Master's thesis

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An empirical assessment of the relationship between ship type variety and the financial performance of shipbuilding firms

Master's thesis in Global Manufacturing Management
Supervisor: Marco Semini
June 2020

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Preface

This master's thesis in production management is written as a part of the 2-year international master's degree in Global Manufacturing Management at the Norwegian University of Science and Technology (NTNU). It is conducted in the 4th and last semester, and amount to 30 credits, i.e. 100 % of the semester workload.

I would like to thank my supervisor Marco Semini, professor at NTNU, and my co-supervisor Jo Wessel Strandhagen for their great ideas, guidance, and feedback during this semester.

I would also like to thank the professors and researchers from the Department of Mechanical and Industrial Engineering, and Per Olaf Brett from Ulstein International AS for their precious feedback during our various meetings.

I would also like to thank my fellow students for their alternative perspectives, their advices, and the motivation they provided me during the research and writing process.

Finally, I would like to thank my friends, my girlfriend, and my family for their great support throughout this semester.

Luxembourg, June 2020

Quentin Jean

Summary

Product variety has been largely studied for its impact on the performance of manufacturing firms. Yet, it appears that there are no such studies in the context of shipbuilding. However, product variety is also a challenge for shipbuilders, as variety becomes a strategic asset in the competitive and globalized market of shipbuilding but is also costly and challenging to achieve.

The goal of the thesis is to gain insight into the relationship between the product variety and the performance of shipyards. Specifically, this thesis focuses on the variety of ship types a shipyard produces. This thesis has two main objectives:

1. Investigate the relationship between ship type variety and the financial performance of shipbuilding firms.
2. Investigate the effect of ship type variety on the ability of shipyards to cope with market downturns.

To meet the objectives, a literature study is carried to formulate a research model and corresponding hypotheses. It is hypothesized that variety of ship types has an influence on the financial performance of shipyards. However, literature suggests that there are both positive and negative effects, which does not allow to predict if the ship type variety is profitable or not. A second hypothesis is that the ship types variety allows shipyards to better cope with a market downturn.

To test the research hypotheses, secondary data is gathered from the financial database Orbis, and the Sea-Web maritime database. The data are gathered for 22 Norwegian shipyards which are chosen based on detailed criterion. Several regression analyses are performed on the measurable variables of the dataset to test the hypothesis.

The results do not suggest that the ship type variety and the financial performance of shipyards are universally related. Which can be explained by the theory but can also result from the limitations of the model and analysis method, especially because the model might lack some predictive factors and because the sample size limits statistical significance. On the other hand, the results indicate that ship type variety is a strategic advantage when a market downturn happened. This highlights the risk dimension of the "focused" strategy of producing only one, or very few, ship type(s) to achieve high efficiency level.

This thesis contributes to the theory by exploring the relationship between ship type variety and financial performance in shipbuilding. Especially, this thesis introduces the use of two diversity measures, the Shannon index and the types count, as measures of the product variety of shipyards. Also, this thesis proposes a discussion of some methodological issues related to the use of financial performance measures to assess shipbuilding performance.

The practical implications of the thesis are that shipyards should not limit their product portfolios based on efficiency objectives, but they rather should try to keep diversified portfolios to secure their long-term stability.

This thesis concludes that further work could investigate the ideal level of variety for shipyards. Also, it suggests developing a methodology to choose whether shipyards should produce new ship type. Finally, it proposes to investigate what are the best strategies to handle variety are and how to develop them.

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List of Abbreviations

AROA	Average Return On Assets
ATO	Assemble-To-Order
CGT	Compensated Gross Tonnage
CODP	Customer Order Decoupling Point
ETO	Engineer-To-Order
FP	Financial Performance
GT	Gross Tonnage
HVAC	Heating, Ventilation and Air-Conditioning
IHS	Information Handling Services
MTO	Make-To-Order
MTS	Make-To-Stock
OECD	Organisation for Economic Co-operation and Development
ROA	Return On Assets
SFI	*Skipsteknisk ForskningsInstitutt* (Ship Research Institute of Norway)
SI	Shannon Index
STV	Ship Type Variety
TC	Types Count

1. Introduction

1.1. Background and motivation

The shipbuilding market is a globalized market which has been increasingly competitive with the rise of Asian shipbuilders in the last decades (Ecorys SCS Group, 2009, Holte et al., 2009). If Europe was historically the global leader of shipbuilding, it was replaced by Japan in the 1970s and then South Korea and China. As a result of the severe competition from Asian shipbuilders, European shipbuilders had to expand their product portfolio and to focus on higher value-added and more specialized ships (Ecorys SCS Group, 2009).

Following the 2008 global financial crisis, a strong decline in world trade growth caused a comparable decline for sea transport. Consequently, the freight rates dropped as well as the sales prices of transport ships (bulk, tanker, and container), while a significant share of new ship orders were cancelled (Holte et al., 2009). As a result, shipbuilding industry have known an important recession and many bankruptcies (Turan and Celebi, 2012). Other historical examples have shown the high uncertainty in the demand for global shipbuilding. Between 1967 and 1975, with the closing of the Suez Canal, the exploding need for large vessels able to travel around the Cape of Good Hope resulted in a boom of demand for larger ships and in an expansion of shipyards capacities. On the other hand, when the Suez Canal reopened, in 1975, the overcapacity in terms of merchant fleet and shipyards capacity caused a global slowdown in shipbuilding activities (Holte et al., 2009).

Shipbuilding has historically been an uncertain market on a global scale, but it was also the case in specialized or niche markets. For example, in Norway, the shipbuilding industry has historically been focused on serving the offshore oil and gas industry since the 1970's (OECD, 2017, Holte et al., 2009, Mellbye et al., 2015)[1]. Norwegian shipyards activity is thus highly dependent on the oil prices and have been struggling with the drop of oil prices especially since 2014. In particular, the demand for offshore support and supply vessels, i.e. vessels specially designed for the logistical servicing of offshore platforms and subsea installations, significantly dropped. As a result, many Norwegian shipbuilders had to switch to other market segments while other went bankrupt (OECD, 2017). In order to cope with the announced

[1] OECD: Organisation for Economic Co-operation and Development

decline in oil exploitation and production in the North Sea and to decrease their dependability on the oil and gas industry, some Norwegian shipbuilders identified diversification in terms of customers and products as a key priority (Mellbye et al., 2015).

Whether their objective is to cope with market changes, increase their market shares, prevent the effects of demand uncertainty, or differentiate themselves from competitors, shipbuilders have been increasingly diversifying their product portfolio. The extent to which a shipbuilder achieve diversification in its product portfolio is a major aspect of a shipbuilder business and manufacturing strategies. Indeed, there is a challenge for shipbuilders to find the optimal product variety to offer to the market. In one hand, limiting the variety to one or a few types may result in economies of scale[2] and learning effects[3], and limit the impact of changes in ship characteristics (type, size…) on operations (yard layout change, need to find new suppliers or sub-contractors…). It can, in the other hand, be disadvantageous for shipbuilders who have the ambition to offer enough variety to satisfy the market requirements, or when the demand for specific ship types drops, as transition to other ship types or other market segments can be very challenging. However, producing a too wide variety of ship types can be difficult to achieve efficiently. Therefore, there is a need to understand how product variety can affect the performance of a shipbuilder.

In a previous project carried by the author of this thesis and titled “Theoretical assessment of product variety in shipbuilding and its effect on performance”, a categorization of product variety “dimensions” was proposed for the particular context of shipbuilding, as well as associated product variety metrics. However, this work could not be pushed to the point where these findings could be used to evaluate the effect of product variety on shipbuilder’s performance.

[2] Economies of scale are the cost advantages that companies gain due to their scale of operation, with cost per unit of output decreasing with increasing scale, because of the spreading of fixed costs, increased bargaining power over suppliers, as well as from more specialized, thus effective equipment.

[3] Learning effect is the process by which learning tend to increase productivity; each time the cumulative production volume doubles, the unit cost and/or production time decreases by a given percentage.

1.2. Problem description

Shipbuilding is the complex process of building ships, which includes a large variety of activities from design to delivery (Hagen and Erikstad, 2014). Shipbuilding also refers to the business of carrying this complex process, a business which is extremely and increasingly competitive (Semini et al., 2018, OECD, 2017, Hagen and Erikstad, 2014, Ecorys SCS Group, 2009). As a result, shipbuilders must seek excellence in all aspects of their business and operations, and improve at all time, usually through a set of small step of improvements (Hagen and Erikstad, 2014). Authors have been studying shipbuilding performance, and the various factors influencing shipbuilding performance (see for example Semini et al., 2018, Sulaiman et al., 2017, Semini et al., 2014, Pires et al., 2008, Saracoglu and Gozlu, 2007, Audia and Greve, 2006, Lamb and Hellesoy, 2002, Moyst and Das, 2005, Pires et al., 2009, Colin and Pinto, 2009). To survive, shipyards must preserve a full order book for new ships at any time (Hagen and Erikstad, 2014). In order to keep a full order book, shipyards must offer variety, and concurrently build a mix of different ship types (Kolic et al., 2012).

Product variety could be defined as “the diversity of products that a company’s value-chain provides to the marketplace” (Götzfried, 2013). Several authors have been studying the relation between product variety and firm performance (see for example Berry and Cooper, 1999, De Groote and Yucesan, 2011, Fisher and Ittner, 1999, Jiao et al., 2008, Johnsen and Hvam, 2018, Lyons et al., 2020, MacDuffie et al., 1996, Ramdas, 2003, Randall and Ulrich, 2001, Salvador et al., 2002, Thonemann and Bradley, 2002, Ulrich, 1995, Um et al., 2017, Wan et al., 2014, Zhang et al., 2007). Randall and Ulrich (2001) have been studying the relation between product variety, supply chain structure and firm performance in the US bicycle industry. MacDuffie et al. (1996) have been assessing the effect of product variety on manufacturing performance of automotive assembly plants. De Groote and Yucesan (2011) and Thonemann and Bradley (2002) have been modeling and studying the impact of product variety on supply chain and logistics performance. Zhang et al. (2007) investigate the link between response time, product variety and firm performance in a Make-To-Order (MTO) automotive context.

The prominence of this field of research shows the interest of academics and manufacturing companies in the question of product variety at the operational and strategic level (Park et al., 2004). Despite this interest, there are only a few studies addressing the question of product variety in shipbuilding. Lamb and Hellesoy (2002) include a proxy of product variety in their predictive equation for shipbuilding productivity, but their statistical analysis doesn’t conclude for a significant impact of this parameter. Pires et al. (2009), Pires et al. (2008) and Erichsen (1994) discuss the learning effect observed while building ships in series, which is definitely one aspect of product variety in shipbuilding. Some authors also discuss standardization and modularization in shipbuilding (Nickelsen, 2017, Erikstad, 2009, Hagen, 1998), which are concepts closely linked to product variety. To a larger extent authors have been discussing the question of product customization in shipbuilding and other Engineer-To-Order (ETO) industries (Sulaiman et al., 2017, Semini et al., 2014, Zennaro et al., 2019, Johnsen and Hvam, 2018, Strandhagen et al., 2018, Trappey et al., 2009, Haug et al., 2009). Even so, there is a lack of understanding on how product variety influences performance in shipbuilding.

Still, given the increased competition and the financial struggles for many actors of the sector, it has been increasingly difficult for shipbuilders to profitably design and produce ship (OECD, 2017, Kanerva et al., 2002, Hagen and Erikstad, 2014, Ecorys SCS Group, 2009). In particular, the approach of building ships as one-of-a-kind products is claimed to no longer be viable for many European shipbuilders (Ecorys SCS Group, 2009). This means that shipbuilders need to spread design costs among different ships, by building ship in series for example, which also allows to benefit from learning process on the production level. On the other hand, in order to survive, shipbuilders must meet the market demands and adapt to market changes. As the order volumes are decreasing, it is not possible for many shipbuilders to only serve one market niche anymore, and thus they must increase the variety of ships they can offer (Kolic et al., 2012).

This study aims to contribute to the understanding of the effect of product variety on performance in shipbuilding. The research objectives are further described in the next section.

1.3. Research objectives and scope

This chapter introduces the research objectives in section 1.3.1 and the research scope in section 1.3.2.

1.3.1. Research objectives

The ultimate intention of this thesis is to contribute to the study of the impact of product variety on shipbuilding performance. Particularly, this thesis has two objectives:

1) **Objective 1: Investigate the relationship between ship type variety and the financial performance of shipbuilding firms.**

The first objective is related to a classical problem in product variety literature, which is to know if product variety is beneficial and to what extent (Götzfried, 2013). Literature indicates that product variety has both costs and benefits for manufacturers. Those costs and benefits refer to the literal financial outcomes but also to the strategic "costs" and "benefits" of product variety. Precisely, for shipbuilders, one important aspect of product variety is the variety of ship types they produce, or ship type variety. The goal is thus to determine if the variety of ship types a shipbuilder manufactures is significantly related to its financial profitability.

2) **Objective 2: Investigate the effect of ship type variety on the ability of shipyards to cope with market downturns.**

One of the "strategic" benefits of product variety suggested by literature is the higher resilience to market downturns (Fisher et al., 1995). This suggests that companies with greater product variety are less sensitive to market downturns because they are more flexible and able to reposition themselves in other product segments quicker and at lower costs.

Additionally, this thesis proposes a discussion of some methodological issues in relation with performance-related studies in shipbuilding.

The next section presents the research scope of the thesis.

1.3.2. Research scope

This thesis studies product variety from a strategic management and operation management research point of view. The research models are based on the existing literature on product variety, diversification strategies and shipbuilding performance. Other approaches such as product portfolio management, risk management, or product design might also be relevant but are not plainly included in the thesis.

In this thesis, shipbuilding companies are considered as being mainly producing “new build” ships. Thus, we do not consider repair works, ship conversion works or the building of other types of structure such as offshore platforms, bridges etc. However, those other activities might have a significant share in shipbuilders’ portfolios.

This thesis intends to be useful for researchers and academics who want to go further in the topic of product variety in shipbuilding. However, this thesis also provides some practical recommendations for decision makers at shipyards.

Finally, the data analysis is focused on the Norwegian shipbuilding industry for various reasons which are discussed in the thesis. This limits the generalizability of the findings to other national contexts.

1.4. Thesis structure

Table 1 Thesis structure

Chapter 1 Introduction	The introduction presents the background and motivation of the master's thesis, the problem description, the research objectives, the research scope, and the thesis structure.
Chapter 2 Theoretical background	The theory chapter presents the results of the literature study about product variety, shipbuilding, and firm performance. The literature study serves as the theoretical foundation for the theoretical model and hypotheses.
Chapter 3 Methodology	The methodology chapter describes the overall research strategy, the literature study, and the data analysis. In particular, the theoretical research model, the hypotheses to be tested, the data collection and the statistical method are detailed.
Chapter 4 Data analysis and findings	This chapter presents the results and findings from the preliminary data analysis and from the regression analyses. The results are discussed and implications for practice are suggested.
Chapter 6 Conclusion	The conclusion presents the main findings of the thesis and discusses to what degree the research objectives have been fulfilled. The chapter also identifies the limitations of the thesis and suggests recommendations for future research.

2. Theoretical background

In this chapter, we develop the necessary theory to support the research. The theory presented below is the result of an adaptation from the specialization project “Theoretical assessment of product variety in shipbuilding and its effect on performance” which was improved and consolidated with a complementary and specific literature study for this master thesis.

The first two sections are adaptations from the literature study of the specialization project, respectively about product variety, and shipbuilding. Some changes have been made to these two sections even if they received a generally positive feedback in the project report.

In the third section, we summarize the main theoretical results from the specialization project which are useful for the execution of this thesis. In the fourth and last section we discuss the concept of firm performance and the related measures that are useful for this thesis.

2.1. Product variety

This section aims to introduce the concept of product variety, to show the importance of product variety management and to identify measures of product variety.

2.1.1. Product variety: definition

There is no clear and universal definition of product variety in the literature (Pil and Holweg, 2004, Ulrich, 2006, Götzfried, 2013, Landahl and Johannesson, 2018). It can be defined differently depending on the research field, and different conceptualization of product variety can be found in economics (Ranaivoson, 2005), design (Ulrich, 2006), operation management (Landahl and Johannesson, 2018)… This makes product variety an ambiguous notion (Stäblein et al., 2011, Lyons et al., 2020). However, when reducing the scope to product variety definition related to manufacturing, there is a common understanding that there are different dimensions of product variety and that this variety induces different levels of complexity (Götzfried, 2013, Blackenfelt, 2001, Ulrich, 1995). Götzfried (2013) and Pil and Holweg (2004) identify two dimensions of product variety commonly used in the literature: external variety and internal variety.

External variety can be defined as the diversity of products visible to the customer or as the number of choices offered to him. It can be measured as the total number of possible configurations of a product, for example the external product variety of a car manufacturing company can be calculated as the number of models multiplied by the number of paint colors multiplied by the number of options and the number of engines configurations, etc. (Pil and Holweg, 2004, Fisher and Ittner, 1999). On the other hand, internal variety is the variety that results from the translation of the customer requirements, i.e. external variety, into a variety of manufacturing process requirements and supply chain requirements (Pil and Holweg, 2004, Holweg and Pil, 2004). In other words, internal variety is the variety of tasks to be performed and materials to be processed inside the manufacturing company in order to meet the external variety (Götzfried, 2013).

External product variety, the variety of product perceived by the customer, can be defined by three characteristics: fit, taste and quality (Ulrich, 2006). A fit attribute of the product is one attribute of the product for which the customer will be satisfied only for precise values, and for which any deviation from those values will strongly decrease the satisfaction (e.g. the size of a piece of clothes is a fit attribute, the customer will only be satisfied if the size literally 'fits'). In the other hand, for a taste attribute, the customer might prefer some values, but his satisfaction will not necessarily decrease with variations from those values (e.g. the color of a piece of clothes). Finally, an increase of a quality attribute will always result in an increase of the satisfaction. A quality attribute is not dependent on the customer, while fit and taste attributes are dependent on the customer (Ulrich, 2006).

Similarly, we can define three categories of internal variety: fundamental, peripheral and intermediate (MacDuffie et al., 1996). Fundamental internal variety includes the diversity of basic products produced by a company in terms of types, platforms[4] and models. Intermediate variety refers to the diversity among components and parts used to differentiate end items without significant impact on the basic design but with an impact on the manufacturing operations and supply chain (e.g. number of engines for a car model). Peripheral variety refers to the diversity of product "options" that does not impact the basic product design (e.g. air conditioning for a car). Stäblein et al. (2011) point out that those categories are dependent on the industry under study, as the three internal variety categories are based on specific product characteristics.

These categorizations are summed up in the Figure 1.

[4] The concept of product platform is introduced in the next section.

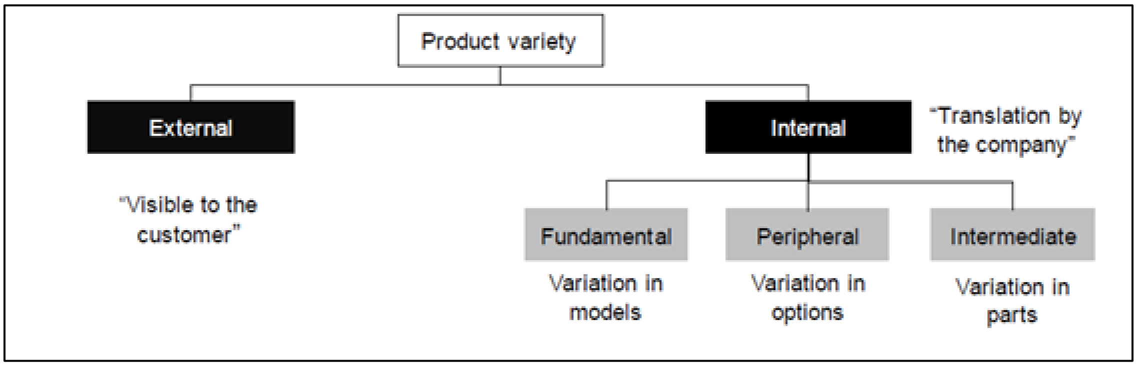

Figure 1 Theoretical categorization of product variety, adapted from Götzfried (2013)

Based on Ulrich (1995), Götzfried (2013) proposes a general to define the product variety as "the diversity of products that a company's value-chain provides to the marketplace". Fisher et al. (1999) add another dimension to this definition, "product variety can be defined on two dimensions: the breadth of products that a firm offers at a given time and the rate at which the firm replaces existing products with new products". This shows that product variety also has a dynamic dimension as it varies with time (Holweg and Pil, 2004, Stäblein et al., 2011). "Dynamic variety" (Fisher et al., 1999) reflects the choice that is offered over time, i.e. more frequent replacements of products by newer ones means an increase in dynamic variety (Stäblein et al., 2011). A similar distinction is made by Martin and Ishii (1996) between spatial variety and generational variety, where the first is the variety at a given time and the second is the variety across product generations.

To meet the market demand for external product variety, a firm translate this demand into manufacturing and value-chain requirements and thus creates internal variety (Pil and Holweg, 2004). However, increasing internal variety, i.e. be able to produce a wider range of products, creates internal complexity, and thus has a cost. This cost must be balanced with the benefits of product variety, as discussed in the next section.

2.1.2. The trade-offs of product variety

Increasing product variety is a way for manufacturing companies to increase their market shares, cope with technology changes and face global competition (Tang, 2006, Ramdas, 2003, Park et al., 2004). However, increased product variety does not guarantee long term profitability. Instead it might have the opposite effect. Indeed, while increasing internal variety, a company brings complexity in manufacturing and increase -among others- its inventory costs, because of increased uncertainty in demand (Tang, 2006, MacDuffie et al., 1996). Therefore, the ability to efficiently, meaning at low cost, manage product variety is seen as a competitive advantage for manufacturers (Ramdas, 2003, Meyer and Lehnerd, 1997, Landahl and Johannesson, 2018).

This problem is classically described as a trade-off between meeting as much market demand as possible and reducing manufacturing costs, by achieving economies of scale and reducing inventory levels. The goal is to have the narrowest internal variety that can meet the largest external variety of market's needs (Blackenfelt, 2001, Lancaster, 1980, Landahl and Johannesson, 2018). It is also pictured in the literature as a compromise between the marketing department and the manufacturing, logistics and purchasing departments; the first wants to fulfill the maximum customer requests and gain the maximum market shares, while the others aim to have the lowest complexity to maximize operations efficiency and profitability.

The focused factory

From the manufacturing point of view, the ideal situation would be to decrease the internal variety to such a point that the factory could be called product "focused". Skinner (1974) introduced the concept of the "focused factory", a factory that focuses on serving a precise and well-defined manufacturing strategy, e.g. producing a limited range of products, as opposed to a 'conventional' factory that has a broader set of objectives and product portfolio. "A factory that focuses on a narrow product mix for a particular market niche will outperform the conventional plant, which attempts a broader mission" (Skinner, 1974). Indeed, as the 'conventional' factory tries to carry out the production of a large set of different product and thus too many conflicting tasks, it becomes non-competitive, because its manufacturing policies are not focused on one key task. On the other hand, the focused factory gains its competitiveness from its focused purpose, "because its equipment, supporting systems, and procedures can concentrate on a limited task for one set of customers, its costs and especially its overhead are likely to be lower than those of the conventional plant" (Skinner, 1974). Schroeder and Pesch (1994) emphasize that the "focus" of a factory is achieved by limiting the range of products but also the variety of the processes and of the customers. Furthermore, they outline that limiting the product variety in terms of features is more important than limiting the number of products, because producing products with similar features is not too demanding for manufacturing in terms of process flexibility.

The costs of variety

Limiting the internal product variety indeed allows to avoid the costs associated with internal complexity. According to the literature, those costs include the cost of inventory. Indeed, increasing variety is associated with a raise of inventory levels, including work-in-progress and finished goods inventory because of a less predictable demand (Yeh and Chu, 1991, Fisher et al., 1995, Randall and Ulrich, 2001). Besides, external product variety brings diversity of raw materials and components requirements, i.e. intermediate variety, which increases the overall number of SKUs (Stock Keeping Units) and requires more inventory and material handling systems, resulting in an increase of the overall inventory costs (Fisher and Ittner, 1999, Yeh and Chu, 1991, Randall and Ulrich, 2001, Martin and Ishii, 1996, Thonemann and Bradley, 2002, Anderson, 1995, Salvador et al., 2002). However, these cost increases can be mitigated by standardization or modularization strategies[5] (Salvador et al., 2002).

Purchasing costs are similarly affected by product variety, with higher purchasing costs for higher product variety, due for example to diseconomy of scale that suppliers could experience while they are ordered for lower quantity of more various components (Fisher et al., 1999, Randall and Ulrich, 2001, Salvador et al., 2002).

From an engineering and design perspective, product variety is also likely to increase costs (Fisher et al., 1995), with more complex designs (Salvador et al., 2002) and higher R&D resources requirements (Yeh and Chu, 1991). Although, mitigation strategies, such as platform-based[6] engineering and design, can also be used to limit the increase of those costs.

In the literature, manufacturing costs are also largely considered to increase with product variety (Anderson, 1995, Child et al., 1991, Thonemann and Bradley, 2002). In particular, this is the case for manufacturing overhead costs, because of the increased diversity in processes specifications, increased frequency of set-ups, need for more overhead working hours, more complex scheduling, etc. (Fisher et al., 1995, Anderson, 1995), but also for quality assurance costs (Fisher et al., 1995, Anderson, 1995, Yeh and Chu, 1991) or material costs (Tang and Yam, 1996).

The benefits of variety

On the other hand, increasing product variety can be beneficial for the company. Increasing product variety is a way to gain new market shares because it allows the company to meet the diversity of customer’s requirements, i.e. external variety, more closely (Kekre and Srinivasan, 1990, Park et al., 2004) and to increase customer satisfaction (Kekre and Srinivasan, 1990, Yeh and Chu, 1991, Khan, 1998). In result, revenues and profits tend to increase, because customers are willing to pay more for this external variety

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[5] See the section “Achieving efficient product variety” below.

[6] See the section “Achieving efficient product variety” below.

(Child et al., 1991, Kekre and Srinivasan, 1990, Ulrich, 2006). Some authors also suggest that product variety could be a competitive advantage from the point of view of marketing (Tang and Yam, 1996, Martin et al., 1998, Yeh and Chu, 1991).

Additionally, increased variety can help to increase capacity utilization. In fact, producing a larger variety of products helps to deal with demand drops for some of those products by switching the capacity used for those products to other ones (Fisher et al., 1995). Moreover, product variety can be understood as a form diversification strategy which aims to reduce the risk associated with one specific market segment (Bausch and Pils, 2009). Indeed, portfolio diversification is commonly presented as a risk reduction strategy (Bausch and Pils, 2009, Pandya and Rao, 1998). By extension, product variety, which is an aspect of business diversification, is also a risk reduction strategy. (Pandya and Rao, 1998)

Achieving efficient product variety

Being able to produce an high internal product variety efficiently is a strategic objective that can be labeled as manufacturing flexibility in the literature, or more specifically as (product) mix flexibility (Slack et al., 2010, Anderson, 1995). The topics of manufacturing flexibility, product mix flexibility, and how to achieve flexibility are largely discussed in the literature (e.g. Fernandes et al., 2012, Berry and Cooper, 1999, Upton, 1994, Sethi and Sethi, 1990, Gerwin, 1993). Achieving a cost-efficient flexible mix can also be seen as a form of economies of scope (Anderson, 1995). Economies of scope are achieved when producing different products in a single facility is less expensive than producing those products in different facilities, e.g. by only investing for a machine once and using it for processing two products instead of having a machine per product. In other words, economies of scope are "efficiencies formed by variety, not volume" (Goldhar and Jelinek, 1983), in opposition with economies of scale, which are achieved when the unit cost decreases when the volume increase.

However, the extent to which a company can increase its external product variety cost-efficiently does not exclusively depend on the flexibility of its supply chain and manufacturing processes. Indeed, several product architecture strategies can be implemented to increase external variety without creating too much internal complexity. Modularization and platform-based product development are two such strategies.

Modularization is a term with various meanings, used in different contexts, research fields and industries. However, there are common ideas behind those contextual differences (Erikstad, 2009):

- Division of a larger system into smaller parts, components, or sub-systems.

- Individual parts are relatively self-sufficient.
- Individual parts can be recombined into various end products, following “rules” of an overall “system architecture”, or product architecture.

Product architecture is “the scheme by which the function of a product is allocated to its physical components” (Ulrich, 1995). Götzfried (2013) highlights a trend for switching from integral to modular product architecture when product variety increases. In an integral product architecture, parts have typically several functions, are close to each other and synchronized, while in a modular product architecture, the parts are typically interchangeable, made of blocks connectable to each other, upgradable independently, and with standardized interfaces (Fine, 1998, Blackenfelt, 2001). Modularity is a way to “increase commonality” across the product portfolio, and thus to decrease internal product variety, while having several product variants, i.e. external variety (Salvador et al., 2002). Arnheiter and Harren (2005) argue that product modularization can reduce the costs, shorten development time, and help to better adapt to market changes.

A product platform consists of the set of parts and product variants designs shared among different products within a same product family. Product platforms allow to reduce engineering and design costs while decreasing time to market (ElMaraghy et al., 2013). A product platform is thus the core module of a product family, it is used as the base for all products within this product family. The platform has standardized interfaces, like every module, and it is combined with several “side” modules to create a product variant (Schuh et al., 2009).

2.1.3. Measuring product variety

The key measurements of product variety dimensions derivate directly from their definitions (Stäblein et al., 2011). Thus, measures should be defined for a specific dimension (i.e. internal or external) and, if necessary, level (i.e. fundamental, intermediate, or peripheral).

Internal peripheral variety can be measured by the number of options that can be added without altering the fundamental product structure and design (Stäblein et al., 2011, MacDuffie et al., 1996). MacDuffie et al. (1996) also propose, in the context of automotive manufacturing, a measure of internal intermediate variety, or “parts complexity”, which is an index based on different sub-measures. Those sub-measures include the number of parts variants which affects sequencing of operations, material flow and part flow into assembly. The intermediate variety index is then obtained by a ponderation of those sub-measures. Finally, they measure the internal fundamental variety based on the diversity of different product types and products variants. In his example, i.e. the automotive industries, this includes the number of platforms, the number of models (sharing a same platform), body styles, drive train configuration and export variations. Then each of those items is given a weight based on interviews from plant managers and scale, from 0 to 100, to obtain a variety index.

Stäblein et al. (2011) point out that while using those measures of variety, it is not easy to separate distinctly peripheral and intermediate variety or intermediate and fundamental variety as they are linked with each other. Furthermore, it is not clear what to include or not in those different measures. Finally, they insist that if these measures allow to compare firms within the same industry, they do not allow such comparisons across different industries.

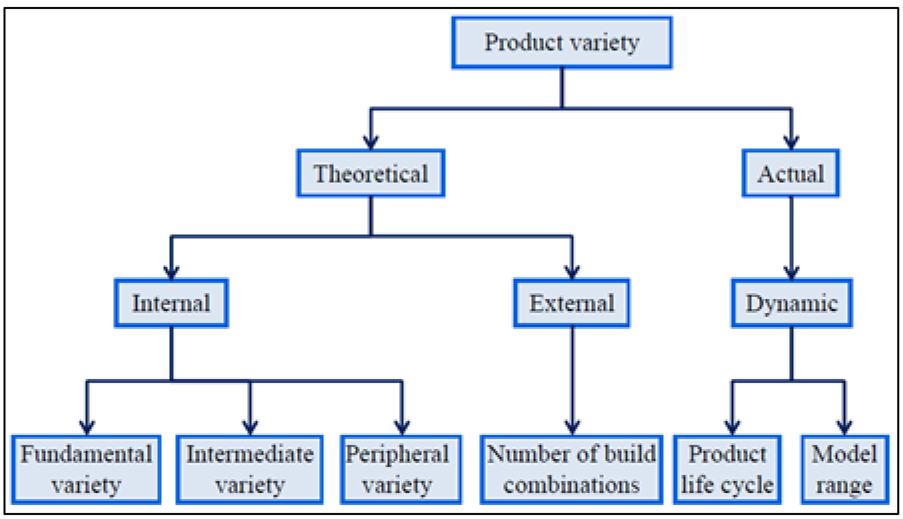


Figure 2 Classification of product variety dimensions and measures, adapted from Stäblein et al. (2011)

The dynamic dimension of product variety is also important to measure. Dynamic variety is driven by market changes and can be quantified by two measures: product life cycle and model range (Holweg and Pil, 2004, Stäblein et al., 2011). Product life cycle is the duration during which one product is on sale; it is usually measured in years. Model range is the range of products offered for a given model, in other words it is the number of variants within one "model" (or type, or product family), which varies over time. It can simply be measured by dividing the number of unique product configuration by the number of product model. A high dynamic variety is characterized by a large model range (i.e. many variants per product type) and short product life cycles (i.e. short time between one generation of product and its replacement) (Holweg and Pil, 2004).

Product variety being a multidimensional and multi-level construct, the measures related to this construct are also multidimensional and multi-level, as suggested in Figure 2 (Stäblein et al., 2011). However, past this question of variety "dimension" and "level", which could be ask as "where are we measuring variety?", there is also the question of "what are we measuring?". In the previous examples, what is measured in mainly a "number" of items (e.g. number of parts, number of variants, etc.).

In a very general way, diversity literature says we can measure the variety among several items, which are classified in different types, along three "axes" (Ranaivoson, 2005, Patil and Taillie, 1982, Stirling, 1998):

- The "multiplicity" of the types, which represents the number of different types among these items.
- The "balance" between the types, which represents the proportion for every type.
- The "disparity" between the types, which represents how much each type is different from another.

This distinction originates from ecological diversity literature but has later been adopted in economics and business (Stirling, 1998). Some of the most used indexes to measure variety are (Ranaivoson, 2005, Patil and Taillie, 1982):

- Species Count $= N - 1$,
- Shannon index $= -\sum_i^N \pi_i \log(\pi_i)$,

with N being the number of different types and π_i the proportion of type i, where $i \in [1, N]$.

"Species count" only measures multiplicity whereas "Shannon index" measures at the same time multiplicity and balance (Ranaivoson, 2005). Other indexes exist, some of them also measure disparity, which requires to estimate the "distance" between each type and another (Ranaivoson, 2005, Stirling, 1998). Stirling (1998) proposes an "integrated multicriteria diversity index":

$$M = \sum_{i,j}^{N} \pi_i \pi_j d_{ij},$$

with N being the number of different types and π_i the proportion of type i, π_j the proportion of type j, and d_{ij} the distance between type i and type j, where $i, j \in [1, N]^2$.

2.2. Shipbuilding

This section introduces the industrial context of shipbuilding. The main characteristics of ships as manufactured products are also presented. Then, the existence of a learning effect in shipbuilding is discussed. Finally, the development of modularization in shipbuilding is examined.

2.2.1. Process and characteristics

This section summarizes the characteristics of the shipbuilding industry and shortly introduces the process behind ship development and construction.

A shipyard, which as a main activity produces ships, is a typical Engineer-To-Order (ETO) company, which means that it designs, engineers and builds products on shipowner's orders and specific requirements (Nam et al., 2018, Mello and Strandhagen, 2011). In such a context, the Customer Order Decoupling Point[7] (CODP) is positioned before the design and engineering stage, and the production is directly determined by actual customer orders, and typical order winners are design, delivery speed and flexibility (Olhager, 2003). The main characteristics of ETO products and operations are (Hicks et al., 2000, Mello and Strandhagen, 2011) :

- Highly customized products to meet specific customer requirements.
- Very low production volume (one-of-a-kind or small series).
- Deep and complex product structures, levels of assembly process.
- Components are needed in different volumes from low to large volume.
- Similarly, components can be highly customized or standardized.
- Some systems need advanced control while other does not (e.g. structural steel work).
- Projects are costly, with a high share of risk and long lead times.

However, in shipbuilding, there are different degrees of product specialization and customization. "Ships range from highly customized types produced in low volumes, such as bespoke warships and cruise ships, to standard ship types produced in long runs over many years, as found, for example, in most contemporary builders of bulkers, tankers, and container vessels" (Semini et al., 2014). Thus, the position of the CODP

[7] The customer order decoupling point indicates how deep in the value chain a product is linked to an actual customer order. (Olhager, 2003)

can vary among shipbuilders and one shipbuilder can have different CODP positioning strategies (Semini et al., 2014). Indeed, in shipbuilding, as in other ETO industries, the customized product can be the result of a standard customization or of a non-standard customization. This means that the final product can be the result of completely new design and engineering processes, or that it can reuse, to varying extent, the design of existing parts, modules or platforms (Hagen and Erikstad, 2014, Johnsen and Hvam, 2018).

Shipbuilding is a complex process that involves numerous activities, such as design, tendering, negotiating, contracting, engineering, procurement, production, commissioning, testing, delivery, and guarantee service. The shipbuilding process is also complex by the numerous interactions between several actors: the shipyard organization, the customer, ship designers, partners, suppliers, sub-contractors, class, and authorities.

The key actors, from our perspective, are described below:

- The **customer** is the company, or private person, which purchases the ship, usually the future shipowner that will operate the ship as part of his fleet. In this thesis, the customer is considered to be the future shipowner and both terms are used to refer to the same.
- The **ship designer** is the company that completes most of the design and engineering work of the ship.
- The **shipyard**, or **yard**, or **shipbuilder**, is the company that builds the ship. It can outsource some part of the production to suppliers and subcontractors, but usually carries the final assembly. It can also be the ship designer.
- The **suppliers** are the companies that provide the yards with different kind of supplies, such as raw material (e.g. steel), equipment and finished ship systems (e.g. engines).
- The **sub-contractors** are external companies that provide workforce and services to the shipyard to carry the ship construction, typically specialized in one task (e.g. an electrician company).

It is not possible to give a generic description of the shipbuilding process. However, the main phases of the project shown in Figure 3 need to occur in order to complete the shipbuilding process.

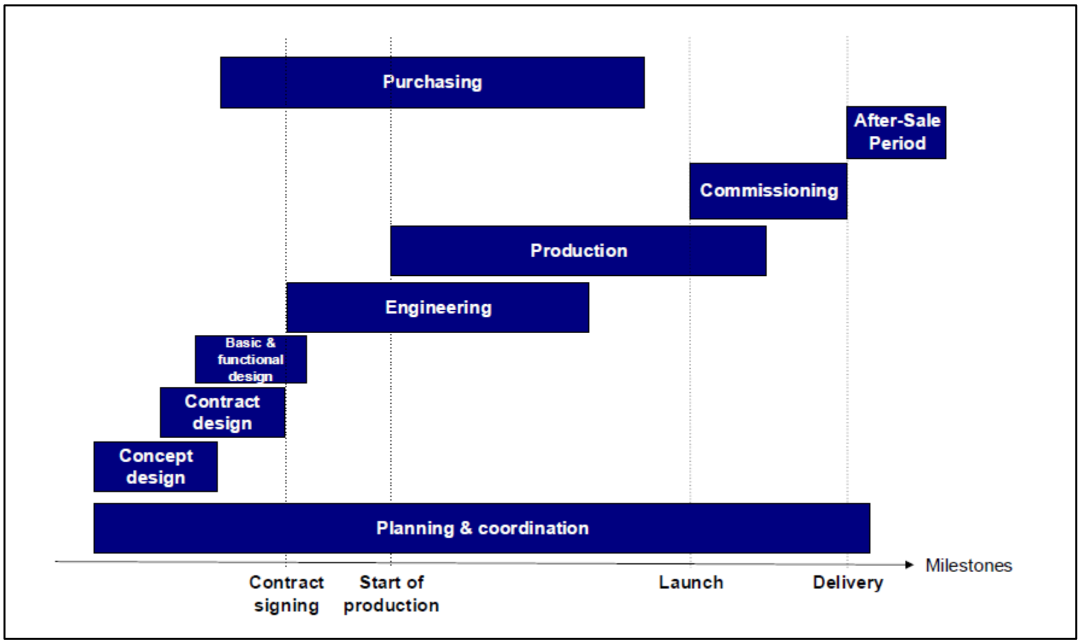


Figure 3 Main activities in the design and production of a customized ship (Semini et al., 2014)

However, the process may vary in different ways. For example, the shipyard can own the ship design, while in other cases the customer owns the design and asks for quotes from shipbuilders, while in other cases, the shipyard cooperates with a design company where design and engineering are outsourced. This will greatly influence the way the tendering and contracting processes will occur, as well as obviously the engineering and design phase (Hagen and Erikstad, 2014, Kanerva et al., 2002).

Ship production is the physical process of building a ship from raw materials, it can be divided in six different steps: steel block fabrication, the processing of steel into hull blocks; block outfitting; ship assembly; dock outfitting, before launching; quay outfitting, after launching; and commissioning and testing. Outfitting is the process of installing pipes, machinery, Heating Ventilation and Air-Conditioning (HVAC), cables, electrical system, and accommodation. Production is often started before precise design and engineering are finished in order to reduce lead time and costs (Kanerva et al., 2002, Hagen and Erikstad, 2014, Lamb, 2003, Semini et al., 2014).

The extent to which production is done inhouse is also variable. As shipyard become more advanced and professional, they tend to outsource and subcontract more and more work, resulting in a decrease of labor costs and an increase of purchase costs (Hagen and Erikstad, 2014). There are multiple reasons for this trend. A first reason is that customers are asking for well-proven and high-quality complex systems (e.g.

engines) supplied by recognized firms. Using sub-suppliers to provide such complex and costly systems also allows to achieve economies of scale (Hagen and Erikstad, 2014).

To reduce costs, some shipyards from countries with high labor cost, such as Norway, offshore the first steps of ship construction to low labor cost countries. Indeed, the initial steps of ship construction, such as steel works and block outfitting, are the lowest value-added tasks. The offshoring of those tasks, to Eastern-Europe for example, allows to reduce their costs by executing those tasks where the needed skills are available but at a lower cost. Indeed, large shipyards from Eastern-Europe can efficiently achieve those low value-added steps because of lower local wage and the possibility for those large shipyards to achieve economies of scale on the purchasing and processing of steel for example. On the other hand, high value-added tasks, such as advanced outfitting, are more likely not to be offshored as they require more skills and their quality is harder to check. However, the level of tasks done abroad can vary from a yard to another (Semini et al., 2018).

Sub-contracting and outsourcing also allows to reduce labor costs for shipbuilders. Indeed, a lower permanent workforce, and thus a highest use of outsourcing and sub-contracting, allows more flexibility for the shipyard and decreases the fixed costs. A low permanent workforce allows the yard to be more resilient when demand drops occur (Hagen and Erikstad, 2014).

Overall, it is hard to give a generic overview of shipbuilding processes as the way projects are carried and the extent to which design, engineering and construction are outsourced, sub-contracted or offshored will depend on the yard’s strategy and on the project. From this point of view, the variety of ships to be manufactured by a shipbuilder is also a challenge as more product variety implies more variety in the processes.

As an ETO industry, shipbuilding is subject to important fluctuations in sales volumes and product mix, implying a high uncertainty for future demand (Bertrand and Muntslag, 1993). Indeed, the customer order driven nature of shipbuilding makes it highly sensitive to macro-economic changes as mentioned and exemplified in the introduction. Uncertainty also exists in the product specification, as product specifications only become clearer when the project goes on and the design and engineering are carried out. Furthermore, these specifications vary with the frequent order changes (Kanerva et al., 2002, Sjøbakk et al., 2014). In the next section, a characterization of ships as products is developed.

2.2.2. Product

In this section we describe the main products of shipbuilders, i.e. ships. We explain how ships can be described as system and how they are categorized.

Ships as complex systems

Ships are big sized and complex products with deep product structure. They include a high level of customization and are typically produced in low volume. The ship is in general a one-of-a-kind product and is carried out as a single project (Kanerva et al., 2002, Mello and Strandhagen, 2011).

The complexity of ships as systems implies complexity in the shipbuilding process. Each new system requires new drawings, new purchases, and sometimes new suppliers. This will add a lot of complexity to the physical and informational processes. The management of this information during a project requires a lot of organization. To organize this information and to be able to find and reuse it in a subsequent project, system breakdown structures are typically used. The SFI[8] group system is an example of a standard coding system, first developed for accounting, which is largely used in shipbuilding (Hagen and Erikstad, 2014). It provides a function-oriented code to breakdown all ship characteristics in a structured and standardized way, with 8 main groups as shown in Table 2 (Urke, 1976).

Table 2 The SFI coding system main groups: a typical breakdown structure for ships

Group	Name	Description
1	General	Details or costs that cannot be linked to any specific vessel function (e.g. general arrangement, quality assurance, launching, dry-docking and guarantee work).
2	Hull Systems	Hull, superstructure, and material protection.
3	Cargo Equipment	Cargo equipment and machinery.
4	Ship Equipment	Ship specific equipment and machinery, navigational equipment, maneuvering machinery, anchoring equipment, and communication equipment. Also includes special equipment (e.g. fishing equipment).
5	Crew and Passenger Equipment	Equipment, machinery, and systems serving crew and passengers (e.g. furniture, water, and food supplying equipment, sanitary).

[8] SFI: *Skipsteknisk Forskningsinstitutt*

6	Machinery Main Components	Primary components in the engine room, for example engines, propellers, and generators.
7	Systems for Machinery Main Components	Systems serving main machinery components, for example fuel systems, exhaust systems and automation systems.
8	Common Systems	Central ship systems, for example ballast and bilge systems, firefighting and wash down systems, electrical distribution systems etc.

The SFI system is one example of a systemic approach to ship description. Such an approach considers a ship as a complex system combining diverse subsystems and their parts. Each of them are serving precise ship functions (Papanikolaou, 2010). The ship functions (and the corresponding subsystems) can be divided in to two groups (Papanikolaou, 2010):

- "*Inherent*" ship functions, which are common to all ships (e.g. propulsion, safety, navigation);
- "*Payload*" ship functions[9], or mission specific ship functions, which are related to the specific purpose of the ship (e.g. fishing equipment for fishing vessels, cargo handling equipment for cargo ships).

Ship characteristics and structure are to a large extent dependent on the type of ship they belong to. Indeed, the ship type defines what mission specific, or "payload", functions the ship must be able to execute, and thus the corresponding subsystems it must carry. For example, cranes for handling cargo for cargo ships, fishing equipment for fishing ships, leisure facilities for cruise ships… Besides, the ship subsystems corresponding to the inherent ship can have a different importance from a ship type to another. For example, systems related to crew accommodation will have much more importance on a cargo traveling on long distances than on a ferry providing short links.

The variety in ship characteristics and building processes is, in consequence, highly related to the ship type. Thus, it is of interest for the purpose of this project to explain how ships are classified into types.

[9] "For cargo ships, the payload functions are related to the provision of cargo spaces […]. Likewise, for passenger ships, the payload functions are trivially referring to the provision of passenger accommodation and public spaces." (Papanikolaou, 2010). Similarly, we can extend the notion to all mission specific ship functions.

Ship types

There is no universally applicable categorization of ship types (International Maritime Organization, 2019), and the way ships are categorized depends on the pursued goal and can be more or less deep and precise. As a first classification, Colton (2003) divides the world fleet of ships and “floating structures” into five broad categories:

- cargo ships: commercial ships, primarily designed to carry world’s trade on oceans;
- passenger vessels: commercial vessels designed to carry passengers and vehicles;
- naval vessels: ships, boats and craft operated by navies, coast guards and other military or law enforcement agencies;
- other self-propelled vessels including:
  - ships and craft used for catching, processing, and transporting fish and fish products,
  - ships and craft used for the offshore exploration and production of oil and gas,
  - tugs and towboats,
  - and all other commercial vessels that do work rather than carry cargo or passengers;
- barges and other inshore and river vessels.

For this work, it would be interesting to use a more detailed classification. Furthermore, our focus can be narrowed to commercial and working ships, thus excluding naval vessels and barges. The *Statcode 5 Shiptype Coding System* is a coding system that classifies ships in different types and subtypes in a 5-level system developed by IHS Markit and the Lloyd’s Register – Fairplay (IHS Markit, 2017). It is widely used and recognized by the International Maritime Organization and the OECD. The first three levels of this classification are summed up in Table 3, for a complete overview of the coding system see Appendix 1.

Table 3 First 3 levels of the Statcode 5 ship type classification

Level 1	Level 2	Level 3
Cargo carrier	Tankers	Liquified Gas
		Chemical
		Oil
		Other Liquid
	Bulk Carriers	Bulk Dry
		Bulk Dry/Oil

		Self-Discharging Bulk Dry
		Other Bulk Dry
	Dry/Cargo/Passenger	General Cargo
		Passenger/General Cargo Ship
		Container
		Refrigerated Cargo Ship
		Ro-Ro Cargo
		Passenger/Ro-Ro Cargo
		Passenger
		Other Dry Cargo
Work vessel	Fishing	Fish Catching
		Other Fishing
	Offshore	Offshore Supply
		Other Offshore
	Miscellaneous	Research
		Towing/Pushing
		Dredging
		Other Activities

Ship dimensions

Another set of key characteristics of ships are their physical dimensions and capacities. These dimensions, capacities and their measures are of diverse nature and varies with the ship types and industries (Hagen and Erikstad, 2014).

The ship physical dimensions include (Kemp and Dear, 1976):

- The length, that can be measured as the length overall (LOA), the length on load water line (LWL), the length between perpendiculars (LBP)…
- The breadth, or beam (width).
- The depth.

One of the most important parameters for commercial ships owner is the load that a ship can carry. The measures for this load are specific to ship types, but the most common are (Hagen and Erikstad, 2014, Kemp and Dear, 1976):

- Deadweight (DWT). The weight of cargo possible to carry for cargo ships;
- Container capacity (TEU). The number of twenty-foot equivalent (TEU) containers that a containership can carry;
- Cubic feet (CUF) or cubic meters (CUM) of gas, for tankers;
- Passenger units (PAX), lane meters (LM) or car units (CEUs), for passengers/Ro-Ro ships;
- Bollard pull (BP), tank capacity (CUM), deck area for cargo (M2), rescue capacity (numbers of persons), for offshore supply/support vessels.

However, for statistics and other purposes, a common measure has been largely used: Gross Tonnage (GT). Gross tonnage is a measure of volume (and not weight), which is related to the internal ship volume (Hagen and Erikstad, 2014). It is mainly used as a measure of the output of ship production, but also in legislations, regulations, and other classifications.

However, because of the expanding variety of ship types, the Compensated Gross Tonnage (CGT) was introduced by the OECD in 1977, and revised in 2007, to also reflect the complexity of the ships being produced, and not only their volume (Hagen and Erikstad, 2014). This measure allows to represent the quantity of work needed for the building of a ship, allowing to compare between different ship types, where GT only allows comparison between ship from the same type (OECD, 2007).

The CGT of a ship is calculated as follow, according to OECD guidelines (OECD, 2007):

$$CGT = A * GT^B$$

Where GT is the gross tonnage of the ship, and the coefficient A and B depends on the ship type as shown in Table 4.

Table 4 The CGT factors (OECD, 2007)

Ship type	**A**	**B**
Oil tankers (double hull)	**48**	**0.57**
Chemical tankers	**84**	**0.55**

Bulk carriers	**29**	**0.61**
Combined carriers	**33**	**0.62**
General cargo ships	**27**	**0.64**
Reefers	**27**	**0.68**
Full container	**19**	**0.68**
Ro-ro vessels	**32**	**0.63**
Car carriers	**15**	**0.70**
LPG carriers	**62**	**0.57**
LNG carriers	**32**	**0.68**
Ferries	**20**	**0.71**
Passenger ships	**49**	**0.67**
Fishing vessels	**24**	**0.71**
NCCV	**46**	**0.62**

2.2.3. Learning effect in shipbuilding

For the scope of this study, a relevant stream of research is the research about learning effect, or series effect. Learning effect is the process by which learning tend to increase productivity; each time the cumulative production volume doubles, the unit cost and/or production time decreases by a given percentage (Erichsen, 1994). Several studies have investigated the learning effect which occurs when building ships in series, which means that several ships of the same design are built consecutively (Erichsen, 1994, Pires et al., 2008). Their main findings can be summarized as follow:

- There is a learning effect when building ships in series. Indeed, it is observed that there is a reduction of the production cost per ton of steel (Erichsen, 1994) and of the total required workload per ship (Pires et al., 2008) between successive ships in a same series;
- We can model this effect mathematically (see Figure 4);
- Some factors can deteriorate the learning effect: e.g. stopping a series for an 'odd' contract (i.e. producing a different ship model in the middle of a series) or changing of subcontractors.

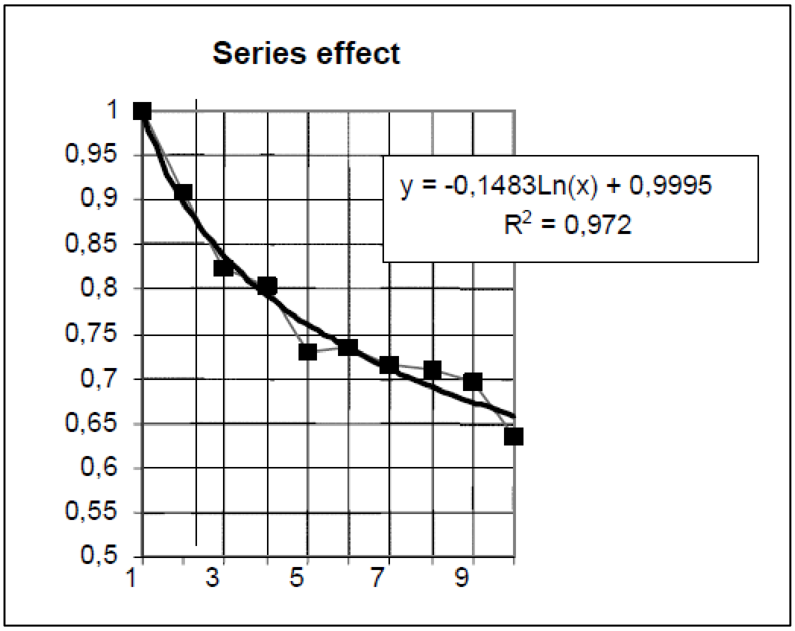


Figure 4 Relative workload (number of man-hour) from the first to the 10th ship (OECD, 2007)

It is assumable that a similar learning effect might be observable for ships which are similar enough, meaning for example between ships from the same type.

2.2.4. Modularization in shipbuilding

Shipbuilding is usually described as an ETO industry, and ship production has traditionally been carried based on one-of-a-kind projects with very limited modularization efforts (Erikstad, 2009). However, modularity in product architectures design allows flexibility in product configuration by mixing and matching standard components, which could be highly relevant in shipbuilding due to the high cost and work charge of design and engineering tasks. Salvador et al. (2002) highlight that it is commonly claimed that modularity allows companies to increase product variety without major effect on operational performance. That is why there are still some relevant initiatives in regard to modularization in shipbuilding, Erikstad (2009) lists several projects that have been exploring and/or implementing modularization in shipbuilding.

The project “Equipment, modularization and arrangement”[10] (Hagen, 1998) aims to identify key factors to select and design module-based arrangement solutions. Among other conclusions, this report shows that:

- Module-based solutions have benefits, but they also have costs that need to be offset and spread.
- Shipbuilders, shipowners (customers) and suppliers have different objectives to achieve when it comes to modularization and design of modules:
    - Shipowners require a focus on operational efficiency and maintainability;
    - Shipbuilders and suppliers will prefer solutions which decrease production time and costs.
- There are several factors that can act as barrier to modularization of shipbuilding. These factors are from diverse nature:
    - *Technical factors*, for example a reduction in freedom for customers to specify exact performances, but instead having to choose from a collection of predetermined configurations;
    - *Techno-economic factors*, for example increased weight, volume and area requirements because of standardized foundations replacing specifically optimized solutions;
    - *Business relationship related factors*, for example in order to implement modular solutions, the yard needs to collaborate with the suppliers, while without modularization the yard had a higher bargaining power as it could choose between competing suppliers;
    - *Financial factors*, for example large modules can require early installation, which may increase the need for capital early in the construction;
    - *Production related factors,* for example large modules require increased crane capacity, and maintaining openings in the ship in order to proceed to their installation.

The main drivers and drawbacks of modularization in shipbuilding, according to Erikstad (2009), are summed up in Table 5.

[10] « *Utstyr, modularisering og arrangement* » in Norwegian.

Table 5 Drivers and drawbacks of modularization in shipbuilding (Erikstad, 2009)

Drivers	**Drawbacks**
• Product variety and customization • Production efficiency • Reduced lead time • Product development and design • Reduced risk • Outsourcing and globalization of supply chain	• Less optimized physical architecture, increased weight, and size • Less optimized performance, excessive capability • Risk of product similarity

2.3. Results from "Theoretical assessment of product variety in shipbuilding and its effect on performance"

The theory presented below is a summary of the main and most relevant theoretical findings from the specialization project "Theoretical assessment of product variety in shipbuilding and its effect on performance".

2.3.1. Product variety in shipbuilding

The main contribution of the previously cited project is a proposition of a categorization of shipbuilding product variety dimensions. Indeed, the applicability of the generic classification of product variety in the context of shipbuilding is questionable.

External variety in shipbuilding

External variety is defined as the variety of products that is visible to the customer (Pil and Holweg, 2004). In more "classical" manufacturing situation, such as Make-To-Stock (MTS), Assemble-To-Order (ATO) or Make-To-Order (MTO)[11], the customer chooses from already designed and engineered products. On the

[11] See Ohlager (2003) for a description of MTS, ATO and MTO strategies.

other hand, in ETO the CODP is positioned before the design stage, this means that the customer does not choose a product which is designed and engineered, or at least not completely.

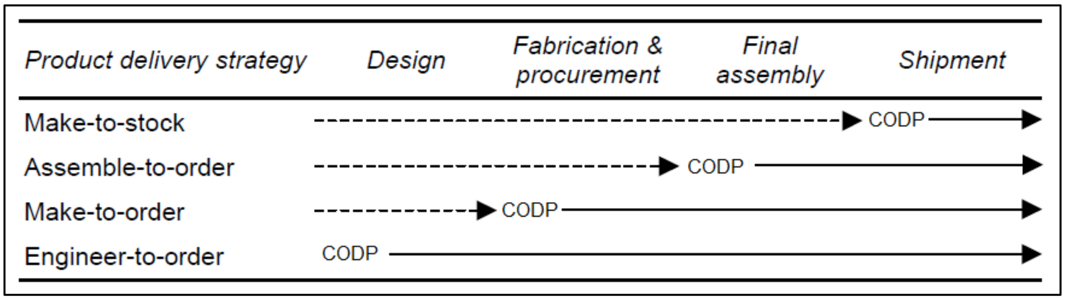


Figure 5 Position of the Customer Order Decoupling Point for different delivery strategies (Ohlager, 2003)

Thus, it is impossible to measure the choice for a customer as the number of possible or existing configurations for a customized ship. Indeed, unlike in an MTS, ATO or MTO context, where external variety can be measured as the number of possible or existing product configurations, the number of possible product configuration for a customized ship is infinite. Actually, for ETO companies, product variety has to be observed from the perspective of a “product solution space” which is infinite, rather than as a finite number of product variants (Haug et al., 2013). Haug et al. (2013) define a product solution space as “all the product variants, which variable product characteristics can produce (e.g. length, component type, assembly principle, etc.)”. For ETO companies, which shipbuilding companies are a typical example of, this solution space does not have precise limits, and identified product solutions part of this space are not guaranteed to be manufacturable at a reasonable cost (ElMaraghy et al., 2013).

If the number of possible “ship configurations” inside the solution space of a shipyard is infinite, it does not mean that all shipbuilders manufacture ships from all types and sizes. They are positioned on certain market segments, depending on their geographical and economic environment, on their manufacturing capacities and on their historical choices. Such a positioning result in a limitation of the solution space. Again, the limits of a shipyard’s solution space are blurry and are not fixed in time. For example, a yard may have a length limit for the ships it can manufacture because of the length of its dry dock. However, they can still be able to perform quay outfitting tasks on longer ships or they can at some point decide to extend their dry dock capacity to increase the size of ships.

We can describe the external variety, i.e. the choice “visible” to the customer, of a shipyard as the variety of ships that exist in the solution space of this shipyard. In other words, the external variety of a shipyard is the variety of ships it can offer to build. This includes the range of choice in all ship characteristics, some of those characteristics have a finite number of possible value (e.g. a shipyard is able to produce N ship types), some have values in a given interval (e.g. the shipyard layout does not allow to produce ships longer than x meters), while many of those characteristics are entirely customizable to customer order. This external variety includes the collection of "on the shelf" designs that the shipyard owns and can propose to adapt to customer's requirements, but also the ships it is hypothetically able to design and build in response to customer's needs. In that sense, external variety of a shipyard is dynamic, meaning it will change with yard capacities expansions, changes of market positioning, recruitment, and formation of workforce...

Internal variety in shipbuilding

The internal variety was defined as the variety that results from the translation of the customer's requirements into variety of requirements for the company's manufacturing process requirements and supply chain requirements (Pil and Holweg, 2004, Holweg and Pil, 2004, Götzfried, 2013). In other words, the question is to understand what the ability to answer and solve a variety of customer's requests implies for the shipyard, and to understand how this variety is handled internally. A first distinction from external variety is that internal variety refers to the variety of the ships that have actually been built, designed, and engineered. This means that it includes the diversity that was realized in order to respond to actual customer orders, or the diversity that was created by the shipyard as an anticipation for future models, or through standardization and modularization programs for example.

Based on MacDuffie et al. (1996), three categories of internal variety were defined: fundamental, peripheral and intermediate. However, Stäblein et al. (2011) points out that what those categories include and how they relate to each other depend on the industry under study. Therefore, the specialization project included a discussion on how to apply them to shipbuilding. Eventually, an adaptation of this categorization is proposed because the generic ones does not fit in the context of shipbuilding.

Fundamental variety

Fundamental internal variety includes the diversity of basic products produced by a company in terms of types, platforms and models (MacDuffie et al., 1996). For a shipbuilder, this could be described as the diversity in the main characteristics of the ship it builds. Although it could be discussed what the main characteristics of ships as manufactured products are, some relevant ones can be listed based on the previous description of ships as products. The fundamental product variety for a shipbuilder can be characterized by:

- the variety of ship types it builds and has built;
- the range of ship dimensions it builds;

- the variety of hull and ship design it owns and creates;
- the number of ship platforms it uses to carry design and building of ships;
- and, the degree to which its ships are modular.

We could also add other characteristics in relation with the building process, such as the diversity of the building strategies (including offshoring, outsourcing, sequencing of activities, etc.) applied to carry the construction of the ships, although this goes beyond the strictly speaking "product" variety.

Intermediate variety

Peripheral variety was described as the diversity of product features (or "options" in the context of automotive industry) that does not impact the basic product design, while intermediate variety refers to the diversity among components and parts used to differentiate end items without significant impact on the basic design but with an impact on the manufacturing operations and supply chain (Götzfried, 2013, MacDuffie et al., 1996, Stäblein et al., 2011). Stäblein et al. (2011) notes that the difference between peripheral and intermediate variety is sometimes not obvious. Furthermore, given the ETO nature of shipbuilding, it is difficult to define optional features for ships as for cars or other mass customized product.

That is why we consider the second level of variety as the intermediate variety, which also somehow capture the peripheral variety as defined by MacDuffie et al. (1996). For shipbuilders, this can be described as the diversity at the ship sub-systems level, rather than at the "parts" level. The peripheral product variety for a shipbuilder can be characterized by:

- the variety of engine types, size, etc.;
- the variety of machinery equipment;
- the variety of mission specific equipment, including e.g. the variety of fishing systems for fishing vessels or the variety of cabin size and models for cruise ships;
- more largely, the variety in all the ship subsystems and equipment, e.g. navigational equipment, maneuvering machinery, anchoring equipment, or communication equipment.

Again, the above list is not exhaustive, and it can be discussed that the listed features have different impacts on both the general ship design and structure, and on the manufacturing processes or supply chain requirements. It is also interesting to note that intermediate variety, as discussed here, is largely inherited from the variety at the higher level, i.e. the fundamental variety. For example, building a larger variety of ship types requires a larger variety of equipment and systems.

Component level variety

To go deeper in the product structure, another level of variety can be introduced to capture the variety at the component, or “parts” level. Here, the attention is drawn on the fact that the concept of intermediate variety was adapted which is why it differs from the original definition. This diversity at the component level has a low impact on general ship design and main manufacturing production sequence and operations. It includes, among others, the variety in parts such as screws and bolts, the variety of paint types and colors, the diversity of raw materials (e.g. steel types), the variety of required hand tools used during ship production or the variety of pipes diameters.

Table 6 Description of the different dimensions and levels of product variety for a shipyard

Dimension of variety	**Level of variety**	**Description**
External		Diversity of **potential** product variants solutions available to the customer Shipyard’s “solution space”
Internal		Diversity of **actual** product variants solutions designed and built to meet customer’s orders and diversity of the corresponding processes
	Fundamental	Diversity at the ship level Includes the variety of ship type, ship dimensions, hull and ship designs, ship platforms, building strategy
	Intermediate	Diversity at the sub-systems level, with low impact on general ship design but relatively important impact on manufacturing processes or supply chain requirement Includes the variety of engine types, variety of required machinery
	Component	Diversity at the part level, with low impact on general ship design and main manufacturing processes Includes variety in parts such as screws and bolts, paint colors, required hand tools

2.3.2. Measures of the product variety in shipbuilding

Stäblein et al. (2011) point out that the measures of the different dimensions of product variety:

- derivate directly from the definition of these dimensions;
- are usually **industry specific** allow to compare firms within the same industry, they do not allow such comparisons across different industries;
- are complex to develop because it is not clear what to include or not in those measures.

Thus, it is needed to review measures which are specifically related to shipbuilding in regard to the categorization of the dimensions of product variety in shipbuilding. Unfortunately, due to the lack of studies regarding product variety in shipbuilding, there are very few such measures. However, a first measure of product variety, at the fundamental level, is the number of ship types produced. Lamb and Hellesoy (2002) propose, in their formulation of the productivity of a shipyard, to investigate the effect of the following variable:

$$\frac{Total\ number\ of\ ships\ produced\ during\ the\ last\ \boldsymbol{n}\ years}{Number\ of\ ship\ types\ during\ the\ last\ \boldsymbol{n}\ years}$$

Other measures can be implemented at different level of variety (e.g. diversity of engines at the intermediate level) and along the different axes of variety (e.g. number of different engines, share of each type of engine and degree of difference between each engine type). In the end, there are a plenty of possible measures and the choice of the measure should be in adequation with the objectives.

Conclusion

The specialization project concludes that the generic categorization does not match completely with the context of shipbuilding. Indeed, in an ETO context, customization is inherent to the product design and the concept of “optional” feature is not pertinent. Thus, we cannot clearly define a peripheral variety as in a mass customization context (e.g. automotive industry). Furthermore, due to the high complexity of ships and their deep product structure, we differentiated the variety on the sub-system level, the intermediate variety, and on the component level. An overview of the adapted categorization is proposed in Table 6.

In the next section, the concept of firm performance is reviewed.

2.4. Firm performance

This section will provide an overview of the concept of firm performance, as described and used in the strategic management literature.

2.4.1. Firm performance: definition

Strategic management is an applied field of research that aims to understand and explain the success or failures of firms, and, ultimately, to maximize the performance of firms (Rumelt et al., 1995, Selvam et al., 2016, Guerras-Martín et al., 2014). Firm performance, or organizational performance, is thus a crucial concept for strategic management researchers and practitioners (Combs et al., 2005, Rumelt et al., 1995). Firm performance could be defined as the ability of a firm to maximize "the utilization of resources in relation to organizational objectives which are in conformity with the demands of the business environment" (Selvam et al., 2016). However, strategic management researchers do not come to a consensus on the conceptualization of firm performance, and on the measurements of performance (Selvam et al., 2016, Combs et al., 2005). Indeed, Combs et al. (2005) and Venkatraman and Ramanujam (1986) point out that strategic management literature contains a high variety of different and unconnected performance measures. For Combs et al. (2005), this demonstrates that performance is a construct with a broad definition and multiple dimensions. Yet these dimensions are usually undefined and unrelated to each other.

2.4.2. Multidimensionality of firm performance

Venkatraman and Ramanujam (1986) propose a model composed of three concentric circles representing the three areas of performance measures in strategic management (see Figure 6). The largest circle represents organizational effectiveness, which is a too broad concept to be utilized in research, according to Venkatraman and Ramanujam (1986). The middle circle represents operational performance, which contains measures, which are non-financial and specific to some operational areas, e.g. product quality, level of innovation or construction time. The smallest circle represents financial performance, which contains measures of the firm financial outcomes, including sales growth, accounting returns (e.g., Return on Investment (ROI), Return On Equity (ROE) or Return On Asset (ROA)), and the stock market (e.g. share price). The two smallest circles together (both non-financial, i.e. operational, and financial measures) represents "Business Performance".

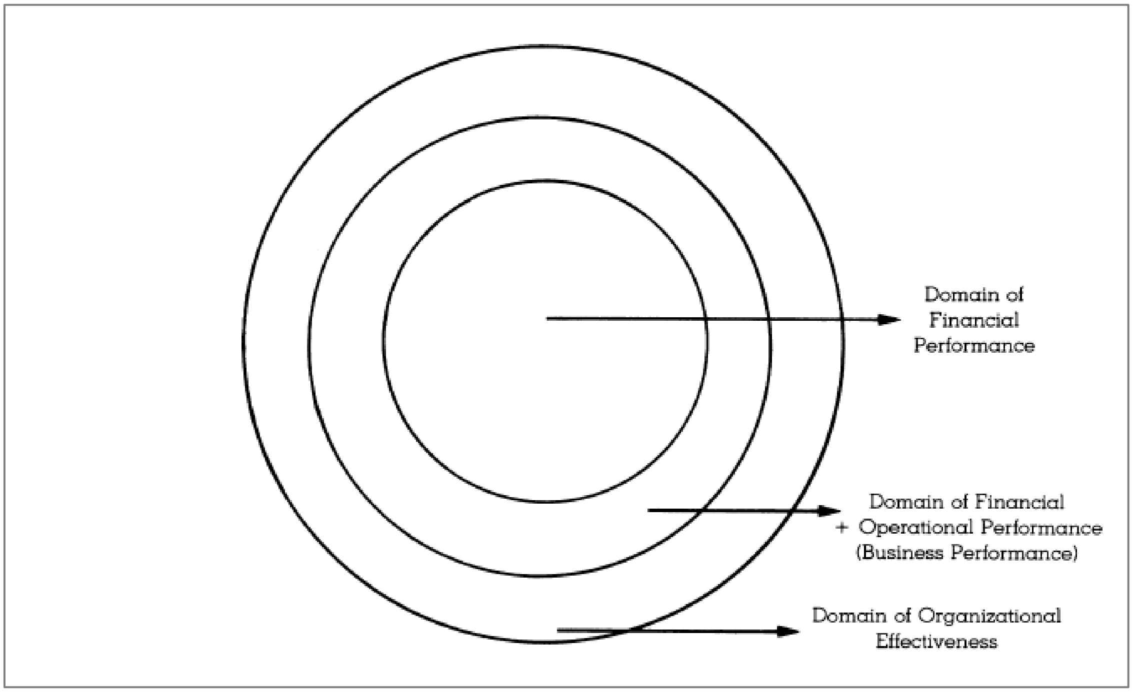


Figure 6 The domains of firm performance, from Venkatraman and Ramanujam (1986)

According to Venkatraman and Ramanujam (1986), using only measures from the two inner circles is desirable in order to reduce the scope of performance. However, inside the two inner circles there is still an important multidimensionality (Combs et al., 2005).

Based on a literature review, Selvam et al. (2016) propose a classification of nine determinants of firm performance. Those determinants, or dimensions, are profitability performance, growth performance, market value performance of the firm, customer satisfaction, employee satisfaction, environmental performance, environmental audit performance, corporate governance performance and social performance. Those nine determinants are grouped in two performance groups: financial performance and strategic performance.

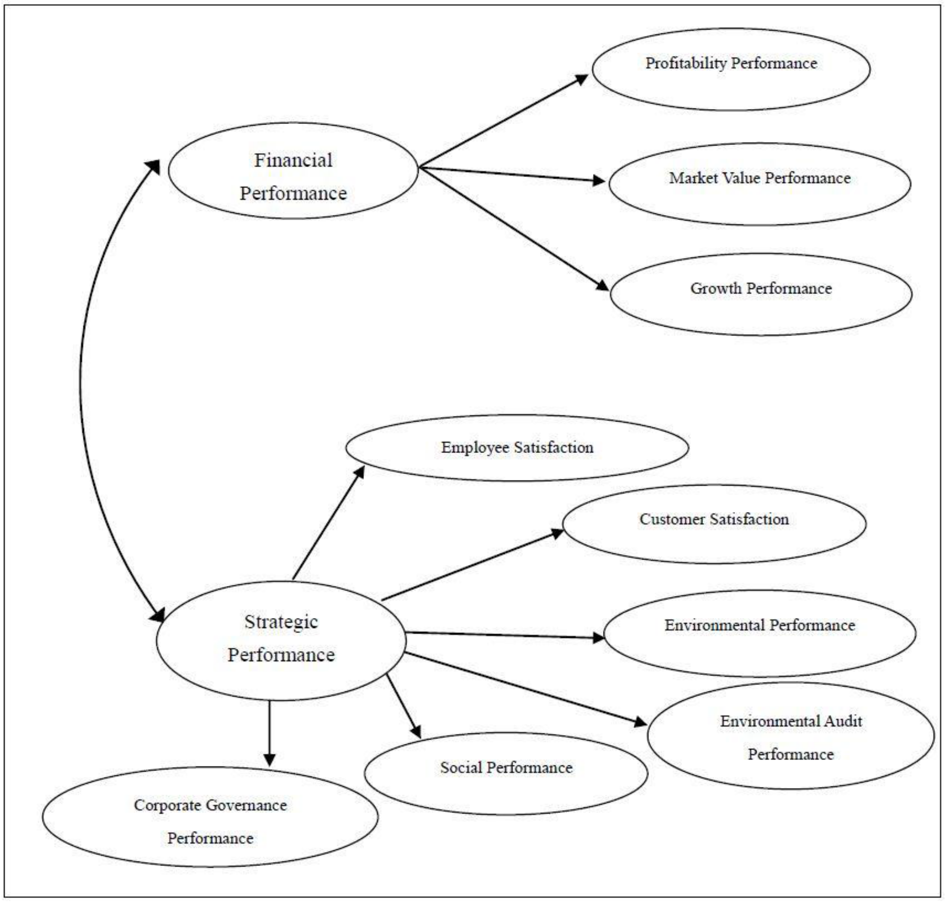


Figure 7 Grouping of nine dimensions of performance, from Selvam et al. (2016)

For each of the nine determinants, Selvam et al. (2016) proposes indicators that reflect performance in each dimensions[12]. They also list associated parameters or ratio that allow to assess performance[13].

This category is not universal, even if it gives a foundation for other research (Selvam et al., 2016). Moreover, it shows that multidimensionality of firm performance should be investigated as part of the research process.

For the current study, relevant dimensions of performance could be grouped in financial performance and operational performance. Both groups are discussed in the two next sections.

[12] See Appendix 2.

[13] See Appendix 3.

2.4.3. Operational performance

Operational performance regroups all the performance criteria which are non-financial ones (Venkatraman and Ramanujam, 1986). Operational performance is also multidimensional, and most of the dimensions proposed by Selvam et al. (2016) could be used in the context of shipbuilding (e.g. customer satisfaction or environmental performance), depending on the purpose of the study.

However, it is important to note that, in most of the literature regarding shipbuilding, the preferred approaches are the study of shipyard's manufacturing performance, and to a lesser extent, on design, engineering and customer satisfaction related performance. Some of the operational performance indicators used in the literature are presented in Table 7, together with related assessment methods and limitations.

Table 7 Operational performance objectives and indicators in shipbuilding studies

Study	**Objective**	**Performance indicator(s)**	**Performance assessment method(s)**	**Identified limitation(s)**
Lamb and Hellesoy (2002)	Develop a predictor (formula) for shipyards productivity	Productivity in MH/CGT (Man-Hour per Compensated Gross Tonnage)	Surveying of shipyards	Low response rate to the survey
Pires et al. (2009)	Propose an identification method to identify efficient and inefficient shipyards	Labor productivity MH/SCGT (SCGT: Series effect CGT) Building Time Index (Building time: keel laying to delivery) (Quality: impractical to measure in this study)	Shipyards visit, interviews, and online databases (e.g. Lloyd's Register)	Divergences between databases
Semini et al. (2014)	Compare strategies for customized ship from the perspective of the CODP	Production cost, Lead time, Delivery precision, Customization level…	Qualitative assessment, interviews	No empirical validation

Semini et al. (2018)	Compare offshoring strategies for shipbuilding	Five performance "objectives": Cost, quality, delivery dependability, delivery time, and flexibility	Interviews, open source data, company reports, conferences…	Mainly qualitative approach Lack of data availability
Koenig et al. (2003)	Quantitative indication of productivity improvement and trends in Japan and South Korea	Productivity in CGT/M (CGT per Man, i.e. worker) and CGT/MH Delivery time	Secondary data from other studies	

Shipbuilding literature usually use productivity as a measure of shipyard's performance (Colin and Pinto, 2009). Productivity is measured as the production output divided by its input (Lamb and Hellesoy, 2002). The usual measures for the output of shipbuilding are GT (Gross Tonnage), CGT (Compensated Gross Tonnage), or, less frequently, SCGT (Series effect Compensated Gross Tonnage[14]) (Lamb and Hellesoy, 2002, Pires et al., 2009, Pires et al., 2008, Colin and Pinto, 2009).

Usually, employee hours (in MH) is used as the input for productivity, which is thus generally expressed in CGT/MH, to get a measure of productivity (Colin and Pinto, 2009, Krishnan, 2012). However, Colin and Pinto (2009) point out that if this measure is powerful to compare the operational performance of shipyards, this is only relevant for shipyards with similar level of automation and outsourcing strategies for example. They further develop:

> *"A work force productivity comparison of shipbuilders with different levels of automation can be misleading since more automation usually means more productivity (fewer employee hours) but more depreciation costs. Thus, an automated shipyard may have exchanged the work force cost by the capital employed cost, and a smaller workforce in this context does not necessarily mean too much for the financial outcome or long-term success of the shipyard." (Colin and Pinto, 2009)*

[14] While CGT takes into account differences in the necessary workload to produce different ships, SCGT, as introduced by Pires et al. (2008), also takes into account the difference of workload that appears with series effect.

Colin and Pinto (2009) therefore suggest using total cost (C) per CGT (including labor, materials, outfitting, indirect cost, subcontractors, and other costs) as a more complete measure of productivity. This measure of performance allows better comparison of shipyards' competitiveness.

Other performance measures might be related to time variables (e.g. building time, delivery precision/dependability) or quality (e.g. percentage of re-work), according to the builder's performance objectives. Finally, additional performance objectives can be described as flexibility objectives, which can be divided as follow (Slack et al., 2010, Semini et al., 2018):

- Product flexibility: ability to introduce new and modified products;
- Mix flexibility: ability to produce a wide range or mix of products;
- Volume flexibility: ability to change the level of output;
- Delivery flexibility: ability to change the delivery dates.

Product flexibility and mix flexibility are strongly related to product variety. Indeed, we could define product flexibility as the ability to achieve generational variety and mix flexibility as the ability to propose spatial variety, as discussed earlier. In this study, we consider product variety more as a strategic input rather than a performance objective, however, it can be considered as both.

The use of operational performance measures is widespread in shipbuilding literature as shown above. However, some authors note that there is a major limitation to their use in large scale studies. The data availability is somehow limited when it comes to shipyards strategic performances. For example, Lamb and Hellesoy (2002) note a "disappointing" response rate for their survey, notably in the US with a 17% response rate, and in Europe with a 14% response rate. The main reason is that shipbuilding is a very competitive business, and shipbuilders are therefore reluctant to share data about their performances and costs (Semini et al., 2018, Krishnan, 2012). Thus, it seems unpractical and optimistic to carry a large scale study using operational performance measures, without the straight support of a majority of shipbuilding firms (Lamb and Hellesoy, 2002).

On the other hand, it seems that financial performance measures can overcome this barrier, as discussed in the next section.

2.4.4. Financial performance

Profit and profitability is the ultimate goal of private firms, thus it is natural to consider financial performance as the main performance objective of any firm (Venkatraman and Ramanujam, 1986). Moreover, we can consider that operational performance objectives are just intermediary steps to achieve financial performance (Combs et al., 2005). Indeed, financial performance objectives and measure are commonly used in strategic management research (Combs et al., 2005).

Financial performance measures have been used in multiple studies related to shipbuilding performance. Some examples are given in Table 8.

Table 8 Financial performance objectives and indicators in shipbuilding studies

Study	**Objective**	**Performance indicator(s)**	**Performance assessment method(s)**	**Identified limitation(s)**
Audia and Greve (2006)	Study the relationships between risk taking behavior (factory expansion), firm size and performance levels in shipbuilding	Accounting measures of returns: Return On Equity (ROE), Return On Assets (ROA) and Return On Sales (ROS)	Secondary data from various databases and reports	
Mellbye et al. (2015)	Benchmarking study of the GCE Blue Maritime Cluster	Market share and Return On Investment (ROI)	Primary data from shipbuilders and secondary data from databases	
Ecorys SCS Group (2009)	Benchmarking study of the European shipbuilding industry	Profit Margin, Operating Revenues, Value of Sales	Amadeus: European financial database	Missing and inconsistent data

These studies show that financial performance measures are relevant in the context of the shipbuilding industry. Financial performance indicators include the following three dimensions: profitability performance, market value performance and growth performance (Selvam et al., 2016). Some of the measures related to those three dimensions are summed up in Table 9.

Table 9 Dimensions and measures of financial performance, based on

Financial performance dimension	**Financial performance measures**
Profitability Performance	Return on Assets, EBTIDA Margin, Return on Investment, Net Income/Revenues, Return on Equity, Economic Value Added (EVA)
Market Value Performance	Earnings Per Share, Changes in Stock Price, Dividend Yield, Stock Price Volatility, Market Value Added (Market Value / Equity), Tobin's Q
Growth Performance	Market-Share Growth, Asset Growth, Net Revenue Growth, Net Income Growth, Number of Employees Growth

Venkatraman and Ramanujam (1986) review the main benefits and limitations of using financial measurements to assess the performance of firms. The benefits and limitations of this approach are not the same whether the data used are primary or secondary (Venkatraman and Ramanujam, 1986). Primary data are data which are originally produced and collected for the purpose of one's research (Hox and Boeije, 2005). Secondary data, on the other hand, are data which were initially collected for another purpose and not specifically for the current study (Hox and Boeije, 2005). The main advantages and limitations of the use of primary and secondary financial data to assess firm performance are listed in Table 10.

Table 10 Benefits and limitations of the use of financial data to assess firm performance, adapted from Venkatraman and Ramanujam (1986)

	Benefits	**Limitations**
Financial data from secondary sources	• Provides data on financial outcomes which cannot be obtainable otherwise • Can be used to compare firms within the same industry	• Different accounting policies limits the possibility for comparison, especially for studies of different countries

	• Possibility to use stock-market based indicators	• Cannot be used at the level of a specific business unit because of the “aggregation” of the financial results at the firm level
Financial data from primary sources	• Provide “self-reported” financial data which minimize interpretation problems and aggregation effect • Allow analysis at a specific business unit level	• Data might be biased • Data might not be available due to confidentiality issue

Once again, because of the strategic nature of the financial results, and based on previously cited concerns about this issue (Lamb and Hellesoy, 2002, Krishnan, 2012, Semini et al., 2018), it is likely that the reserve with which manufacturers are prepared to share strategic information is a brake on the use of primary data. Thus, it appears that the use of secondary data sources for the assessment of financial performance of the shipyard has a major advantage because it allows to avoid those “confidentiality issues”. Indeed, various open databases gather the public financial results of private firms (e.g. Amadeus, Orbis, etc.).

However, the limitations that are identified by Venkatraman and Ramanujam (1986) are also relevant for studies of the shipbuilding industry. Researchers should consider the following potential limitations in the use of secondary financial data sources:

- **Aggregation issues**: firm level financial data might not be relevant for the study of shipyards which are subsidiaries of larger corporations or groups. Indeed, in such shipyard groups or corporation, the financial results will depend of complex mechanisms and might account for other activities than shipbuilding[15]. Thus, an extra effort should be provided to identify the scope of the financial measures used, and to what activities they can be attributed to.
- **Data availability issues**: public financial results, should be public and available by definition. Yet, in practice, financial databases can be incomplete (Ecorys SCS Group, 2009).

[15] For example, Hyundai Heavy Industries Co. Ltd, one of the largest shipbuilders in the world, owns and operates several shipyards, and is a subsidiary of the Hyundai Heavy Industries Group, which itself is part of the broader Hyundai Group.

- **Accounting policies issues**: Venkatraman and Ramanujam (1986) warn for differences in accounting policies which could limit the possibility for comparison across firms. This should be a concern, especially for shipbuilding firms in different countries.

The use of financial performance measures to assess shipyards' performance has both benefits and disadvantages. That is why the choice of the performance dimensions to be investigate should be carefully decided in relation to the specific research objectives.

In the next chapter, the methodology for the thesis and especially for the data analysis is introduced and argued for.

3. Methodology

This chapter presents the research strategy and methodology that were applied to carry the realization of this master's thesis. In order to meet the research objectives, a clear research plan should be chosen as well as appropriate research methods (Cooper and Schindler, 2013). This chapter first resent the research strategy and connects this thesis to previous works. Then, the methodology for the literature research is presented. Finally, the methodology of the data analysis is detailed.

3.1. Research strategy

Prior to the writing of this master's thesis, a specialization project titled "Theoretical assessment of product variety in shipbuilding and its effect on performance" was written by the author of this thesis. The main contributions of this project were to propose a categorization of shipbuilding product variety dimensions, while appropriate measures of variety and possible effects of product variety on performance were only promptly discussed.

This specialization project can be seen as preliminary literature study for this thesis. This thesis is in connection with the previous project and is building upon the theoretical findings of the precedent project. The previous literature study is reworked and adapted to fit with the present research objectives. Still, as this previous study was imperfect, it is necessary to carry an additional literature study to fill the gaps in the previous one and to further explore the available theoretical material.

Based on this previous project and the additional literature study, this thesis aims to continue the research on this topic. Especially, this thesis aims to examine empirical data to meet the research objectives 1 and 2.

The next sections will detail the methodology for the literature study and the data analyses.

3.2. Literature study

It is essential to carry a literature study to be completely familiar with the theory on investigated issues (Ridley, 2012). The literature study allows the researcher to refine the research objective, and ultimately to propose a relevant and adapted research design (Cooper and Schindler, 2013).

The literature research focuses on the following topics:

1) Product variety
   a) Definition
   b) Measures
2) Firm performance
   a) Definition
   b) Measures
3) Shipbuilding
   a) Characteristics
   b) Product
   c) Process

To search for literature in the listed categories the search words shown in Table 11 were the most used.

Table 11 Search words for literature study

Main search words	Additional search words
Product variety **Product diversity** **Product mix** **Product portfolio**	Definition Concept Measure Measurement Effect Performance
Shipbuilding **Shipyard** **Ship manufacturing** **Ship construction** **Ship production** **ETO** **Engineer-To-Order** **One-of-a-kind**	Product variety Product diversity Product mix Product portfolio Characteristics Performance
Firm performance **Operational performance** **Financial performance**	Definition Concept Measure Measurement Metrics Product variety Shipbuilding

Relevant literature was principally found by searching with the following search engines and databases: Web of Science, Scopus, Google Scholar, ProQuest, Science Direct, Springer, Taylor & Francis, and Oria, NTNU's library search engine.

The relevance of the articles was assessed based on their titles, abstracts, and key words. Relevant articles were saved for reading. Moreover, the reference lists of relevant articles were studied to help finding relevant literature, using a snowball sampling technique. The number of citations for each article was systematically checked to ensure the quality of the literature found, and, for the most relevant articles, cited-by analyses were conducted. This helped to expand the literature corpus contributing to certain topics and issues. The reference management tool EndNote has been used to store and manage references of the selected articles during the project.

This literature study is retrieved through chapter 2 "Theoretical background", which is a synthesis of the most relevant findings of this research. Moreover, chapter 2, propose a characterization of product variety in shipbuilding. This research is also the theoretical foundation for the empirical investigation, which is carried as a data analysis, as presented in the next section.

3.3. Data analysis

This section presents the methodology applied to carry the statistical data analysis. First, the data analysis objectives are presented. Then, the conceptual research models, variables, and research hypothesis are introduced. Next, the data collection and transformation methods are detailed. Finally, the data analysis technique to be used, namely linear regression, is argued for and presented.

3.3.1. Objective

Empirical testing of theoretical models is an essential step to support and validate theory (Cooper and Schindler, 2013). Particularly, statistical data analysis are quantitative methods which are used to validate theoretical hypothesis based on empirical data.

In this thesis, statistical data analyses are carried to meet the research objectives. Data from Norwegian shipbuilders is used to statistically test research hypotheses and meet the research objectives, which are reminded here:

1) **Objective 1: Investigate the relationship between ship type variety and the financial performance of shipbuilding firms.**
2) **Objective 2: Investigate the effect of ship type variety on the ability of shipyards to cope with market downturns.**

It was chosen to specifically investigate Ship Type Variety (STV) for the following reasons:

- STV is a characteristic of the fundamental variety of a shipyard;
- STV is one of the most direct illustrations of variety when observing the output of a shipyard;
- STV is relatively easy to observe and measure;
- STV is assumed to have a substantial and direct impact on the variety at the fundamental level and lower levels (intermediate and component levels) [16];
- STV is directly linked with a shipbuilder's business strategy and market positioning, which connects this analysis to the original motivation of the thesis.

[16] Difference in the ship type implies difference in the payload functions (missions), and thus in the basic design, ship size, mission related sub-systems, etc.

On the other hand, it was chosen to investigate financial performance for the following reasons, which have been discussed before:

- There are limitations on the availability of strategic operational performance data for shipbuilding;
- Financial performance can be assessed from publicly available data, which allows to overcome such limitations.

To carry a data analysis, an important step is to choose an appropriate data analysis technique (Hair et al., 2010). Multivariate data analysis techniques are adapted when analyzing multiple measurements on the investigated objects. To select the appropriate multivariate data analysis technique, the starting point is to state the research problem and to produce a conceptual model.

3.3.2. Research model development

Hair et al. (2010) states that a conceptual research model, even a simple one, should always be developed as a starting point for any empirical analysis. This model should, at least, specify the concepts under study and, in the case of a dependence relationship, specify the dependent and independent concepts.

The concepts of interest are the Ship Type Variety (STV) of a shipyard, and the Financial Performance (FP) of a shipyard. These concepts have been discussed in the theory review; however, we remind their basic definitions. STV can be defined as the variety of ship types produced by a shipyard on a given period. FP can be defined as the ability of a shipyard to generate profits on a given period.

To establish a model of the relationship of STV on FP of shipyards, we will build a model upon previous studies of the impact of product variety on firm performance. Product variety has been studied for its impact on manufacturing's firm performance. According to the literature, the main beneficial effects of product variety consist of:

- Increased market shares because of an higher diversity of customer's requirements that can be met (Kekre and Srinivasan, 1990);
- Increased revenues and profits, because customers are willing to pay more for variety (Child et al., 1991, Kekre and Srinivasan, 1990, Ulrich, 2006);
- Increased utilization of manufacturing capacities (Fisher et al., 1995);
- Higher resilience to demand downturns and market changes (Fisher et al., 1995).

On the other hand, the main negative effects of product variety on firm performance consist of:

- Increased demand uncertainty (Fisher et al., 1995, Randall and Ulrich, 2001);
- Higher cost of inventory, because of higher inventory levels and number of stock keeping units (Fisher and Ittner, 1999);
- Increased diversity in processes specifications, increased frequency of set-ups, need for more overhead working hours, etc. (Fisher et al., 1995, Anderson, 1995);
- Higher product design costs (Tang, 2006, Salvador et al., 2002);
- More complex quality assurance (Fisher et al., 1995, Anderson, 1995).

Based on this literature, we qualitatively assess the effect of ship type variety on the performance of shipbuilding firms and deduct the expected effect of STV on FP, in Table 12.

Table 12 Qualitative assessment of the impact of ship type variety on shipbuilding performance

Impact	**Impact on operations and design**	**Impact on sales**
+	• Lower underutilization of manufacturing assets and workforce during market downturns	• Increased market shares • Lower sensitivity to macro-economic factors variations • Adaptability to market downturns and demand declines • Increase of the stability on long-term
-	• Reduced benefits from learning effect (Erichsen, 1994) and economies of scale • Higher variety on intermediate level: more variety in parts • Need for more complex or parallel supply processes and a larger supplier and sub-contractors base • Need to adapt the yard's layout • Need for flexible capabilities • Irregularity in the required size and skills of the workforce • Increased inventory related costs • Increased purchasing costs • Increased complexity • Harder to reuse design and engineering • Standardization effort can be limited	• Higher selling prices which can moderate the competitive advantage of variety
Impact on financial performance	• **Higher costs**	• **Higher revenues**

When considering objective 1, this assessment suggests that there is a dependence relationship between STV and FP. In this relationship, STV is the independent concept and FP the dependent concept. STV is expected to have multiple and contradicting effects, i.e. both positive and negative effects, on shipbuilder's FP. A simple representation of this relationship is proposed in Figure 8. Because of the existence of contradicting effects, it is difficult to predict the exact nature of the relationship between STV and the overall FP. Furthermore, product diversification literature offers a variety of theoretical models and empirical findings which are not consistent with each other when it comes to the relationship between variety and overall FP (Benito-Osorio et al., 2012). Some authors bring out linear positive relationship, others linear negative relationship, or inverted U-shape relationships, or even no significant relationship. However, none of those studies is related to shipbuilding. Besides because of the inconsistency between those results there generalizability is limited (Benito-Osorio et al., 2012). Consequently, our first theoretical proposition can be expressed as:

Proposition 1: *"The financial performance of shipyards is related to their ship type variety."*

Note that this proposition does not assume the nature of the relationship (e.g. linear or U-shaped) or its direction (i.e. positive or negative).

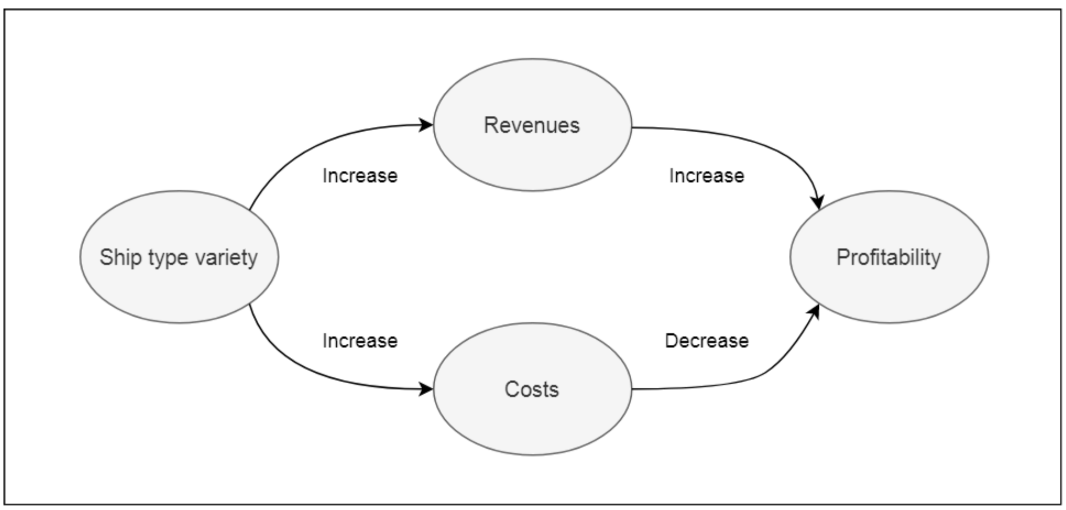


Figure 8 A model of the relationship between ship type variety and financial performance

On the other hand, there is a broader consensus on the idea that product variety allows to reduce risks related to the market uncertainty (Benito-Osorio et al., 2012, Tang, 2006, Pandya and Rao, 1998). The main idea is that if a company is present on several market segments, then it can always rely on several other products if the demand for one product drops. Moreover, in a context of unpredictable and changing demand, Fisher et al. (1995) argue that product variety is rewarding for manufacturers. Indeed, manufacturers who can offer higher product variety have more flexible manufacturing capabilities and are able to rapidly adjust to customer requirements and market change. Considering objective 2, this leads to suppose that past ship type variety is beneficial for the shipbuilders which are facing a market downturn. This reasoning supports the formulation our second theoretical proposition:

Proposition 2: *"After a market downturn, the financial performance of shipyards is positively related to their past ship type variety."*

These theoretical propositions are to be formulated in a way that they can be statistically testable. Therefore, once the conceptual model representing the relationship between the concepts is established, variables should be selected to represent the concepts (Hair et al., 2010).

3.3.3. Variables

In this section, the measures and variables chosen to represent the concepts of STV and FP are presented.

Ship Type Variety

To operationalize Ship Type Variety (STV), the following measures are used:

- Ship Types Count $= N - 1$, referred as "species count" in diversity literature.
- Ship Type Shannon Index $= -\sum_i^N \pi_i \log(\pi_i)$.

With the following notations:

N the number of different ship types built by the yard (during the period of interest),

n the total number of ships built by the yard,

And, for each $i \in [1, N]$:

π_i the proportion of type i ships among all ships.

The first measure captures the multiplicity aspect ("how many types?"), whereas the second one captures both the multiplicity and the balance aspects ("how much of each type?") (Stirling, 1998). However, none of these measure captures the disparity aspect ("how much difference is there between a type and the next?"), which is more complex to include[17] (Stirling, 1998).

Therefore, the ship type Shannon Index (SI) is selected as a measure to represent STV, because it depicts more "information" about variety. However, as the interpretation of the SI is not straightforward, the ship Types Count (TC) is also used to increase the practical significance of the results.

Financial Performance

The Return On Assets (ROA) is an accounting measure which is widely used to quantify FP. The ROA translates a firm's ability to generate profit by an efficient use of resources and an efficient management (Selvam et al., 2016, Combs et al., 2005, Audia and Greve, 2006).

ROA is computed as a percentage (no unit) of the net income divided by the value of total assets:

$$ROA = \frac{\text{Net Income}}{\text{Total Assets}} \times 100$$

To represent the FP of shipbuilding firms, the Average Return On Asset (AROA) will be used. The AROA is computed for each firm as the average of the yearly ROA (in percent) on the investigated periods. The AROA reflects the average profitability of the studied firms on the period of interest.

Variables definition

In this section we define the variables names as they are used in the following analyses. The variables are defined on three specific periods, as it is intended to study the relationship between STV and FP both in general and after a specific event, i.e. during market downturns. The considered event is the 2014 oil crisis, which caused a drop of the offshore vessels market. That is why the variety and performance variables (AROA, SI and STC) are measured for the whole investigation period (2008 to 2018), but also before and after 2014.

[17] The estimation of the mutual "distances" from a type to the next is especially problematic, although it could be interesting to investigate this lead.

The variable names are defined in Table 13.

Table 13 Variables names

Variable name	Description
AROA	Average Return On Assets of the yard on the whole investigation period (2008 to 2018)
$AROA_{before}$	Average Return On Assets of the yard on the period before 2014 (2008 to 2013)
$AROA_{after}$	Average Return On Assets of the yard on the period after 2014 (2014 to 2018)
SI	Ship type Shannon Index of the yard on the whole investigation period (2008 to 2018)
SI_{before}	Ship type Shannon Index of the yard on the period before 2014 (2008 to 2013)
TC	Ship Types Count of the yard on the whole investigation period (2008 to 2018)
TC_{before}	Ship Types Count of the yard on the period before 2014 (2008 to 2013)
Offshore	Dummy variable ▪ =1 if the yard built "Offshore" ships (either “Offshore supply” or “Other offshore” categories); ▪ =0 else.

In the next section, the previously introduced variables are used to formulate the research hypothesis.

3.3.4. Research hypotheses

Cooper and Schindler (2013) define a proposition as a statement about concepts that can be evaluated as true or false. A proposition which is formulated to be empirically tested, is call a hypothesis. A null hypothesis is a hypothesis formulated so that it can be tested for rejection, and if it is rejected, then alternative hypotheses related to the tested relationship can be supported.

The first theoretical proposition of interest is Proposition 1:

“The financial performance of shipyards is related to their ship type variety.”

Proposition 1 can be translated into the null hypothesis H_{0-I}:

H_{0-I}: *“There is no significant relationship between the* AROA *and the* SI *or the* TC.*”*

Alternate hypotheses can be stated for each of the independent variables, as follow:

$H_{1\text{-}I}$: "The AROA *of shipyards is related to their* SI*."*

$H_{2\text{-}I}$: "The AROA *of shipyards is related to their* TC*."*

The second theoretical proposition of interest is Proposition 2:

"After a market downturn, the financial performance of shipyards is positively related to their past ship type variety."

Proposition 2 can be translated into the null hypothesis $H_{0\text{-}II}$:

$H_{0\text{-}II}$: "There is no significant relationship between the $\mathrm{AROA}_{\mathrm{after}}$ *and the* $\mathrm{SI}_{\mathrm{before}}$ *or the* $\mathrm{TC}_{\mathrm{before}}$*, when* Offshore=1*."*

Alternate hypotheses can be stated for each of the independent variables, as follow:

$H_{1\text{-}II}$: "The $\mathrm{AROA}_{\mathrm{after}}$ *of shipyards is related to their* $\mathrm{SI}_{\mathrm{before}}$*, when* Offshore=1*."*

$H_{2\text{-}II}$: "The $\mathrm{AROA}_{\mathrm{after}}$ *of shipyards is related to their* $\mathrm{TC}_{\mathrm{before}}$*, when* Offshore=1*."*

In the next section, the methodology for the data collection is detailed.

3.3.5. Data collection

This section presents the data collection process and the data sources that are used for the thesis.

Financial data

The ROA of the shipbuilding firms of interest are collected from the Orbis database. Orbis gathers information on more than 365 million companies across the globe (Bureau van Dijk, 2020). It contains standardized company data, including financial data.

The ROA records are collected for each of the previously found shipbuilding company on the 2008 to 2018 period. Then the AROA measures are obtained by averaging the yearly ROA on the periods of interest for each company.

Ship and shipyard data

To collect ship and shipyard data, the IHS Markit Sea-web maritime database was used. Sea-web is a maritime reference tool, provided by IHS Markit, which contains around 600 data fields for more than 200 000 ships of 100 GT and above (IHS Markit, 2020). The database was accessed with NTNU's access and data were collected in March 2020.

The data is gathered based on a ship research on the Sea-web database, using the following criteria:

1) The ship was ordered in, or prior to, December 2018;
2) The ship was delivered in, or after, January 2006;
3) The shipbuilder of the ship is, or was, located in Norway.

The above dates were chosen to reflect the effect of STV on the long-term and for data availability reasons. Also, it was chosen to include ships back to 2006 (and not 2008) because literature suggests a lag effect in the association between variety and financial performance (Benito-Osorio et al., 2012, Bausch and Pils, 2009).

Besides, it is chosen to focus on Norwegian shipbuilders because using a single national context reduces the specification error for the research model. Indeed, factors related to the national industrial and social environment can be neglected. Furthermore, since the research department has an extensive knowledge of those shipyards, it is easier to select the yards which are compatible with a financial based analysis of performance (main activity, affiliation to a larger group, etc.). Finally, Norwegian shipbuilders have been involved in the building of offshore vessels for the oil and gas industry, which means they had to face the market downturn that followed the 2014 oil crisis (OECD, 2017, Mellbye et al., 2015). This is particularly interesting regarding objective 2. Yet, it was also considered and attempted to investigate different national contexts, especially South Korea, but eventually dropped because of the lack of time and expertise of the shipyards in question.

For each of the selected ships, the following information are collected on the Sea-web database:

- Ship identification number;
- Shipbuilder name;
- Shipbuilder identification number;
- Ship type;
- Delivery date;

- Order date.

Some of the shipyards are not included in the analysis because they meet at least one of the following exclusion criteria:

1) The building of new ships is not the firm's main activity (i.e. it can be repair, design, building of offshore structure, etc.). This is assessed based on personal knowledge of the shipyards and publicly available information.
2) The shipyard is not present on the Orbis database, or the shipyard is present on the Orbis database, but the financial results data is not available for the period of interest.
3) The shipyard is part of a bigger corporation or a group, and the financial results are available only for the group or parent firm. This allows to reduce aggregation related issues.

The list of the included and excluded shipyards is presented in Appendix 4. For the included shipyards, a complementary ship research is carried. Indeed, on Sea-Web, the shipbuilder of a ship is by default the builder of the hull. Thus, because of the offshoring strategies implemented by Norwegian shipbuilders (Semini et al., 2018), this would exclude a significant part of the ships they actually built.

To perform the desired analyses, this data is transformed using Microsoft Excel. Firstly, the ship types are transformed to match the chosen standard which is the level 3 of the IHS Statecode 5 classification (see Appendix 1). Originally, the raw data from IHS Sea-web let appears ship types which are filled in manually and inconsistently. Thus, transforming the data, allows to ensure a uniform denomination of the ship types and a control over the level of discrimination of ship types. Finally, the ship Types Count (TC) and Shannon Index (SI) are computed for each shipyard and on the different periods of interest.

In the next section, the statistical method used for the analyses is presented.

3.3.6. Data analysis methods

Once the objective and conceptual model are specified, the appropriate multivariate technique can be chosen based on the measurement characteristics of the dependent and independent variables (Hair et al., 2010). The relationships under study are a dependence relationship, including only one dependent variable (SI or TC) which are measured on a metric scale thus a regression technique is appropriate (Hair et al., 2010).

Regression techniques are used to (Hair et al., 2010):

1) Test the existence of a significant relationship between variables;
2) Predict the dependent variable from the independent variable(s).

Linear regression

The basic regression technique used in this thesis is linear regression. A linear regression model can be used to model the dependence relationship between one dependent and one independent variable (Hair et al., 2010):

$$Y = b_0 + b_1 * X$$

Where Y is the dependent variable, X the independent variable, b_0 the intercept and b_1 the coefficient of the linear effect.

To statistically test the relationship between X and Y, the null hypothesis H_0 (of absence of relationship between X and Y) can thus be written "$b_1 = 0$". This model can be estimated by an ordinary least square method based on the sample data, i.e. estimation of b_0 and b_1 are made to fit with the data. Based on this estimation, the null hypothesis H_0 should be tested as well as the overall statistical significance of the model. This is done by an F-test, which allows to reject or not the null hypothesis based on the value of F and on the observed significance level p (or p-value) which should be below a required level of significance α (Hair et al., 2010).

Type I error, also termed alpha (α), is the probability of incorrectly rejecting the null hypothesis H_0 (e.g. saying a correlation exists when it does not). Type II error, also termed beta (β), is the probability of failing to reject the null hypothesis H_0 when it should be rejected (e.g. not finding an existing correlation).

Table 14 Error types and probabilities, based on Hair et al. (2010)

		Null hypothesis (H_0) is	
		True	False
Decision about the null hypothesis (H_0)	Do not reject	Correct inference (probability = 1 – α)	Type II error (probability = β)
	Reject	Type I error (probability = α)	Correct inference (probability = 1 – β)

Typically, the level of statistical significance α required to reject the null hypothesis level is set to $\alpha = 0.01, 0.05\ or\ 0.10$ (Hair et al., 2010, Cooper and Schindler, 2013). On the other hand, the statistical power, which is defined as $1 - \beta$, i.e. the probability of correctly rejecting the null hypothesis, should at least be 80%, i.e. $1 - \beta \geq 0.8$ (Hair et al., 2010). The statistical power depends on the sample size (number of observations), significance level (α) and effect size[18] (Hair et al., 2010). Given the low sample size in the following regression analyses (22 and 11 data points), it seems acceptable to set the level of statistical significance α to .1, as lower α would negatively affect the statistical power of the regressions. However, it should be noted that this represents a limitation of this thesis.

When the null hypothesis can be rejected, i.e. if there is a statistically significant ($p < \alpha$) relationship between Y and X, the model is associated with a coefficient of determination R^2 which is a statistical measure of how well the regression model predicts the actual data. R^2 varies from 0 to 1, 1 being a perfect prediction of the data by the model.

Quality of the regression analysis

To ensure the quality of the regression model, Hair et al. (2010) state the importance of establishing the statistical significance (low α) of the model and to achieve decent level of statistical power (low β), but also to establish the practical significance of the model (i.e. "Is the effect detected meaningful in practice?").

Furthermore, an effort should be out into verifying the underlying assumptions of the regression technique:

[18] The effect size represents "how strong" the association is (in the case of a regression), in simple regression analysis R^2 can be used to evaluate the effect size, see Hair et al. (2010).

- Normality of the error terms;
- Linearity of the phenomenon;
- Homoscedasticity, i.e. constant variance of the error terms;
- Independence of the error terms.

These assumptions are assessed via graphical methods (normal probability plot, residual plots, etc.) before and after the regression model estimation. If violation of the assumptions is found, corrective actions should be taken (Hair et al., 2010).

Pearson's r

Pearson's r is a statistic that measures the strength of the linear association between two variables X and Y. The sign of r indicates the direction of the relationship. Its values range from -1 to +1, where +1 indicates a perfect positive relationship, 0 indicates no linear relationship, and -1 indicates a perfect negative relationship. Pearson's r can thus be used to test the correlation, i.e. existence of a linear relationship, between two variables without having to explicitly estimate a regression model.

In the next chapter, the results of these data analyses are presented and interpreted.

4. Data analyses and findings

In this chapter, the results from the data analyses are presented. First, the dataset obtained from the data collection is described. Then the examination of the variables and the testing of the regression assumption are presented. Finally, the results of the regression analysis are presented and discussed.

The regression analyses are performed using the statistical software IBM SPSS version 26, which provides tools to perform the tests, model regression estimation and create graphs and Figures.

4.1. Preliminary examination

The dataset used for the following analyses is examined in this section. Preliminary data examination is an essential preliminary step to the application of any multivariate analysis (Hair et al., 2010). It allows to gain knowledge of the data and to detect any possible violation of the technique assumptions.

After the data collection and the selection of the shipyards, 22 shipyards are remaining in the dataset[19]. Those shipyards are found to have produced 442 ships during the investigation period. Figure 9 shows the distribution of the ship types in the sample.

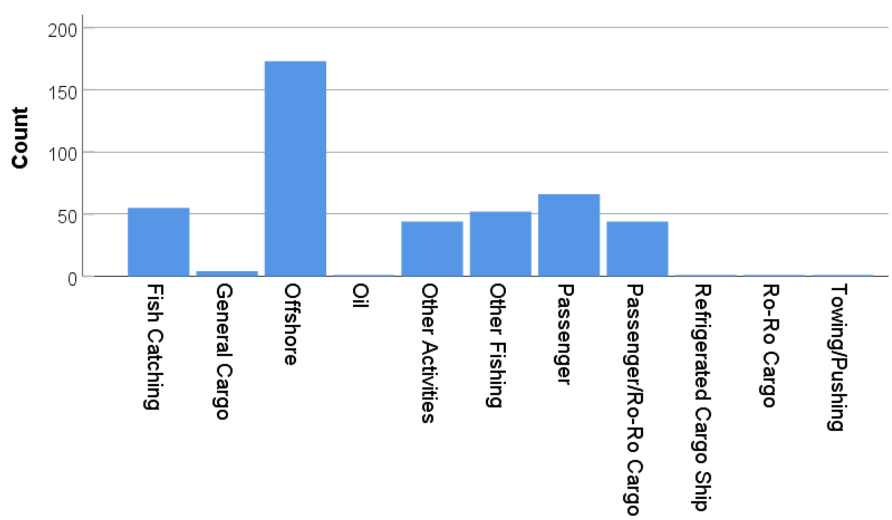


Figure 9 Distribution of ship types in the sample

[19] See Appendix 4.

4.1.1. Univariate examination

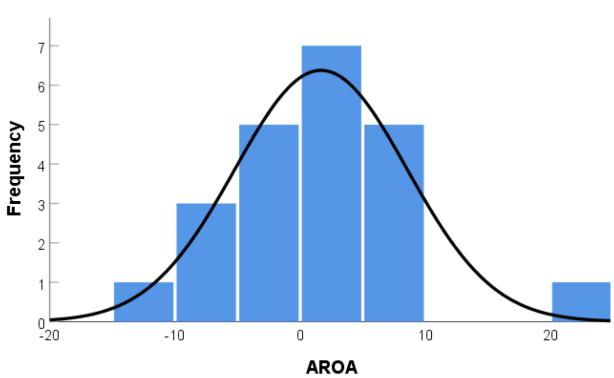
In this section, the variables of interest are examined individually. Especially, a graphical examination of their distributions is presented in this section. Table 15 presents descriptive statistics of the variables. The values of the variables are displayed for the 22 shipyards in Appendix 5.

Table 15 Descriptive statistics of the variables

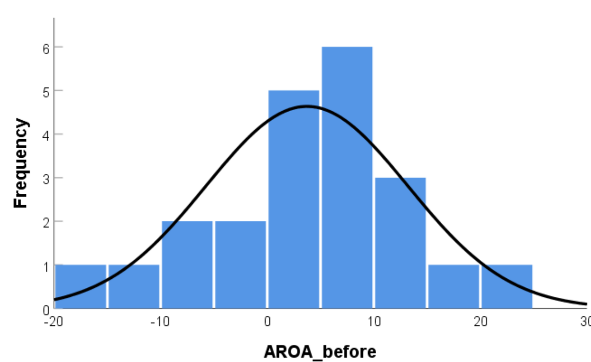
Variable	N	Minimum	Maximum	Mean	Standard deviation
AROA	22	-10.48	20.62	1.66	6.88
$AROA_{before}$	22	-18.89	22.85	3.72	9.47
$AROA_{after}$	22	-14.40	18.38	-.64	8.30
TC	22	0	5	2	1.45
TC_{before}	22	-1	3	.95	1.43
SI	22	0	1.42	.65	.48
SI_{before}	22	0	1.31	.39	.45
Offshore	22	0	1	.50	.51

Average Return On Assets

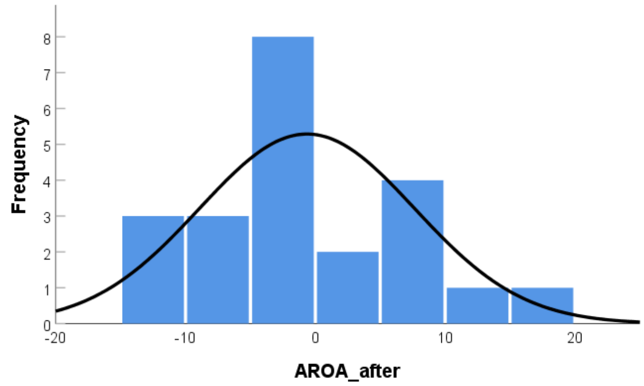
The Average Return On Assets distributions are presented, in Figure 10, for (a) the whole investigation period (AROA), (b) before 2014 ($AROA_{before}$), and (c) after 2014 ($AROA_{after}$).



(a)



(b)



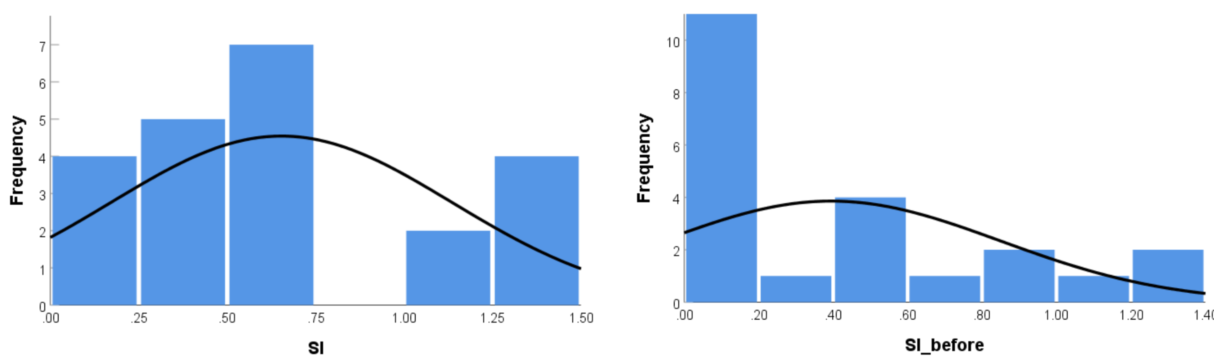
(c)

Figure 10 Histogram of the AROA with the normality curve superimposed (a) on whole investigation period, (b) before 2014, and (c) after 2014

The distribution curves of the AROA fit well with the normality curve, which is confirmed by the normal Q-Q plots (see Appendix 6).

Shannon Index

The Shannon Index on the whole period (SI) and before 2014 (SI_{before}) have their distributions plotted in Figure 11 (a) and (b), respectively.



(a) *(b)*

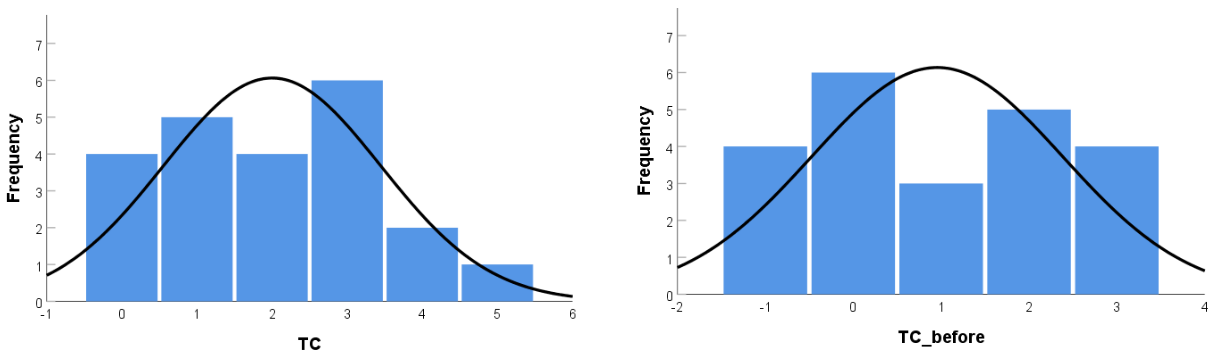
Figure 11 Histogram of the SI with the normality curve superimposed

It is notable that there is a high frequency of $SI_{before} = 0$. This is not unexpected. Indeed, it is remind that SI$= -\sum_i^N \pi_i \log(\pi_i)$, with N the number of different ship types built by the yard (during the period of interest), and, for each $i \in [1, N]$, π_i the proportion of type i ships among all ships. Thus $\mathrm{SI}_{\mathrm{before}} = 0$ is equivalent to $N = 1\ or\ N = 0$, i.e. the shipyard only built one ship type or did not built between 2006 and

2014. Therefore, it is not surprising to find a high frequency of SI=0, this mean that a significant share of the shipyards is focused on one type of ship on this specific period.

Types Count

The Types Count on the whole period (TC) and before 2014 (TC_{before}) have their distributions plotted in Figure 12 (a) and (b), respectively.



(a) *(b)*

Figure 12 Histogram of the TC with the normality curve superimposed

In Figure 12 (b), it is remarkable to find 4 shipyards with $TC_{before} = -1$, which means they did not build between 2006 and 2014. Also 6 shipyards are found to have $TC_{before} = 0$, which means they only produced one type between 2006 and 2014.

Offshore

The distribution of the offshore variable is presented in Figure 13. It is reminded that Offshore is a dummy variable which takes the value 1 if the shipyard built offshore vessels and else takes the value 0.

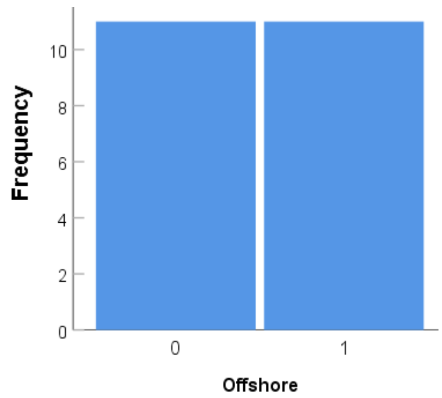


Figure 13 Histogram of the Offshore variable distribution

Half of the shipyards of the sample have been building offshore vessels, while the other half did not. Only the shipyards with Offshore = 1 are included for the assessment of the second null hypothesis $H_{0\text{-}II}$. Indeed, those shipyards are the one facing the market downturn.

4.1.2. Bivariate examination

A correlation analysis is performed among the independent variables. The results are displayed in Table 16.

Table 16 Correlation analysis of the independent variables

		TC	**SI**	**TC_{before}**	**SI_{before}**
TC	Pearson Correlation	1	.833*	.828*	.702*
	Sig. (2-tailed)		.000	.000	.000
SI	Pearson Correlation	.833*	1	.788*	.830*
	Sig. (2-tailed)	.000		.000	.000
TC_{before}	Pearson Correlation	.828*	.788*	1	.891*
	Sig. (2-tailed)	.000	.000		.000
SI_{before}	Pearson Correlation	.702*	.830*	.891*	1

** Correlation is significant at the 0.01 level.*

The results suggest that the TC and the SI are highly correlated. This is not surprising but confirms that we cannot use both in the same regression model, without creating multicollinearity, i.e. correlation between the independent variables, which is usually not desirable in multiple regression analysis. Therefore, it is chosen to perform regression analysis separately with both variables.

In the next section the underlying assumptions for linear regression are tested to ensure the applicability of the method.

4.1.3. Examination of the underlying assumptions for linear regression

An important issue, before - and when - estimating a regression model, is to know if the assumptions of regression analysis are verified. These assumptions are (1) the linearity of the phenomenon, (2) the normality of the error terms, (3) the constant variance of the error terms, and (4) the independence of the error terms (Hair et al., 2010).

Linearity

Linearity is an essential assumption of linear regression. This first assumption states that the predicted relation between the dependent and independent variable is linear. The four linear relationship to be assessed are:

$$AROA = b_0 + b_1 * SI \qquad \text{(A)}$$

$$AROA = b_0 + b_1 * TC \qquad \text{(B)}$$

$$AROA_{after} = b_0 + b_1 * SI_{before} \qquad \text{(C)}$$

$$AROA_{after} = b_0 + b_1 * TC_{before} \qquad \text{(D)}$$

To check for the linearity of the relationships, linear regression models are estimated (they are detailed later), and scatterplots of the standardized predicted values of the dependent variable against the standardized residuals are plotted (Hair et al., 2010). The corresponding scatterplots are presented in Appendix 7 for the four equation (A), (B), (C), and (D). Note that (A) and (B) are estimated for the entire sample (22 shipyards), whereas (C) and (D) are estimated for the offshore shipyards (11 shipyards). A non-linear "best fit" line, the Loess Curve, is plotted on the graphs to detect non-linearity. The plots of the Loess curve suggest that the models match the linearity assumption.

Homoscedasticity

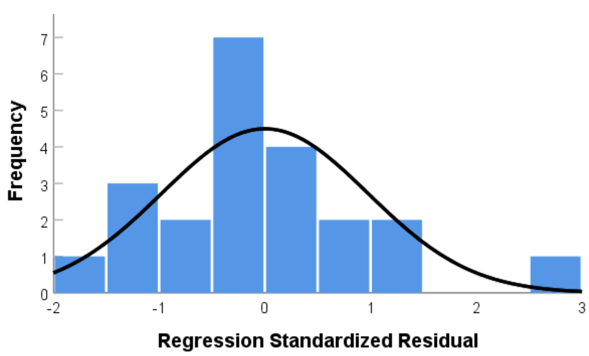
A second assumption of linear regression is the homoscedasticity, or constant variance of the error terms. To check for this assumption, a check of the scatterplots of the standardized residuals against standardized value (Appendix 7). The plots tend to indicate that the variances of the residual are roughly constant for the four models.

Independence

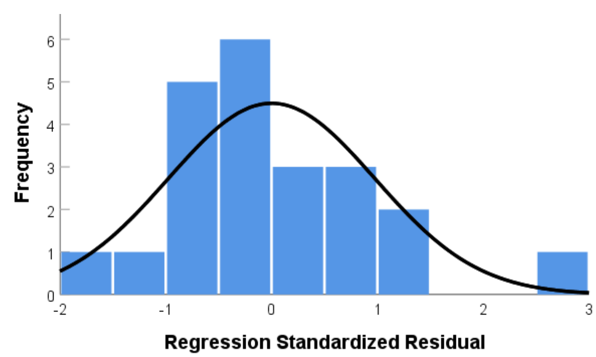
A third assumption of linear regression is the independence of the error terms. This can also be check from the scatterplots of the standardized residuals against standardized value (Appendix 7). The plots do not reveal apparent patterns, which tends to indicate no violation of the independence assumption.

Normality

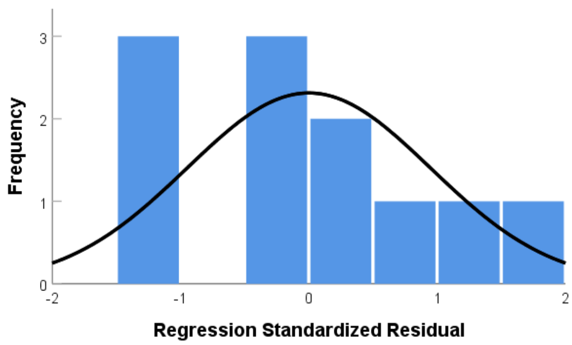
Finally, multiple regression assumes that the error terms are normally distributed. To check for this assumption, a histogram of the standardized residuals of the quadratic model estimation is plotted (see Figure 14).



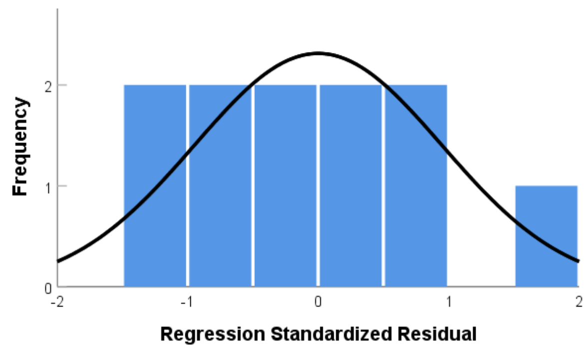
(a) Dependent Variable: AROA, *Independent Variable:* SI



(b) Dependent Variable: AROA, *Independent Variable:* TC



(c) Dependent Variable: $AROA_{after}$, *Independent Variable:* SI_{before}



(d) Dependent Variable: $AROA_{after}$, *Independent Variable:* TC_{before}

Figure 14 Histograms of the standardized residuals with the normality curve superimposed

The histograms of the standardized residuals indicate that the distributions slightly deviate from the normal distribution, especially for model (C) and (D). However, this can be explained by the small size of the sample. The normal Q-Q plots of the standardized residuals are plotted, they also indicate a slight deviation from the normal distribution (see Appendix 8). It is assumed that the deviation from the normal distribution is not strong enough to violate the normality assumption.

This assessment does not reveal critical violations of the underlying assumptions of linear regression. The regression models' estimations are therefore presented in the next sections.

4.2. Results

In the previous sections, the dataset, variables, and regression models were described. Moreover, the assumptions for the regression analysis have been tested. Thereafter, the results of the model estimation are presented.

4.2.1. Testing of H_{0-I}

To fulfill objective 1, the first null hypothesis was formulated as follow:

H_{0-I}: "There is no significant relationship between the AROA *and the* SI *or the* TC.*"*

To test this hypothesis, two linear regression models, (A) and (B), are estimated on the whole sample (22 points).

$$AROA = b_0 + b_1 * SI \qquad \text{(A)}$$

$$AROA = b_0 + b_1 * TC \qquad \text{(B)}$$

A simple linear regression is calculated to predict AROA based on SI. This regression equation (A) is not found to be significant at the .10 level, $F(1,22) = .119, p = .733 > .1$, with R^2=.006 (see Table 17). This test fails to reject the null hypothesis H_{0-I}.

A simple linear regression is calculated to predict AROA based on TC. This regression equation (B) is not found to be significant at the .10 level, $F(1,22) = 1.188, p = .289 > .1$, with R^2=.056 (see Table 17). This test fails to reject the null hypothesis H_{0-I}.

Table 17 Results of the regression estimations

Model Summary*					**Coefficients estimates**	
Model	R^2	F	df	Sig. (p)	b_0	b_1
Model (A)**	.006	.119	1	.733	.939	1.098
Model (B)***	.056	1.188	1	.289	-.594	1.125

*Note: *Dependent variable:* AROA, ***Independent variable:* SI, ****Independent variable:* TC, *N=22.*

The regression line for model (A) is plotted on the scatterplot of the AROA against the SI for the 22 shipyards in Figure 15.

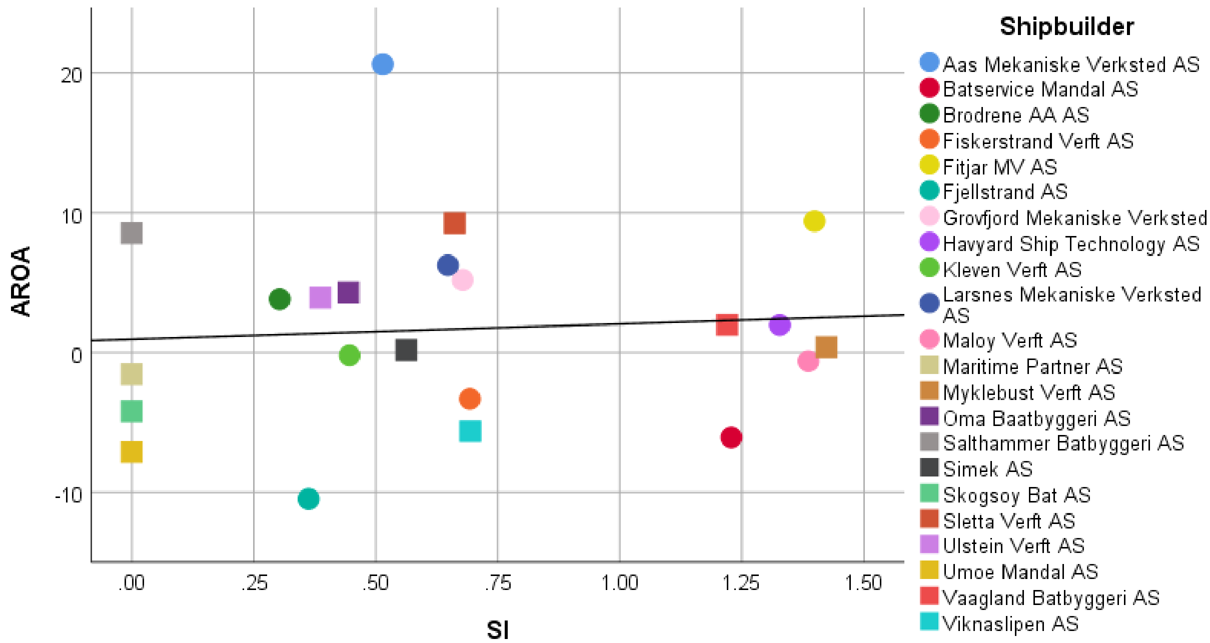


Figure 15 Scatterplot of AROA *against* SI *with linear regression line, model (A)*

The regression line for model (B) is plotted on the scatterplot of the AROA against the TC for the 22 shipyards in Figure 16.

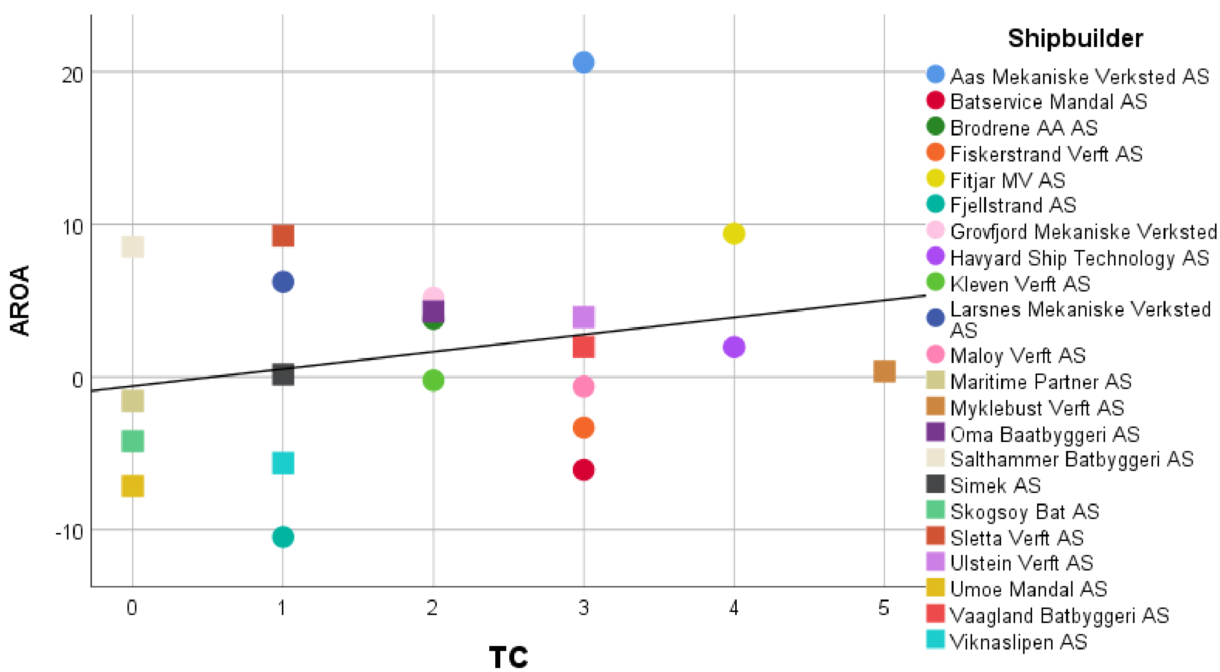


Figure 16 Scatterplot of AROA *against* TC *with linear regression line, model (B)*

4.2.2. Testing of $H_{0\text{-}II}$

The null hypothesis to be tested is reminded:

> *$H_{0\text{-}II}$: "There is no significant relationship between the* $AROA_{after}$ *and the* SI_{before} *or the* TC_{before}*, when* Offshore=1.*"*

To test this hypothesis, two linear regression models, (C) and (D), are estimated on the "offshore" sub-sample, i.e. the 11 shipyards that produced offshore vessels.

$$AROA_{after} = b_0 + b_1 * SI_{before} \qquad \text{(C)}$$

$$AROA_{after} = b_0 + b_1 * TC_{before} \qquad \text{(D)}$$

A simple linear regression is calculated to predict $AROA_{after}$ based on SI_{before}. This regression equation (C) is found to be significant at the .10 level, $F(1{,}11) = 3.374, p = .099 < .10$, with R^2=.273 (see Table 18). This test allows to reject the null hypothesis $H_{0\text{-}II}$, and to accept the alternate hypothesis $H_{1\text{-}II}$. A value of R^2=.273 means that the model allows to explain 27% of the variance of $AROA_{after}$ based on SI_{before}. The predicted $AROA_{after}$ of the shipyards is equal to $-8.3 + 5.7 \times SI_{before}$.

A simple linear regression is calculated to predict $AROA_{after}$ based on TC_{before}. This regression equation (D) is not found to be significant, $F(1{,}11) = 2.343, p = .160 > .10$, with R^2=.207 (see Table 18). This test fails to reject the null hypothesis $H_{0\text{-}II}$.

Table 18 Results of the regression estimations

Model Summary*					**Coefficients estimates**	
Model	R^2	F	df	Sig. (p)	b_0	b_1
Model (C)**	.273	3.374	1	.099	-8.275	5.702
Model (D)***	.207	2.343	1	.160	-8.104	2.010

*Note: *Dependent variable:* $AROA_{after}$, ***Independent variable*: SI_{before}, ****Independent variable:* TC_{before}, *N=11.*

The regression line for model (C) is plotted on the scatterplot of the $AROA_{after}$ against the SI_{before} for the 11 shipyards in Figure 17.

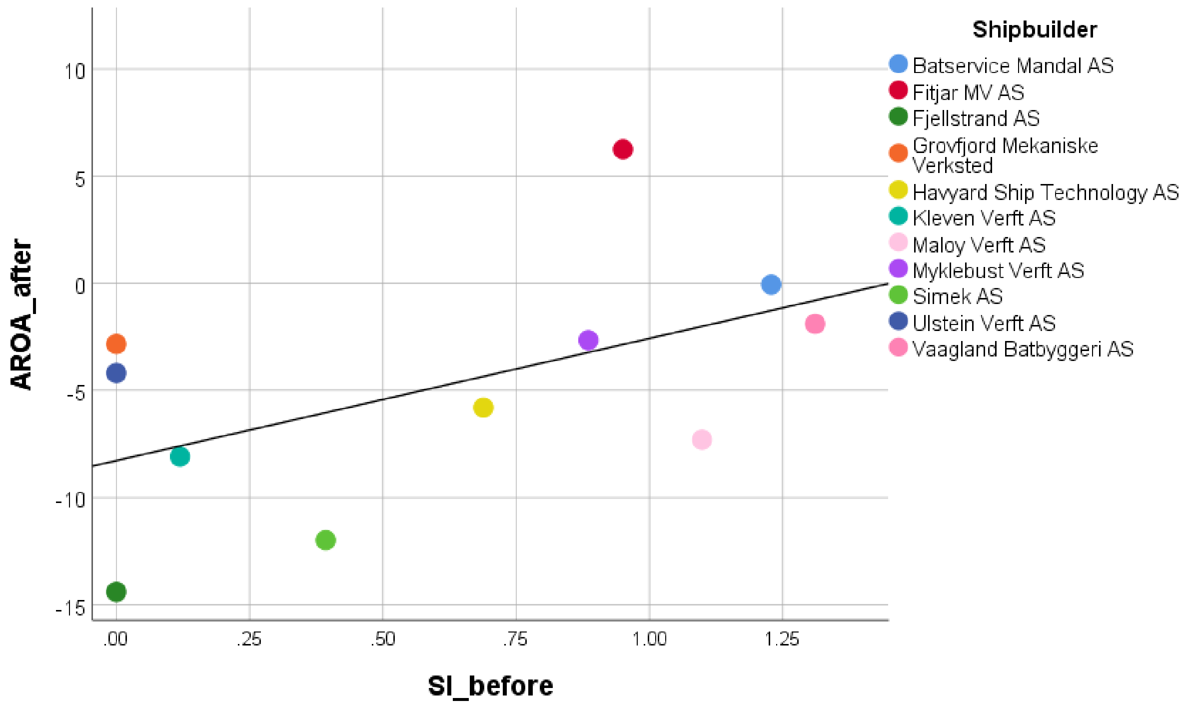


Figure 17 Scatterplot of $AROA_{after}$ *against* SI_{before} *with linear regression line, model (C),* $R^2=.27$

The regression line for model (D) is plotted on the scatterplot of the $AROA_{after}$ against the TC_{before} for the 11 shipyards in Figure 18.

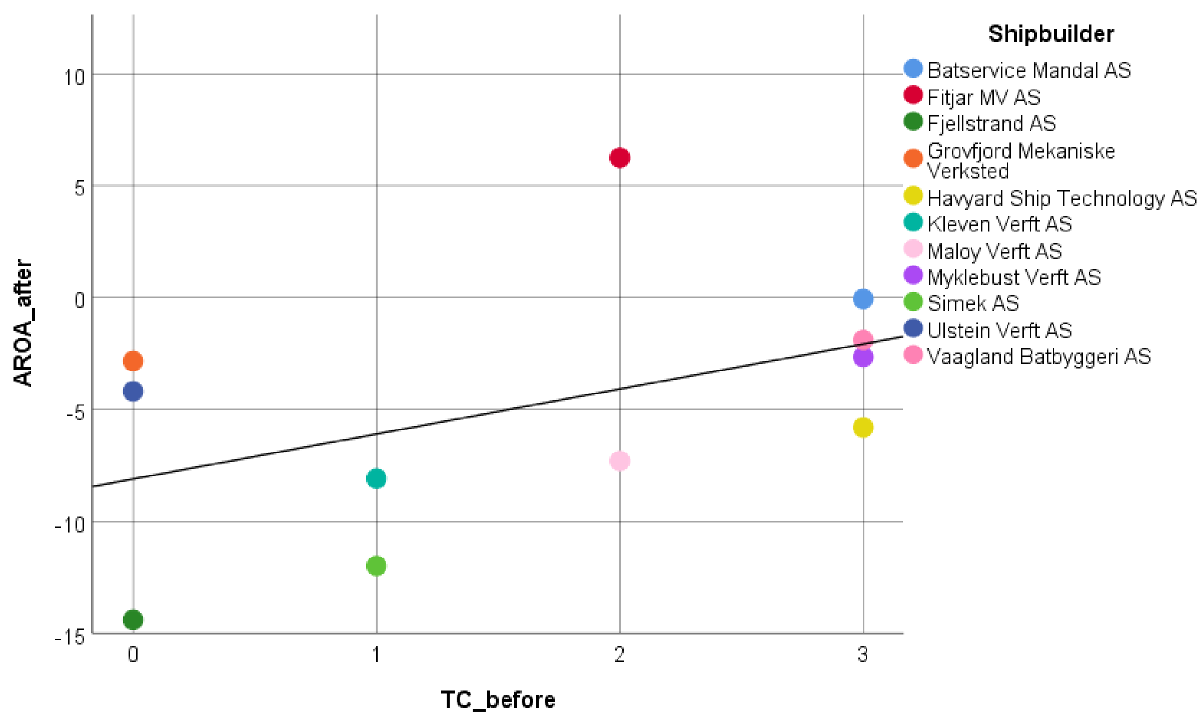


Figure 18 Scatterplot of $AROA_{before}$ *against* TC_{before} *with linear regression line, model (D)*

The model (C) was found to be significant at the .10 level. The statistical power (1-β) of the linear regression is then computed to evaluate the probability β of making type II error. With 1 predictors, 11 observed values, an observed R square of $R^2 = .273$, and a significance level of $\alpha = .10$, the statistical power is (based on Soper, 2020):

$$Statistical\ power = 1 - \beta = 0.60.$$

This is not satisfying, as the power level ideally be at least .80 (Hair et al., 2010). This is likely to be due to the small sample size and is an obvious limitation of the study.

In the next section, the results of the hypothesis testing are summarized.

4.2.3. Summary of the regression results

The decisions about the tested research hypothesis are summed up in Table 19. Only one significant relationship was found, between the $AROA_{after}$ and the SI_{before} for the "offshore" shipbuilders (model (C)). These results are discussed in the next section.

Table 19 Summary of the decision for the tested hypothesis

Hypothesis	**Model(s)**	**Decision**
$H_{0\text{-}I}$: "There is no significant relationship between the AROA and the SI or the TC."	(A), (B)	Failed to be rejected
$H_{1\text{-}I}$: "The AROA of shipyards is related to their SI."	(A)	Rejected
$H_{2\text{-}I}$: "The AROA of shipyards is related to their TC."	(B)	Rejected
$H_{0\text{-}II}$: "There is no significant relationship between the $AROA_{after}$ and the SI_{before} or the TC_{before}, when Offshore=1."	(C)*, (D)	Rejected
$H_{1\text{-}II}$: "The $AROA_{after}$ of shipyards is related to their SI_{before}."	(C)*	Accepted
$H_{2\text{-}II}$: "The $AROA_{after}$ of shipyards is related to their TC_{before}."	(D)	Rejected

**The estimated model regression is statistically significant.*

4.3. Discussion of the results

The main objectives of this thesis were (1) to investigate the relationship between the ship type variety (STV) and the financial performance (FP) of shipbuilding firms, and (2) to investigate the effect of ship type variety on the ability of shipyards to cope with market downturns. To meet these objectives, a literature study was performed to develop the research models and corresponding research hypothesis. Then, data was gathered from online databases, preliminary analyzed and submitted to regression analyses. The results of these regression analyses are presented in the previous sections and are interpreted and discussed in this section.

4.3.1. Financial performance and ship type variety

In this section, the results of the first two regression analyses are interpreted and discussed.

The regression analysis of models (A) and (B) did not allow to reject the null hypothesis $H_{0\text{-I}}$. This means that the dataset does not let appear a significant relationship between the AROA and the SI, or between the AROA and the TC. A look at Figure 15 and Figure 16, indeed indicates that there are no clear trends or pattern in the scatterplot of AROA against SI or TC. However, this is not sufficient to accept $H_{0\text{-I}}$, which mean it cannot be concluded that there is no relationship between the STV and the FP of shipbuilding firms. Moreover, the fact that $H_{0\text{-II}}$, could be rejected shows that, under certain circumstances, there is a relationship between the STV and the FP. Figure 16 even suggests that most of the shipyards producing 2 ship types or less (i.e. $TC \leq 1$) are not profitable in average on the period. On the other hand, a majority of those producing more than two types (i.e. $TC \geq 2$) are profitable in average on the period. This also contradicts the usual idea in the literature that increasing variety is ultimately unprofitable. An explanation is that shipbuilding is an ETO and project-based industry, and that there are such levels of variability in the products that, in the end, the ship type variety do not matter much.

The nonappearance of significant relationship can also be interpreted as a weakness of the measures. Indeed, as FP and STV are both multidimensional constructs, the use of single measures to represent them implies some limitations, which are recurring in the studies of the relation between product diversification and financial performance (Bausch and Pils, 2009). Even if it was tried to include several aspects of STV (i.e. the multiplicity and the balance), by using both the types count and the Shannon index, the disparity aspect (i.e. the degree of difference between two types) was not accounted for. However, it is possible that the disparity has a critical influence on the performance of shipyards. Indeed, intuitively, building two very different ship types would affect performance more than building three “similar” types. This can be explained with the theoretical categorization of the product variety, as the disparity of the ship types would increase the internal variety at the lower levels (i.e. the variety of subsystems and parts) more than the multiplicity would.

On the other hand, the use of the AROA alone to represent the FP is also a limitation, even if the ROA is usually found to be a reliable measure of the FP (Combs et al., 2005). The use of multiple variables on the form of summated scales for example could increase the validity of the measure (Hair et al., 2010). Besides, even if they were anticipated, there are limitations to the use of secondary data related to financial performance. In particular, the aggregation issue has been a major concern which led to exclude shipyards from the sample, because their accounting results were not directly attributable to their shipbuilding activity. This contributed to reduce the sample size, as well as the lack of data for some shipyards. Also, it is possible that the effect of STV on FP is too weak to be detected, especially given the small size of the sample.

Finally, it is possible that some factors are missing from the model. Indeed, it is likely that the level of standardization, and modularization would also have a moderating effect on the relationship between the FP and the STV, because they can enable cost efficient variety. Bausch and Pils (2009) point out that the literature suggests that product diversification strategies are translated into FP only under the conjunctions of other factors such as the firm’s environment. It was chosen to reduce the analysis scope to the single national context of Norway, to be able to neglect most of these external factors. However, this might not be sufficient to neglect these other factors.

In the next section, the results of the last two regression analyses are interpreted and discussed.

4.3.2. Ship type variety and the offshore vessels market downturn

In this section, the results of the last two regression analyses are interpreted and discussed. These analyses focus on the effect of ship type variety on the ability of the Norwegian shipyards to cope with the offshore vessels market downturn.

The estimation of model (C) allowed to reject the null hypothesis $H_{0\text{-}II}$ and to accept the alternate hypothesis $H_{1\text{-}II}$. A statistically significant relationship was found between the $AROA_{after}$ and the SI_{before} of offshore ship manufacturers, and it was found that model allows to explain 27% of the variance of $AROA_{after}$ based on SI_{before}:

$$AROA_{after} = -8.3 + 5.7 \times SI_{before}$$

It is reminded that the SI measures the multiplicity (i.e. number of ship types) and the balance between the ship types. The SI increases with the number of ship types, for a constant balance. On the other hand, for a constant number of types, the SI increases when the relative shares of each types are comparable (e.g. producing the same number of offshore vessels and fishing vessels) and decreases if one type is predominant (e.g. producing mainly offshore vessels and a fishing vessel every now and then). Although it is hard to directly interpret the values of the SI, we can derive some conclusions from the previous results.

In the next years after the offshore vessels market downturn, the shipyards which were the more diversified from the SI point of view tended to be more profitable in average. Especially, the difference between the offshore-focused shipyards (i.e. $SI_{before} = 0$) and the most diversified (i.e. $SI_{before} \approx 1.25$) represents around 7 points in the $AROA_{after}$. This suggests that the past STV has a practically significant positive effect on the FP during and after the market downturn. Indeed, more diversified portfolios and order books allow to avoid the risks of a "focused" strategy. Furthermore, diversified shipyards are automatically requiring more flexibility which they would more likely include in there manufacturing strategies. Whereas "focused" shipyards are more likely to optimize their operations in order to produce one type, which might lead to more "rigidity" and make it harder to switch to other ship types.

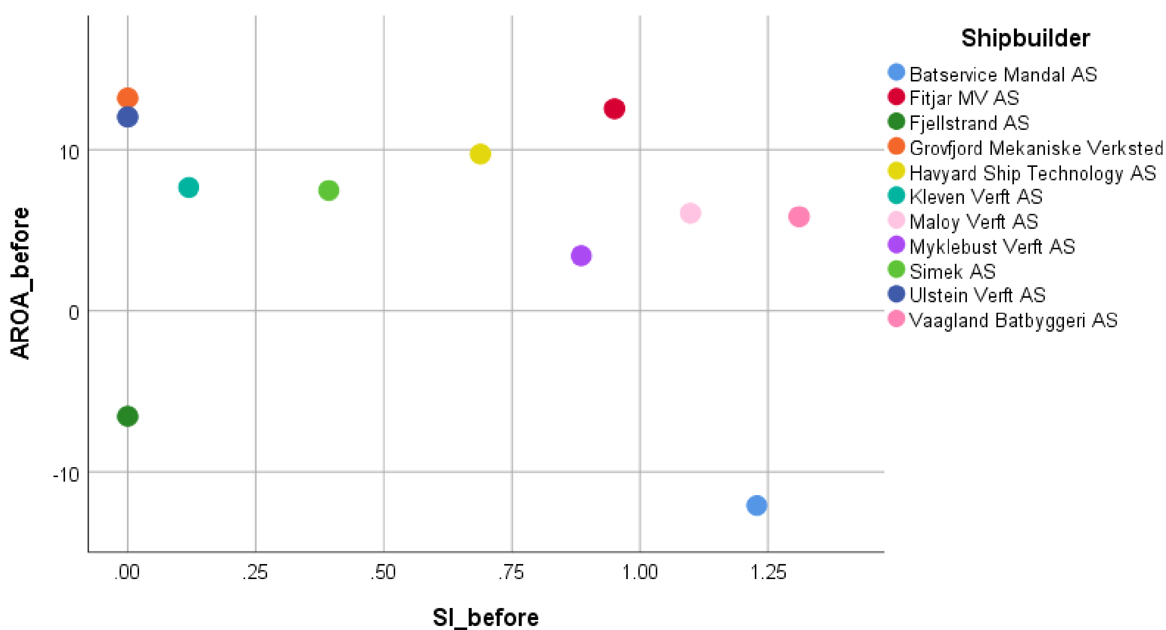


Figure 19 Scatterplot of the $AROA_{before}$ *against the* SI_{before} *for the "offshore" shipyards*

On the other hand, Figure 19 shows that 9 of these 11 shipyards were largely profitable before the market downturn. This plot also suggests that there was no relationship between STV and FP before the downturn, and that they roughly had similar level of profitability on the period independently of their SI. Which is consistent with the results of the first analyses.

A possible interpretation is that diversified strategies, with multiple and balanced ship types, allow to increase the stability of the sales and production. Such a strategy allows to mitigate the damages caused by a market downturn. On the other hand, a "focused" strategy might allow higher level of optimization and might allow to avoid the disadvantages of variety suggested by theory (table 15). However, this implies to accept the risks of a narrow portfolio and the struggles of shifting to "unknown" ship types if necessary. Thus, such a strategy should also take into consideration the risk associated with one market and should preferably not be applied for market segments with unstable demand. In the case of the offshore vessels market downturn, the fluctuations of the oil price, on which the whole industry was relying, represented a major risk which was maybe not foreseen (Mellbye et al., 2015).

The next section summarizes the practical implications of the results.

4.4. Practical implications

Based on the previous discussion and according to the results of this thesis, some practical implications can be formulated.

First, the results show that it is possible to produce a high variety of ship types without being less profitable than a "focused" shipyard. Accordingly, shipyards should not try to limit their portfolio as an effort to be efficient. Indeed, portfolio restrictions do not produce significant advantages in term of profitability.

Moreover, the results show that ship type variety is a strategic advantage in a context of market uncertainty. More precisely, ship type variety is found to be an advantage for the shipyards that have to face a market downturn. This means that shipyards should try to keep diversified portfolios to secure their long-term stability.

The next chapter concludes the thesis, by summarizing the main findings and limitations of the research and providing suggestions for further works.

5. Conclusion

This chapter concludes the thesis. First the main findings and practical implications are summarized, and the achievement of the research objectives is assessed. Then the research limitations are highlighted. Finally, recommendations for future research are suggested.

5.1. Main findings

This thesis aimed to explore the relationship product variety and the performance of shipyards. The two main objectives of the thesis were (1) to investigate the relationship between ship type variety and the financial performance of shipbuilding firms, and (2) to investigate the effect of ship type variety on the ability of shipyards to cope with market downturns.

To meet the objectives, a literature study was carried to formulate a research model (figure 8) and corresponding hypotheses. The main theoretical hypotheses were that (1) the financial performance of shipyards is related to their ship type variety, and that (2) after a market downturn, the financial performance of shipyards is positively related to their past ship type variety. Ship type variety and financial performance were operationalized using the Shannon index and the types count for the former, and the average return on assets for the latter.

In order to test the research hypotheses, secondary data is gathered from the financial database Orbis, and the Sea-Web maritime database. The data are gathered for 22 Norwegian shipyards for a period from 2008 to 2018. Based on this dataset, the previous variables are measured and aggregated. Linear regression analyses are performed on this dataset to find relationships between the variables and validate or invalidate the research hypotheses.

Regarding objective 1, the results do not suggest that the profitability of Norwegian shipbuilding was related to their ship type variety during the investigation period. This suggests that "high variety" strategies are not as unprofitable as it could be expected. However, the limitations of the model and analysis method implies that further research is required to validate these conclusions.

Regarding objective 2, the results suggest that ship type variety is a strategic advantage when a market downturn happened. Indeed, the example of the offshore vessel market downturn, which followed the 2014 oil price crisis, indicates that shipbuilders with wider portfolios were more resilient than those who were focused on offshore vessels production. The main implication is that shipbuilders should be aware of the risk associated with single type portfolios.

The next section summarizes the main theoretical and practical contributions of this thesis.

5.2. Theoretical and practical contributions

This thesis contributes to the theory by exploring the relationship between ship type variety and financial performance in shipbuilding. Especially, a theoretical classification of product variety in shipbuilding has been proposed. Moreover, this thesis has introduced the use of two diversity measures, the Shannon index and the types count, as measures of the product variety of shipyards. Finally, this thesis has proposed a discussion of some methodological issues related to the use of financial performance measures to assess shipbuilding performance.

The thesis also suggests implications for practice. First, shipyards should not narrow down their product portfolios based on efficiency objectives. Indeed, narrow portfolio do not produce significant advantages in term of profitability. Moreover, shipyards should try to keep diversified portfolios to secure their long-term stability.

The next section highlights the limitations of the research.

5.3. Limitations

This section outlines and discusses the main limitations of this study.

The data analysis method has shown some limitations. First, the lack of data availability on the used databases have led to reduce the size of the sample. Then again, the use of public data was chosen because of the common non-response issue identified in the literature.

The sample size was further reduced by the exclusion of shipyards for which the financial results suffered from aggregation issues. As a result, it was difficult to achieve statistical significance. Besides, the use of the single national context of Norway, which has allowed to simplify the model, also limited the sample size and the generalizability of the findings to other contexts.

From a theoretical perspective the main limitations are related to the model specification. Indeed, it was already discussed that several factors might be missing from this model. Furthermore, only one dimension of product variety has been investigated, and it was the same for financial performance. However, the multidimensionality of both constructs should be further taken into account (Bausch and Pils, 2009).

Additionally, there are limitation regarding the causality of the relationship between ship type variety and financial performance. Indeed Bausch and Pils (2009) point out that the studies that suggest product diversification strategy causes performance do not put enough effort in justifying that the causality of the relationship. Especially, the collection of data in simultaneous period does not allow to draw conclusions about the causality. However, for the analysis related to objective 2, the data were collected over two separate and consecutive periods, which allows to suppose causality.

In the next section, some recommendations are made to overcome the current limitations and to further investigate the topic.

5.4. Recommendation for further work

Some opportunities and recommendations for further work were identified during the writing of this thesis.

First, regarding the identified limitations, it is advised to:

- Carefully chose the shipyard performance data collection method, especially consider the advantages and drawbacks of the different possible approach (e.g. database vs survey) and when possible use "hybrid" approaches.
- Further include the multiple dimensions of variety and performance. For example, multiple regressions techniques and summated scales could be used to find the interrelationships between the dimensions of both constructs.
- Investigate the factors influencing the relationship between variety and performance, such as the industrial environment, the degree of standardization.
- Put effort into the justification of the causality of the relationship between variety and performance. Especially, it is important to consider the temporal sequence of the measures.

Besides, the problem can be investigated from the perspective of other research fields. For example, the variety in ETO industries is investigated in the fields of product portfolio management (Trappey et al., 2009, Yunes et al., 2007), or product configuration systems (Kristjansdottir et al., 2017, Brière-Côté et al., 2010).

Additionally, further studies could investigate if there an ideal level of variety in term of profitability, stability and efficiency. Also, it could be relevant to propose a methodology for shipyards to choose whether they should start producing a new ship type. Finally, it could be interesting to investigate, through case studies, what the best strategies to handle variety are and how to develop them.

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Appendix 1: StatCode 5 Coding System (IHS Markit, 2017)

Level 5	Level 4	Level 3	Level 2	Level 1
LNG Tanker	LNG Tanker	Liquefied Gas	Tankers	Cargo Carrying
LPG Tanker	LPG Tanker			
LPG/Chemical Tanker				
CO2 Tanker	CO2 Tanker			
Molten Sulphur Tanker	Chemical Tanker	Chemical		
Chemical Tanker				
Chemical/Products Tanker	Chemical/Oil Products Tanker			
Wine Tanker	Wine Tanker			
Vegetable Oil Tanker	Vegetable Oil Tanker			
Edible Oil Tanker	Edible Oil Tanker			
Beer Tanker	Beer Tanker			
Latex Tanker	Latex Tanker			
Shuttle Tanker	Crude Oil Tanker	Oil		
Crude Oil Tanker				
Crude/Oil Products Tanker				
Products Tanker	Oil Products Tanker			
Tanker (unspecified)				
Asphalt/Bitumen Tanker	Bitumen Tanker			
Coal/Oil Mixture Tanker	Coal/Oil Mixture Tanker			
Water Tanker	Water Tanker	Other Liquids		
Molasses Tanker				
Glue Tanker	Glue Tanker			
Alcohol Tanker	Alcohol Tanker			
Caprolactam Tanker	Caprolactam Tanker			
Fruit Juice Tanker	Fruit Juice Tanker			
Bulk Carrier	Bulk Carrier	Bulk Dry	Bulk Carriers	
Bulk Carrier, Laker Only				
Bulk Carrier (with Vehicle Decks)				
Ore Carrier	Ore Carrier			
Bulk/Oil Carrier (OBO)	Bulk/Oil Carrier	Bulk Dry/Oil		
Ore/Oil Carrier	Ore/Oil Carrier			
Bulk Cargo Carrier, self-discharging	Self-Discharging Bulk Carrier	Self-Discharging Bulk Dry		
Bulk Cargo Carrier, self-discharging, Laker				
Cement Carrier	Cement Carrier	Other Bulk Dry		
Wood Chips Carrier, self-unloading	Wood Chips Carrier			
Urea Carrier	Urea Carrier			
Aggregates Carrier	Aggregates Carrier			
Limestone Carrier	Limestone Carrier			
	Refined Sugar Carrier			

Level 5	Level 4	Level 3	Level 2	Level 1
Powder Carrier	Powder Carrier	Other Bulk Dry	Bulk Carriers	Cargo Carrying
General Cargo Ship (with Ro-Ro facility) General Cargo, Self-discharging Open Hatch cargo Ship General Cargo/Tanker (Container/oil/ bulk - COB ship) General Cargo/Tanker General Cargo Ship	General Cargo Ship	General Cargo	Dry/Cargo/Passenger	
Palletized Cargo Ship	Palletized Cargo Ship			
Deck Cargo Ship	Deck Cargo Ship			
General Cargo/Passenger Ship	Passenger/General Cargo Ship	Passenger/General Cargo Ship		
Container Ship (Fully Cellular) Container Ship (Fully Cellular with Ro-Ro Facility)	Container Ship	Container		
Passenger/Containership	Passenger/Containership			
Refrigerated Cargo Ship	Refrigerated Cargo Ship	Refrigerated Cargo Ship		
Ro-Ro Cargo Ship Rail Vehicles Carrier	Ro-Ro Cargo Ship	Ro-Ro Cargo		
Vehicles Carrier	Vehicles Carrier			
Container/Ro-Ro Cargo Ship	Container/Ro-Ro Cargo Ship			
Landing Craft	Landing Craft			
Passenger/Ro-Ro Ship (Vehicles) Passenger/Ro-Ro Ship (Vehicles/Rail)	Passenger/Ro-Ro Cargo Ship	Passenger/Ro-Ro Cargo		
Passenger/Landing Craft	Passenger/Landing Craft			
Passenger/Cruise	Passenger (Cruise) Ship	Passenger		
Passenger Ship	Passenger Ship			
Livestock Carrier	Livestock Carrier	Other Dry Cargo		
Barge Carrier	Barge Carrier			
Heavy Load Carrier Heavy Load Carrier, semi-submersible Yacht Carrier, semi-submersible	Heavy Load Carrier			
Nuclear Fuel Carrier Nuclear Fuel Carrier (with Ro-Ro facility)	Nuclear Fuel Carrier			
Pulp Carrier	Pulp Carrier	Fish Catching	Fishing	Work Vessel
Factory Stern Trawler Stern Trawler Trawler	Trawler			
Fishing Vessel	Fishing Vessel			

Level 5	Level 4	Level 3	Level 2	Level 1
Fish Factory Ship	Fish Factory Ship	Other Fishing	Fishing	Work Vessel
Fish Carrier	Fish Carrier			
Live Fish Carrier (Well Boat)	Live Fish Carrier			
Fish Farm Support Vessel Fishery Patrol Vessel Fishery Research Vessel Fishery Support Vessel	Fish Farm Support Vessel			
Seal Catcher	Seal Catcher			
Whale Catcher	Whale Catcher			
Kelp Dredger	Kelp Dredger			
Pearl Shells Carrier	Pearl Shells Carrier			
Crew/Supply Vessel Pipe Carrier Platform Supply Ship	Platform Supply Ship	Offshore Supply	Offshore	
Anchor Handling Tug Supply Offshore Tug/Supply Ship	Offshore Tug/Supply Ship			
Offshore Support Vessel Diving Support Vessel Accommodation Ship	Offshore Support Vessel	Other Offshore		
Drilling Ship	Drilling Ship			
Pipe Layer Crane Vessel Pipe Layer	Pipe Layer			
Production Testing Vessel	Production Testing Vessel			
FPSO, Oil Gas Processing Vessel	FPSO			
Well Stimulation Vessel	Well Stimulation Vessel			
Standby Safety Vessel	Standby Safety Vessel			
FSO, Oil	FSO (Floating, Storage, Offloading)			
Trenching Support Vessel	Trenching Support Vessel			
Pipe Burying Vessel	Pipe Burying Vessel			
Research Survey Vessel	Research Vessel	Research	Miscellaneous	
Tug	Tug	Towing/Pushing		
Articulated Pusher Tug Pusher Tug	Pusher Tug			
Bucket Ladder Dredger Cutter Suction Dredger	Dredger	Dredging		

Level 5	Level 4	Level 3	Level 2	Level 1
Grab Dredger Backhoe Dredger Bucket Wheel Suction Dredger Suction Dredger Dredger (unspecified)	Dredger	Dredging	Miscellaneous	Work Vessel
Bucket Hopper Dredger Grab Hopper Dredger Suction Hopper Dredger Trailing Suction Hopper Dredger Hopper/Dredger (unspecified)	Hopper Dredger			
Hopper, Motor Stone Carrier	Motor Hopper	Other Activities		
Crane Ship Pile Driving Vessel	Crane Ship			
Icebreaker Icebreaker/Research	Icebreaker			
Cable Repair Ship Cable Layer	Cable Layer			
Incinerator Waste Disposal Vessel Effluent carrier	Waste Disposal Vessel			
Fire Fighting Vessel	Fire Fighting Vessel			
Pollution Control Vessel	Pollution Control Vessel			
Patrol Vessel	Patrol Vessel			
Crew Boat	Crew Boat			
Training Ship	Training Ship			
Utility Vessel	Utility Vessel			
Search & Rescue Vessel	Search & Rescue Vessel			
Pilot Vessel	Pilot Vessel			
Salvage Ship	Salvage Ship			
Buoy Tender Buoy & Lighthouse Tender Lighthouse Tender	Buoy/Lighthouse Vessel			
Supply Tender	Supply Tender			
Mooring Vessel	Mooring Vessel			

Level 5	Level 4	Level 3	Level 2	Level 1
Work/Repair Vessel	Work/Repair Vessel	Other Activities	Miscellaneous	Work Vessel
Hospital Vessel	Hospital Vessel			
Tank Cleaning Vessel	Tank Cleaning Vessel			
Trans-Shipment Vessel	Trans-Shipment Vessel			
Anchor handling Vessel	Anchor Hoy			
Log Tipping Ship	Log Tipping Ship			
Bunkering Tanker	Bunkering Tanker			
Exhibition Vessel Theatre Vessel Mission Ship	Leisure Vessels			
Bulk Dry Storage Ship Bulk Cement Storage Ship	Dry Storage			
Mining Vessel	Mining Vessel			
Power Station Vessel	Power Station Vessel			
Vessel (function unknown)	Vessel (function unknown)			
Sailing Vessel	Sailing Vessel			

Appendix 2: Dimensions and Sample Indicators of Firm Performance (Selvam et al., 2016)

Sl. No.	**Dimensions**	**Sample Indicators**	***No***
1	Profitability Performance	Return on Assets, EBTIDA Margin, Return on Investment, Net Income/Revenues, Return on Equity, Economic Value Added (EVA)	*6*
2	Market Value Performance	Earnings Per Share, Changes in Stock Price, Dividend Yield, Stock Price Volatility, Market Value Added (Market Value / Equity), Tobin's Q	*6*
3	Growth Performance	Market-Share Growth, Asset Growth, Net Revenue Growth, Net Income Growth, Number of Employees Growth	*5*
4	Employee Satisfaction	Turn-over, Investments in Employees Development and Training, Wages and Rewards Policies, Career Plans, Organizational Climate, General Employees' Satisfaction	*6*
5	Customer Satisfaction	Mix of Products and Services, Number of Complaints, Repurchase Rate, New Customer Retention general customers' satisfaction, Number of New Products/Services Launched	*6*
6	Environmental Performance	Number of Projects to Improve / Recover the Environment, Level of Energy Intensity, Use of Recyclable Materials, Recycling Level and Reuse of Residuals, Volume of Energy Consumption, Number of Environmental Lawsuits	*6*
7	Environmental Audit Performance	Environmental Policy, Environmental Audit Report and Environmental Review	*3*
8	Corporate Governance Performance	Board Size, Board Independence, Outside Directors, Insider Ownership	*4*
9	Social Performance	Employment of Minorities, Number of Social and Cultural Projects, Number of Lawsuits Filed by Employees, Customers and Regulatory Agencies	*4*
		Total	***46***

Appendix 3: Ratio/Parameters for each Dimensions of Firm Performance (Selvam et al., 2016)

Sl. No.	Dimensions	Numbers	Ratios/ Parameters
1	Profitability Performance	6	• ROA • EBIDTA Margin • ROI • Net Income/Revenue • ROE • EVA
2	Market Value Performance	6	• EPS • Changes in Stock Price • Dividend Yield • Stock Price Volatility • Market Value Added • Tobin's Q
3	Growth Performance	5	• Market Share Growth • Asset Growth • Net Revenue Growth • Net income Growth • Number of Employees Growth
4	Employee Satisfaction	6	• Turn-Over • Investment in Employees Development and Training • Wages and Rewards Policies • Career Plans • Organizational Climate • General Employee Satisfaction
5	Customer Satisfaction	6	• Mix of Products and Services • Number of Complaints • Repurchase Rate • New Customer Retention • General Customers' Satisfaction • Number of New Products/Services Launched
6	Environmental Performance	6	• Number of Projects to Improve / Recover the Environment • Level of Energy Intensity • Use of Recyclable Materials • Recycling Level and Reuse of Residuals • Volume of Energy Consumption • Number of Environmental Lawsuits

7	Environmental Audit Performance	3	• Environmental Policy • Environmental Audit Report • Environmental Review
8	Corporate Governance Performance	4	• Board Size • Board Independence • Outside Directors • Insider Ownership
9	Social Performance	4	• Employment of Minorities • Number of Social and Cultural Projects • Number of Lawsuits Filed by Employees • Customers and Regulatory Agencies

Appendix 4: List of the included and removed shipyards

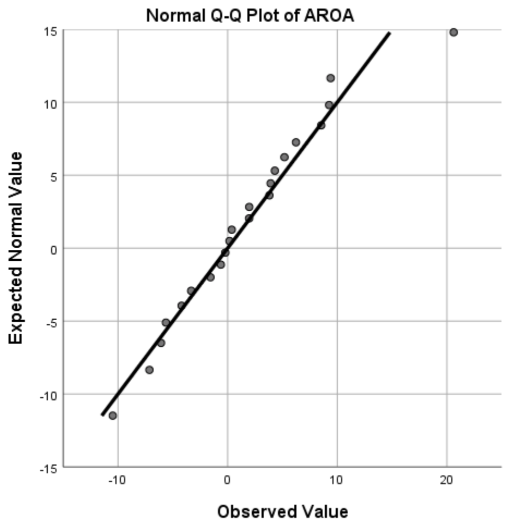
Shipyard	Status
Aas Mekaniske Verksted AS	Included
Aibel AS	Not included
Aker Yards AS	Not included
Batservice Mandal AS	Included
Blaalid AS	Not included
Blokken Skipsverft AS	Not included
Boreal Offshore AS	Not included
Brodrene AA AS	Included
Fiskerstrand Verft AS	Included
Fitjar MV AS	Included
Fjellstrand AS	Included
Flekkefjord	Not included
Grovfjord Mekaniske Verksted	Included
GS Marine Produksjon AS	Not included
Havyard Ship Technology AS	Included
Helgeland Maritime AS	Not included
Hommelvik Mekaniske Verksted	Not included
Kleven Verft AS - Ulsteinvik	Included
Kvaerner Mandal AS	Not included
Larsnes Mekaniske Verksted AS	Included
Maloy Verft AS	Included
Maritime Partner AS	Included
Mundal Bat AS	Not included
Myklebust Verft AS	Included
Noryards BMV AS	Not included
Oma Baatbyggeri AS	Included
Salthammer Batbyggeri AS	Included
Simek AS	Included
Skogsoy Bat AS	Included

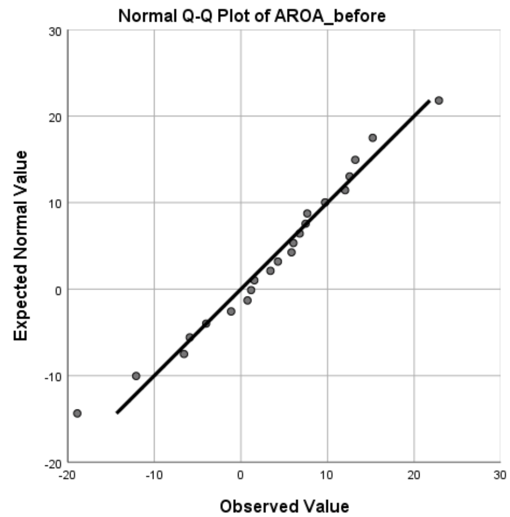
Sletta Verft AS	Included
Solstrand AS	Not included
Solund Verft AS	Not included
Stadyard AS	Not included
Sterkoder Mekaniske Verksted	Not included
Ulstein Verft AS	Included
Umoe Mandal AS	Included
Vaagland Batbyggeri AS	Included
Vard Aukra	Not included
Vard Brevik	Not included
Vard Langsten	Not included
Viknaslipen AS	Included
Westcon Yard AS	Not included
Number of kept shipyards:	**22**

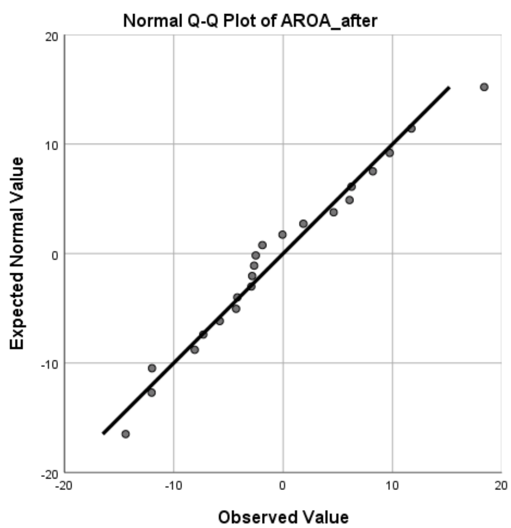
Appendix 5: Values of the variables for the included shipyards

Shipbuilder	AROA	$AROA_{before}$	$AROA_{after}$	TC	TC_{before}	SI_{before}	SI	Offshore
Aas Mekaniske Verksted AS	20.6	22.9	18.4	3	2	0.51	0.51	0
Maritime Partner AS	-1.6	1.2	-4.3	0	-1	0.00	0.00	0
Salthammer Batbyggeri AS	8.5	15.2	1.8	0	-1	0.00	0.00	0
Skogsoy Bat AS	-4.2	-5.9	-2.5	0	0	0.00	0.00	0
Umoe Mandal AS	-7.1	-18.9	4.6	0	-1	0.00	0.00	0
Fjellstrand AS	-10.5	-6.6	-14.4	2	1	0.60	0.87	1
Larsnes Mekaniske Verksted AS	6.2	4.3	8.2	1	1	0.50	0.65	0
Simek AS	0.2	7.5	-12.0	2	2	0.63	0.75	1
Sletta Verft AS	9.3	6.8	11.7	1	0	0.00	0.66	0
Viknaslipen AS	-5.6	0.8	-12.0	1	-1	0.00	0.69	0
Brodrene AA AS	3.8	1.6	6.1	2	2	0.47	0.30	0
Kleven Verft AS	-0.2	7.7	-8.1	3	2	0.73	1.01	1
Maloy Verft AS	-0.6	6.1	-7.3	3	2	1.10	1.39	0
Oma Baatbyggeri AS	4.3	-1.1	9.7	2	0	0.00	0.44	0
Havyard Ship Technology AS	2.0	9.7	-5.8	5	4	1.04	1.60	1
Fiskerstrand Verft AS	-3.3	-4.0	-2.9	3	2	0.52	0.69	0
Ulstein Verft AS	3.9	12.0	-4.2	4	1	0.69	1.01	1
Grovfjord Mekaniske Verksted	5.2	13.2	-2.8	2	0	0.00	0.68	0
Myklebust Verft AS	0.4	3.4	-2.7	6	4	1.20	1.74	1
Vaagland Batbyggeri AS	2.0	5.8	-1.9	3	3	1.31	1.22	1
Batservice Mandal AS	-6.1	-12.1	-0.1	3	3	1.23	1.23	0
Fitjar MV AS	9.4	12.5	6.2	4	2	0.95	1.40	0

Appendix 6: Normal Q-Q Plots of AROA, $AROA_{before}$, and $AROA_{after}$

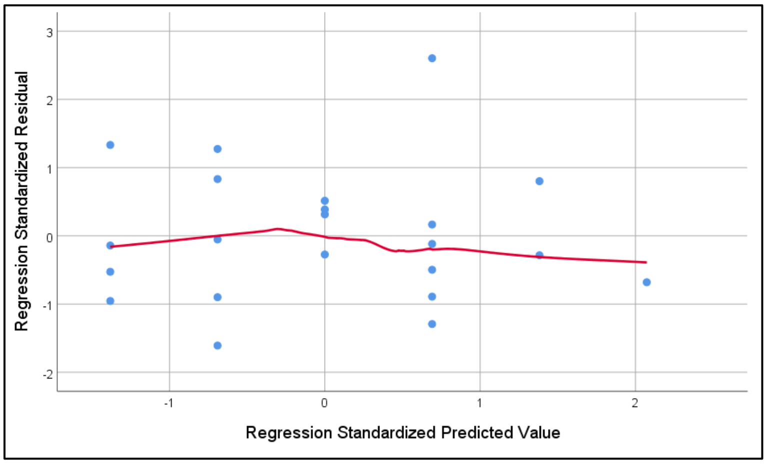




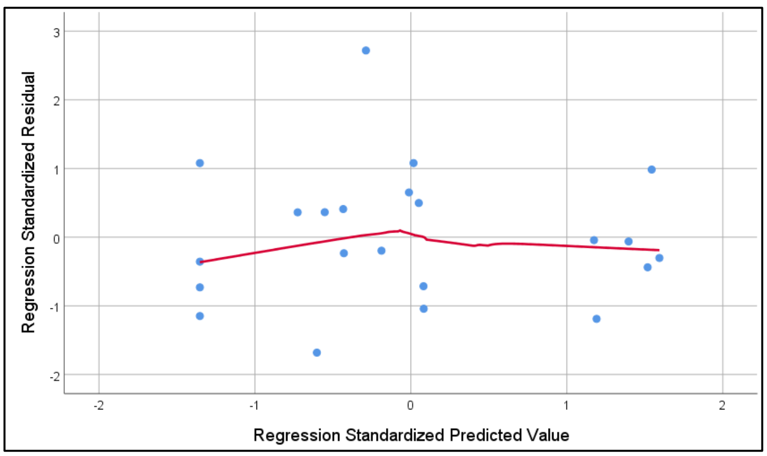


Appendix 7: Standardized residuals plots with Loess curves

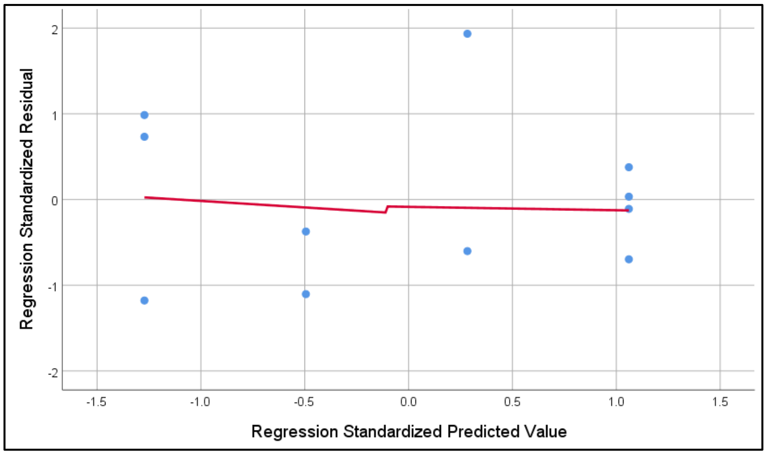
Model (A): Independent variable: AROA, dependent variable: TC



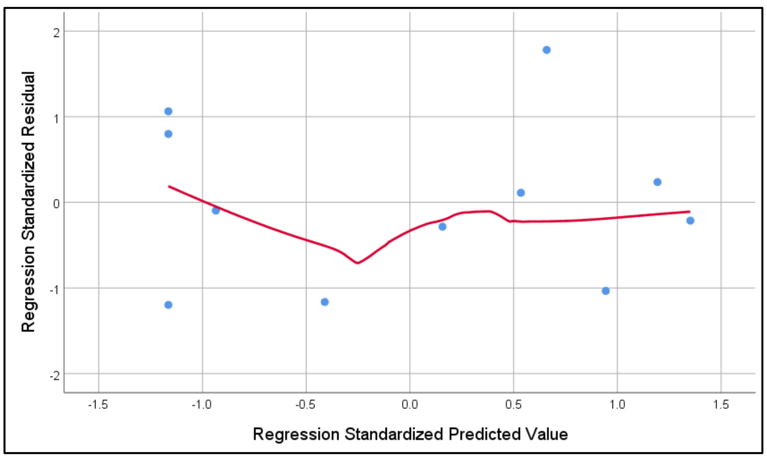
Model (B): Independent variable: AROA, dependent variable: SI



Model (C): Independent variable: $AROA_{after}$, dependent variable: TC_{before}

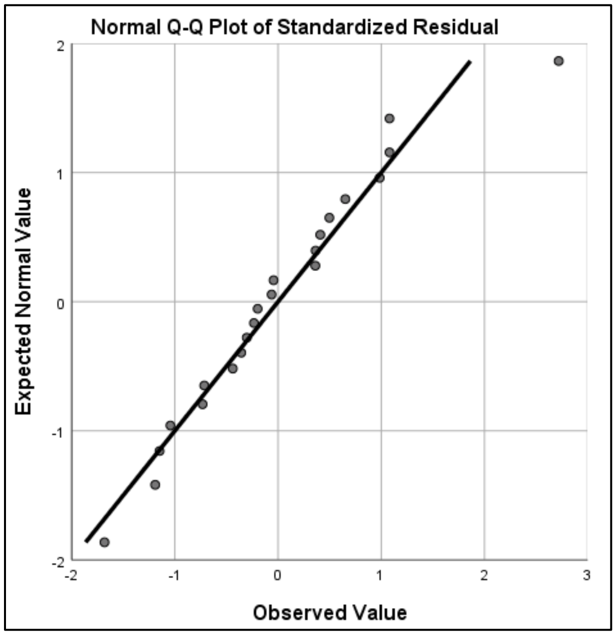


Model (D): Independent variable: $AROA_{after}$, dependent variable: SI_{before}

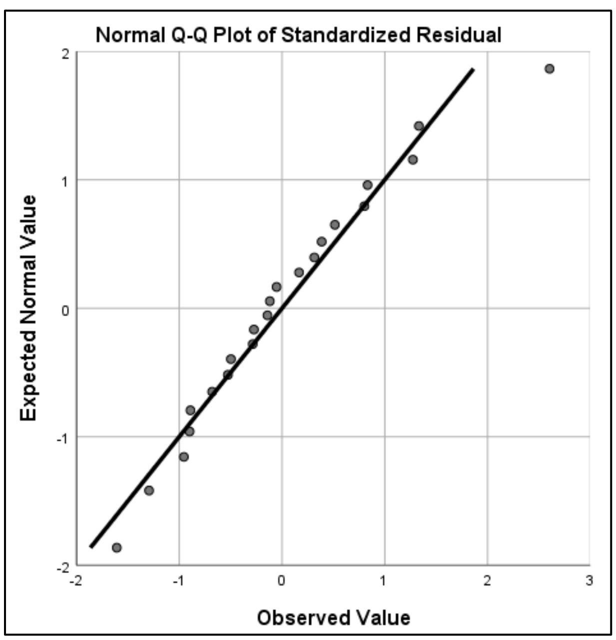


Appendix 8: Normal Q-Q Plots of standardized residuals for models (A), (B), (C), and (D)

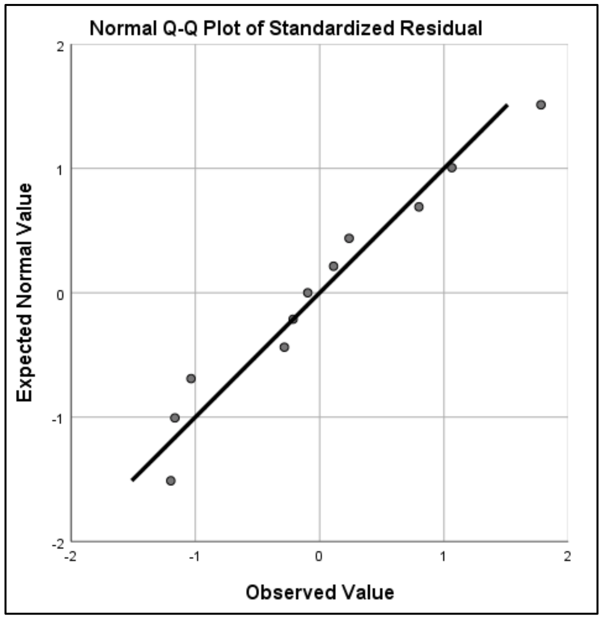
Model (A): Independent variable: AROA, dependent variable: TC



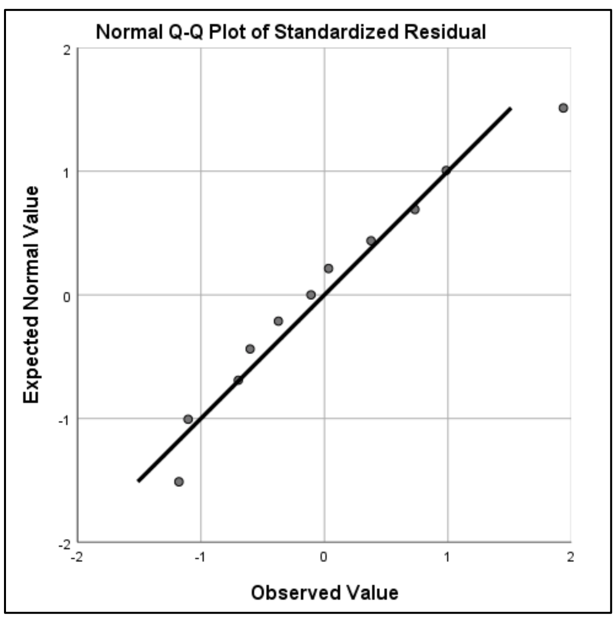
Model (B): Independent variable: AROA, dependent variable: SI



Model (C): Independent variable: $AROA_{after}$, dependent variable: TC_{before}



Model (D): Independent variable: $AROA_{after}$, dependent variable: SI_{before}



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