--- MASTER THESIS ---

"Why dual fueled barges are not thriving in today's transportation sector: a comprehensive study"

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Chapter 1: Abstract

The aim of this work is to offer insights in the currently ongoing diffusion process of liquid natural gas (LNG) as a fuel for barges. In order to coop with emission standards, shipping lines seek alternatives for current technology. LNG is widely perceived as the successor of petrol based fuels. Despite lots of promising research the diffusion is emerging very slowly, with only 5 barges operating on LNG in all of Europe. In this paper the diffusion process is analyzed in order to point out why LNG as a barge fuel is not a big thing yet. With a realistic approach the excitement on LNG technology is put into perspective. The 'Adoption of New Technology' framework (Hall, 2003) is used to analyze the market, which discusses all factors that affect the forces by which the diffusion process is driven. These factors are modeled in the 'Heterogeneity Model' (Geroski, 2000), and together with the 'Real Options Model for Inter Firm Diffusion' (Dixit, 1994) the current state of the diffusion process is interpreted.

Chapter 2: Introduction

2.1 Introduction

Traditionally inland waterway ships (barges) use petrol based fuels for propulsion, because oil has been abundant, practical and cheap. In order to preserve the environment, the European Commission outlined and implemented more and more strict emission regulations, of which the latest standards will enter into force in 2020. Because of this, business is no longer as usual for European barge operators. Solutions had to be found, and from all possible remedies to the emission problem one innovation stands out: the use of liquefied natural gas (LNG) as a fuel. The theory around this is booming: in the recent decade authorities and companies pose it as the mantra of clean and sustainable maritime transport. The shipping world would be at the dawn of the LNG era and it would be only a matter of time before the gas plays a prominent role as a shipping fuel (e.g. (Burel, 2013) (Kumar, 2011) (Semolinos, 2013)). The technology is available and the market is ready (Livanos, 2014). One small detail: it is still not happening. Especially not in the barge sector. Despite a lot of research and pilot projects, the diffusion process passes slowly and wide spread integration of this new shipping fuel is still a far cry. Nowadays only 77 LNG fueled sea-going ships are in operation worldwide (DNV GL, 2016), and only 5 LNG fueled barges in Europe (Observatory of European Inland Navigation, 2016). This paper tends to offer insight in why LNG is not meeting up to the expectations. The scope of this research will be the inland waterway transportation in Western Europe. As explained in paragraph 3.2.1, this seems to be the sector that could benefit the most from cleaner emissions but lacks behind the most in the transition to LNG as a bunker fuel. Special attention will be payed to the angle of shipping lines. In most publications and research committees this party is little exposed, while they are the ones that shall have to invest in the LNG fueled barges.

Prominent research centers forecast a strong upcoming of LNG as a maritime fuel for years now. For example, in 2011 TNO published a report that summed the advantages of LNG propulsion in various ships and conclude with a very attractive business case for ships that switch to LNG, with a payback period of only five years (TNO, 2011). Another example comes from advisory and certification bureau DNV GL, who published in 2012 their ‘Shipping 2020 report’, in which they forecast that by 2020 over 1,000 ships worldwide would be bunkering LNG (DNV GL, 2012). News articles such as “Shell plans to charter 15 LNG-powered barges to operate in northwest Europe” (Shell, 2015) give hope for the near future. However, Shell might have other interests besides a closed business case. By stimulating the conversion to LNG, it also stimulates the sales of the LNG, in which is one of the major suppliers. All these developments and buzz around LNG form the motive for writing a paper on this matter.

2.2 Research Question

In order to gain insights in a structured way, the following research question is formulated:

‘Why is the diffusion of LNG as a shipping fuel for European barges emerging slower than expected?’

Important to this question is that it defines the scope and outlines the field of interest for this thesis, which it does by geographically limiting the research to Europe and by limiting the sector to inland waterway transportation. The tendency of the question towards a slower diffusion than expected is based on the ambiguity why the diffusion process is not yet in a further stage, as described in the introduction.

2.3 Methodology

In this section the methodology on how this research question will be answered is discussed. This roughly describes how the research question will be approached.

The objective of this paper is to shine light on the adoption process of LNG as a barge shipping fuel. For such an objective an inductive research method is the most appropriate approach, since it begins with observing the field of interest, from where eventually theories are formulated (Goddard, 2004). In order to ground these theories in practical observations, patterns should be searched, for which explanations should be developed through series of hypotheses. To guide this thesis, the grounded theory (GT) methodology is followed. This theory is originally developed by Glaser and Strauss (1967), and reviewed by C. Goulding (2002). Her book offers guidelines to structural conduct inductive research with the use of analytical frameworks. The essence of this method is described by its inventors as a research method that aims to penetrate the phenomena by moving through various levels of theory building, from description through abstraction to conceptual categorization, in order to probe underlying conditions, consequences and actions (Glaser, 1967).

To answer the research question with the GT method, an incremental approach is used:

- First a literature study is conducted to observe the field of interest. In the GT method the data collection stage is not separated from the interpretive process. Therefore, an exploratory research is conducted to clarify the potential of LNG as a barge shipping fuel. The GT method demands collection of data from a wide range of sources, in order to control for biased observations. Also the inclusion of secondary data is stimulated to give context to the analysis. For our field of interest this leads to an analysis of the emission requirements for barges in section 3.2, the technological potential of LNG as a shipping fuel in 3.3, the supply chain of LNG to the ships in 3.4 and the fuel prices in 3.5.
- Secondly, a conceptual framework is formed to determine the steps to be taken to come to an answer on the research question. In this phase the scope of the research is defined, which prevents that the study becomes too broad. By applying the framework patterns are identified and eventually theory is built. Since the goal of this paper is to explain why the diffusion process is going slower than expected, the factors have to be identified that have a negative impact on the adoption of LNG as a barge fuel. The conceptual framework is discussed in chapter four.
- In the third step the framework is used to analyze data from the field of interest. This analysis is performed in chapter five and six.
- The fourth step is to summarize these findings and aggregate them into a single theory on why the diffusion of LNG as a shipping fuel for barges is developing slower than expected. This is discussed in chapter seven.

2.3.1 Data Collection

In order to acquire insights in the potential of LNG as a shipping fuel a literature study will be performed. In the past decade plenty of case studies and exploratory studies were conducted in the field of LNG propulsion engines, maritime shipping, inland waterway shipping and supply chains. Several of them are used to form the overview in chapter two and to form the current market insights for chapter four. Online databases and the Erasmus University library gave access to this literature. Besides that, many websites of research agencies and government institutes provided insight in the current state of the market for these engines in the shipping world, and on the current and future regulations on emissions.

Given that LNG is a trending topic, various media facilitated in in-depth interviews with stakeholders in the field of LNG as a shipping fuel. In addition to this two interviews were conducted for this thesis. An interview with the technical director of a barge shipping line, mister D. van Stappershoef from Fluvia Group, offered insights in a company that has conducted several feasibility reports on the use of LNG as a bunker fuel. Also the director of a barge shipping line, mister B. Maelissa from Danser, was interviewed. This offered insights in the first company that refitted a barge to bunker LNG. These sources of expert opinions supported the literature studies.

For the analysis of costs, various digital sources on (fuel)prices, emissions and fuel consumption were used. For investment costs, various case studies were used as a source or assumptions were made based on expert opinions.

Chapter 3: Literature Study

In this chapter the current state of the market for LNG propulsion systems is described. First the barge sector is introduced in section 3.1. Then the emission regulations that are effective come about in section 3.2. The technological aspects of current engines and LNG fueled engines are discussed in 3.3. After this the supply of LNG to barges is discussed in 3.4. Finally, the fuel prices are analyzed in 3.5. The findings are summarized in 3.6.

3.1 Introduction to the European Barge Transportation Sector

From all large scale good transportation sectors within Europe, barge transport is the most sustainable mode. Given the economies of scale compared to truck and rail transport, inland waterway transport emits less greenhouse gasses (GHG) than other modes (TNO, 2011). Also the transportation of goods over longer distances is by barge often the least expensive solution. Transport is however limited to the course of the rivers, which makes it the most preferred mode for transport from seaports to the hinterland (Wiegmans, 2007).

In this sector various actors operate various elements: shipping lines own the ships, shipping agencies charter ships from shipping lines and make sure that the cargo from shippers is linked to them. In some cases, a shipping line and shipping agency are combined in one firm, and in other cases the shipper directly charters a ship from a shipping line. The European barge sector is traditionally characterized by small firms. For example, the Dutch barge fleet counts approximately 6500 vessels, owned by approximately 3650 firms. About three quarters of these firms are family businesses that own a single barge. The other firms are shipping lines (BVB, 2016). Most of them have a fleet of several ships, a handful operates a large fleet of maximum 30 ships (TNO, 2011).

3.2 Emission Regulations

The impact that transportation has on the environment is enormous. But where the growth of land-based transportation emissions is gradually coming down, air pollution from ships is continuously growing. The forecast is that by 2020, shipping will be the largest single emitter of air pollution in Europe, surpassing the emissions from all land-based sources together (European Federation for Transport and Environment, 2016). Although barge transport is relative clean compared to rail and road transport, the development of emission reduction is lacking behind to other types of transport. This is reason for the governmental institutions to implement certain emission control area's (ECA's). Beside ECA's that cover the coastal waters of Western Europe and the east and west coast of the United States, stricter regulations are implemented by the European Commission (EC) for the European inland waterways. These regulations demand barge shipping lines to further reduce the GHG emitted by their ships. Especially the emission of nitrogen oxides (NOx) and particulate matter (PM) should be reduced in the near future, what is reflected in the upcoming regulatory framework (EFTE, 2013). These standards have been structured as gradually more stringent tiers known as Stage I until the most recently announced Stage V. This latter stage will be empowered in 2020 and has far-reaching consequences for shipping lines (Dieselnet, 2016). For barge transport currently the Stage III standard for emissions is effective. This standard is similar to the current American emission norm TIER 2, so that shipbuilders and engine manufacturers can serve both the American and European market with a single product. The requirements on emitted GHG of Stage III and V are given in table 1, note that Stage IV is not applicable to barge transport.

The Central Commission for Navigation on the Rhine (CCR) implements these EC directives for ships on the Rhine river, and has empowered even stricter regulations on NOx and PM, of respectively 7 gr/kWh and 2 gr/kWh. The current stage of these stricter regulations is called CCR2.

Table 1: The upcoming Stage V compared to the currently empowered Stage III for inland waterway vessels in Europe (Stage IV does not apply for inland waterway transport) (Dieselnet, 2016) (AEC Maritime, 2016).

	Stage III	Stage V	*Change*
CO (gr/kWh)	5.0	3.50	*-30%*
HC (gr/kWh)	8.7	0.19	*-97,82%*
NOx (gr/kWh)	8.7	1.20	*-86.61%*
PM (gr/kWh)	0.50	0.02	*-96%*
SOx (% of fuel)	0.1%	0.1%	*0%*

3.3 Technological Aspects

To form an understanding on the diffusion of LNG as a shipping fuel, the technological side of this innovation is summarized in this section. First the characteristics of the common engines fueled by MGO are encountered, then the characteristics of engines fueled by LNG.

3.3.1 Engine and Fuel Technology

Barges nowadays are fueled with marine diesel oil (MDO) or marine gas oil (MGO), which is a fossil fuel made based on petroleum. In order to cope with emission standards, shipping lines take measures to clean their emission. Various systems are available, all for their own purpose. The various measures are listed below on the GHG they reduce (Burel, 2013):

- A gas after treatment system like a wet scrubber installation reduces SOx, NOx, PM and HC emissions.
- Catalysts like diesel oxidation catalysts reduce CO, HC and PM emitted.
- Diesel particulate filters reduce PM emitted.
- SOx emissions can be reduced by using a low sulphur fuel, since the emission is directly proportional to the sulphur content of fuel. MGO has a lower sulphur level than MDO and is therefore used by barges on the European waterways.

Installing after-treatment installations is less expensive, with costs of only 30% of conversion to LNG. The downside of these systems are additional operating costs and the production of toxic solid waste (Deal, 2013).

3.3.2 LNG Fueled Engines

Natural gas is a fossil fuel that is widely available. It has a higher energy density per kilogram compared to MDO and MGO, as displayed in table 2 below.

Table 2: Energy content fuels (Bucci, 2014)

Energy Content	**MDO**	**LNG**	**MGO**
MJ/liter	36.4	25.3	34.0
MJ/kg	45.4	55.0	47.2

The major advantages towards petroleum based fuels are the absence of SOx emissions in the combustion process, and compared to MGO a reduction of NOx emissions by 80%-85%. Also the PM production Is very low and CO2 emissions are reduced by 20%-30% due to higher hydrogen content in the molecules (Burel, 2013). The downside of using LNG as a fuel is the emission of methane that is not fully combusted. This gas leads just like CO2 to global warming, but does so four times stronger (Burel, 2013).

LNG is natural gas that is cooled down to its liquid form, so that the energy density is a lot higher compared to CNG (compressed natural gas). The advantages of liquefying natural gas are twofold: more energy can be stored in a certain tank and there is only limited pressure on the installation (TNO, 2011).

At the moment of the combustion of LNG in an engine, the fuel has warmed up and therefore returned to its gas state. The advantage of injecting a gas in the engine is that the combustion itself is highly efficient and therefore clean. The counterpart is that the mixture of the fuel with oxygen can only vary in a certain range. Technological limitations imply that a combustion engine on LNG has to start using MGO, before it can switch to LNG. MGO is also added to the combustion when extra power is needed, for example when a ship has to accelerate. So the current state of technique demands the use of a dual fuel engine which operates on an average ratio of 98% LNG – 2% MGO. When a barge operates on long distances with a continuous speed, this ratio moves to 99%-1%. In case of short distances and variable speeds the ratio can move to 92%-8%. (Stappershoef, 2016)

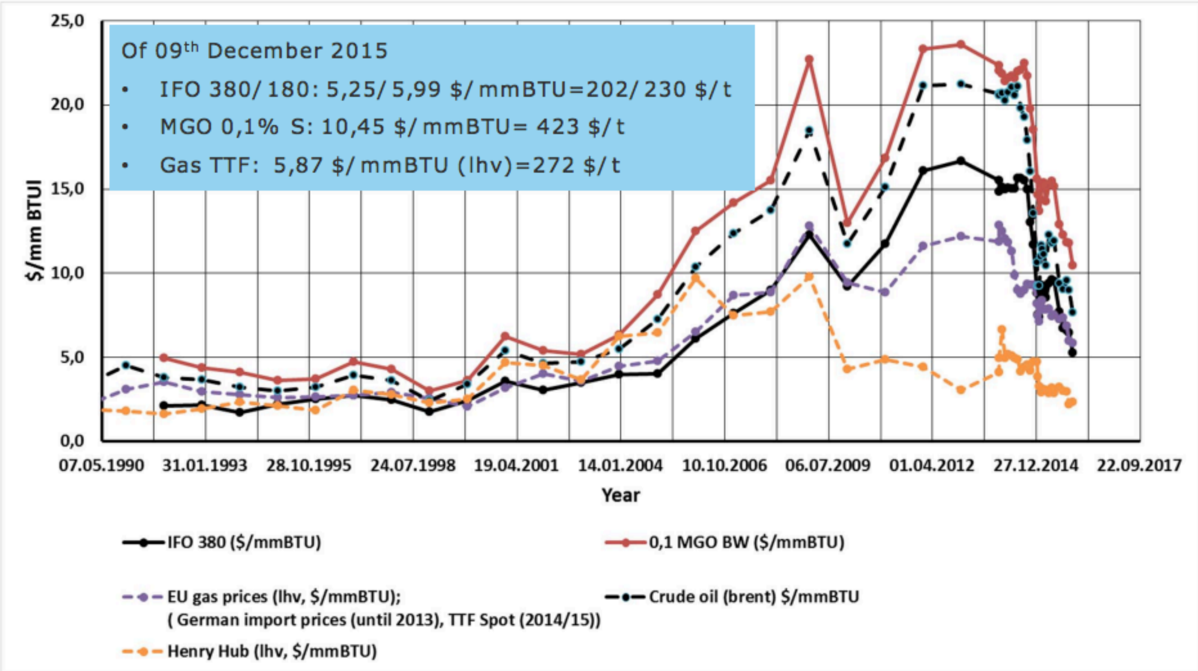
3.4 Supply Chain of Bunkering LNG to Barges

In the literature the supply of LNG to all ports worldwide that seagoing vessels might visit is seen as an important challenge to overcome for a successful introduction of LNG as a maritime fuel (Semolinos, 2013). For barges this problem is less valid, since bunkering is done in smaller quantities than seagoing vessels. Bunkering can be done from a truck directly to a barge. Within five years dozens of marine LNG bunkering hubs will are operational in Northern European ports (Natural Gas Europe, 2016), and also for the barges navigating on the European inland waterways more shore-to-ship options arise within the next few years (Bucci, 2014). The costs of bunkering from a truck are higher compared to bunkering from a bunker station, especially when compared to bunkering MGO (Stappershoef, 2016).

3.5 Fuel prices

The prices of ship fuels MGO and LNG are fluctuating at different levels. In the past the prices of oil have fluctuated the most, where LNG prices are perceived more stable. This feature is preferred in a market with long term contracts, when a firm has a constant usage over time. This is the case in the shipping sector, which implies that the highly fluctuating oil price is seen as a challenge in the maritime industry (Buurma, 2015). In the long run the prices of MGO are likely to rise in a higher rate than LNG, according to stakeholders in the fuel sector (TNO, 2011). The costs of fuel for a barge that fuels MGO are higher compared to the fuel costs for a barge that fuels LNG (see figure 1).

Figure 1: Price development of shipping fuels 5/1990 - 12/2015 (DNV GL, 2016)



3.6 Conclusion

By describing the current state of the barge transport market and the available technology, it becomes clear that various forces put pressure on how the market is functioning. Internal forces are given by the market structure, external forcers come from price developments and regulations. The development of technology and an infrastructure for bunkering LNG offers possibilities for shipping lines. In order to analyze these options and to gain insight in how the diffusion process is affected by these forces, a conceptual framework is formed in the next chapter.

Chapter 4: Conceptual Framework

In this chapter the research outline will be sketched up. For this, first the concept of diffusion and the forces that underlie this process are elaborated upon in section 4.1. Then two frameworks are discussed on how to analyze the factors in this process in 4.2 and 4.3. This chapter will conclude with an overview of the framework to explain how the barge transportation sector will be analyzed in this paper in 4.4.

4.1 Drivers of Diffusion

As a starting point for this paper's conceptual framework the 'Driving Forces Analysis of Diffusion' by Mitropoulos and Tatum (2000) is used. They define diffusion as the process by which a new technology becomes accepted and used by its potential users. Adoption indicates the same process, but from the perspective of the adopting firm. The forces that underlie to this process are showed in table 3 below.

Force	**Factor**	**Trend over time**
Competitive advantage	Core technology Adoption by competitors	Decrease
Process problems	Supply factors Demand factors Sector growth	Increase
Technological opportunity	Technology costs Available skills Availability of complementary technologies	Increase
External requirement	Owner's demands Regulations Use by competitors	Increase

Table 3: Forces for adoption and factors affecting the strength of them (Mitropoulos, 2000)

Competitive advantage is gained when the technology offers qualitative or cost benefits over the current technology. As the diffusion process is taking place, more actors use this technology and relative advantage diminishes. The impact of this force therefore decreases over time.

Process problems indicate all factors that are related to the problems with the current technology, which cannot live up to its desired performance. Because of this adoption of the new technology is induced. These problems tend to become larger over time and therefore the trend of this force is increasing.

When a technology is pushed to the market this is called the technological opportunity force. In the development process of a new technology the usefulness increases until it is ready for the market. This means that the adoption is economical and offers higher benefits compared to costs relative to the incumbent technology. As technologies continuously develop over time, this force that pushes the diffusion process also increases over time.

The last force on adoption is external requirement. This implies the necessity to adopt the new technology as posed from powerful external actors, for example regulators or clients. These parties often have power over the decision process of a firm, as regulators can pose standards or taxes to direct the market to a new technology or clients can switch to a competitor which leads to a loss of competitive position.

Figure 2 first illustrates the forces and their conversion over time. Figure 3 shows an S-curve that is the result of the sum of the four forces on diffusion. The first stage of the diffusion process is driven by the competitive advantage, that strongly decreases over time until more than half of the firms in the market adopted the new technology. From that moment onwards the growth decreases. The other three forces grow in impact over time until all of the users have adopted this new technology.

Figure 2: Forces of adoption (Mitropoulos, 2000)

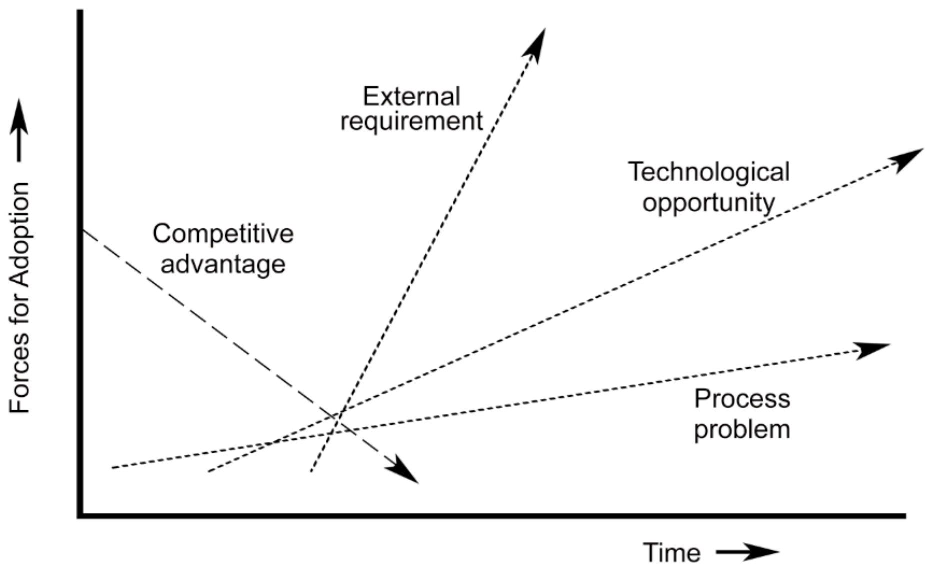
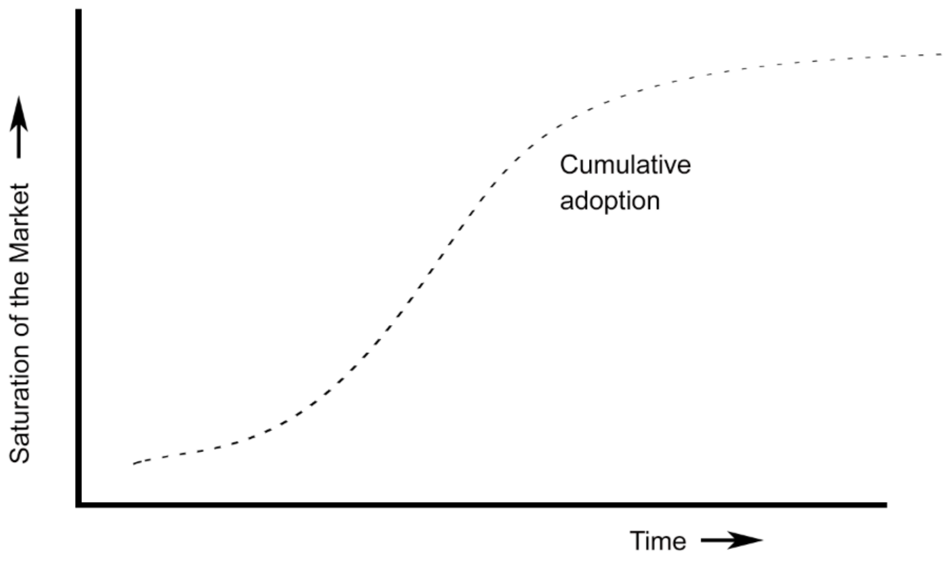


Figure 3: Cumulative forces of adoption (Mitropoulos, 2000)



4.2 Factors Influencing the diffusion

In order to expose the specific factors that negatively influence the diffusion process in the barge sector, a framework that offers an in-depth examination on these factors is implemented. This framework is described by Hall and Khan (2003) in their 'Adoption of New Technology' research paper will be explained in this section.

An important assumption that is made in the framework is that the decision is not whether or not to invest in the new technology, but more of a choice between investing now or postponing the investment. This is assumed because of the nature of the costs and benefits. The costs of the adoption incur at the moment of investing and are then sunk costs, where the benefits of the adoption flow throughout the life of the innovation. Therefore, scaling back to the old technology happens rarely. The fact that investments are largely sunk costs implies that there is an option value to wait until less uncertainty exists about the benefits.

In order to understand the evolution of diffusion, two approaches in modelling this process are suggested in the framework. The 'Epidemic Model' is based on the assumption that adoption is limited by the information availability in the market. It takes time before all actors know that the new technology exists and how it can be used. The 'Heterogeneity Model' (or 'Probit Model' (Geroski, 2000)) follows the assumption that different firms attach different values on the adoption of a new technology, and therefore diffusion occurs when firms adopt the new technology gradually. Both models analyze factors in three given categories. For all factors the impact is investigated and the whether it speeds up or slows down the diffusion process. When these findings are summarized, the specific factors and their impact can then be used to illustrate the diffusion process in the S-shaped graph as posed by in section 4.1 (Mitropoulos, 2000).

In the following paragraphs the three categories of factors influencing the diffusion process are discussed. The first category of factors inquires on the demand for this new technology. The second category of factors deals with the supply side of the new technology, and how this influences the diffusion process. The third and last category encounters the environmental and institutional factors.

4.2.1 Demand Factors

The most obvious factors to be assessed are the changes in benefits and costs a firm expects to make when shifting from the existing technology to the new technology. These factors should be established for both financial and qualitative aspects of the innovated product or service.

The availability of resources to adopt to the innovation is an important factor as well. When the skill level of workers is insufficient, training programs should be started that have their effects on the diffusion process. Also the capital resources should be available, implementation of the new technology should be ready to market and commercially viable.

The firm’s relation to its customers has also effect on the diffusion process. When customers are deeply involved in the firm’s operations and long term contracts are closed, the risk to adopt is smaller and diffusion will occur faster.

When a new technology is introduced to the market, a network has to be built to spread, operate and service the products. Therefore, it is important to analyze the network conditions. Where an advanced network will speed up the diffusion process, it will be slowed down by an existing network that needs to be re-organized for the new technology.

4.2.2 Supply Factors

The supply side of the new technology has its influencing factors on the diffusion process as well. When the first versions of the innovation are imperfect and perform poorly, the subsequent improvements on their performance and costs are important factors in the diffusion process. When these improvements evolve relative slow, the adoption is slowed down as a whole. On contrary, when these improvements evolve rapidly there is more confidence and the diffusion will run more smoothly.

When the incumbent technology is improved during the diffusion period of a new technology, the process is slowed down as well. These improvements may occur because of the threat of the innovation or because of a natural evolution. In either way the relative advantage of the innovation is diminished.

Complementary inputs to the new technology can have a major influence to the diffusion process. By facilitating training programs or complementary resources that are needed for the adoption to the new technology the supplier can accelerate the diffusion process.

4.2.3 Environmental and Institutional Factors

The market structure of an industry can be very determent for the diffusion process. It has been argued that the market power of a company both encourages and discourages the adoption of a new technology. In the framework four arguments are given, based on the research of Dorfman (1987):

- Firm size and its market share are positively correlated with the level of innovative activity and the willingness to adopt new technologies in an early stage. Larger firms have more market share, which implies more market power. These firms have also less competition, and since benefits from new technologies erode when competition adopts them as well, they can benefit longer from the innovation.
- In capital markets information asymmetry exists between investors and firms and therefore investments in new technology can be harder to finance. Larger firms are less sensitive for this since they have more resources themselves and are less dependent on external investors.
- Large firms are abler to spread their risks in new investments out over their operations. Therefore, they are more likely to adopt a beneficial innovation that brings uncertainty along.
- Many new technologies are scale-enhancing. The larger the company, the larger the effects of scale-enhancing innovations. Since the benefits are relative larger they are more likely to adopt the technology in an earlier stage.

On contrary, Hall and Khan mention that the size of the firm and its market power may also slow down the diffusion process in a way, because they may have more levels of bureaucracy that can impede the adoption process. It also may be relative more expensive to change to a new technology when a firm is larger – and older – since it is more likely to have sunk costs from earlier investments in resources and human capital (Henderson, 1990). In the presence of networks this problem may be even more present.

In some industries the diffusion process is influenced by governmental institutions. They can stimulate the adoption of a new technology by changing the regulatory environment, by helping the with the network or by subsidizing in the development themselves. The regulatory environment can be used to exercise influence on market structure to stimulate innovative firms, on the price structure to make innovations more attractive to end consumers, or by means of environmental regulations. Especially the latter can have radical implications for the diffusion process, for example when certain old technologies are prohibited. In a research on the effects of environmental regulation on investment strategies came forward that regulation-driven investments and productive investments crowd each other out. When more investment is done in pollution-abating technologies, the investments in production technology decline (Gray, 1988).

4.3 The Real Options Framework of Inter Firm Diffusion

Another way to model diffusion is suggested by Dixit and Pindyck (1994): to apply the 'Real Options Framework' from the view of a hypothetical firm that has to make an investment decision. In this framework qualitative analysis is done on the real value of investment decisions. These decisions are characterized by the uncertainty on future profits, irreversibility that implies sunk costs, and the opportunity to delay. A structural analysis of these three factors determines whether the benefits exceed the costs. However, at that point the option value of waiting should be considered as well, since delaying the adoption may lead to even higher benefits. By investing the call option is utilized. Deferring an investment decision is referred to as a put option.

Based on this framework is the 'Real Options Model of Inter Firm Diffusion' (Stoneman, 2001), in which specifically the adoption decision is evaluated. A structural analysis determines whether or not the benefits exceed the costs for a specific firm. In this paper the adoption is analyzed in three ways:

- Cost analysis: establish certain future profits
- Scale options analysis: limit irreversibility that implies sunk costs
- Timing options analysis: hold on to the opportunity to delay

Certainty on profits can be offered by a closed business case with contracts on costs and on revenues. Scale options offer flexibility to the firm, so that later on investment decisions can be readjusted. By implementing an option to expand or to contract, irreversibility can be decreased. Timing options introduce the possibility to defer. If on a certain point benefits exceed costs, the call option could be valuated - the decision to adopt the new technology. The put option, the option value of waiting, should be considered as well, since delaying the adoption may eventually lead to higher benefits. So if the call option is valuated higher than the put option, the adoption should pass. If the call option is lower, adoption should be deferred (Stoneman, 2001). The valuation of these options is not an exact science and is up to the management.

4.4 Framework Characteristics

The frameworks discussed in the previous sections in this paper are employed to a structural framework for the research on what factors are responsible for the slow diffusion process of LNG as a barge shipping fuel. In the first two paragraphs of this section both the 'Epidemic Model' and the 'Heterogeneity Model' are tested on their fit to our field of interest. Finally, this section offers an overview of the research steps taken further in this paper.

4.4.1 Fitting the Epidemic Model

The first model proposed by the framework, the 'Epidemic Model', is based on the premise that the adoption is limited by the information availability in the market that the new technology exists and how it can be used (Hall, 2003). This model is not selected for this paper, since the investments in a ship are large and deliberated processes. It can be assumed that a shipping line is aware of the market developments and possibilities in the field of LNG as a fuel. This assumption is made based on a survey from DNV AS (2012) among 23 shipping lines. In this survey the familiarity with technological innovations was asked upon, and familiarity with dual-fuel engines scored relatively high. In the same survey the likelihood of implementing dual-fuel engines in their ships was questioned as well, but scored 'unlikely'. The two main barriers that came forward were the costs of installation and operation, and the technical maturity or reliability. This survey was in a 2012 research, what shows that several years ago many shipping lines were aware of the LNG technology.

4.4.2 Fitting the Heterogeneity Model

The 'Heterogeneity Model' follows the premise that different firms attach different values on the adoption of a new technology, and therefore diffusion occurs when firms adopt the new technology gradually (Hall, 2003). The barge industry has a broad variety in shipping lines. This variety emerges in what is transported, the size of these companies and the dependence on different shippers (Wiegmans, 2007). The model helps to study the progress of the diffusion by denoting the share of firms that use the dual-fuel technology over time. In this model three assumptions are made:

- The distribution of values placed on LNG as a fuel by shipping lines is normal.
- The cost of the investment is constant or declines monotonically over time.
- Shipping lines adopt when the valuation they have for the product exceeds the costs.

This model offers a good fit to analyze the factors in the next chapter, given the large variety of firms in the barge sector. Therefore, the 'Heterogeneity Model' is preferred over the 'Epidemic Model', which is clearly not a good fit as described in the previous paragraph.

The 'Heterogeneity Model' focusses on both the internal and external factors that affect the adoption forces, in three categories described in section 4.2. These categories are applied to the barge shipping sector in chapter 5.

Since the diffusion process of dual-fuel engines in barges is still in an early stage, no data can be extracted from the real world. The model however can offer insights in what we can expect, and based on the factors in the next chapter even forecast how the diffusion process can develop. In other words, by modelling the diffusion process, a point of departure is generated so factors can be analyzed in perspective.

4.4.3 Research Approach

Now all elements of this paper's framework are discussed, an overview of the research approach is that structures the rest of this paper. The common thread is given by the driving forces for adoption as stated in section 4.1. These forces influence the diffusion process so when the factors affecting these forces are identified, remarks can be made on why the diffusion process is going slower than expected.

A bottom-up approach is used, starting with all possible factors, analyzing their effects on the forces, considering the real options, and eventually building a theory. The following steps are followed:

1. All factors influencing the diffusion process are analyzed in three categories, according to the 'Adoption of New Technology' framework. First the demand factors are discussed, then the supply factors, then the environmental and institutional factors. This will be performed in chapter five.
2. The effect of all factors on the adoption forces is analyzed in a matrix in section 6.1.

3. The diffusion process for LNG as a barge fuel is illustrated in the S-curve in section 6.1.
4. Real options in the adoption decision for shipping lines are analyzed discussed in section 6.2.
5. The findings from the analysis are used to formulate an answer to the research question in chapter seven.

Chapter 5: Factors Affecting the Diffusion Process

In this chapter, three groups of factors influencing the diffusion process for the barge market are analyzed. Section 5.1 discusses the demand factors, 5.2 the supply factors and 5.3 the environmental and institutional factors. These factors will be used by the 'Heterogeneity Model' and the 'Real Options Framework' to form patterns to the analysis, in order to determine what factors affect the speed of diffusion. For each factor the impact is indicated and what adoption force it affects.

5.1 Demand Factors

The demand side of the diffusion process exists of the buyers of the new technology. In the case of LNG as a shipping fuel, the investment in a dual-fuel barge is done by the shipping line. The shipping line possess and operates the barge, a fact that is often little exposed in feasibility studies (Stappershoef, 2016). Four factors relating to the shipping line are exposed in this section. First the benefits and costs of LNG as a shipping fuel are equated and compared to MGO, then the available capital goods and human capital are qualitatively examined, thirdly the relation and commitment between the shipping line and the shippers is covered, and finally the effect the network of LNG distribution has on the diffusion is discussed.

5.1.1 Benefits and Costs

When a barge operates with a dual fuel engine instead of an engine that runs on MGO, some benefits and costs alter (Maelissa, 2016). First the altered qualitative aspects are discussed, then the financial changes in costs and revenues are encountered.

Qualitative Aspects

The most important benefit is that dual fuel engines have lower emission values compared to CCR2 approved engines (TNO, 2011). The direct effect of this is that a barge with a dual-fuel engine is in no need of after treatment of the exhaust gasses. These filter and cleaning installations are necessary for CCR2 engines to meet emission regulations. The absence of after treatment aboard has large advantages. When a ship is fitted with after-treatment installations, the operating process becomes more complex. An after-treatment installation reduces the emissions of a ship in theory, but when not adjusted well, not maintained properly or simply not activated, the actual emissions are higher.

Secondly, these systems make use of the produced energy aboard, so the efficiency decreases and fuel consumption increases (Corzo, 2011). This became clear after the CCR2 regulations entered into force, leading to a drastically increased fuel consumption due to the increased engine temperature, what was needed to have a cleaner combustion (Stappershoef, 2016). Another example of inefficiency is the urea after treatment system for removing NOx from the emissions. This product is already on the market and offers a theoretical decrease of NOx emission, but in practice it shows not reliable enough to be operated continuously (Stappershoef, 2016). In short the complexity of after-treatment erects obstacles that diminish the effects of the cleaner emissions. On top of that operational and initial expenses rise when processes become more complex. These systems need to be purchased, installed, maintained and repaired (Semolinos, 2013). These obstacles do not occur when dual-fuel engines are used in barges: the emission reductions are more likely to last when the barge is operating, navigation is more efficient and costs are saved on installation and maintenance of these systems.

> These ‘emission value’ factors have a large impact on the competitive advantage of the technology, since after adoption less GHGs are emitted and no after-treatment is necessary. This is implied by the external requirement of the emission standards, so this force is affected as well.

Financial Aspects

Most shippers are not willing to pay extra for a transportation of their goods by a dual-fuel barge (Semolinos, 2013). This is also the experience from Ben Maelissa, director of container barge shipping line Danser that operates the first refitted dual-fuel barge (Maelissa, 2016). He states that the market trend towards more sustainable operations does not imply that shippers willing to pay extra for environmental friendlier transport like dual-fuel barges (Maritiem Nederland, 2014). The fuel technology that can transport goods in the most economical way is preferred. In order become a competitive alternative for MGO, LNG should therefore have a price advantage. This advantage can origin either on initial investment, or on operational costs. Nevertheless, bunker prices are a very important part (Livanos, 2014). As stated in chapter two and seen in figure 1, the fuel costs of LNG are lower compared to MGO. But this cost advantage diminishes when investment, operation and distribution costs are taken into account (Bucci, 2014). At the current fuel prices a dual-fuel barge generates insufficient operating cost reductions to make up for the high investment costs of the dual-fuel installation (Stappershoef, 2016). Also the opportunity costs of a barge taken out of operation for the refitting make the conversion process more expensive. The conversion of the barge 'Eiger' from shipping line Danser took three months and also was a very costly investment, what is according to B. Maelissa also the reason that other shipping lines are reluctant to follow Danser (Maritiem Nederland, 2014). He states that with the current fuel prices it is not cost-effective to operate a barge on LNG (Maelissa, 2016). His company has no concrete plans to convert other barges in their fleet. With this he hints that refitting a barge with dual-fuel is still not a closed business case (Maelissa, 2016).

> The factor 'investment cost' has a large negative effect on the force technological opportunity, because the technology is less attractive for investors. Especially refitting a barge is considered uneconomical.

> The factor 'operational cost' may impact the competitive advantage in a positive way, since the LNG is cheaper as a fuel. The bunkering process however is more expensive, so the impact is uncertain.

5.1.2 Skill Level of Workers

To adopt to a new technology, operations need to change. The implementation and operation of this revised way of doing business is done by employees. Therefore, this is an important factor in the diffusion process. When the employees are not able to adopt to the technology, they should be trained or replaced. In the case of using LNG as a fuel, the operations aboard change. Since LNG is contained under pressure and at extremely low temperatures, more safety systems are required. The operation and bunkering processes of the barge are subjected to more complex regulations and the employees should be certified to do this. In the case of wet-bulk barges, that transport chemicals, the crew is already familiar with the safety precautions and certified to bunker chemicals. For this reason the chemical wet-bulk segment of barge transportation is more likely to adopt LNG as a fuel sooner than other segments (Stappershoef, 2016).

> The factor of 'crew training' has a slight negative impacts on the technological opportunity force, since costs of implementing the technology are higher.

5.1.3 State of Capital Goods Sector

Barges are characterized by their long lifespan. For example, the IVR data base shows that the average year of build for inland barge engines is 1978 for dry cargo vessels and 1983 for liquid cargo vessels (Boer, 2011). This long lifespan implies that barges are not replaced very often by a shipping line. This is not beneficial for the diffusion of LNG as a barge fuel, since the installation of a new fuel system cannot be taken lightly. First of all, the costs to refit a barge with a new fuel system are very high. Not only a new engine should be installed, but also the LNG tanks and pipeline system with all its safety components. Then there is the issue of no free room on an existing barge for the large LNG tanks, since the height is limited (Bucci, 2014). This results in a significant loss of cargo space. Shipping line Danser was the first to refit a barge with a dual-fuel installation, and had to give up cabin space of six containers for the LNG tanks (Maritiem Nederland, 2014).

So the conversion of a ship to dual-fuel will lead to excessive costs and a decrease in revenues, which are both issues that are very hard to overcome. Therefore LNG is almost exclusively implemented in newly built ships (DNV GL, 2016), and makes the current state of capital goods a factor that is slowing down the diffusion process (Stappershoef, 2016).

> The factor ‘state of the capital goods’ has a large negative impact on the technological opportunity. Since barges are replaced not very often, the technological innovation cannot push itself to the market. This does not apply for newly built barges.

5.1.4 Customer Commitment and Relationships

The relation between a shipping line and its customers can be very determining for the diffusion process. Shareholders and financers need to be convinced that the risk of the new technology is minimized. The uncertainty that comes with large initial investments and payback periods of over 10 years can be tempered with long term contracts with customers (Stappershoef, 2016). When a shipper commits to a long term contract, the risk of the investment is carried by both parties. Therefore, a shipping line with such contracts will have an inclination to adopt LNG as a fuel sooner that a shipping line with short term contracts. These types of contracts do not occur in standard shipping, but are more common in customized transport. This is often the case in the chemicals transportation segment (Wiegmans, 2007).

> The 'shipper commitment' factor positively affects the external requirement force, but only for shippers that are willing to commit to long term contracts when their cargo is transported is by LNG.

5.1.5 Network Effects

A technology has a network effect when the value of the technology to a user increases with the number of total users in the network (Hall, 2003). In the case of dual-fuel engines this is applicable on the supply chain of LNG. Many researchers agree that the construction of a proper supply chain for LNG to ships is the most important step to be taken in the diffusion process (Semolinos, 2013). This will also be the case for inland waterway shipping, however the hurdle is smaller compared to maritime shipping. The routes barges navigate on are fixed, along the course of the river. Maritime routes are more likely to bunker in multiple ports, where in order to be flexible LNG should be available.

Given the relative small tanks aboard of a barge, bunkering can be performed by a truck. A barge with 30m2 tank capacity can easily be bunkered by a truck with 50m2 LNG. This barge can then navigate for almost five weeks on a single tank load (Semolinos, 2013). In some European ports LNG bunkering facilities are already present, and research on port authorities' policy indicates that in the near future all major seaports in Western Europe will have a shore to ship bunkering facility (Notteboom, 2015). These bunkering facilities can bunker barges as well, but also dedicated barge filling stations are being build, for example in Antwerp (Natural Gas Europe, 2016).

> The factor 'the supply network' does have a positive effect on the technological opportunity force. Since it is already possible to bunker LNG to a barge, but at relative large costs. In the future bunkering from a fixed location will be possible, and costs will even be lower compared to bunkering from trucks. When this is the case, the impact will be even larger.

5.2 Supply Factors

After analyzing the demand factors, the supply of LNG and LNG systems is discussed. First the upcoming improvements of the LNG fuel system are discussed, then the developments in the CCR2 engines are analyzed, and finally the complementary inputs offered by suppliers are considered.

5.2.1 Improvements in the New Technology

For decades LNG carriers have been sailing on boil-off gas, making them the first dual-fuel ships in existence. In the past years more and more ships embrace LNG as a fuel, equally pushing the developments around these engines and systems. The quality and speed of these developments form an important factor for the diffusion process as a whole: directly because of an improved product and indirectly because of the placed thrust in the innovation by stakeholders.

Research and Development

The innovation of LNG as a shipping fuel houses high potential. Exiting promises include the elimination of SOx emissions, a reduction of NOx emissions by 80%-85%, CO2 emissions are reduced by 20%-30% and very low PM values (Burel, 2013). These values almost seem too good to be true, and that seems to be the case. With the current state of technology, LNG can only be applied in combination with MGO. That is why only dual-fuel engines are available for LNG ships, because the engine has to start on MGO. Also when extra power is demanded, MGO is used in order to have a richer fuel mixture. As explained in chapter two, the fuel consumption is on average 98% LNG and 2% MGO. Although MGO embodies only one fiftieth of the fuel consumed, it influences the emissions significantly. An important factor to this is that shipping lines that operate services on long routes, have a relative advantage on services on short routes, since they have to start up the engine less often (Maritiem Nederland, 2014).

So the first technological limitation to overcome would be the necessity of MGO in the process. As long as a ship on LNG needs MGO to start and to accelerate, it will have difficulties to coop with emission regulations. To develop these techniques, the engine manufacturers have to invest in research and development. However, dual-fuel engines for ships are marketed by only a few suppliers, who serve a relative small market. For the barge sector there is nowadays only a single manufacturer active that is producing dual-fuel systems, which is Wärtsilä (Stappershoef, 2016). The standards for which they develop their engines are the worldwide ECA standards. Barge engines that need lower emissions are only demanded on the European market. This market comprises of 8.500 ships, and only 80 ships are newly built each year. This number is simply too small for an engine constructor to develop rapidly new engines (Stappershoef, 2016). This is supported by research on these developments, which indicates that engine manufacturers have little interest in improving their engines for the barge sector because of the limited market, and their relative strict emission regulations (Boer, 2011). These slow developments are an issue since emission regulations are rapidly becoming stricter. In order to keep up with these after-treatment installations will become necessary for dual-fuel engines, similar to CCR2 after-treatment installations.

Also the emission of not combusted methane is a problem to what the solution has not been found yet. In order to overcome this methane slip through the engine, the overall design of the dual-fuel engine should be revised. These developments are ongoing, but no fix has been found yet (Stappershoef, 2016).

In essence this means that the practical differences between a CCR2 engine with after-treatment and a dual fuel engine are diminishing. Dual-fuel engines emit a little less CO and NOx, but currently do have an inevitable methane-slip through the engine as mentioned in chapter two. On top of that, this slight advantage would be nullified for a ship in case of a cleaning error once a year. Before and after the engine is started the pipelines need to be flushed. In case of such an error the methane is not collected properly, but released in the air.

> The factor ‘MGO necessity’ has a large negative impact on the forces competitive advantage and technological opportunity. The relative advantage to MGO fueled engines diminishes and the technology is less able to push itself to its customers. This applies to a lesser extend also for the methane slip.

Alternative Technology

To conclude this paragraph a positive note on the development of the technology can be stated. Since 2013 a revolutionary barge – the Greenstream - is in operation that is propelled by three electronic engines. The electricity is generated by four LNG powered turbines, which do not need MGO since they are operated continuously. This barge is an operational proof of concept but this technology is still far from diffusion because of the high investment costs – approximately 50% higher compared to a dual-fuel barge (EICB, 2016).

> The factor ‘alternatives’ has a slight negative impact on the technological opportunity force. The technology for dual fueled barges is less able to push itself to shipping lines when alternatives are being developed.

5.2.2 Improvements in the Old Technology

Although the ships can be quiet old, the average lifetime of the engine is around 10 years (Boer, 2011). This implies that improvements to the old technology are a familiar phenomenon, and cover the installation of a new engine or extra after-treatment installations.

In order to coop with the current and future emission standards, and without writing of their fleet, shippers are forced to invest in enhancing the existing CCR2 installations with after-treatment installations. A recent study of DNVGL (2016) shows that the installation of scrubbers (exhaust gas cleaning installations) is growing way more rapidly compared to the expected rise of dual-fuel engines. Also for the placed orders for newly build ships and retrofit installations combined, orders for scrubbers almost double the orders for dual-fuel ships. Although barges can meet emission standards, these systems do produce toxic waste from the GHG's they filter out the emissions (Deal, 2013).

> The factor 'CCR2 engine improvements' has a large negative impact on the competitive advantage of dual-fuel engines, since the advantage of emissions diminishes.

5.2.3 Complementary Inputs

In the diffusion process of LNG as a shipping fuel can be observed that suppliers contribute to the industry in order to promote their innovations. For example, Shell is a supplier of the fuel LNG. Besides their plans on bunkering facilities, Shell also plans to charter 15 dual-fuel barges, of which the first three are currently being build (Shell, 2015). It also charters the first barge with electrical engines which was mentioned before. Although this promotion brings some experience to the market, it is not perceived as an important factor influencing the diffusion process (Stappershoef, 2016).

> Suppliers of LNG offer no complementary inputs that have a significant effect on the adoption forces. This factor is therefore not included in further analysis.

5.3 Environmental and Institutional Factors

After analyzing the demand factors and supply factors, the scope is shifted to the environment in where the innovation is to be implemented. The structure of the dual-fuel barges market might affect the diffusion process, as well as the size of shipping lines. The influence of governmental institutions and their regulations on diffusion is also discussed, which also includes the safety aspect of LNG as a shipping fuel.

5.3.1 Market Structure and Firm Size

The framework offers four arguments why market power and firm size can positively influence the diffusion process. The first argument states that firms with great market power, thus little competition, can benefit longer from innovations. Therefore, they are more likely to invest in these innovations. In the case of LNG as a shipping fuel, the end product is not differentiated. The innovation is in the operating process which implies that when other shipping lines also adopt LNG, the benefits are not diminished. So this argument is not suitable.

The second arguments states that larger firms have more resources and can more easily attract resources to invest in new technology. For shipping lines this is certainly the case, since initial investments are very high (Semolinos, 2013). Unfortunately, the barge sector is characterized by small firms as mentioned in the chapter three. On top of the negative influences of the size of the firms, the investments in LNG are perceived as political tinted. Governmental institutions might alter todays regulations in the not so distant future, what leads to uncertainty of the future costs and benefits of the investment (Stappershoef, 2016). In short, the effect of the firm sizes in the sector, along with the ability to reserve sufficient resources and the political influences, are important factors that influences the diffusion of LNG as a barge fuel.

The third argument is that a larger shipping line could distribute the risk from an investment over larger operations, and therefore has a relative smaller risk compared to a smaller firm. For barge shipping lines the reasoning for this argument is similar to the previous one, as this sectors consists of mainly small firms that have relative small operations in relation to the investments in dual-fuel technology. Therefore, this argument is also considered valid in the diffusion process.

The fourth and last argument is that many new technologies are scale-enhancing. In case of barge transport, economies of scale are hardly found since each barge operates apart from the rest of the fleet. Perhaps that a shipping line can close better bunker contracts when it fuels more ships with LNG, but this effect is not accounted for in this analysis.

A counter argument for firm size poses that large firms have more bureaucracy that can impede the adoption process. Given the major considerations that are in the adoption process, and the absence of very large shipping lines, this argument is also not included in further analysis.

> The factors ‘size of shipping lines’ and ‘resources to invest’ negatively impact the adoption force of process problem. It is a structural problem for many shipping lines, that because of their size have relative larger risks and less resources to invest than larger shipping lines. Therefore, they stick to their existing material.

5.3.2 Government and Regulation

Governmental institutions and the laid down regulatory framework have far reaching influences in the barge sector. The introduction of LNG as a barge fuel faces two important sets of regulations that are factors influencing the diffusion process: emission regulations and safety regulations. The effects of both regulations are discussed in this paragraph.

Emission Regulations

By the restriction of the emissions to certain levels, shipping lines are forced to implement engine technologies that can meet these demands. Research on emission regulations has shown that from a society point of view, the benefits of after-treatment installations outweigh the costs (Boer, 2011). So when the costs of these installations can be eliminated, the benefits will even be higher.

As discussed in chapter two, LNG offers emission reductions along all GHGs, except for methane. So in general, these regulations have a positive effect on the diffusion process of LNG. As Semolinos et.al. (2013) stretch in their research on implementation of LNG as a shipping fuel, strict emission regulation is the single most important success factor for widespread demand for LNG as a shipping fuel. This reasoning is based on the major benefit that this new engine technology offers: the redundancy of after-treatment installations aboard. In order to coop with current emission norms this is the case. A shipping line that operates a barge with a dual-fuel engine can operate this without worrying about the GHGs emitted. But when a shipping line has to decide to invest in dual-fuel, it will also look at the future. Then this positive picture is going to change for shipping lines operating on the European inland waterways. As discussed in chapter two, in 2020 the Stage V regulations will enter into force, with drastically lower emission standards. With today’s technology, the dual-fuel technology simply is not able to meet these regulations (Stappershoef, 2016) (Maelissa, 2016) (Stappershoef, 2016). This is due to the small amount of MGO that is needed to operate these engines. For this reason, the barge still needs to be fitted with after-treatment installations. So despite the emission regulations are a large factor in favor of the diffusion of LNG as a shipping fuel, but the very strict Stage V regulations are currently slowing down the diffusion process of LNG as a barge fuel in Europe.

Shippers and manufacturers have requested the EC to stick to harmonized worldwide emission standards, what has been the case for the past decades. They invoke to postpone the Stage V regulations for the inland waterways in Europe. It would be impossible for the engine constructors to develop and deliver improved engines that can cope with the Stage V regulations for the relatively small European barge fleet, in which market only 80 barges a year are newly constructed (Dieselnet, 2016). They proposed to replace the strict Stage V standard with the worldwide Tier 4 standard, that is applied in inland waters in the USA and Canada. By doing so a single worldwide market for barge engines would be shaped, so more engines are developed and marketed for the European market. The legislators in the EU however hold on to the Stage V requirements for 2020 and further (Stappershoef, 2016).

In summary, the sector faces a situation where emission regulations could limit the inefficient use of after-treatment installations in barges, but where the inverse effect threatens to take place. When from 2020 onwards shipping lines will not be licensed to navigate on the Rhine with their current material, they seem to have no other choice than to invest in after-treatment installations to clean and filter their emissions. As mentioned before, this is likely to have the contradictory effect of higher fuel consumption.

> The effect '2020 emission regulations' has a negative impact on the external requirement. Since these standard is too strict for dual-fuel engines to coop with without after-treatment, the influence of the regulator is smaller. Also the competitive advantage is decreased by this, since the absence of after-treatment is not practically possible anymore.

Safety

Governmental institutions implement regulations on safety as well. For LNG, which is stored under pressure at extremely low temperatures, the safety of the ship and its installations are of major importance (D. Chang, 2008). If there would be an accident with an LNG fueled vessel, the reputation would be soiled, the entire market for these ships would be harmed, and governmental support would be revoked. In order to prevent such an incident, certification for LNG fueled ships is very strict. This has been the case for decades for gas carriers that have been using the boil-off gas of their cargo as a fuel, and their safety record is extremely good (DNV GL, 2016). The introduction of LNG as a fuel for conventional ships requires new installations with associated risks. Aspects of high risk are the high energy content of the LNG tank, the explosion hazard in case of gas leakage and the extremely low temperatures of LNG fuel (DNV GL, 2016). Regulation on safety incorporates these risks and therefore the diffusion is influenced by this factor.

> The factor ‘Safety regulations’ has a slight negative impact on the external requirement force, since these rules make the adoption less attractive for shipping lines. The chemical transport segment already has strict safety standards, so these shipping lines are less impacted.

Stimulating Policy

Governmental factors can also have positive effects on the diffusion by stimulating the development or the network. When analyzing governmental activities in the barge transport sector, lots of initiatives are taken or supported by governmental institutions to promote the use of LNG. Especially the supply network of LNG is actively supported on a European level. Despite that the bunkering facilities in the network will be operated by private industrial players, the government steps forward to kick-start the diffusion process and to bypass the chicken-and-egg problem (Wang, 2014). In their study on the role of port authorities in the development of LNG bunkering facilities in Europe, Notteboom and Wang (2015) observed this proactive role in all European seaports. Port authorities establish feasibility studies, cooperate in strategic partnerships with LNG suppliers, invest in infrastructure and apply lower port dues to LNG fueled ships. Not all this stimulating policy is induced by port authorities themselves, as the EC also contributes to the diffusion process. It grants subsidies to port authorities for building LNG bunkering facilities (Port of Antwerp, 2013).

The port authorities’ regulatory frameworks can however be further improved. For example, by leveling these regulations among ports, it will become easier for shipping lines to coop with these regulations (Ship & Bunker, 2016).

> The factor ‘stimulating policy’ has a positive impact on both the forces technological opportunity and external requirement. These policies help the technology push itself to shipping lines and are initiated by external institutions.

Chapter 6: Synthesis of Diffusion Factors

After all factors were separately analyzed in the previous chapter, the findings will be synthesized in this chapter. The diffusion factors will be merged into a matrix with their impacts on the adoption forces in section 6.1. With this as a basis the 'Heterogeneity Model' is further implemented and the current state of the diffusion process is described, supported by the 'Real Options Model of Inter Firm Diffusion in 6.2.

6.1 Adoption Forces Analysis

The structural factor analysis in the previous chapter offered insights in the factors influencing the diffusion process of LNG as a barge fuel. The most important factors are noted in table 4 below, along with the direction and magnitude of their influence on the diffusion process, the adoption force they affect, and the effect on the diffusion process.

The overview in table 4 is composed of factors influencing the adoption forces. The forces are listed in the fourth until the seventh column. In what ways these four forces are affected is summarized in the following paragraphs.

6.1.1 Competitive Advantage Forces

The factors that negatively influence the force of competitive advantage of LNG lead to a slower diffusion process. This is the case with large impact for 'CCR2 engine improvements', an average impact for the 'MGO necessity' and '2020 emission regulations', and a small impact for 'methane slip'. From a technological point of view, the dual-fuel engines are not yet future proof. They still need MGO and emit methane, which implies that from 2020 onwards after-treatment installations are necessary. Existing material can be updated with these after-treatment installations for a fraction of the price, so the diffusion process is slowed down by these factors.

Category	Factor	Impact	Comp. advantage	Process problem	Techn. opportunity	Ext. requirement	Effect
Demand factors	Emission values	+++	x			x	No need for after-treatment, so more efficient.
	Investment costs	---			x		Initial investments are high, especially for refitting.
	Operational costs	+/-	x				Savings on fuel, higher operational costs.
	Training of crew	-			x		Crew needs to be trained on safety, except chemical
	State of capital goods	---		x			Barges have a long lifespan, refitting is not economical, replacing is a waste of capital.
	Shipper commitment	+				x	Long term contracts can reduce uncertainty and spread risks.
	LNG supply chain	+			x		Bunkering barges is possible, will become more competitive in the near future.
Supply factors	MGO necessary	--	x		x		No solution yet to eliminate MGO from the process, so from 2020 onwards after-treatment is necessary. Small market -> no high priority.
	Methane slip	-	x		x		No solution yet for polluting methane emissions
	Alternatives	-	x		x		Alternative configuration of LNG with electricity brings hope but currently defers diffusion.
	CCR2 improvement s	---	x				With after-treatment installations on currently employed CCR2 engines, the 2020 regulations will be met.
	Size of shipping lines	--		x			Large investments are relative risky for small firms, small shipping lines are reluctant to invest when future is uncertain.
	Resources to invest	--		x			Small shipping lines have difficulties to finance newly built barges.
Environmental & Institution. factors	2020 emission regulations	--				x	Stage V emission standards are too strict for dual-fuel engines to operate without after-treatment. Advantage is reduced.
	Safety regulations	-				x	Increased safety precautions slow down the diffusion process
	Stimulating policy	+			x	x	Governmental institutions stimulate the roll-out of the LNG supply network

Table 4: Overview of factors influencing the diffusion process of LNG as a barge fuel.

6.1.2 Process Problem Forces

Factors that influence the 'process problem force' negatively, lead to a delayed adoption of LNG as a fuel. This is because less process problems occur with the current technologies. The factor 'state of capital goods' has a large negative impact, the factors 'size of shipping lines' and 'resources to invest' both have an average negative impact on the process problems. Given the fact that barges have a long lifespan and are expensive to refit, and that most shipping lines are too small to handle a large and risky dual-fuel investment the diffusion process is slowed down.

6.1.3 Technological Opportunity Forces

The factors that negatively influence the technological opportunity force lead to a slower diffusion process, since the ability of the technology to promote itself to shipping lines decreases. The factor 'investment costs' has a large negative impact, the factor 'MGO necessity' has an average negative impact, the factors 'training of crew', 'methane slip' and 'alternatives' have a small negative impact. The initial investment costs for refitting a barge are unmanageable high. Replacing a barge for a newly built is given the long lifespan of the ship seen as a waste of capital. The fact that MGO still is necessary promotes the technology not to shipping lines. Also the need for extra training of the crew, the additional emission of methane and the development of alternative technologies delay the diffusion process of LNG as a shipping fuel.

6.1.4 External Requirements Forces

The factors that negatively influence the external requirements decrease the external driver for adoption. The factor '2020 emission regulations' has an average negative impact and 'safety regulations' a small negative impact to this force. The upcoming Stage V emission standard is too strict for current dual-fuel technology, which takes away the advantage of no after-treatment aboard a dual-fuel barge. This and the safety requirements that are involved in dual-fuel technology tend to slow down the diffusion process.

6.1.5 Illustration of Affected Forces

As the analysis on the forces brings forward, all four forces are negatively affected by the factors. The competitive advantage force is shifted downwards, where the other three forces are shifted to the right. This is illustrated in figure 5. The effect of these shifts on the S-curve of cumulative adoption is shown in figure 6.

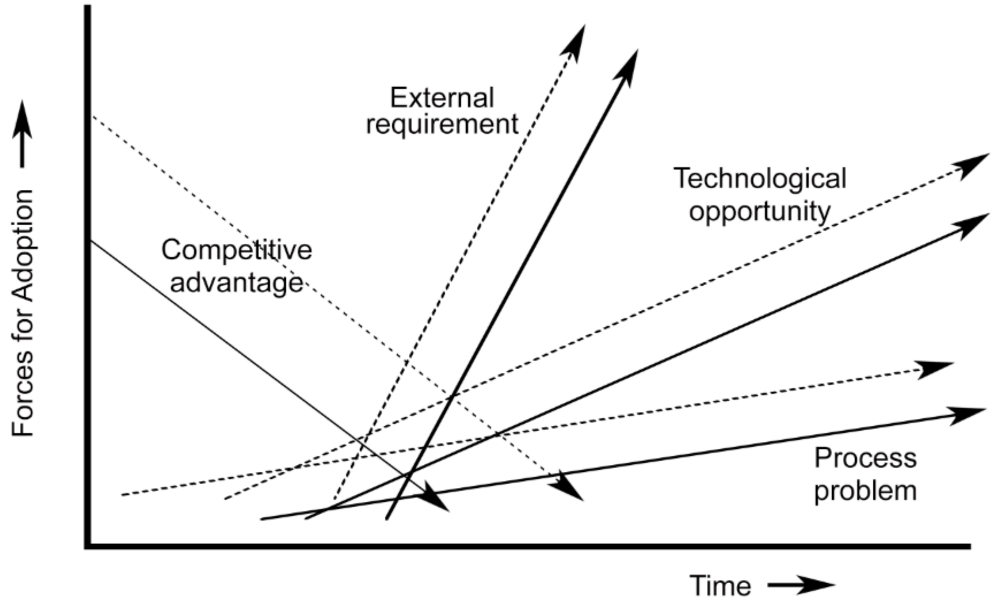


Figure 5: Forces of adoption not affected (dotted lines) and affected (straight lines) by the factors that slow down the diffusion process

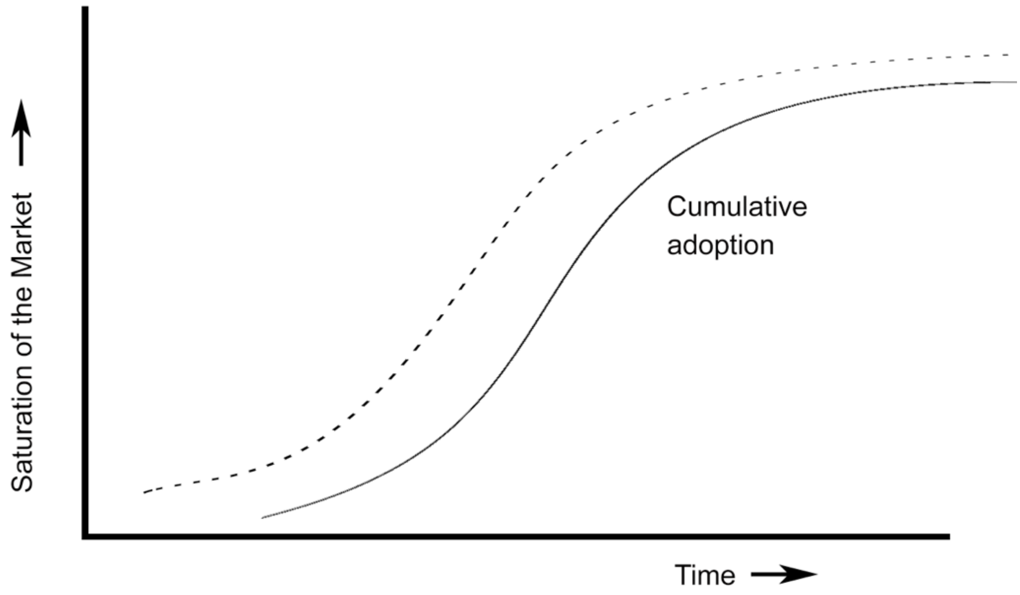


Figure 6: Cumulative forces of adoption not affected (dotted lines) and affected (straight lines) by the factors that slow down the diffusion process

6.2 The Real Options Model of Inter Firm Diffusion

When a shipping line considers to invest in a dual-fuel barge, the decision process is characterized by uncertainty over future profit streams, the irreversibility that creates sunk costs, and the opportunity to delay. In order to analyze the diffusion process, these three characteristics are discussed in this section: a future profit analysis, a scale options analysis and a timing options analysis. By analyzing these elements better understanding in the investment decision is brought, which helps to determine why the diffusion process is emerging slowly. Note that the valuation of real options is not an exact science and is up to the shipping line's management. Conservative shipping lines will be more likely than progressive shipping lines to defer their investment.

6.2.1 Future Profit Analysis

The first step of the investment decision is to consider how future profit can be guaranteed. Future profits are determined by the investment costs, future operational costs and the future revenue. Given the large initial investment and the long payback period also the costs of capital should be encountered in the analysis. The uncertainty on future revenue can be reduced by closing long term contracts with shippers (Schipco, 2011). On the future operational costs side, which is heavily depending on future bunker prices, long term contracts can also be constructed to take away uncertainty.

To bring insights to these future profits, a firm can conduct a comparative cost analysis. In such an analysis only the costs are to be encountered since the revenues will not change when another fuel is bunkered (Maritiem Nederland, 2014).

In table 5, four options are sketched up for a company that plans on preparing a ship for the Stage V emission regulations. To indicate the impact of costs, a classification system is used. 0 indicates no impact, + indicates little impact, ++ average impact, +++ high impact. When a classification is stated in brackets, the costs are highly dependent on the situation or simply uncertain.

Table 5: Investment options for a shipping line to make a barge Stage V proof

Investment option		Investment costs							Operational costs		
Option #	Action	Sunk costs current material	Ship	Engine & installation	After-treatment	Opportunity costs during conversion	Crew training	Financing	Opportunity costs lost cargo space	Bunker fuel	Maintenance
1	Replace ship for newly built MGO fuel barge	(+++)	+++	+	+	0	0	++	0	(+++)	+
2	Replace ship for newly built dual-fuel barge	(+++)	+++	++	+	0	+	+++	0	(+)	++
3	Refit ship with dual-fuel engine	(+)	0	+++	+	+++	+	+	++	(+)	++
4	Fit ship with after-treatment	0	0	0	+	+	0	0	0	(+++)	+

The first two options propose a newly built ship. Important decision determents on whether a ship should be newly built are (1) is a ship in the current fleet about to be replaced? And (2) are there plans to extend the fleet with a ship? If both questions are answered negative, replacement of the current ship will bring large sunk costs along because of the disposed capital. In order to be economical in such a case, the operational cost savings should outweigh the sunk costs of the replaced ship plus the investment costs.

The last two options base the investment on improving the current ship. The decision determent in the consideration whether a ship is to be refitted with a dual-fuel engine or with extra after-treatment installations is the remaining life span of the engine. This can be determined by comparing the residual value of the existing engine to the savings of the refitting option. If the engine is not written off yet, then sunk costs would arise when a dual-fuel engine is refitted. These costs are to be taken into account in the comparative cost analysis.

For all relevant options the shipping line calculates the NPV, and selects the option that results in the smallest costs. Given its long lifespan, the current ship will not be written off before 2020 in most cases. The sunk costs from a not fully written off engine are less likely to prevent the adoption of LNG, since the lifespan of an engine is a lot shorter. These sunk costs can be prevented by timing the refitting on a moment in the near future when this engine is to be replaced. The decision between dual-fuel and MGO is influenced by a lot of factors as seen in section 5.1, of which some are firm specific and some segment specific. The outlook is that most barges will be equipped with extra after-treatment installations to meet the Stage V regulations.

6.2.2 Scale Options

When a shipping line invests in a dual-fuel installation which cannot be used for other operations in case LNG is no longer economical viable, sunk costs arise. In case of such a scenario, these sunk costs can be reduced by implementing scale options. By implementing an option to expand or to contract operations, irreversibility can be decreased. For a shipping line this can be implemented by designing newly build barges in such a way that both dual-fuel engines and MGO engines can be installed. This brings flexibility to the firm, so that later on investment decisions can be readjusted. When a newly built barge is equipped with a dual-fuel installation, the shipping line could reserve space for MGO fuel tanks. This is also an option the other way around. A newly build ship that is equipped with a standard MGO engine, should have sufficient space for LNG tanks aboard. In this way a future refitting to a dual-fuel system is possible with less disadvantages.

6.2.3 Timing Options

When a shipping line considers to invest in a dual-fuel barge, it should also consider the options to defer this decision. Even when benefits seem to exceed the costs coming from the investment, a put option defers the decision to a later moment when payoff might be even higher. With the current state of technology and the upcoming Stage V regulations on emissions, most shipping lines will use this put option to wait for future developments. They have this option to defer because of the to convert any CCR2 engine with after-treatment to meet the 2020 emission standards.

Chapter 7: Conclusion

7.1 Conclusion

The objective of this paper was capsulized in the research question *'Why is the diffusion of LNG as a shipping fuel for European barges emerging slower than expected?'.* This diffusion process is analyzed using the 'Adoption of New Technology Framework'. The most important factors that negatively influence the adoption of this technology are:

- Refitting a barge with a dual-fuel installation is uneconomical. Newly builds are rare given the long lifespan of barges so replacement of the fleet will take a lot of time.
- Dual-fuel engines have higher emissions than aloud from 2020 onwards, therefore after-treatment installations are still necessary.
- Current barges are able to meet Stage V regulations with updated after-treatment.
- Most barge shipping lines are too small to handle a large and risky dual-fuel investment.

Apart from these factors a reason for a slower diffusion than expected is that shipping lines utilize real timing options to defer the adoption decision. Shipping lines wait for technology to improve, for their ships to be written off or for a higher cost advantage. The latter can be realized by lower LNG prices, higher MGO prices, lower distribution costs for LNG or lower investment costs.

7.2 Discussion

The most important insight gained from the framework analysis is that the EC had in theory a powerful tool to limit environmental impact of the barge sector, but by making the upcoming Stage V regulations too strict, shipping lines are reluctant to switch to dual-fuel technology. Instead firms hold on to their current material and enhance this with inefficient after-treatment solutions to filter and clean their emissions. When emission standards were harmonized with the rest of the worlds ECA standards, engines were more widely available and adopting would have the advantage of eliminating after-treatment from the operating process.

The EC could promote LNG by expanding the emission regulations to a system that measures also the efficiency of a barge, so after-treatment systems become less attractive. This can be achieved by limiting the emissions per distance instead of emissions per kWh. By doing so an incentive is created for shipping lines to navigate more efficiently.

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