# Economics of the LNG Value Chain and Corporate Strategies

# An Empirical Analysis of the Determinants of Vertical Integration

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Abstract

This paper analyzes corporate strategies in the emerging global LNG industry. In particular, we provide an empirical analysis of the determinants driving companies towards increasing vertical integration – a typical corporate behavior currently observable. Our hypothesis of high transaction costs along the LNG value chain inducing a higher degree of vertical integration is tested by implementing an Ordered Probit Model. The degree of vertical integration of a player along an actual LNG value chain is defined as a five-level discrete measure ranked on an ordinal scale. To explain determinants of vertical integration in the LNG industry we derive proxy variables by using explicit project data on 85 LNG projects – both, importing and exporting – worldwide. We measure the transaction cost attributes asset specificity, uncertainty and frequency and furthermore include industry and firm characteristics into our analysis. Our results suggest that firms tend to be more integrated in the presence of high transaction costs due to investments in highly specific infrastructure and environmental uncertainty. During the last decade a shift in corporate strategies has taken place; with start up dates since 2002, companies excessively follow a strategy of integration. Private companies' degree of vertical integration exceeds the one of state entities; players tend to be more integrated the larger the size of the firm. The degree of vertical integration in projects situated in the Atlantic Basin tends to be higher than in projects located in the Pacific Basin. Besides these main results we find that exporting and importing players control the midstream-stage transportation to a similar extent.

Keywords: liquefied natural gas, vertical integration, LNG value chain, corporate strategies, liberalization
JEL-Codes: D23, L22, L95

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# 1 Overview

This paper analyzes corporate strategies in the emerging global liquefied natural gas (LNG) market. In particular, we provide an empirical analysis of the determinants pushing companies towards vertical integration; a trend recently observed in a large number of cases (i.e. Iniss, 2004). We analyse determinants of vertical integration in the LNG industry with a focus on transaction cost economics and an application to 85 LNG projects – both, export and import – worldwide. We test the hypothesis of increasing transaction costs along the LNG value chain inducing a higher degree of vertical integration.

According to IEA (2005) natural gas will account for 30% of the rise in world primary energy demand. Different forces, from supply security to environmental concerns, drive this natural gas hype. In times of raising energy needs worldwide and forthcoming competition between demanding regions – new (Asian) importers with strong economic growth enter the stage – security of supply issues are on political agendas. Transporting natural gas via LNG has been around for 40 years, but it is only now that it increasingly gains in importance. The first commercial tanker shipment of LNG took place in 1964 when the UK was the first country receiving a delivery supplied by the Algerian Sonatrach.

The past five years have seen the development from an *"infant"* towards a *"maturing"* LNG industry. Even if LNG technologies enabled transport over longer distances, in the old world, transport remained expensive and markets therefore regional in nature. Most of the infrastructure along LNG value chains remained under state control, private or foreign companies were hardly involved and markets were not competitive. Inflexible bilateral long-term contracts with rigid take-or-pay and destination clauses between the LNG export project as seller and national energy companies as buyers secured huge infrastructure investments on the one hand and security of supply on the other hand. These contracts were signed before any investment took place. A crucial element, ship ownership, was traditionally embedded in these contracts; with transportation capacity thus dedicated to special import and export projects and routes.

Fostered by increasing natural gas demand and diminishing costs along the whole value chain (due to significant economies of scale, improvements in technologies, etc.) investments in LNG infrastructure grew rapidly during the 1990s. Liquefied natural gas has turned from being an expansive and only regionally traded fuel to a globally traded source of energy with rapidly diminishing cost. LNG plays an increasing role for energy supply of all major coastal countries worldwide such as the United States, Spain, India or China. For a survey of the globalizing LNG market see Jensen (2005). Making large volumes of natural gas accessible for importing regions, bulky investments in asset specific infrastructure remain a crucial issue. During the last five years 46 billion cubic meters (bcm) regasification capacity started operation worldwide (11.3% of today's capacity), additional 140 bcm are expected to be completed until 2010. With cumulated nominal project costs of nearly €7.5 billion, companies will invest a similar amount during the coming five to seven years like what has been spent during the last 35 years into European LNG import capacities, for the U.S. the extent of proposed projects is even higher. Today, a large number of countries as well as original distributors and power producers participate in the LNG business. Different companies order own uncommitted vessels. Natural gas trade gains in flexibility, regional markets become linked; (short term) trade on natural gas hubs evolves. The Middle East, accounting for more than 40% of worldwide proven natural gas reserves, evolves to a swing producer. Deliveries to European as well as Asian markets are feasible without a significant difference in (transportation) cost.

Changes in the institutional framework have moved away from monopolistic structures opening up for competition thus stipulating fundamental changes in the organizational behavior of market participants. Increasing competition, mirrored by functioning spot markets and increasing international trade, puts traditional players (incumbents) under pressure. Recent years have been characterized by strategic partnerships becoming a common corporate behavior in the industry. Global oil and natural gas producing companies as well as original distributors heavily engage in all stages of the value chain of LNG production. Export projects, a long time dominated by state-owned entities, are increasingly developed by private oil and gas companies. Former (European) monopolists of natural gas are facing their traditional markets at stake by the intrusion of oil and gas majors integrating downstream into the import markets. Traditional buyers integrate upstream to secure supplies. Several case studies (e.g. Cornot-Gandolphe (2005), Iniss (2004)) focus on activities in LNG trade in the Atlantic Basin and indicate that coexistence of long- and short-term trading activities is increasingly accompanied by vertical integration in the LNG industry. Vertical integration in response to market deregulation features several drivers: upstream producers aiming to benefit from downstream margins, ownership of transportation capacities to exploit arbitraging possibilities, and distribution and power companies moving upstream to ensure margins and security of supply in times of increasing demand worldwide. However, vertical integration, strategic partnerships and mergers lead to an industry in which a small number of large and powerful players are active. Jensen (2004) concludes that in the developing global LNG market *"super majors"* will play an important role. Vertical integration along the whole value chain limits competition at the horizontal level thus counteracting liberalization efforts in downstream markets.

A large number of empirical case studies examine firms' motivations to choose alternative institutions of governance and determinants of vertical integration in different industries, such as Monteverde and Teece (1982), Masten (1984), and Klein (1988). Whereas the first studies typically focused on the manufacturing sector the work of Joskow (1985), discussing coal fired power plants in the US, distinguishes between different situations leading to procurement of coal on spot markets, based on long-term contracts or through vertical integration. The transaction cost economic approach has been followed in most of the empirical work. An in-depth overview on existing empirical approaches for the choice of certain organizational structures is provided by Klein (2004). All mentioned case studies explain vertical integration with institutional factors basically represented by proxy variables for transaction costs, industry characteristics or other exogenous factors. We place ourselves in the continuation of this literature analyzing the determinants of vertical integration in the LNG industry from the perspective of transaction cost economics. The main hypothesis of increasing transaction costs along the LNG value chain (mainly due to increasing asset specificity and uncertainty) leading to a higher degree of vertical integration is tested by applying an Ordered Probit Model. Main findings are consistent with theory and suggest that investments in specific infrastructure have a positive impact on the degree of vertical integration. The extent of vertical integration increases significantly with start up dates of projects since 2002, likely to be explained as firms' response to changes in the institutional environment due to (European) liberalization of natural gas markets. Furthermore, private companies' degree of vertical integration exceeds the degree of vertical integration of state entities. With rising firm size players tend to be more integrated, which is explained by the increasing capability of financing integration.

The remainder of this paper is organized as follows: Section 2 provides an overview on existing theoretical and empirical literature explaining determinants of vertical integration. Section 3 derives testable hypothesis and summarizes used data and the econometric methodology. In Section 4 we present and interpret results before concluding in Section 5.

## 2 Related Literature

In order to empirically test the hypothesis of increasing total costs (decreasing total efficiency) inducing a higher degree of vertical integration we can follow two main streams of literature. Since there exist no uniform theory of vertical integration as pointed out by Joskow (2003) we will identify different motivations of firms to prefer the internal form of organization as opposed to others.

The transaction cost economics approach finds its origins in Coase's theory of the firm (1937) and has been developed further by contributions from Williamson (1971, 1983, etc.), and Klein, Crawford and Alchian (1978). Asset specificity, uncertainty, complexity, measurability, and frequency of transactions are the main drivers influencing the extent of arising transaction costs in an exchange relationship. Individuals are assumed to be characterized by bounded rationality. In uncertain environments contracts will be unavoidable incomplete, since it is impossible to specify all contingencies ex ante. Once, a sunken investment in specific infrastructure is realized, parties are caught in a so called lock-in situation. The hold-up problem – 50 percent of the total ex post surplus are held up by the non-investing party – results in inefficient ex-ante investment levels and decreasing efficiency. Organizing the transaction within the hierarchy avoids these problems by internalizing arising quasi rents into the firm.

Similar to the transaction cost approach, the property rights theory emphasizes the importance of incomplete contracts and ex post opportunism on ex ante investment decisions. Following this explanation, incentives to integrate vertically are generated by the advantage of possessing residual rights of control over assets in the presence of relationship specific investments. According to Grossman and Hart (1986), defining ownership as the possession of these residual rights, bargaining power over ex post distribution of surplus inhibits positive investment incentives. The party owning residual rights of control over an asset tends to over-invest whereas the other party will under-invest. Hence, vertical integration is the optimal solution, when one party's investment is of particular importance.

Several other industrial organization approaches conclude that market imperfections such as the existence of market power, barriers to entry, price discrimination, and asymmetric information are possible drivers for vertical integration. Vertical integration can avoid successive monopolies and efficiency losses due to double marginalization. However, as pointed out by Joskow (2003) vertical integration is not only an answer to market power but potentially creates market power by gaining control over different stages of a value chain. Rising rivals costs may be a motivation to organize downstream sectors within the firm. Stigler (1951) develops a life cycle theory of vertical integration concluding that infant industries will exhibit a higher level of vertical integration since the extent of the market does not allow for specialization. As the industry grows, costs of using the market for input procurement, marketing etc., will be lower than those of internal organization, the degree of vertical integration decreases.

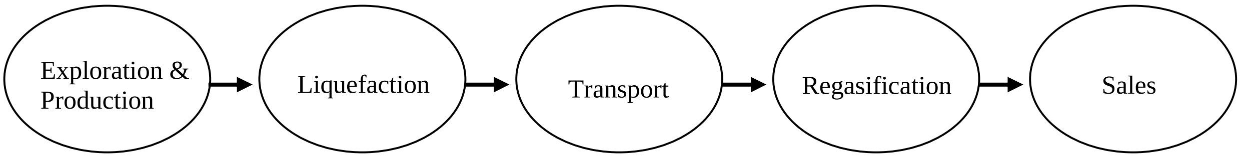
Analyses concerning a firm's motivation to choose alternative institutions of governance in different industries have a long-standing history. A large number of empirical case studies, such as Monteverde and Teece (1982), Masten (1984), and Klein (1988), examine firms' motivations to integrate vertically rather than to choose market exchange. The work of Joskow (1985), discussing coal-fired power plants in the U.S., distinguishes between different situations leading to procurement of coal on spot markets, based on long-term contracts or through vertical integration. Whereas the first studies typically focused on the manufacturing sector and the impact of investments in specific physical assets on corporate behavior, later studies introduce the human asset specificity aspect. During the 1980s a rise in the prominence of a transaction cost approach of vertical integration could be observed. This theory has been followed in most of the empirical work until today and generally strong support for the transaction cost theory could be found. Since predictions of the property rights approach differ from transaction cost issues, this empirical literature in general does not provide empirical evidence for both theories. We are only aware of a small number of empirical studies based on the property rights approach (e.g. Acemoglu et al, 2005). An in-depth overview on different empirical papers for the choice of certain organizational structures is provided by Klein (2004).

All mentioned case studies explain vertical integration by institutional factors basically represented by proxy variables for transaction costs, industry characteristics or other exogenous factors. We place ourselves in the continuation of this literature by analyzing the determinants of vertical integration in the LNG industry from the perspective of transaction cost economics, following our main hypothesis of increasing transaction costs along the LNG value chain (mainly due to increasing asset specificity and uncertainty) leading to a higher degree of vertical integration.

## 3 Data, Variables, and Methodology

Liquefied natural gas is a cryogenic liquid being odorless, colorless, non-corrosive, and non-toxic. Figure 1 depicts the LNG value chain with field development forming the first stage.

**Figure 1: The LNG Value Chain**




Following exploration and production from onshore or offshore fields (stage 1) natural gas is transported per pipelines to the liquefaction facilities.[2] There it has to be pre-treated; natural gas liquids and all components that would freeze under cryogenic temperatures (propane, butane, ethane, carbon dioxide, and water) have to be removed. Under atmospheric pressure using a cooling process the gas is cooled down to 111K (-161°C or -259°F), thus becoming liquid and shrinking to about 1/600$^{th}$ of its original volume (stage 2). This liquefied natural gas is loaded into specially constructed vessels, containing complex cooling systems which are essential to keep the gas liquid. These ships have double walled tanks manufactured of nickel steel, aluminum, and pre-stressed concrete; in between, insulation keeps the gas cool. Today, two types of tankers are common, Moss design (spherical tanks) and Membrane design (tanks in the form of the cargo). The typical size of a ship is about 138,000 cm; larger designs up to 250,000 cm are currently considered. LNG is transported by ship to its destination country (stage 3); where through a heating process the gas is converted to its original state of aggregation in regasification plants (stage 4). At regasification utilities, storage tanks are used to enable a more continuous flow into the pipeline grid, since vessels only arrive about twice a month. Furthermore, these storage tanks can be used to cover peak demand. Finally, natural gas is fed into the national pipeline grid and sold (stage 5) to marketers, distributors or directly to power producers and large industrial consumers. In some instances, LNG is transported in its liquid state by truck to single consumers (e.g. from the U.S. to Mexico).

Whereas liquefaction facilities usually run at full capacity to amortize these capital intensive investments, regasification plants often do not so, they are also used as strategic supply sources to cover seasonal demand spikes. In cold winter periods, Spain and South Korea for example, purchase extra cargoes on a spot basis on top of their long-term agreements.

Investment costs within the five stages vary significantly with the largest share caused by the liquefaction project. The typical structure described by EIA (2003) is exploration and production accounting for 15-20% of the total costs of the LNG value chain; liquefaction for 30-45%; shipping for 10-30%; and regasification and distribution finally for 15-25%. Concrete values depend on different driving factors like the distance between exporting and importing region, employed technologies, or the traded volumes. Jensen (2004) estimates the cost structure of a hypothetical LNG value chain from West Africa (two 3.3 mtpa liquefaction trains) to the U.S. Gulf Coast. Total capital costs are $5 bn, LNG could be delivered at a cost of service of $3.39.

**Table 1: Cost Structure LNG Value Chain**

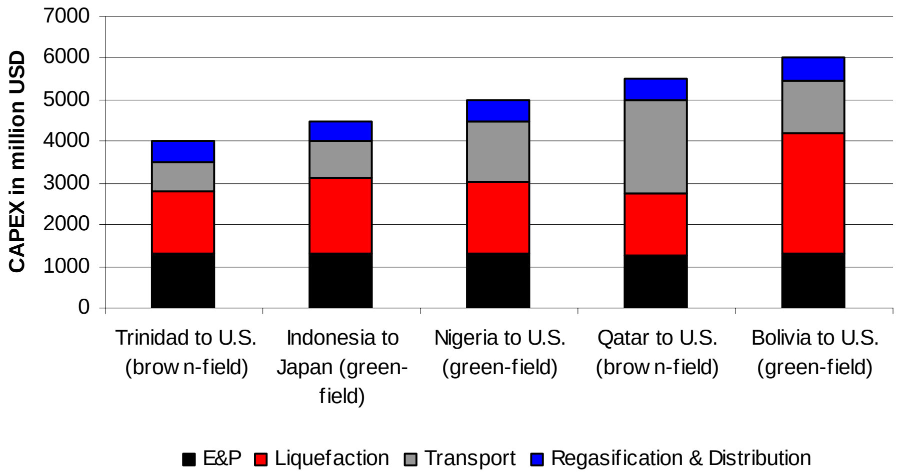
| | Capex | Costs of Service |
|---|---|---|
| Field Development | $1.3 bn | $0.80 |
| Liquefaction | $1.6 bn | $1.22 |
| Transport (10 ships à $160 mn) | $1.6 bn | $0.98 |
| Regasification | $0.5 bn | $0.39 |
| **Total** | **$5.0 bn** | **$3.39** |

Source: Jensen (2004)

Figure 2 compares detailed cost structures for concrete value chains from different exporting countries to importers in the Atlantic and Pacific Basin.[3]

[2] Pipelines from the field to a liquefaction plant are considered as part of the “liquefaction project”, so are storage tanks, loading and other operational facilities.
[3] Assumptions: two 3.3 mtpa liquefaction trains, a field investment of $3.85 per annual MBtu, pipelines between fields and liquefaction facility are part of the „liquefaction project“ (especially important for Bolivia).

**Figure 2: Capital Costs for Different LNG Value Chains**




Source: Jensen (2003)

It is evident that transportation costs vary strongly with distance and have a significant influence on the price of LNG, which is a difference to oil trade, where transportation expenses have only marginal influence on price.

Physical asset and site specificity of liquefaction facilities tend to be higher than those of regasification facilities. Investment costs for the same capacity are twice as high and asset specificity decreases with deregulation of network industries (Dahl and Matson, 1998). Third party access to infrastructure enhances redeployability, resulting in lower specificity. Required transportation infrastructure is a substantial element linking exporting and importing projects. As opposed to oil tankers, vessels for LNG transport remain dedicated assets to certain routes booked under extensive long term contracts. Moreover, alternative use of liquefaction, transportation, and regasification facilities is strongly limited. However, an increasing number of vessels for uncommitted trade are in the order books of shipyards thereby reducing dedicated asset specificity.

We have compiled a dataset on the LNG industry from various publicly available information and expert interviews. It comprises detailed information on capacities, ownership structures, investment costs, financing structures and expansion plans of liquefaction and regasification projects and data on the LNG world fleet. Our sample includes 271 datasets which are comprised as follows: out of 60 importing and 25 exporting LNG projects[4] we identify actual value chains. For instance, BP participates in the Point Fortin project in Trinidad and Tobago delivering LNG mainly to terminals in the US and Spain. On the importing side we identified BP to secure quantities of LNG to be delivered to the Bilbao regasification plant in Spain with supplies stemming basically from Trinidad and Tobago, and Abu Dhabi. Natural gas deliveries to Point Fortin liquefaction train 1 originate from a field of which BP is the sole owner. Expansion trains are supplied by fields in which BP owns a significant share. In a next step, transportation capacities of BP are included. Basically, BP Shipping owns two vessels (with a capacity of 138,200 cm each) assigned to ensure deliveries from Abu Dhabi and Qatar to Spain. Additionally, one tanker with a similar capacity is available for various shipping routes. The regasification plant in Bilbao consists of four shareholders (with equal stakes) of which BP is one. The only stage which BP misses out in this particular chain is final sales.

Applying this methodology to all existing and currently built liquefaction and regasification projects provides a dataset with a total of 271 series, of which 162 value chains are located in the Atlantic and 109 in the Pacific Basin. The degree of vertical integration is a discrete measure counting the number of successive stages in which a player is active along an actual value chain. Since the value of controlling different stages differs, it is not possible to say that participating in four stages has twice the value than being active in only two stages. Therefore, this variable is distributed on an ordinal scale and defined by:

$$VI_i = \begin{cases} 1 & \text{if } n = 1 \\ 2 & \text{if } n = 2 \\ 3 & \text{if } n = 3 \\ 4 & \text{if } n = 4 \\ 5 & \text{if } n = 5 \end{cases}$$

where *VI* is a dummy indicating vertical integration, *i* the number of the observation and *n* the number of successive stages over which the player has control along the actual value chain.

[4] For all existing regasification and liquefaction plants worldwide as well as projects being under construction or planned to be operational before 2010.

The degree of vertical integration in a transaction cost framework is defined by three main dimensions: asset specificity, uncertainty, and frequency of transactions. Proxy variables to test the hypothesis of increasing transaction costs (due to higher asset specificity and environmental uncertainty) leading to a higher likelihood of vertical integration are defined. Furthermore, we use several industry and firm characteristics as control variables.

Liquefaction projects require investments in much more specific infrastructure than regasification facilities. Located near natural gas fields to avoid high pre-export transportation costs they are highly site specific. Furthermore, a liquefaction terminal lacks redeployability and exhibits physical asset specificity. Additionally, investment costs are twice as high as those of comparable regasification terminals. Another issue leading to lower specificity of import terminals is the introduction of third party access as a result of the liberalization process in Continental Europe, which leads to increased redeployability, since alternative LNG importers can use the terminal. As different other empirical studies we use a dummy variable indicating export projects (DX) and therefore a higher degree of asset specificity.

Different parts of the value chain are subject to differing laws and regulations. As Jensen (2003) stated, *"The fact that differing regulatory systems impact the success of the project introduces an element of political risk into the process."* Inhomogeneous distribution of natural gas in often political critical regions is introduced into the analysis by including a political country risk index (RISK).[5] For example, guerilla activities of Aceh separatists in Western Sumatra (Indonesia) have led to a temporary shutdown of the Arun liquefaction facility in 2001. The index ranks countries on a seven-scale ordinal scale. Following the transaction cost theory we expect that with higher investments in specific infrastructure and increasing uncertainty the degree of vertical integration increases.

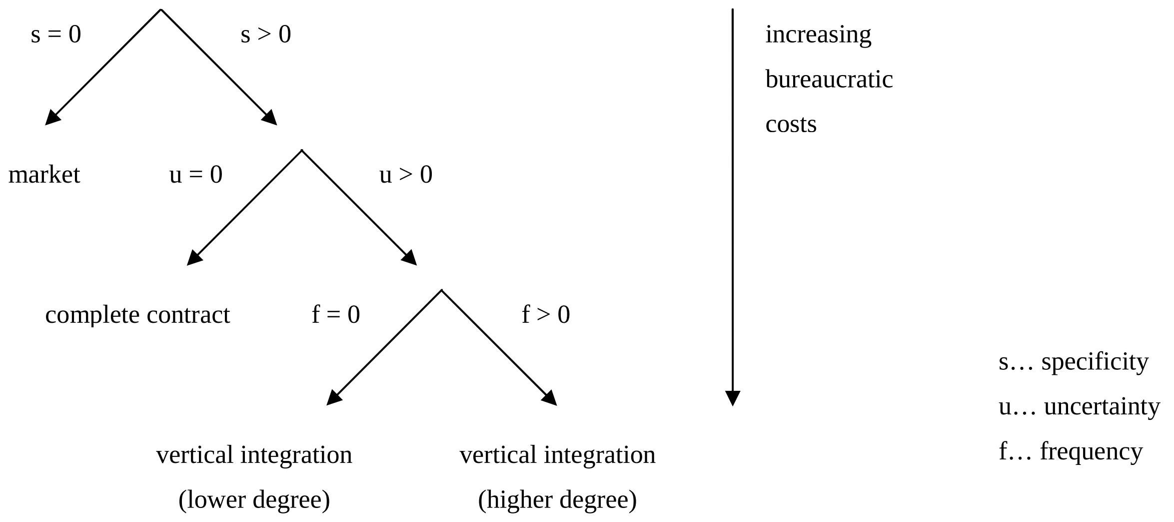
The frequency of a player's activities in the LNG industry is measured by cumulating regasification and liquefaction capacities owned worldwide by this firm (CAPOWN). We argue, that a firm owning more LNG (export or import) capacities has more experience in the industry and can benefit from economies of scale and

[5] As reported by Coface Country Rankings (2005).

therefore tends to integrate stronger than new entrants. Other empirical studies (e.g. Simoens et al, 1999) provide evidence of frequency being positively correlated with the likelihood of integration.

Summarizing, the following figure is used to describe the relationship between the transaction cost determinants of vertical integration used in our analysis and the expected firm’s choice of an organizational structure.

**Figure 3: Choice of an Organizational Structure in Dependence from Transaction Attributes**




Source: Own illustration, scheme structure following Williamson (2006).

Transaction cost economics predicts that asset specificity is the strongest determinant of vertical integration; therefore the examination starts with this issue. In exchange relationships that do not involve any investment in specific assets, theory assumes that trade on a spot market is the most efficient solution. Markets become inefficient as bilateral dependencies – resulting from investments in specialized assets – arise. Specific investments in environments without any uncertainty can be secured through complete long-term contracts. In contrast, the existence of uncertainty results in vertical integration being more efficient than long-term contracts, since those contracts would be incomplete and hold-up potential may be created. Transaction frequency, understood as commonness and experience in the industry leading to the availability of specific knowledge, personal, and economies of scale, is assumed having a positive influence on the degree of vertical integration. But the more integrated a firm, the higher additional bureaucracy costs occuring through internal organization; benefits and costs of integration always have to be compared to choose the optimal corporate structure.

First success of efforts of introducing competitive market structures into the natural gas industry (not only within Europe) since the late 1990s is evident. Monopolistic market structures have been partially broken up allowing new players to enter the market. Works of Ohanian (1994), Lieberman (1991), and Rosés (2005) indicate that market concentration as a measurement of transaction costs resulting from a small number bargaining problem has a significant positive influence on the degree of vertical integration. Following this argumentation and taking into account restructuring efforts underway in Europe; we use the Herfindahl-Hirschman Index for the importing market (HHI).[6] It is argued that the higher the persistent HHI in a country the fewer the number of alternative LNG buyers, thus the higher transaction costs resulting from small number bargaining and therefore the higher the degree of vertical integration to avoid these costs.

International LNG trade has only picked up since the late 1990ies as pointed out by Iniss (2004). The introduction of a dummy variable (D2002) identifying project start up dates before 2002 allows for structural changes in the LNG industry, mainly the observed mergers and acquisition activities in the industry. This should allow an examination of the impact of a changing market environment due to the liberalization of Continental European natural gas markets, which started in the late 1990s and is still under way, on corporate behavior.

Furthermore, we use a dummy variable (ATLANTIC) to allow for differences in corporate strategies resulting from regional factors, varying between Atlantic (deliveries to Europe and North America) markets, where natural gas hubs are evolving and Pacific (Asian) markets where importers are strongly dependent on LNG as a mean to import natural gas. For the analysis of a sub-sample, which only includes value chains situated in the Atlantic Basin, we use an additional dummy indicating value chains connecting European instead of North

[6] The Herfindahl-Hirschman Index is a function of the number $n$ of suppliers in the natural gas importing market and their market shares ( $x_i$ ) and equals the sum of all suppliers' squared market shares. The HHI can range from 0 (monopolistic structure) to 1 (perfect competition). HHI < 0.1 indicates not concentrated market, 0.1 < HHI < 0.18 indicates moderately concentrated market, HHI > 0.18 indicates highly concentrated market. This index is chosen because it has the advantage to give higher weight to parties with larger market shares, because the shares are squared, not summed.

American import markets (EUR) to find out, weather there are significant differences between the European market currently in a liberalization process and the competitive U.S. market.

Two additional variables accounting for differences in firm characteristic are included. A dummy (ST) allows analyzing differences between state-owned entities and private firms. Countries reliant on income streams from the exploration of fossil fuels traditionally follow planned exploration in order to secure and maximize national income. In most cases, these activities are carried out by state-owned entities. We expect that private firms' degree of vertical integration exceeds the one of state-owned entities, since they are not able to control certain risk and thus face higher uncertainty.

The value of firms' assets in million US$ (ASSETS) is used as a proxy for firm size, expecting that larger firms tend to be more integrated since balance sheets enable the financing of integration. Furthermore, authors of former studies have argued that scale economies in finding, holding, and utilizing (management) skills are likely to play an important role in integration decisions and can show a positive influence of firm size, often expressed by the assets value, on the likelihood or degree of vertical integration (e.g. Anderson and Schmittlein, 1984, Ohanian, 1994).

**Table 2: Exogenous Variables**

| **Characteristic** | **Proxy** | **Denotation** | **Exp. Sign** |
|---|---|---|---|
| Asset specificity | Dummy export project (high specificity) | DX | + |
| Uncertainty of a project | Political country risk (ranked on ordinal scale) | RISK | + |
| Transaction frequency | Firm's participation in projects (standardized) | CAPOWN | + |
| Small number bargaining | Market concentration index (HHI) | HHI | + |
| Industry characteristics | Dummy start up before 2002<br>Dummy value chain situated in Atlantic Basin<br>Dummy value chain connecting Europe | D2002<br>ATLANTIC<br>EUR | - |
| Firm characteristics | Dummy state-owned entity<br>Firm size (assets in million US$, standardized) | ST<br>ASSETS | -<br>+ |

Since the variables measuring frequency and firm size have a high variance in comparison to all other variables, they are standardized to be normally distributed and to have the mean of zero and a standard deviation of one for the regression. Table 1 provides an overview on all explanatory variables and the expected influence on the degree of vertical integration.

The average degree of vertical integration of all datasets included into our analysis is about 2.46 implying that on average companies are integrated along two or three stages of the value chain. The mean Herfindahl Hirschman Index of 0.64 indicates very high concentration of suppliers in natural gas importing countries which is characteristic for the whole industry. Player's firm size varies strongly, ranging from US $151mn (Spanish EVE) and US $279bn (Japanese Nippon Oil Corporation).[7] Only about 40% of our dataset includes projects which started operation between 1964 and 2001. This is a sound representation of the booming capacity construction period starting in the 21st century. About 45% of the dataset include oil and gas majors as players, 38% original distributors and 17% others. In 36% of all projects we identify active state entities. Table 2 summarizes descriptive statistics of the whole dataset:

**Table 3: Descriptive Statistics**

| | VI | DX | RISK | CAPOWN | HHI | D2002 | ATLANTIC | ST | ASSETS |
|---|---|---|---|---|---|---|---|---|---|
| Mean | 2.46 | 0.52 | 0.32 | 13.6 | 0.64 | 0.43 | 0.60 | 0.36 | 68,769 |
| Median | 1 | 1 | 0.17 | 12.3 | 0.55 | 0 | 1 | 0 | 60,000 |
| Maximum | 5 | 1 | 1 | 54.5 | 1 | 1 | 1 | 1 | 279,177 |
| Minimum | 1 | 0 | 0 | 0.15 | 0 | 1 | 0 | 0 | 151 |
| Std. Dev. | 0.49 | 0.50 | 0.31 | 10.86 | 0.30 | 0.49 | 0.49 | 0.47 | 62,596 |
| Observations | 271 | 271 | 271 | 271 | 271 | 271 | 271 | 271 | 271 |

[7] We assume an average value for assets for state-owned entities if data was not available of US $ 60,000.

The correlation matrix in Table 3 exhibits some insights into the general relationships between the variables included into our analysis. Political country risk and export projects are correlated strongly positive, supporting the hypothesis of LNG exporting regions often being characterized by a certain political instability. Furthermore, large companies seem to own more liquefaction and regasification capacities, since they are able to finance these capital intensive investments. Moreover, we find that market concentration in importing countries in the Pacific Basin exceeds the one in the Atlantic Basin. State owned entities control the natural gas sector of Asian countries, mainly China, South Korea, and Taiwan whereas private firms and new entrants are active in North America and Europe.

**Table 4: Correlation Matrix**

| | VI | DX | CAPOWN | RISK | HHI | D2002 | ST | ATLANTIC | ASSETS |
|---|---|---|---|---|---|---|---|---|---|
| VI | 1.000 | 0.282 | 0.298 | 0.083 | 0.115 | -0.173 | -0.148 | 0.111 | 0.364 |
| DX | | 1.000 | 0.152 | 0.441 | 0.315 | 0.135 | 0.001 | 0.080 | 0.366 |
| CAPOWN | | | 1.000 | 0.095 | 0.092 | 0.194 | 0.083 | -0.021 | 0.353 |
| RISK | | | | 1.000 | 0.126 | 0.052 | 0.219 | -0.000 | 0.137 |
| HHI | | | | | 1.000 | 0.205 | 0.142 | -0.393 | 0.165 |
| D2002 | | | | | | 1.000 | 0.051 | -0.188 | -0.030 |
| ST | | | | | | | 1.000 | 0.140 | -0.372 |
| ATLANTIC | | | | | | | | 1.000 | -0.050 |
| ASSETS | | | | | | | | | 1.000 |

We define the degree of vertical integration as a discrete measure distributed on an ordinal scale. It is possible to identify outcomes of a higher value; but not to define quantitative intervals between two successive categories. An ordinary least squares regression employed for our dataset, where five levels of vertical integration – 1, 2, 3, 4, and 5 – are coded, would treat the differences between five and four the same as the one between three and two, what would lead to useless results. The degree of vertical integration is explained by different exogenous variables, the determinants of vertical integration, as presented below.

$$VI_i = \alpha + \beta_1 DX + \beta_2 CAPOWN + \beta_3 RISK + \beta_4 HHI + \beta_5 D2002 + \beta_6 ST + \beta_7 ATLANTIC + \beta_8 ASSETS + \varepsilon_i$$

where *VI* is the degree of vertical integration along an actual value chain *i*, $\alpha$ and $\beta_n$ are parameters, $\varepsilon$ the error term expected to follow a normal distribution and the other variables defined as explained in the preceding section. For the analysis of the sub-set including only value chains situated in the Atlantic Basin the degree of vertical integration is explained in the following way:

$$VI_{AB,i} = \alpha + \beta_1 DX + \beta_2 CAPOWN + \beta_3 RISK + \beta_4 HHI + \beta_5 D2002 + \beta_6 ST + \beta_7 ASSETS + \beta_8 EUR + \varepsilon_i \, .$$

## 4 Estimation Results

Estimation results based on an Ordered Probit Model are consistent with the transaction cost approach. Table 3 presents estimated coefficients and associated statistics for the world dataset.

**Table 5: Estimation Results Ordered Probit Model (World Dataset)**

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| DX | 0.525 | 0.171 | 3.073 | **0.0021** |
| RISK | -0.086 | 0.248 | -0.347 | 0.7289 |
| CAPOWN | 0.395 | 0.078 | 5.059 | **0.0000** |
| HHI | 0.694 | 0.273 | 2.542 | **0.0110** |
| D2002 | -0.535 | 0.145 | -3.691 | **0.0002** |
| ST | -0.384 | 0.171 | -2.252 | **0.0243** |
| ASSETS | 0.134 | 0.086 | 1.565 | 0.1176 |
| ATLANTIC | 0.346 | 0.159 | 2.172 | **0.0299** |

The occurrence of investments in specific assets has a positive impact (5% level) on the degree of vertical integration. The second transaction cost variable RISK has not the expected sign, but is statistically not significant at all. With increasing frequency, the degree of vertical integration of players increases (1% level). Also the hypothesis of increasing transaction costs resulting from small number bargaining in the importing country leading to a higher degree of vertical integration can be confirmed (5% level). It can be shown, that a shift has taken place, along value chains which started operation before 2002 the degree of vertical integration is lower (1% level). State-owned entities tend to be integrated less than private firms (5% level). Firm size seems to have a positive impact on the degree of vertical integration. And finally, for value chains situated in the Atlantic Basin the degree of vertical integration exceeds the one of Pacific Basin value chains (5% level).

The expectation-prediction table compares the number of actual observations in each category with the number of observations that should be classified into these categories since their probability for the corresponding response is maximal.

**Table 6: Expectation-Prediction Table Ordered Response Model (World Dataset)**

| Value | Count | N° of observations with max prob. | Error |
|---|---|---|---|
| 1 | 32 | 0 | 32 |
| 2 | 114 | 176 | -62 |
| 3 | 82 | 90 | -8 |
| 4 | 21 | 0 | 21 |
| 5 | 22 | 5 | 17 |

We observe that for 176 observations the level of vertical integration should be two, whereas only 114 observations actually take on this value. This leads to a negative error of 62. It can be summarized that in the outer categories one finds more observations than predicted and in the inner categories less observations than predicted. Hence, firms tend to chose more likely a polar structure rather than a medium degree of vertical integration.

Focusing on the LNG business in the Atlantic Basin we generate similar results. Coefficients exhibit the expected signs, but statistical significance decreases since the number of datasets is reduced from 271 to 162. The occurrence of high environmental uncertainty – measured through an index of the political country risk – has a positive impact (10% level) on the degree of vertical integration. With increasing frequency, the degree of vertical integration of players increases (1% level). It can be confirmed that along value chains which started operation before 2002 the degree of vertical integration is lower (5% level). State-owned entities tend to be integrated less than private firms (5% level). Firm size seems to have a positive impact on the degree of vertical integration. Adding an additional dummy variable indicating regasification projects situated in Europe, we can show that the degree of vertical integration is higher in Europe than in other regions worldwide. Table 7 summarizes the estimation results for a detailed Atlantic Basin analysis.

**Table 7: Estimation Results Ordered Probit Model (Atlantic Basin Sub Sample)**

| | Coefficient | Std. Error | z-Statistic | Prob. |
|---|---|---|---|---|
| DX | 0.351 | 0.310 | 1.133 | 0.2572 |
| RISK | 0.723 | 0.376 | 1.924 | **0.0544** |
| CAPOWN | 0.525 | 0.115 | 4.561 | **0.0000** |
| HHI | 0.441 | 0.351 | 1.257 | 0.2086 |
| D2002 | -0.446 | 0.201 | -2.217 | **0.0266** |
| ST | -0.631 | 0.239 | -2.642 | **0.0082** |
| ASSETS | 0.180 | 0.120 | 1.492 | 0.1357 |
| EUR | 0.642 | 0.302 | 2.123 | **0.0337** |

Analyzing the predictive power of the model, it can be observed that for 111 observations the level of vertical integration should be two, whereas only 66 observations actually take on this value. This leads to a negative error of 45. It can be summarized that – as already observed for the world dataset – in the outer categories one finds more observations than predicted and in the inner categories less observations than predicted.

**Table 8: Prediction Table Ordered Response Model (Atlantic Basin Sub Sample)**

| Value | Count | N° of observations with max prob. | Error |
|---|---|---|---|
| 1 | 17 | 3 | 14 |
| 2 | 66 | 111 | -45 |
| 3 | 41 | 30 | -11 |
| 4 | 18 | 0 | 18 |
| 5 | 16 | 14 | 2 |

Figure 4 summarizes the influence of certain transaction cost attributes and firm characteristics on the degree or likelihood of vertical integration:

**Figure 4: Influence on the Degree of Vertical Integration**

Positive:

- player originally situated on export side of the value chain and has to invest in highly specific infrastructure
- high frequency of player's activities in the LNG industry
- high market concentration of natural gas suppliers in the importing country
- large firm size
- value chain situated in the Atlantic Basin
- value chain connecting European

Negative:

- start up value chain before 2002 (in the "infant LNG industry")
- state-owned entity instead of private company

Estimation results show (with differing statistical significance dependent on the sample size) that players tend to choose integration if highly relationship specific investments in LNG infrastructure – here indicated through LNG liquefaction projects – have to be realized. This is a result consistent with the transaction cost approach. To avoid the hold-up problem resulting from incomplete contracts and large quasi rents firms integrate vertically and evade an exchange relation with a third party. Following the transaction cost approach; this motivation should increase with the degree of environmental uncertainty and the impossibility of writing complete contracts.

The variable indicating environmental uncertainty – the political country risk – shows varying signs and is not statistical significant for the world dataset. We argue that the true indicator for uncertainty accompanying relationships in the LNG industry has not been found, yet, the employed variable is not able to measure the inability to predict all contingencies which could happen due to changes in the industry and trading environment. An indicator of price volatility should be included to improve the model for further research.

With increasing frequency of transactions in the LNG industry, a player integrates stronger. This is due to increasing experience on the one hand and the possibility to benefit from economies of scale on the other hand. Firms that already participate in a number of LNG (export- or import-) projects are in general endued with specialized human capital (like a business unit LNG) and have intensive relationships to trading partners. The effort to participate in an additional project is lower for those firms than for new entrants into the business. It can also be shown, that larger firms are more integrated. This is due to an increasing ability to finance integration, meaning investing in infrastructure and human capital, potentially merging other companies, and organize strategic partnerships and joint ventures.

Also the last transaction cost variable shows the expected influence on the likelihood or degree of vertical integration. The higher the market concentration of natural gas suppliers in the importing country the higher the transaction costs resulting from small number bargaining and the higher the motivation to integrate downstream to avoid these costs.

Furthermore, it can be shown, that a shift in corporate strategies has taken place. Whereas during the infant LNG industry trade was typically organized via bilateral long-term contracts between the LNG export project as seller and energy companies as buyers, since about five years, vertical integration becomes more and more common to secure supply in times of increasing demand worldwide and the amortization of capital intensive specific investments. Global players diversify their LNG (export and import) portfolios in order to be able to trade more flexible and optimize transportation routes.

State-owned entities are significantly less integrated than private firms. This can be explained by the fact, that one of the main uncertainty factors is the problem of political instability in export countries and regulatory instability in import countries. For state-owned entities these problems are much less important since the state has a strong influencing power.

For value a chain situated in the Atlantic Basin rather than in the Pacific Basin the degree of vertical integration is higher. This can be explained by the fact that in the Pacific Basin the deregulation process is just in its inception and relations between export and import projects often have still the character of the "old world" with bilateral long-term contracts. As these inflexible agreements are not defined as pure vertical integration in this analysis, the degree of vertical integration is lower for this region.

Finally, resulting from the sub sample analysis of the Atlantic Basin, it becomes obvious that for value chains connecting European instead of U.S. value chains, the degree of vertical integration in average is higher. This is an interesting issue since the liberalization process in North America has started during the 1980s, about 15 years before Continental Europe. We hypothesize that in the U.S. where the natural gas market is already competitive, players may not need to integrate to secure their supply and the amortization of investments anymore. It can be speculated that in Continental Europe in about ten years competition could also enhance the emergence of independent non-integrated players operating LNG import terminals as "tolling facilities" and just selling the service of regasification and storage to natural gas importing companies like for example Chenière actually in the U.S.

Beside these main results we find that exporting and importing players control the mid-stream stage transportation to a similar extent: both, oil and gas majors as well as original distributors, have chartered vessels under long-term contracts and possess or have ordered own ships. Controlling transport capacity is the key to trade more flexible and to benefit from price difference between different regions. Order books of international shipyards include a large number of ordered vessels of which a certain number will be owned by major players of the industry, not dedicated to neither project nor transport route.

## 5 Conclusions

Increasing natural gas demand and the ongoing process of liberalization and deregulation in Continental Europe lead to fundamental changes in corporate behavior. Global oil and natural gas majors as well as original distributors engage in all stages of the LNG value chain. The today's industry is characterized by more flexible long-term contracts, accompanied by short term agreements, and companies integrating vertically to internalize risk factors resulting from investments in capital intensive LNG infrastructures.

We use a transaction cost economics approach to empirically analyze determinants of vertical integration in the (liquefied) natural gas industry. Vertical integration and strategic partnerships become a common form of organization to face changing market conditions. The main hypothesis of increasing transaction costs along the LNG value chain (mainly due to increasing asset specificity and uncertainty) leading to a higher degree of vertical integration is tested by applying an Ordered Probit Model. Main findings are consistent with theory and suggest that investments in specific infrastructure have a positive impact on the degree of vertical integration. The extent of vertical integration increased significantly with start up dates of projects since 2002, what can be explained as firms' response to changes in the institutional environment due to (European) liberalization of natural gas markets. Furthermore, private companies' degree of vertical integration exceeds the degree of vertical integration of state entities. With rising firm size players tend to be higher integrated, which is explained by the increasing capability of financing integration. The continuing growth of LNG short-term trade accompanied by an increasing flexibility inherent in contracts enhances reshaping of the industry. In addition, players order uncommitted vessels thereby creating uncommitted transport capacities which will be the key to exploit arbitraging profits from price differences between regions.

The natural gas industry develops to an industry dominated by global "super majors" benefiting from a certain market power as well as from the financial strength to finance integration, mergers and large investments. The high degree of vertical integration in the LNG industry is limiting horizontal competition, thus in contrast to liberalization efforts, currently under way in Continental Europe. We argue that in about ten years, when natural gas markets in Europe reach a competitive level, firms integrating along the LNG value chain will be only one type of observable strategies. New entrants, non-integrated merchants, may enter the stage just operating import facilities under a kind of "tolling" agreements.

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