors. As a moving puzzle, industrial organization evolves through the continuous interplay of technology and economics in a process of configuring and reconfiguring technological linkages across multiple bounded capable agents. Any industrial organization form is based on an economic relation of technological complementarity.

Second, to analyze industrial organization dynamics, it is key to define what the unit of analysis is. Since the *sine qua non* condition of any industrial arrangement is the existence of at least two economic agents, the essence of industrial organization should be found at their techno-economic boundaries, in other words, not only at the transactions level, but also at what is referred to as technological interfaces. The complexity of any industry can be observed as the sum of these techno-economic linkages.

Third, by defining industrial organization as the sum of various technological interfaces, it is possible to understand the basic mechanisms behind the structuring of different types of economic arrangements such as, productive and supply chains, clusters, business ecosystems, productive networks, and so on. These concepts share the same nature:

how bounded capable economic agents create and organize technological know-how in a way that makes economic sense to produce results.

Forth, to approach the essence of industrial organization dynamics, the method of research should allow a deep dive into the subject matter in order to account for the facts about how various individual firms influence industrial shape and scope. Case studies were the primary choice as they allow the use of multiple sources of information.

By setting these conceptual ground basis, technological interfaces create a framework of analysis on how the organization of the industry takes place, evolves and perish. What is sought with such approach is a deep understanding on the factors that determines shape, scope and dynamics of industrial organization, and provide some practical tools for business decision as well as policy makers to better plan, select and choose strategic priorities in building specific capabilities.

The following sub-sections present some theoretical, methodological, practical and policy implications of this research.

10.1. Theoretical Implications - Industrial Organization Dynamics

In the beginning of this study, it was argued that, neoclassical mainstream industrial organization is limited in providing a clear view of how industries emerge and organized. However, it is not the goal of mainstream economics to provide these answers. Transaction costs and evolutionary economics provide complementary views to give light to this process.

To answer the question of economic development it is necessary to take a deeper look into mechanisms behind the emergence and structuring of industries, in other words, it is necessary to understand what determines the dynamics that gives industrial organization its shape and scope.

This is better explained as an evolutionary process. Evolutionary theory of technical change explains the increments of knowledge that constantly modify internal routines. However, the modification of firms boundaries depends on the capabilities of carrying different clusters of routines internally efficiently. The collection of knowledge, assets and routines make up for the firms bounded capabilities. While assets can be bought, the knowledge to operate these assets require experience. Experience, nonetheless, presumes previous knowledge and skills on doing something. When the referenced knowledge and experience are already available in the market, the relative costs of buying the outcome of these capabilities rather than internalizing them is initially more advantageous. However, besides the comparative costs of organizing production internally, there are the costs of building capabilities which may involve the costs of developing, transferring, acquiring and absorbing the necessary assets and knowledge to establish the necessary routines.

The path for building capabilities involve gaining experience and catching-up on capabilities that are already available in the market, stability, rather than dynamics, eases the path for learning. However, when the necessary capabilities are not available because the challenges to problem solving involve novelty solutions, a different type of learning is necessary. While the first can change, the scope of industry by simply moving where economic activities will be undertaken by which firms, the second can expands or at least modify industrial shape and scope through new standards and modularization.

10.2. Methodological Contributions

The organization of the industry is a continuous movement of shape and scope. That is the change in the technical sequence of industrial activities and how this sequence is distributed across different firms. This movement is impossible to capture in a snapshot.

To understand the determinants of shape and scope of industrial organization and its underlying dynamics it is necessary to describe the technological sequence of activities (technological interfaces) and how they are distributed across firms and markets. To do so, the analysis the boundaries of capabilities and the set of technological interfaces that form the thread of industrial organization allows a further understanding on the technological content behind economic transactions, the gaps and frictions that impede development.

The re-emerging shipbuilding industry was chosen for its complexity set of technologies and industrial relations which have been changing rapidly in Brazil. Moreover, this type of sector has sine distinctive features. These are Complex Product Systems that form a temporary coalition of organizations which cuts across the boundaries of single supplier or firms and it involves various capabilities in order to combine different physical components into a larger functioning system Hobday (1998).

However, different industrial arrangements can be subjected to the same type of analysis. The important issues to be considered in two levels: technology and economics. The first relates to a) the technological the nature of the knowledge involved across different interfaces (fields and complicatedness); b) the characteristics that make possible technological linkages with different interfaces. The second, economics, influence the choices of interfaces to be undertaken by different firms depending on their capabilities. In this sense, a deeper analysis on the Scope firms given their levels of assets, knowledge and routines to handle different technological interfaces.

A close description of these technological and economic boundaries and interfaces allow for a close examination on the requirements and challenges over the choice of economic activities that can be undertaken by and developed within economic arrangements.

10.3. Managerial Implications

Orchestrating complex projects with multiple interfaces require efficient organizational interfaces. The current struggles shown in the case study, highly related to production and organizational issues. If capability building costs are high and time consuming, they can become even higher if industrial actors do not know how to organize routines and interfaces soundly. As Penrose (1959) had once put, the role of management is to continuously reach for the expanding knowledge boundaries of the firm.

This involves identifying, mastering and coordinating a set of capabilities and technological interfaces. To reach for these expanding boundaries of firms, management must develop ways to overcome inexperience costs through improving skills and routines, and move its capabilities to start dealing with innovation costs. These costs eventually lead to the redefinition of technological interfaces, extraordinary profits.

Mapping technological interfaces lead to the identification of the capabilities gaps and potential new linkages that may change the shape and scope of industrial organization generating economic develop and new dynamics. The choice over capabilities require the mastering of the technological base, as well as, the organization of this technological base. While dealing with mature sectors, learning requires clear projects stability at technological interfaces to improve routines, innovation requires the new combinations of technological interfaces and capabilities to deal with novel challenges and value propositions. The type of capabilities that are sought, require different approaches to managing technological interfaces.

10.4. Policy Implications

Governmental policies directly impact in the economic activity will be organized and the type of activities that may or may not take place in particular regions. Support institutions are on the background of most industrial arrangements. “Getting these institutions right” may favor the successful development of the arrangement specially by creating the conditions for the industry to flourish and achieve economic performance. (Freeman, 1987; Edquist, 1997;

Kim and Nelson, 2000). According to Lundvall and Maskell (2003), one of the key aspects of setting up institutions is the influence that it has on the economic structure of what is done and what will be learnt.

While the focus of this research was not institutions, they played a crucial role in making the industry possible. If economic development of a particular country presumes a certain industrial dynamics of different sectors, when this dynamic is not generated spontaneously by the very activity of firms, it can be induced through institutions. However, only limitedly so. While institutions allow the formation of market to carry transactions, economic agents must be sufficiently astute in successful acquiring and absorbing knowledge that will sustain and create the basis for industrial dynamics. In this sense, it is necessary to understand the various aspects of market needs and capabilities available to fulfill those needs and the technological interfaces that have to be established.

When choosing a particular industrial sector, there will be capability building costs involved that will be higher or lower depending on the current levels of capabilities already present within the economic system. It is key to identify these levels and plan a path for building capabilities by choosing a coherent set of technological interfaces possible and the way forward.

However, it seems key to understand the different levels of incentives and the kinds of capabilities to be developed. Capabilities are always bounded by technical and economic reasons. When the knowledge to solve problems is available and the nature of "boundeness" is inexperience, there must be incentives for reducing the knowledge gaps through transfer of know-how that will reduce costs of learning and bring efficiency to operations. This type of learning intends to reduce variability and bring stability to routines. When the nature of boundedness is the bounded knowledge on how to solve a novel problems, incentives and investment in R&D are the requirement. Policy makers should be able to recognize the nature of these two type of projects to prevent misleading and misguided policies.

10.5. Note on Political Will and Corruption

Organizing an industry almost from scratch is not something that can be done overnight. It is import to state clearly that any endeavor such as this would be hard to attempt (if not impossible) if there were no public backing through institutional incentives and market reserves. In order words, this type of industry is unlikely to emerge spontaneously from the interest of national firms. In this sense, public backing is an effort to provide companies with incentives and some timing to catch up on the necessary capabilities. In a 'government free' competitive environment, this would be relatively inconceivable or (to say the least) highly risky for national firms that have little experience in the sector.

However, it is also important to say that in every single successful story in this type of heavy construction industry, government intervention was always present and national firms always involved as the main actors. The success, however, depends on long term plan and investment matching of national strategy with well-defined path to building industrial capabilities and the choice of how to organize technological interfaces. Moreover, to achieve such goals, long-term commitment of politics and industrialist has to be made. This require a relative stable political environment which is hard to achieve.

It is necessary to mentioned that, as a strategy that involves political will, it is also subjected to corruption. This is an issue in the Brazilian Shipbuilding Industry. As this research was in course, lawsuits and investigations started to take place in Brazil with respect to bribery and political influence in contracts involving the main client and politicians. Political opportunism necessarily produce transaction and social costs. As commissions are paid based on the number of contracts, incentives are created to generate more contractual interfaces. The more interfaces are created the harder it may become to orchestrate the necessary production activities. This creates instability and interfere in the learning process.

Unfortunately, without the correct strategy and with the excess of political interest and corrupt intermission in the process of creating industrial dynamics, the Brazilian Shipbuilding Industry can become gridlock in its capacity to build capabilities and become competitive. Corruption is one of the main contributing factors to frictions which leads to higher costs impeding capability building.

10.6. Future Research Opportunities

This thesis was an assessment on industrial organization dynamics and the factors the influence its shape and scope. By industrial organization it is meant the way economic activity is create and distributed across various economic agents (firms and markets). The chosen unit of analysis the technological interface that connects bounded capable economic agents. This is a quite broad definition that could be applied to any type of economic activity. In this thesis, the Shipbuilding Industry in Brazil was the chose one. However, there are several possibilities for further research.

1) While the shipbuilding and offshore industry was used as the object of analysis, this type of analysis can further help understand the dynamics of different chains of

economic activity. Economic activities have been classified as belonging to agriculture, industry and services (Kuznetz, 1971), or further refined into industrial standard classifications. However, the current diffusion of knowledge and the different economic settings of nations had deepened the possibilities of dividing labor/capabilities. In fact, different firms compete on capabilities and not necessarily on specific industries. So the further descriptions of different types of possible techno-economic relations seems an issue to be researched.

2) This thesis did not use nor discussed the concepts of *networks* (Granovetter, 1985, 1995), *clusters* (Porter, 1998); *global value chains* (Gereffi, Humphrey & Kaplinsky, 2001) or *business ecosystems* (Moore, 2006). The argument is that the underlying mechanism for the dynamics of any economic arrangement ('industrial organization' as previously defined) are the movements on the boundaries of capabilities and technological interfaces that complements them. Industrial organization is based on economic relations of technological complementarities. In this sense, further analysis on the technological interfaces that tie together different clusters, chains and ecosystems as well as how they evolve overtime seems to be an apparent next step.

3) Additionally, it seems clear that institutions play a relevant role in the dynamics of capability development. If firms compete on capabilities, nations and regions compete on institutions. The *systems of innovation* (Edquist, 1997) approach emphasizes the role of institutional set-up directing what will be pursued within in the system. The challenge is to bring coherence to the building blocks for development given the possibilities of economic agents. Goals have to meet what can be accomplished once there is a cost to build capabilities. It is unlikely that a country with very low tradition in a high-tech sector can enter the industry by institutional act without some favorable technological and economic pre-conditions. Understanding how institutions influence the building blocks of capabilities and interfaces is another challenging research agenda.

4) While institutions can create stimuli to economic activity, it is the role of economic agents (individual and firms) to choose and decided over the boundaries of capabilities and technological interfaces. As discussed in this thesis, catch-up strategies involve reducing the cost of capability building. Different mechanisms of technological transfers will allow the movement of the boundaries of firms. *Technological transfer* is one of them, but also involves some costs (Teece, 1976). Joint-ventures and merger

and acquisitions also have their advantages and disadvantages in different contexts which remain to be analyzed. The role of firms' *absorptive capacity* (Cohen and Levintal, 1989, 1990) on reducing this costs of building capabilities and the role of *dynamic capabilities* (Teece et al 1997, Pitelis & Teece, 2010) and *innovation capabilities* (Zawislak et al, 2012) in creatively destroying technological interfaces and creating new markets also remains to be explored.

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Appendix A – Research Protocols

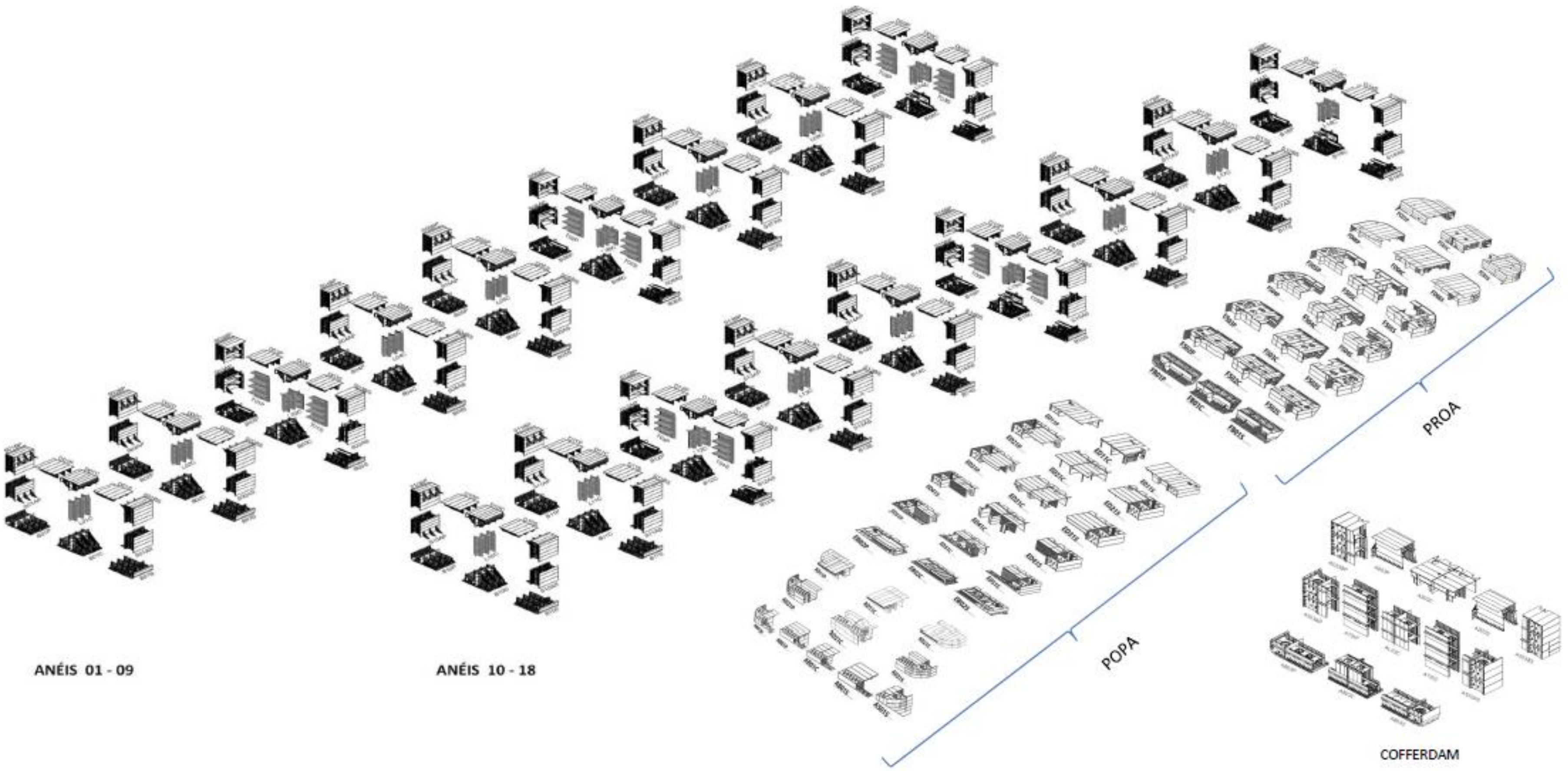
PROTOCOL 1 – Executive Project
(Interface planning)

Level	**Questions**	**Dimensions**
SHAPE	✓ What are the key fields of knowledge involved at this stage of production? ✓ Who defines the standards of the industry (safety and technical standards) ✓ What are the *de facto* standards ✓ Where does the operations start and where it ends? ✓ What are de key processes the company is involved in shipbuilding before it contracts out or moves to the next stage? ✓ How does the company define the distribution of activities among the several participants in the chain? What are the technical and economic criteria involved? ✓ What can be separated and what is indivisible? ✓ What comes from the previous processes and what moves to the next one? ✓ What are the technological boundaries of this stage of production?	Technological Domain, Technology Base (Standards), Modularity
SCOPE	✓ After an order is placed, how does it manage the interfaces between the different productive stages? ✓ How does it mitigate risk and uncertainty? ✓ How does the company decide what to *make*and what to*buy*in this whole process? ✓ How does do company know what it its optimal size? ✓ What is the budget for each Project? ✓ How the firm manages the various technical-economic arrangements with the other participants firms? ✓ What is the level of coordination and control during the process? ✓ What is the budget for this stage of production?	Uncertainty, Frequency andAsset Specificity
DYNAMICS	✓ What are the main sources of change in this field? ✓ What is the rhythm of technological change in the industry? ✓ How does it affect the firms' process? ✓ Where the firm positioned in terms technological frontier compared to world-class standards? ✓ What are the technological boundaries of this firm? ✓ How is the process of technological development? ✓ Who participates in the process? ✓ In what extent do other firms in the process the productive change participate in the development process? ✓ What happens after the technological interfaces are established?	Science and Technology, Technological mastering (know-how), Innovation Capabilities

PROTOCOL 2 – Execution of Projects
(Module builders and Final Integration)

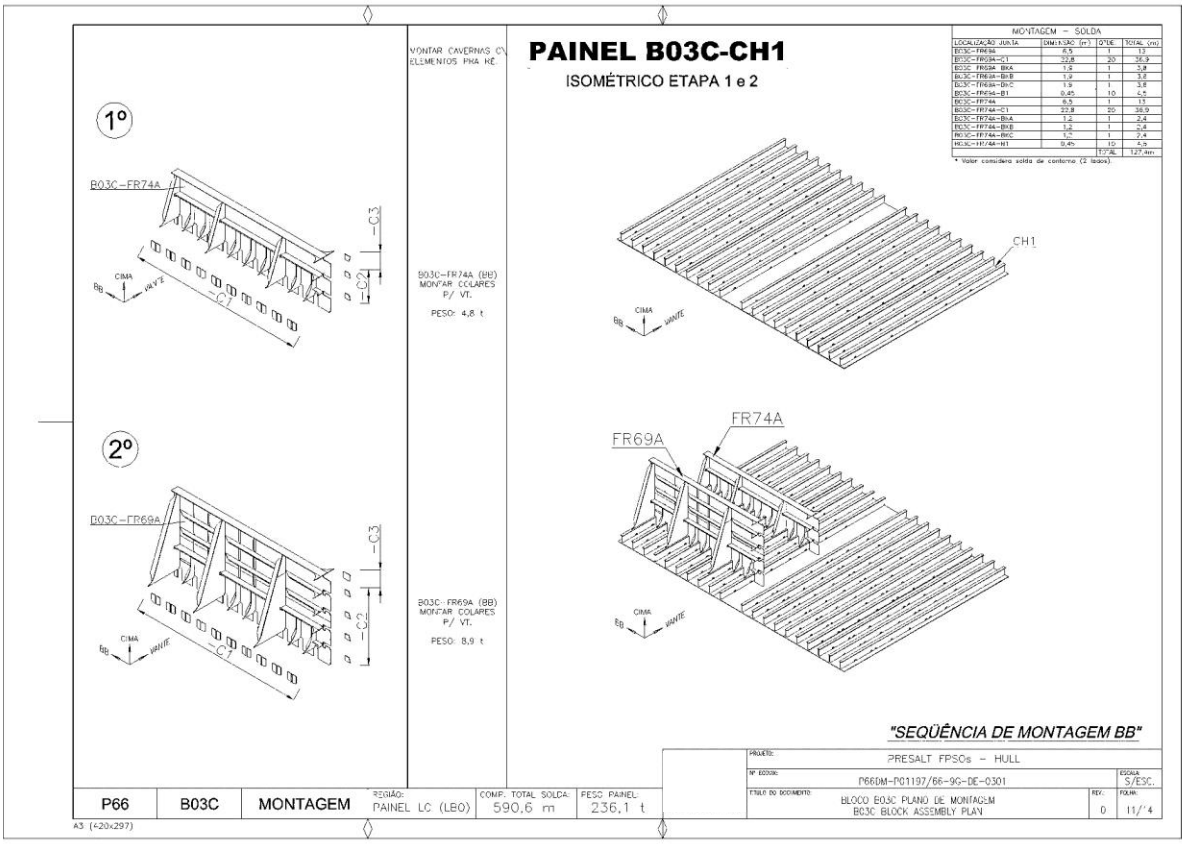
Level	**Questions**	**Dimensions**
SHAPE	✓ What is the technological base of the company? ✓ What are the technical standards that the company needs to follow? ✓ How is the technical relationship with previous stages of the chain? ✓ How is the technical relationship to the next stage of the process? ✓ What are characteristics and volumes of the product supplied to the next stage? ✓ What are the technical boundaries of the firm?	Technological Domain, Technology Base (Standards), Modularity
SCOPE	✓ What level of coordination and control of indoor activities? ✓ How to decide between what to make and what to buy? ✓ What does the company outsource and what it makes? ✓ What is the degree of managerial autonomy to run the business after establishing contracts with the client and suppliers? ✓ What has already internalized and outsourced? ✓ What is the percentage of imported supplies relatively to the national ones? ✓ What is the budget for this stage of production?	Uncertainty, Frequency and Asset Specificity
DYNAMICS	✓ What are the main sources of change in this field? ✓ What is the rhythm of technological change in the industry? ✓ How does it affect the firms' process? ✓ Where the firm positioned in terms technological frontier compared to world-class standards? ✓ What are the technological boundaries of this firm? ✓ How is the process of technological development? ✓ Who participates in the process? ✓ In what extent do other firms in the process the productive change participate in the development process? ✓ What happens after the technological interfaces are established?	Science and Technology, Technological mastering (know-how), Innovation Capabilities

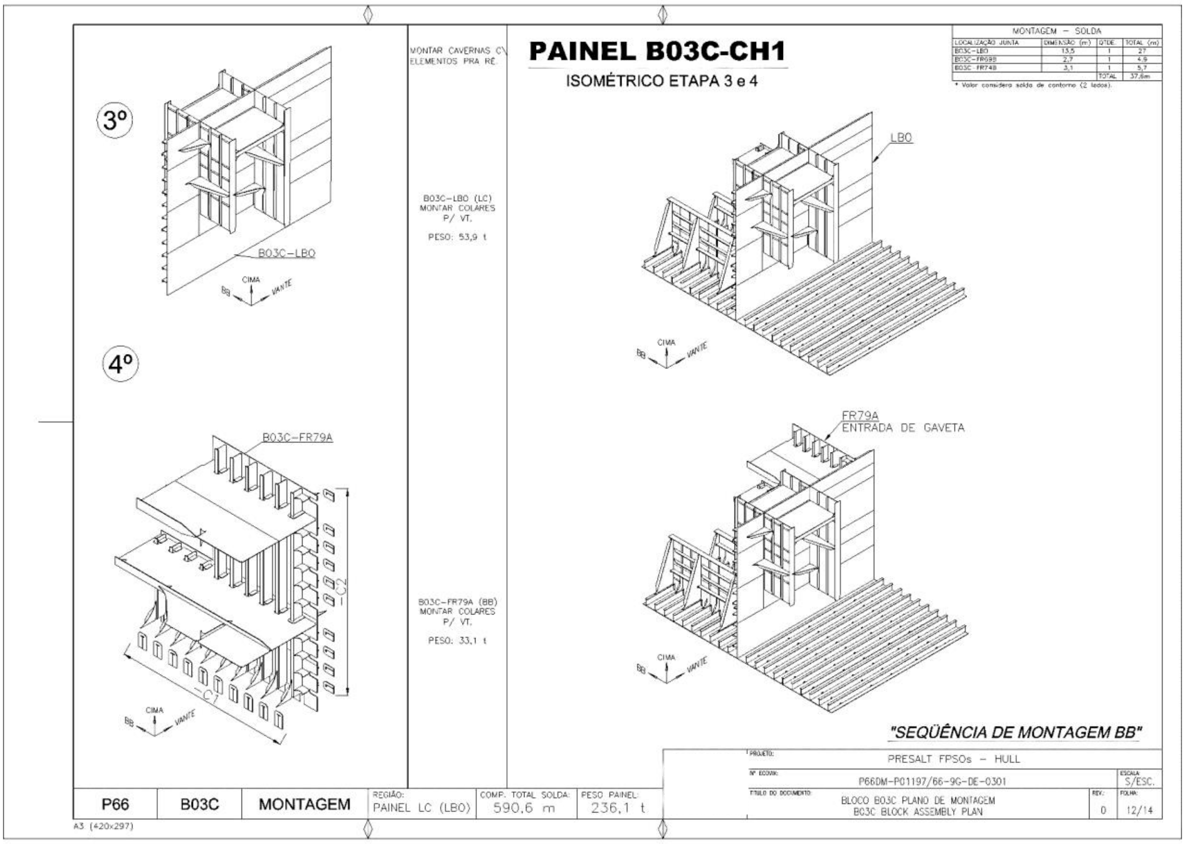
Appendix B – Overview of the Lego-Like Structure of Blocks

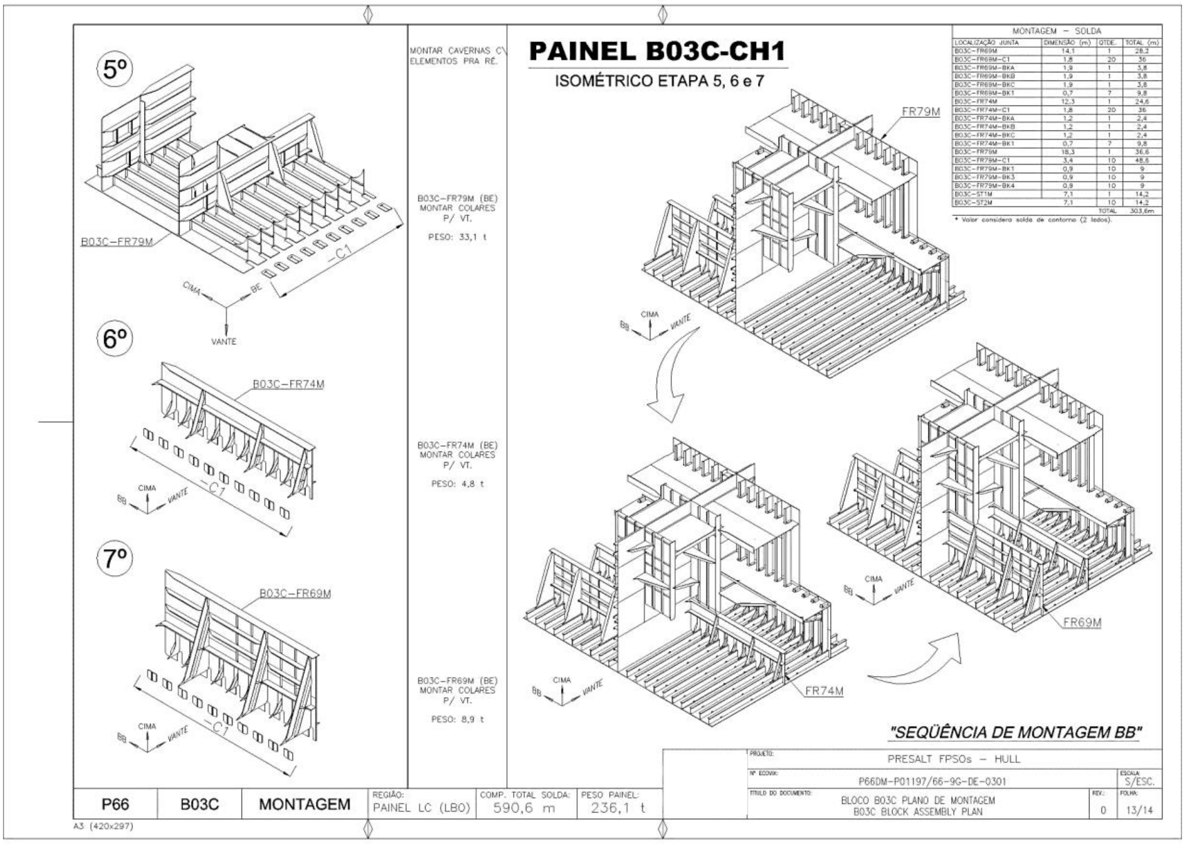


Source: Shipyard A

Appendix C – Block Construction Instructions

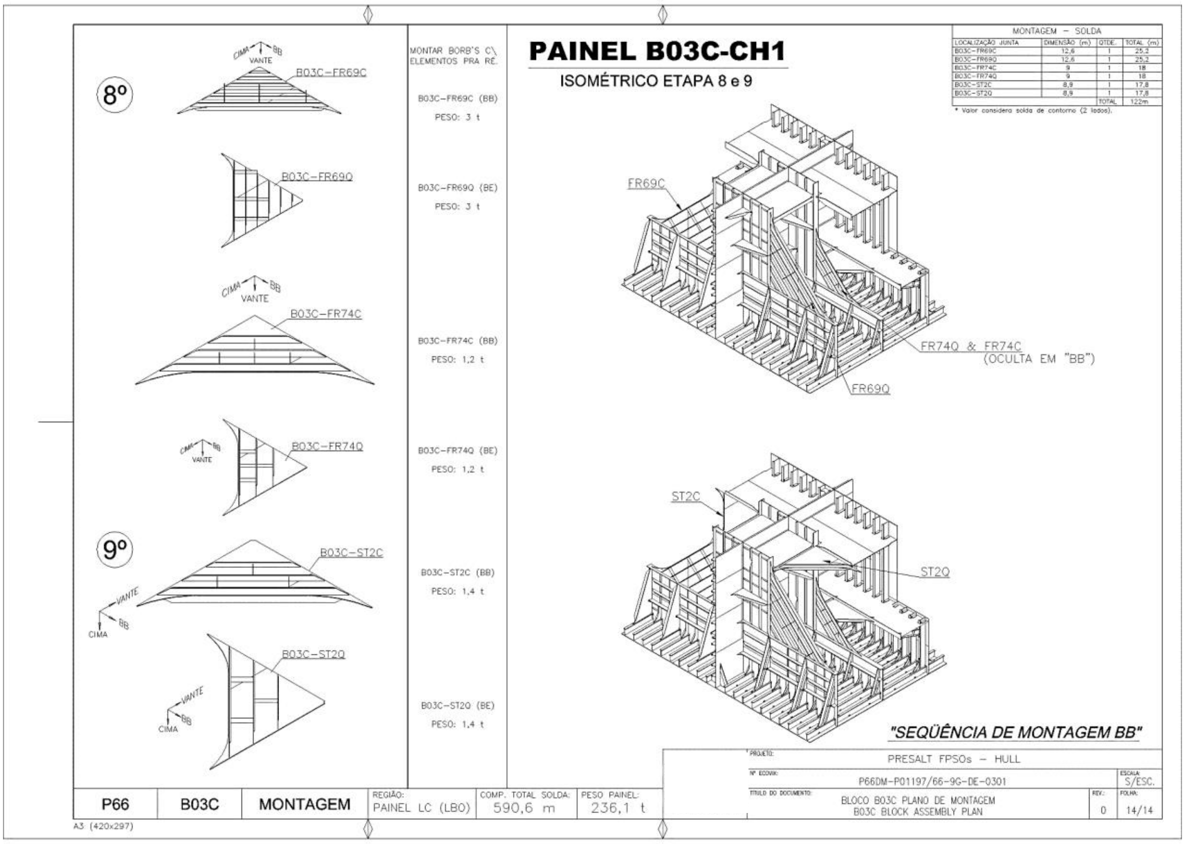






MONTAGEM – SOLDA			
LOCALIZAÇÃO JUNTA	DIMENSÃO (m)	QTDE.	TOTAL (m)
B03C-FR69M	14,1	1	28,2
B03C-FR69M-C1	1,8	20	36
B03C-FR69M-BKA	1,9	1	3,8
B03C-FR69M-BKB	1,9	1	3,8
B03C-FR69M-BKC	1,9	1	3,8
B03C-FR69M-BK1	0,7	7	9,8
B03C-FR74M	12,3	1	24,6
B03C-FR74M-C1	1,8	20	36
B03C-FR74M-BKA	1,2	1	2,4
B03C-FR74M-BKB	1,2	1	2,4
B03C-FR74M-BKC	1,2	1	2,4
B03C-FR74M-BK1	0,7	7	9,8
B03C-FR79M	18,3	1	36,6
B03C-FR79M-C1	3,4	10	48,6
B03C-FR79M-BK1	0,9	10	9
B03C-FR79M-BK3	0,9	10	9
B03C-FR79M-BK4	0,9	10	9
B03C-ST1M	7,1	1	14,2
B03C-ST2M	7,1	10	14,2
		TOTAL	303,6m

* Valor considera solda de contorno (2 lados).



MONTAGEM – SOLDA			
LOCALIZAÇÃO JUNTA	DIMENSÃO (m)	QTDE.	TOTAL (m)
B03C-FR69C	12,6	1	25,2
B03C-FR69Q	12,6	1	25,2
B03C-FR74C	9	1	18
B03C-FR74Q	9	1	18
B03C-ST2C	8,9	1	17,8
B03C-ST2Q	8,9	1	17,8
		TOTAL	122m

* Valor considera solda de contorno (2 lados).

Appendix D – Sub-Contracted Firms by Discipline and size of Workforce

Firms by Discipline	Number of Workers
PAINTING	**1043**
ULTRABLAST	323
EUROMARINE	165
MILLS	108
EPASA	86
BRASFOR	84
K.S. SERVIÇOS LTDA	60
JMI	53
CIMEC	44
AMBCORE	42
RVT	38
JCOSTA	35
RIP	5
OTHER	**541**
PRATO FEITO	142
UNIMED	76
GRSA	67
GOCIL	64
TECNISAN	35
AGUIA	21
MERCOFRIO	13
VETORIAL	12
GPS BRIO CONSULTORIA	11
SUPER PAO	11
PAMPA GESTAO DE SERVIÇOS	10
TOPICO	9
TIAGO	9
DIVE TECH MERGULHO PROFISSIONAL TODA	8
MOTORMAC	7
MARKING SERVICES IDENTIFICAÇÃO	5
EQUIPASUL	5
CRISTIANO	4
ECLIPSE	4
MILLS RENTAL	4
COLMEIA	3
HENZ COMUNICAÇAO	3
ADMIX	2
ASAP	2
GLUF	2
RIO CLEAN	1
WEG EQUIPAMENTOS ELETRICOS	1
SHERWIN WILLIAMS	1
ANTONIO L G PEREIRA	1
PC&M	1
UNICONTROL	1
ROHR	1
RT FICHE	1
STARTA AUTOMAÇAO	1
ABIX TECNOLOGIA	1
ECONSULTING PROJ CONS AMB	1
NIELAND B.V.	1
LOGISTICS AND HEAVY LIFTING	**528**
IRIGARAY	448
EMBRASMAQUI	59
3Z	8
MAMMOET	4
GREGA	4
ADM LOG	3
M. SANTOS	2
EIT	**439**
SGS	253
NASA	178
JMX SERVIÇOS TECNICOS LTDA	8

Firms by Discipline	Number of Workers
PIPE	**341**
RVT	238
PROFAB	64
ITP	20
AVF	14
TERMOBRAS	5
STRUCTURE	**237**
PROFAB	149
RVT	88
SCAFFOLDING	**146**
MILLS	142
ANDAIME	4
ARCHITECTURE	**67**
TECNOLITE	67
QUALITY	**65**
ITP	18
ISI	17
CAPAZ	15
SURVEY	8
ABS	7
MECHANICS	**64**
PROFAB	63
RVT	1
CIVIL	**50**
GIACOBBO	19
ETTUN	16
AGAPE	7
DWD	3
UDF	3
FAGEL	2
ISOLATION	**49**
RIP	49
SEAMANSHIP	**44**
BLUE OCEAN	29
REPARMAR	15
HVAC	**36**
AIRMARINE	28
SAO CARLOS	8
ENGINEERING	**34**
COSCO	21
FUGRO ONSHORE GEOTECHNICS	4
FOR SHIP ENGENHARIA	3
PROSEP	2
ALTUS	2
GEOTOP	2
SUPPORT	**25**
EURONEMA	13
GLUF	9
HYDRATIGHT	2
MILLS	1
IT / SYSTEMS	**17**
HANT SOLUÇOES EM INFORMATICA	13
DELL	4
SMS	**11**
AMBCORE	11
OUTFITTING	**6**
RVT	6
Total	**3.743**

Source: Shipyard A. Data from October 2014

Appendix E – Distribution of internal workforce across disciplines

SHIPYARD A

Distribution of Workers of SHIPYARD A.	Number of Workers
ASSEMBLY	1447
MANUFACTURING	869
SUPPORT	750
OUTFITTING	692
EDIFICATION	650
SCAFFOLDING	403
SMS	311
OTHER	268
PAINTING	258
COMMISSIONING	255
QUALITY	238
MECHANICS	224
ENGINEERING	191
TH	171
EIT	142
WAREHOUSE	107
ADMINISTRATIVE	97
STRUCTURE	94
CFP	91
LOGISTICS	86
SUPPLIES	54
PIPE	39
PLANNING	36
HUMAN RESOURCES	35
DOCUMENTATION	28
OVERSIGHT	28
CONTRACTS	23
SUPERVISOR	22
TRAINING	18
FINANCIAL	10
IT / SYSTEMS	10
BOARD	8
VICE-PRESIDENCY	6
ACCOUNTING	5
PRESIDENCY	3
LEGAL	1
Total	7.670

Source: Shipyard A. Data from October 2014

Appendix F – Firms in nº of Workers

October of 2014

Nº	Firm	Nº of Workers	Nº	Firm	Nº of Workers
1	SHIPYARD A	7663	47	JMX SERVIÇOS TECNICOS LTDA	8
2	IRIGARAY	448	48	DIVE TECH MERGULHO PROFISSIONAL TODA	8
3	RVT	371	49	SURVEY	8
4	ULTRABLAST	323	50	SAO CARLOS	8
5	PROFAB	276	51	MHI	7
6	SGS	253	52	MOTORMAC	7
7	MILLS	251	53	ABS	7
8	NASA	178	54	AGAPE	7
9	EUROMARINE	165	55	TERMOBRAS	5
10	PRATO FEITO	142	56	MARKING SERVICES IDENTIFICAÇÃO	5
11	EPASA	86	57	EQUIPASUL	5
12	BRASFOR	84	58	ECLIPSE	4
13	UNIMED	76	59	GREGA	4
14	GRSA	67	60	FUGRO ONSHORE GEOTECHNICS	4
15	TECNOLITE	67	61	ANDAIME	4
16	GOCIL	64	62	CRISTIANO	4
17	K.S. SERVIÇOS LTDA	60	63	MILLS RENTAL	4
18	EMBRASMAQUI	59	64	DELL	4
19	RIP	54	65	MAMMOET	4
20	JMI	53	66	FOR SHIP ENGENHARIA	3
21	AMBCORE	53	67	UDF	3
22	CIMEC	44	68	ADM LOG	3
23	ITP	38	69	COLMEIA	3
24	TECNISAN	35	70	HENZ COMUNICAÇAO	3
25	JCOSTA	35	71	DWD	3
26	BLUE OCEAN	29	72	ALTUS	2
27	AIRMARINE	28	73	M. SANTOS	2
28	AGUIA	21	74	ADMIX	2
29	COSCO	21	75	FAGEL	2
30	GIACOBBO	19	76	GEOTOP	2
31	ISI	17	77	PROSEP	2
32	ETTUN	16	78	ASAP	2
33	REPARMAR	15	79	HYDRATIGHT	2
34	CAPAZ	15	80	ABIX TECNOLOGIA	1
35	AVF	14	81	RIO CLEAN	1
36	EURONEMA	13	82	ANTONIO L G PEREIRA	1
37	MERCOFRIO	13	83	SHERWIN WILLIAMS	1
38	HANT SOLUÇOES EM INFORMATICA	13	84	RT FICHE	1
39	VETORIAL	12	85	WEG EQUIPAMENTOS ELETRICOS	1
40	SUPER PAO	11	86	ROHR	1
41	GLUF	11	87	ECONSULTING PROJ CONS AMB	1
42	GPS BRIO CONSULTORIA	11	88	PC&M	1
43	PAMPA GESTAO DE SERVIÇOS	10	89	STARTA AUTOMAÇAO	1
44	TIAGO	9	90	UNICONTROL	1
45	TOPICO	9	91	NIELAND B.V.	1
46	3Z	8		**Total**	**11.413**

Source: Shipyard A. Data from October 2014

October of 2015

Nº	Firm	Nº of Workers	Nº	Firm	Nº of Workers
1	SHIPYARD A	5993	31	DELL	3
2	ULTRABLAST	187	32	ECO JUNIOR	3
3	EUROMARINE	144	33	SURVEY	3
4	PRATO FEITO	112	34	AIRMARINE	3
5	PROFAB	105	35	ABIX TECNOLOGIA	2
6	UNIMED	72	36	SGS	2
7	TOME EQUIPAMENTOS	68	37	UNICONTROL	2
8	EMBRASMAQUI	56	38	SORIA & LUCAS	2
9	KS	43	39	GOCIL	2
10	IRIGARAY	16	40	SUPER PAO	2
11	RICARDO ALEXANDRE GABRIEL E CIA	13	41	ASAP	2
12	BLUE OCEAN	11	42	AGUIA	2
13	MB RECICLADORA	10	43	WEG EQUIPAMENTOS ELETRICOS	2
14	VETORIAL	9	44	BUFFON COMB. E TRANSPORTES	2
15	AVF	9	45	MERCOFRIO	2
16	ECLIPSE	7	46	FRAMATIG	2
17	CAPAZ	6	47	MHI	2
18	HANT SOLUÇOES EM INFORMATICA	6	48	SOUZA E MONTEIRO SERVIÇOS TECNICOS LTDA	1
19	PAMPA GESTAO DE SERVIÇOS	6	49	WORK	1
20	SHERWIN WILLIAMS	6	50	DIVE TECH MERG	1
21	OXIPEL COM. REPRES. LTDA	5	51	S5 ENGENHARIA	1
22	TOPICO	5	52	CHENG GONG ENGENHARIA	1
23	ISI	5	53	ADMIX	1
24	LANA CALIBRAÇÃO DE INSTRUMENTOS	5	54	HENZ COMUNICAÇAO	1
25	TERMOBRAS	4	55	PC&M	1
26	CRISTIANO	4	56	SYSTECH	1
27	TIAGO	4	57	POSTO ESTORIL	1
28	MOTORMAC	4	58	TECNISAN	1
29	ABS	4	59	TOZETTI LTDA	1
30	SAO CARLOS	4		**Total**	**6.973**

Source: Shipyard A. Data from October 2015