A system dynamics approach to the expansion of liquefaction capacity in the LNG industry

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Abstract: **Capacity and price cycles in capital-intensive industries affect firms' performance and profitability, and there is a need for understanding the mechanisms and dynamics of investment in capacity expansion. We report the main results of the analysis of investment decisions in the LNG industry, specifically in the liquefaction segment. We propose a model in which investors estimate the capacity needed from their expectations for future demand. This estimation changes as market sentiment encourages or discourages investments. Market sentiment is increased by profitability and is decreased by projects under construction as investors would find stronger competition for allocating their supply According to the results, liquefaction capacity increases until 2030 as a result of increasing forecast of demand and high prices. In the 2010s capacity even overpasses demand expectations due to decisions prior 2011. When investors are driven only by profits of the market, cycles of capacity appear, which agrees with other markets such as electric ones. This result suggests that investors indeed are aware of the likely saturation of the market in the near term. Under low and high prices, industry is still profitable, being those results very similar although model seems to be more sensitive to low prices.**

Keywords: **Liquefied Natural Gas (LNG), investment decisions, capacity expansion, lumpy investments, capital-intensive industries**

1. INTRODUCTION

In capital intensive industries new facilities are usually large and have few alternative uses. Lumpiness of investments (infrequently built and large [1]) is associated to capacity and price cycles. Since industry-wide fluctuations impact income and profitability, there is a need for understanding how investors behave and what determines the magnitude and timing of their investment decisions.

The Liquefied Natural Gas (LNG) industry is an example of a capital intensive industry. Recent cost figures for a typical liquefaction plant range between USD250 million and USD400 million [2] per million ton per year (mmtpy), for a nominal capacity between 4 mmtpy and 5 mmtpy [4]. In addition, there are few alternative uses for LNG plants, terminals and carriers. New capacity is added with long delays, which generates some booms and busts in project construction. One example of this was observed during 2008-2009 when charterers over-contracted shipping requirements [3].

Construction cycles bring uncertainty to the market, increasing the complexity of decision-making. Uncertainty, in turn, decreases both market efficiency and return of investment. As discussed before, this problem is important because profitability is lower with excess capacity while the high profits earned when there are capacity constraints increase the use of LNG substitutes and the entry of new capacity. Cycles emerge because people tend to invest in capacity when expected profits are high and they tend to disinvest when profits are low. Disinvestment imposes costs on society in the form of lay-offs and lost revenues, which is why it is important to understand how investment cycles emerge [4].

Investment decisions are the most strategic decisions a firm can make[5]. Capacity additions can change the structure of an industry, and have a significant impact on the market price. As capital investments are usually long-lived, they are a critical determinant of how market competition evolves in the long run. According to [5], mistakes in the form of overly-aggressive or poorly-sequenced capacity expansions can result in unintended over-capacity that can “spoil” a market for years, even for decades.

This paper reports the main results of the analysis of investment decisions in the LNG industry, specifically in the liquefaction segment, using System Dynamics (SD). SD is used because the investment process is non linear with long delay times and multiple feedback relationships, and because SD is particularly robust in its ability to use qualitative and quantitative data [6].

We focus on liquefaction capacity because this segment of the supply chain leads the investments in the other links of the value chain. Before presenting the model and its results, we briefly describe the LNG industry and LNG market in Section 2. In Section 3 we briefly review previous research on the factors that determine investment decisions, while in Section 4 we present some reviewed models concerning capacity expansion. Then we present the dynamic hypothesis of the model and its assumptions in Sections 5 and 6, respectively. Model validation is presented in Section 7 while and results are presented in Section 8. Finally, in Section 9 we present the conclusions of the paper.

2. THE LNG INDUSTRY

LNG is a colorless, odorless, and non-toxic clear liquid that is one six-hundredth of the volume of methane in its gas state. LNG is safe to transport over long distances and it is estimated that it is more economical than pipeline gas for distances larger than ca. 3000 km[7]. Liquefied gas overcomes several geographical and political factors faced by long-distance pipelines and it is increasingly competitive at shorter distances because it lowers logistics costs [8]. LNG value chain has four main stages: from field development to liquefaction and transportation to regasification in the importing country.

Liquefaction and transportation costs are the largest cost components of the chain[7], [9]. There is no strong evidence of economies of scale in these activities, although liquefaction costs seem to decrease with plant size. Liquefaction costs of a project with 2 trains (plants) of 4 million LNG tons per year (mmtpy) are 30% less than the costs of a project with 4 trains of 2 mmtpy [9]. Although evidence of scale economies is inconclusive [10], train capacities have been increasing. The first commercial train built in Arzew, Algeria started operations in 1964 and had a capacity of 1,1 mmtpy but trains built during the 2000s had a capacity up to 7,8 mmtpy. Shipping capacities have also increased from 40.000 cubic meters (cm) in 1970 to 250.000 cm in 2010, also decreasing costs [7].

Although liquefaction costs decreased between the 1980s and early 2000s, through learning and technology improvements, capital costs have been increasing since 2005 due to overbooking of engineering, procurement and construction contractors, high raw materials prices and regional labor constraints. The impact of these constraints in LNG industry is high since these projects need specialist equipment and personal, and are mostly located in remote regions with limited infrastructure [11]. Shipping capital costs follow a similar pattern, decreasing from USD280 million in 1980 to USD155 million in 2003, and increasing again by 2008.

Shipyards gain in experience and an increasing number of shipyards are capable of constructing LNG vessels, thus increasing competition. Hence, bigger ships allow LNG to be transported more economically on longer distances [7].

World LNG sales have grown in the last years from 143 billion cubic meters (bcm) of gas in 2001 to 330,8 bcm of gas in 2011. In 2011 global LNG sales totaled 32,3% of all the natural gas movements around the world, including pipeline exportations[12]. 20 countries exported LNG in 2010 and 25 countries imported it. Most of LNG trade has traditionally been made through bilateral contracts lasting 20-25 years. As the market has matured, sales have become more flexible, with sales in the spot market increasing from 15% in 2002 to 25% in [3]. Excess capacity in transportation and production surpluses have allowed the increase in short term, more flexible contracts and spot trade might change the conditions for investment [2].

Although many long-term gas contracts are linked to oil prices, there have been major changes in the natural gas industry and gas prices are increasingly decoupled from oil prices in North American and European markets. In addition, gas demand growth and deregulation of gas and electricity markets have increased the convergence between electricity and gas prices. These changes in gas markets are also reflected on LNG prices and markets. LNG price is now linked to regional gas prices in the U.S. (Henry Hub) and the U.K. (NPB), whereas in the rest of Europe and Japan LNG price is still linked to crude oil (Brent and Japan Crude Cocktail- JCC, respectively). As a result, LNG price in the Asia-Pacific markets is exposed to the volatility of oil price and this, in turn, increases the need for long-term contracts in order to hedge from price and demand instability.

Furthermore, long-term contracts help to coordinate investments along the LNG chain, and supply contracts are often required for financing[3].For example, Kogas, which has the legal monopoly of gas in South Korea, signed a 4,8 mmtpy 25 year supply agreement with RasGas, a joint venture between Qatar General Petroleum Corporation (70%) and Mobil Corporation (30%) [13].

Long-term contracts do not imply any kind of property on liquefaction capacity from the buyers. However, oil companies often have interests in gas exploration, extraction, production, liquefaction, shipping, regasification and sales. Private oil and gas companies join long-established state-owned entities in exporting countries securing low cost sources and connecting the fuel to high value markets [7]. In turn, vertical risk-sharing of long-term contracts is increasingly complemented by vertical integration and risk taking in liquid markets [14].

The delays experienced by LNG projects evidence these risks. Some of the host countries are developing countries and use to experience financing, environmental, social, regulation and politic problems, which increases the risk of no completion or of delays in some stages of the project. For example, projects such as Brass (Nigeria), which was announced in 2004; Arzew and Skikda (Algeria), and Olokola (Nigeria) that were announced in 2005; and Ayacucho and San Jose (Venezuela) that were announced before 2004 were in their early stages or had not started by 2010.On the other hand, other projects such as Qatar Gas II and III were both started on 2004 and were completed in time, in 2009 and 2010, respectively[15]. As a result of uncertainty in project completion dates, potential investors find it hard to assess the exact amount of projects that will meet demand in the future, which adds complexity to the decision making process.

3. INVESTMENT DECISIONS

It has been noted that LNG supply rather than demand is the force behind the growth of LNG trade around the world [3]. Then, to understand the dynamics of growth in the LNG industry, we focus on the behavior of investors in comparable industries. According to [16], investors look at the future price and decide whether to start building or not depending on the profitability they perceive. Investors also shape their decisions using information about the difference between forecasted demand and supply [17]. Research by [6] suggests that decisions to build new power generation plants are based on expectations of capacity needs and profitability. There are other theories that address coordination and vertical integration issues. In the rest of this section we discuss these theories and their ability to explain LNG capacity building.

According to game theory, decisions should take into account other players' reactions and their effects on firm value [18]. Mason & Nowell [19] find that capacity decisions depend typically on firm interactions with other firms' economic decisions. As discussed before, lack of coordination generates boom and busts in construction, and also, overcapacity and under capacity periods. According to [20], in a vertically integrated industry, overcapacity occurs because market and government failures cause enterprises to ignore full information on the future changes supply and demand balances.

In the industrial organization literature, capacity expansions have been studied as a strategy to deter new players from entering into the market [21]. Entry-deterrence behavior increases when sunk costs are high [22]. In the same way, Besanko *et al*.[5] suggests that irreversible investing incapacity makes preemption more credible and thus more likely to be pursued. However, empirical work in some industries suggests that firms are able to avoid excessive capacity and that investment decisions can be coordinated. Capacity overbuilding preemption arises when product differentiation is weak, but is only transitory. According to that, coordinated decisions in an industry depend on differentiation of product and investment sunkness (see *Table 1*). Differentiation affects the competitiveness of the product market and thus firms' profits. Reversibility of investment affects the costliness of capacity expansion decisions that turn out ex post to be excessive.

LNG industry would be located on the bottom of the right of the table because LNG is a homogenous product and this is a capital intensive industry characterized by lumpy investments. As stated by [5] "When sunk costs are high and differentiation weak, a mild preemption race takes place as each firm tries to secure a capacity advantage. The preemption race in this case is softer than others because the firms foresee that the industry will become stuck with overcapacity and, consequently, reins in their aggressiveness. This is a dynamic manifestation of the maxim that exit costs are entry barriers."This could explain why there is no evidence that capacity expansion is used for entry-deterrence in the LNG industry. This industry uses other mechanisms to deter entry, such as contracts that prevent third-parties entry [23] and impose exclusivity on exports destinations [14].

Table 1. *Capacity expansion and withdrawal processes under no or low depreciation depend on differentiation and investment sunkness. Taken from Besanko et al. [5]*

	Coordinated Withdrawal	Uncoordinated Withdrawal
Coordinated Expansion	Differentiation: strong Investment Sunkness: low	Differentiation: strong Investment Sunkness: high
Uncoordinated expansion	Differentiation: weak Investment Sunkness: low	Differentiation: weak Investment Sunkness: high

One of the main causes of excess capacity is the discrete nature of capacity additions. While demand grows gradually, capacity grows discretely as projects are completed, which means there are periods of excess capacity [24]. While investing in larger plants can result in significant scale economies [25], getting the timing wrong, and investing simultaneously with a number of rivals, can result in significant overcapacity and poor returns. Thus, an effective corporate governance system could act as a brake on firms attempting to add too much capacity simultaneously [26].

Similarly, according to [6] two mechanisms drive over construction (or, later, under construction) of capacity. First, projects in development are not fully accounted for, so the signal to develop more capacity continues until it is evident that new plants are being built. Second, high prices and high profit expectations lead each developer to assume that their new and efficient plants will capture a profitable share of demand even when there are more plants than needed in development. For both these reasons, orders for new capacity continue past the point of exactly meeting future demand. This agrees with the idea that investors do not decide as a group or coalition that seeks to meet demand [27].

This shortsightedness of investors is treated in [28], where investors' behavior is studied deeply. In [28] investors are classified into three categories: (i) *believers*, who will believe a new plant is for real when they see it in operation; (ii) *pre counters*, who count the new capacity into their forecasting process as soon as construction is initiated, revealing their confidence that any unit that starts construction will finish construction; and (iii) *followers*, whose commitment to construction does not occur until others have initiated some construction, showing a herd-mentality factor.

This is important because, although LNG projects are too big not to be noticed, there is one complicating factor that could cause companies to discount reports of plants already under construction. This factor is the uncertainty of construction lead times. As a result on this uncertainty on lead times, skepticism about completion of announced power plants is expected, and one can conclude that investors in LNG behave as *believers*.

About the coordination of investments into an industry, [4] suggests that it is impossible to coordinate when there is no market power. Then, a regulated monopoly can coordinate its actions because it knows its own plans. In a deregulated environment firms do not trust completely in other firms, so they cannot establish any coordination [6]. Coordination in the LNG industry could be more difficult to achieve than in other industries because many players are national companies representing public rather than private interests. Based on the theories examined in this section we build a dynamic hypothesis for investment decisions in the LNG industry and present it in the next section.

4. MODELING THE DYNAMICS OF CAPACITY EXPANSION

System dynamics has been used by many authors in an attempt to explain capacity cycles in several industries. Traditionally, studies deal with macroeconomic cycles or cycles in agricultural commodities, but there is a body of literature expanding this line of research to capital-intensive industries.

For example, SD has proven to be useful for explaining feedback mechanisms in electric systems [27]. Bunn & Larsen [29] use a SD approach to see how power-generation capacity evolves under certain scenarios. In [28] the Loss of Load Probability (LOLP) is used for providing a signal for new investment. LOLP takes into account demand uncertainty and the stochastic nature of generating unit failures. It essentially depends on reserve margin seen as capacity utilization. Hence, when there are periods of excess capacity, the LOLP should be relatively low, and there will be few incentives to invest in new capacity. Alternatively, when there is heavy demand relative to the available capacity, LOLP would raise and provide the required investment incentive.

Cyclicality has been studied in pulp and paper industry [4], airline market [30] and oil tankers market [31]. Berends & Romme [4] analyze the impact of two elements in cycles: (i) several building technologies such as Computer-aided design CAD, that diminish the delay between the investment decision and the moment the new capacity actually comes available for production and (ii) utilization of information systems in order to diminish the desired inventory coverage. Both elements have a negative effect on cycle amplitude. New capacity depends on demand projection and a capacity addition factor, which in turn, depends on equilibrium price and expected price by producers.

Liehr *et al.*[30] analyze aircraft orders. In airline market, aircraft orders depend on expected amount of passengers, desired seat load factor (SLF) and surplus level. It also considers order processing, decision and manufacturing delays. Results from this study are similar to [4].

On the other hand, Ford [27] analyses price and construction cycles in electric market, in which investments are based on forecasted profits. The author proves that capacity payments make cycles disappear because of investors' motivation. Even more interesting is figuring out that power generators do not vary capacity utilization in order to increase prices.

A similar behavior is found in the oil tanker market [31], where high fleet utilization triggers market pressure, which increases time charter (TC) freight rates.TC rates, in turn, have an impact on desired fleet utilization. Unlike other models, Randers & Goluke [31] introduces a delay in this effect, which implies that ship owners do not react immediately to TC rates changes, but after a time. Ship orders depend on TC rates and are adjusted from obsolescence rate and demand trend.

The main conclusion of these and other models is that although exogenous factors amplify cycles, cycles are caused by endogenous factors, which remain on the base of industry structure. Although exogenous factors (heat rates; operational, construction and emission costs; rates; deregulation; and economic growth) trigger cyclical behavior, [6] establishes that capacity growth and prices are governed by feedback loops.

Other models do not focus on price or capacity cycles, such as [32] that makes one of the first approaches to explain shipping industry dynamics, and [6] that proposes a model for assessing the impact of deregulation in power capacity growth.

The LNG industry has numerous similarities with the aforementioned industries, particularly with the pulp and paper industry. Since quality is rather homogeneous across a broad range of different suppliers, price is the main decision criterion for buyers. Producing pulp and paper or LNG in a competitive manner requires significant scale economies and thus large amounts of invested capital, and in both industries there are long delays between the moment investment decisions are made and the moment that new capacity is available for actual production[4].

On the other hand, investment in LNG industry is different from the pulp and paper industry because most of capacity is contracted, with prices indexed to oil. Also, since the spot market is small, firms have little room to vary their capacity utilization in order to increase price. This is considered in the model presented in Section6. As Figure 1shows, there is no clear evidence of cycles in the LNG industry and capacity additions follow no apparent pattern; moreover, the reviewed literature does not explain what factors encourage investment or disinvestment in liquefaction capacity.

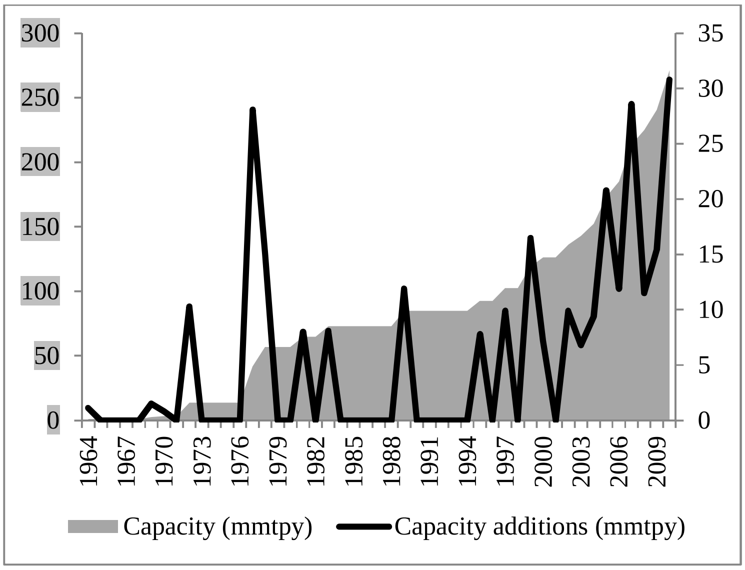

Figure 1. *Liquefaction capacity between 1964 and 2010, and yearly entrance of new capacity. Elaborated by authors with data from [33].*

As discussed before, individual investors consider demand growth, under construction and under operation capacity, marginal costs and profitability when making decisions. When looking at the industry as a whole, however, it is necessary to explain how these variables interact, causing the dynamic behavior of capacity in LNG industry. In the next Section (5) we present a SD model in which the capacity investments depend on short-run and long-run expectations.

5. A SYSTEM DYNAMICS MODEL OF EXPANSION OF LIQUEFACTION CAPACITY

The dynamic hypothesis states that the construction of liquefaction plants depends on short and long-run expectations of profits. Hence, from a forecasted future demand (long-run expectations), investors determine the expansion needs and then adjust them based on the current state of the industry (short-run expectations). Expectations are influenced by the current profitability of liquefaction and by the amount of projects under construction. Profits depend on revenues and total costs which, in turn, depend on average production costs and other costs (levelized capex, exploration, extraction, liquefaction, shipping and regasification costs).

As shown in ***Figure 2***, a technically feasible project passes from the planning stage to the construction stage depending on the short term expectations. Profits encourage new players to enter the market or encourage existing players to increase their investments seeking higher future profits, but ignoring the fact that other players could make the same decision. This is what Randers & Goluke [31] define as “market sentiment”[1]. If the industry is underperforming, new players would prefer not to enter and current players would prefer not to expand.

Also, capacity increases after new projects enter. If the demand growth anticipated when these projects were planned does not materialize, post-entry competition increases as a result of overcapaciy. Players anticipate to

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[1] According to [31] market sentiment can be described as the average mood of the shipping community, its degree of optimism and willingness to invest. This mood is strongly influenced by recent earnings and general expectations for the next year or so.

overcapacity, and postpone or downsize their investments, which eventually slows down capacity growth. In the model, investors foresee the possible saturation of the market in the future and the increase of competition as a consequence. Thus, projects under construction are taken into account as they are supposed to meet future demand. However, these projects are considered only as an indicator of the difficulties to find a buyer in the future, and not when assessing the capacity gap. In other words, investors behave as what [28] describes as "followers" since they just consider capacity under operation when they have to evaluate the future needs of the market.

Likewise, if there are too many projects operating, there is less need for new capacity and the industry would decrease investment because there is not enough demand to supply. A similar behavior is expected when the market shows poor future returns or high costs.

We suppose that firms are competitive and produce a quantity such that their marginal costs equal market price. When prices rise, more plants are able to produce profitably. Marginal costs are a function of production levels and increase asymptotically when production approaches available liquefaction production capacity (near to 90% of nominal capacity [34]), as depicted in equation (10).

As discussed before, profits depend on revenues and total costs, and firms would like to increase their capacity as long as they are able to supply at the market price. This reinforcement loop is balanced by the fact that increasing supply also increases costs which constrains the ability of the industry to increase production. If average variable costs increase, fewer plants will be able to produce at the market price. Market price is based on netback prices, which we take as exogenous. Forecast of future demand is also taken as exogenous.

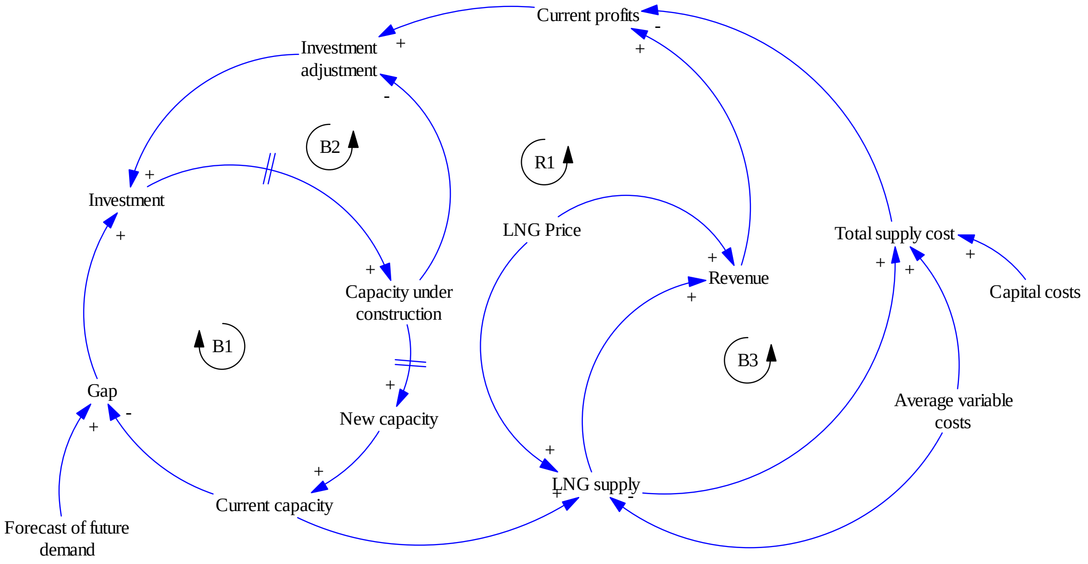


Figure 2.*Dynamic hypothesis.*

6. DATA AND ASSUMPTIONS

LNG production is distributed around the world and the share of transportation costs on LNG supply cost is high. Producing companies seeking to minimize transportation costs usually have operations in different continents. One can therefore assume that LNG producers look at their investments globally, rather than concentrating in a particular market (Atlantic or Pacific).

The model has two stock variables: capacity under construction and capacity under operation. Under construction projects (*UC*) are increased by construction initiation of projects (I_t) and are decreased by projects that enter to operation (E_t). Both initiating and entering projects are discrete variables, representing an average train size of 5 mmtpy trains. I_t and E_t are rounded to the nearest 5 multiple. Each project has fixed planning and construction times.

$$\frac{d}{dt}UC = I_t - E_t \qquad (1)$$

In the same way, under operation projects (*UO*) are increased by the entry of projects (*E*) and are decreased by obsolescence of current capacity (*O*).

$$\frac{d}{dt}UO = E_t - O_t \qquad (2)$$

The gap between future demand and under operation capacity determines the initiation of projects. In other words, initiation depends on the capacity needed to meet future demand. Capacity under construction is not considered by investors because we suppose they behave as *believers* (see Section 3).

Future demand is an exogenous variable, and it is taken from BP's forecast [35] that suggests a fixed growth rate of 4,3% from 2010 to 2030. Future demand corresponds to 6 years forward, as this is the time delay assumed for planning (2 years) and construction (4 years). Therefore, capacity needed is assessed as follows:

$$KN_t = D_{t+6} - UO_t \qquad (3)$$

As explained before, demand uncertainty and information asymmetry lead to delays in decision process and thus, induce errors in the forecasting of capacity needed. In addition, investment changes to reflect changes in "market sentiment". "Market sentiment" is explained as the willingness of players to increase or decrease their investments based on industry profits. Decision theory assumes that people have proper knowledge and thus, rational and predictable expectations. Psychological theory, however, suggests that people often exhibit a herd behavior. For example, when the economy is growing, people are induced to take higher risks and when the economy slows down, players behave in a pessimistic way, which reinforces risk-averse behavior and lowers investment [36].

The adjustment of the 'Market sentiment' factor is negatively affected by projects under construction. Under-construction projects are usually contracted before construction begins, which means that a part of future demand is already met and that the plants planned today would face strong competition to market their production. If these plants ever enter the market, they would face low industry profits and capacity utilization. 'Market sentiment' is modeled using a factor that comprises the short-term dynamics of the market: current profits and capacity under construction.

The current profitability of the market is represented by a profitability factor ($F_{R,t}$), which is related with the profits ($R_{R,t}$) of year *t* and a reference profitability (R_0) as indicated in the following equation

$$F_{R,t} = \frac{R_{R,t} - R_0}{Max\left(R_0, R_{R,t}\right)} \qquad (4)$$

where $R_{R,t}$ is the net margin, α is the taxes level (average 35% [37]) that firms pay over their operational utilities, and $R_{N,t}$ is the operating margin.

$$R_{R,t} = R_{N,t}(1-\alpha)\text{, Si } R_{N,t} \geq 0 \qquad (5)$$
$$R_{R,t} = R_{N,t} \text{ in other case}$$

$R_{N,t}$ is the average operating margin of market, defined as follows:

$$R_{N,t} = \frac{I_t - TC_t}{I_t}\text{, if } I_t > 0 \qquad (6)$$
$$R_{N,t} = M \text{ , where } M \longrightarrow \infty \text{ , if } I_t = 0$$

Revenues are given by

$$R_t = P_t \times S_t \qquad (7)$$

P_t and S_t are price and supply of LNG, respectively. Firms produce until unit costs (C_t) equal price (P_t), and there are no surpluses in the market. Total costs (TC_t) are defined as

$$TC_t = \int_0^{Q_t} C_{O,t} dS_t + \int_0^{X_t} C_K dIC_t \qquad (8)$$

C_K is a fixed value that represents the levelized capital cost per unit. Capital costs (K) are the equivalent costs of building a 1 mmtpy capacity plant. Unit capital costs (C_K) are charged for n years to each LNG unit produced at the liquefaction plant, such that the initial investment is recovered with a discount rate i. n is the life time of plant and C_K is calculated using present value with annuities.

$$K = C_K \frac{1-(1+i)^{-n}}{i} \qquad (9)$$

Operational costs (C_O) include exploration, extraction, production, liquefaction, transportation and regasification costs. Only liquefaction costs are taken as variable and other mentioned costs are considered as fixed and are taken as the average costs presented in [3]. To represent short-run capacity constraints, an asymptotic function for LNG marginal liquefaction costs (C_L) is proposed:

$$C_{L,t} = \frac{a}{\left(g \times UO_t - S_t\right)^{1/2}} \qquad (10)$$

Where g is the average capacity availability (90%). The costs in t for the marginal producer are C_t; total supply S is such that C_t equals price, P_t. Then,

$$C_t\left(S_t\right) = P_t \qquad (11)$$

To model the likely increase of competition after under construction projects are completed, $F_{C,t}$ is limited by contractors' availability, represented by a maximum number of projects under construction, K_{Max}, and the current number of projects under construction.

$$F_{C,t} = 1 + \frac{UC_t - K_{Max,t}}{Max\left(UC_t, K_{Max,t}\right)} \qquad (12)$$

K_{Max} increases in time, as a result of technological progress and economic growth:

$$K_{Max,t} = b_0 + b_1\left(t - t_0\right) \qquad (13)$$

b_0 is the maximum capacity under construction at simulation start, $b_1$is the growth rate of EPC capacity, t is the current simulation time and t_0 is start time of simulation.

The profit factor described in (4) has a positive effect on investments, while the construction factor (12) has a negative effect. The total effect of expected profits and capacity addition is denoted $F_{E,t}$ and calculated as the weighted sum of both factors:

$$F_{E,t} = a_0 \times F_{R,t} - a_1 \times F_{C,t} \qquad (14)$$

Where a_0 and a_1 are the weights for each factor. The adjusted investment factor $F_{A,t}$ represents the non-linear relationship between investors' mood and their expectations. An S-shaped curve is used to make the adjustment of projects assuming that investors are not perfectly rational. Instead, they are driven by their expectations on the short-term dynamics. For instance, when profits are higher than reference profits, people are encouraged to invest more than they should, but if profits are lower than reference profits, people diminish their investments in an excessive way. A logistic function is used to represent the short-term adjustment ($F_{A,t}$), i.e. response provided to those expectations, which equation is as follows:

$$F_{A,t}\left(F_{E,t}\right) = \frac{u}{1 + he^{-mF_{E,t}}} \qquad (15)$$

Where u is a carrying capacity, h is a real number and m is the function growth rate. The parameter m is linked to the sensitivity of investors to industry changes. The higher the value of m, the stronger the effect of expectations on investment adjustment is. After adjusting for expectations, the investment in capacity is:

$$I_t = KN_t * F_{A,t} \qquad (16)$$

We use a forecast to model LNG price, which is based on netback prices. To account for the increasing effect of gas prices on LNG price, the forecast is a weighted average of expected LNG prices in Japan and the USA. We use oil prices for forecasting Japan's gas prices and a EIA forecast for Henry Hub [38]. The LNG price was calculated as follows:

$$P = P_{Japan} * (1 - r) + P_{USA} * r \qquad (17)$$

Where r is the share of each price, i.e. r represents the link between oil and LNG prices. At the start of simulation $r = 10\%$, and by 2030 it is 30%, then

$$r = 0.1 + 0.2 \frac{t - t_0}{t_f - t_0} \qquad (18)$$

Where t_0 and t_f are star time and stop time of simulation, respectively. Before simulating our problem, it was necessary to calibrate model and estimate some parameters, as is described next.

7. VALIDATION

To ensure the conceptual validity of the model, we perform several of the tests proposed by [39]. The model's equations correctly represent the structure in Figure 2, include all of the feedback cycles in Figure 2 and are dimensionally consistent. In addition, assumptions about the behavior of the industry are supported by the literature reviewed in sections 2 and 3.

Some parameters are not observable and need to be calibrated. In this case, the parameters of the logistic function: u, m and h; the parameter a of the liquefaction production function, and parameters for assessing the maximum possible construction (b_0 and b_1) are calibrated by comparing capacity expected for 2025 according to [40]. Weights of both profitability and construction factors (a_0 and a_1, respectively) are assumed to be equal. Section 10 shows the estimation of LNG prices using historical data. The whole simulation is run in Powersim Studio 8 from 2012 to 2030 with a timestep of 90 da, using data presented in *Table 2*.

Table 2. *Model parameters.*

Calibrated parameters	
A	0,7
U	6,0
M	5,0
H	5,0
b_0	100,0
b_1	2,0
Assumed data	
Initial capacity under construction	77 mmtpy [41], [42]
Initial capacity under operation	278,8 mmtpy [41], [42]
Time to adjust	1 yr
Construction time	4 yr

Planning time	2 yr
Life time	40 yr
Train size	5 mmtpy
Reference profitability	8% [43]
Capital costs	$400.000.000/mmtpy [44]
Unit capital cost	$1,19/MMBTU
Exploration-Production cost	$0,75/MMBTU [3]
Shipping cost	$0,7/MMBTU [3]
Regasification-Storage cost	$0,4/MMBTU [3]
Discount rate	14,43% [43]
Growth rate (for future demand)	4,3% [35]
Taxes	35% [37]
Weight of profitability factor (a_0)	0,5
Weight of construction factor (a_1)	0,5

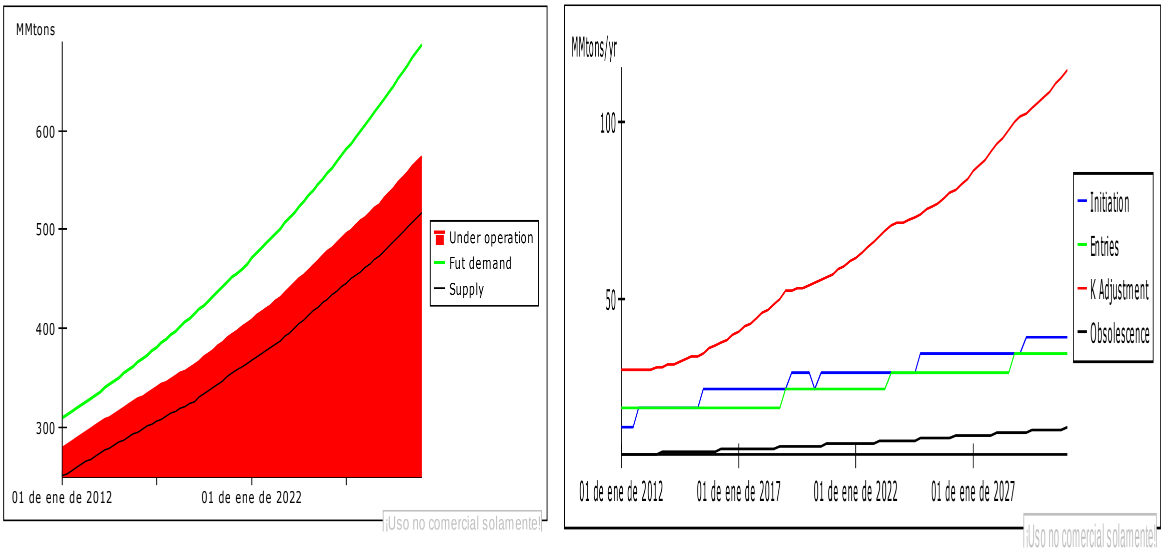
8. RESULTS AND SENSITIVITY ANALYSIS

In the following sections, we investigate the effect of changing oil and gas prices, and of risk attitudes on investment in liquefaction. First, we run the model for a base scenario that represents a world with high gas and oil prices. We use this base scenario to test whether risk attitudes contribute to create capacity cycles. Then, we run the model for the low and high oil price scenarios of EIA [45]. Considering that oil price is highly volatile, we model oil price as a random variable and test the effect of oil price volatility on LNG investment.

8.1. Base scenario

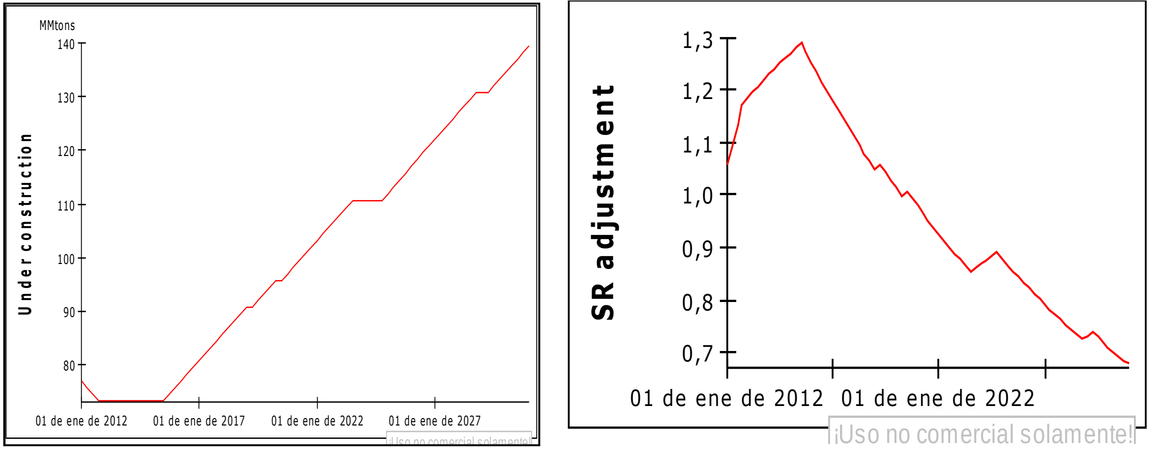
Using calibrated parameters, we simulate future liquefaction capacity from 2011 to 2030. By 2011, capacity under construction was 77 mmtpy and capacity under operation, 278,8 mmtpy [41], [42]. As shown in Figure 3(a), simulated liquefaction capacity increases rapidly between 2011 (279 mmtpy) and 2030 (574 mmtpy), but there is always a gap of demand that needs to be covered by new capacity assumed to enter in 6 years. This could be explained if suppliers seeking to meet future demand observed the demand-and supply gap before investing. In this scenario, supply increases as a result of capacity growth. Given that oil prices in the reference scenario are high (above USD8,4/MMbtu) with an increasing trend during the whole simulation, LNG producers use all of their available capacity (90%).

Capacity growth is non-linear, as illustrated by Figure 3(b): capacity needed (KN_t). The small peaks in capacity needed are caused by the discrete nature of capacity expansion (min. 5 mmtpy) and by the realization that projects initiated in previous years are either larger than the supply/demand gap or not enough to fill it. For instance, during the first 7 years of simulation, 20 mmtpy of capacity start operation. In those years, the gap increases rapidly to reach a peak by 2018. As projects under construction accumulate and the need of the market increase, the capacity that starts operation in 2019 is 25 mmtpy. Then, for that year, the gap slightly flattens (54 mmton). A similar situation is observed in 2023 and 2028.



(a) *Capacity (red) grows over time due to growth in future expected demand (green). Supply (black) grows as a result of capacity increase*

(b) *Capacity needed (red), projects that enter to planning stage (blue), projects that start operation (green) and obsolescence (black)*



(c) *Capacity under construction*

(d) *Short-term adjustment of capacity needed. When SR Adjustment is 1, initiated projects are the same as capacity needed to meet future demand.*

Figure 3. *Simulation results*

Simulated price varies between USD 8,40/MMBTU and USD 12,03/MMBTU. As discussed before, reference price is an average of Henry Hub price and Japan’s LNG price. Although gas price in the USA is expected to decrease, oil price is expected to continue increasing, and as a result, we expect the reference LNG price to increase.

High prices translate into high profits, and profitability is always higher than reference profitability (8%). Short-term adjustment (‘market sentiment’) follows prices behavior but it is also influenced by projects under construction (see Figure 3(c)). Projects under construction discourage investment because it is supposed to increase competition within the market in the near future, which would lower profits. Although one of the main assumptions of model is that investors behave as *believers* [28], investors also perceive (potential) market saturation.

“Market sentiment” (Figure 3(d)) is adjusted throughout the simulation. The largest adjustments occur in 2014, just a year after the stock of projects under construction is at its lowest level (73 mmtpy). As Figure 3(b) shows, the short run adjustment is larger than 1 until 2019, which means that the industry invests in more capacity than it is needed to meet future demand. After 2019, the stock of projects initiated is in such a level that willingness to invest decreases (adjustment lower than 1). Indeed, the decreasing trend of short-term adjustment after 2019 is tightly related to the increasing trend of projects

The shape of capacity under construction (Figure 3(c)) is consistent with the short run adjustment reflected in (Figure 3(d)).Although capacity under construction remains almost constant around 110 mmtpy from 2022 to 2025, adjustment keeps decreasing because of the monotonic increasing trend of projects under construction. Those keep growing since 2019 because prices and revenues grow offset the marginal cost increase. Before 2019, projects under construction decrease until 2014 because needs were covered by the initial stock of projects under construction, i.e. projects that started to be built before 2011 and are part of the model’s initial conditions. Between 2014 and 2015 under construction projects remain stable because potential investors perceive that the capacity needed is not enough to encourage their investments. In this case, it does not matter how many projects are entering simultaneously because the industry is expecting strong future demand and high prices.

8.2. Adjustment mechanisms and overinvestment

As mentioned before, this paper aims to gain understanding about how investors decide the timing and magnitude of their capacity expansions. In the model we propose, investments are adjusted according to expectations. Investors form their expectations using the information from the market, specifically current profits and likely saturation of the market in the future. Investors weigh both factors and decide whether to increase or not their investments. The relative weight assigned to current profits and saturation represents investors’ attitudes towards risk and their perceptions of the market. Some investors are be optimistic about prices while others make conservative price assessments.

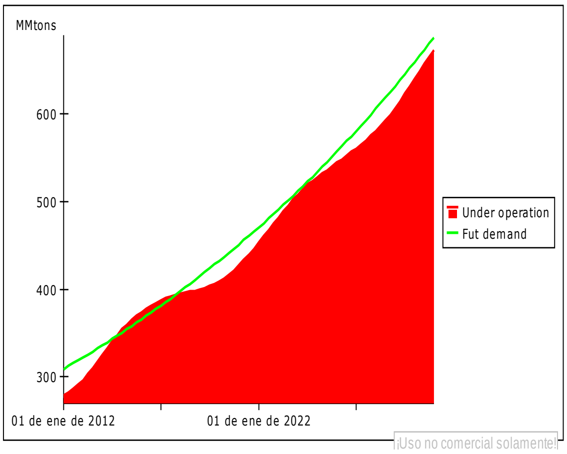
When investors are assumed to be totally myopic regarding the units that are being built and to trust entirely in market prices, investments are driven by profits only. This would be the case of investors being extremely optimistic concerning the state of the market. Indeed, they believe that the entire capacity (even if it is large) would find enough buyers to secure its economic feasibility.

Simulation shows that when adjustment depends on the profit factor only, capacity cycles are possible. As Figure 4(a) shows, if investors assign a weight of 1 to profits, capacity under operation grows with a cyclical trend. As in the previous scenario, capacity that was started to be built before 2011 enters between 2014 and 2016 (see Figure 3(a)). Installed capacity, however, is larger than the demand expected within six years because investors do not take into account future profit expectations. Firms also continue investing because prices are high. By 2014 there is no perceived need of capacity, but previous investments are completed and new capacity keeps entering to the market. However, while this happens, the stock of projects under construction decreases (see Figure 4(b)), which leads to fewer capacity units entering to operation in the forthcoming years, resulting in new increases of the supply/demand gap.

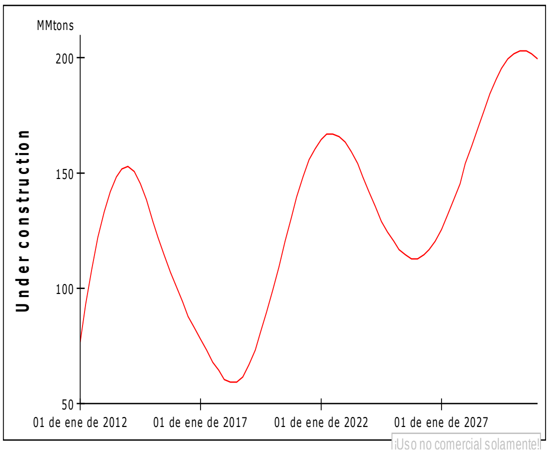
The lack of immediate responses from investors and the long delays of the industry, lead to accumulation or withdrawal of projects under construction for later periods. Although by 2023 the difference between future expected demand and current capacity becomes tighter than in the other years, it is still positive. In this case, capacity does not overpass the future demand, which is explained by the behavior of the entry of projects (see Figure 4(c)). The amplitude of cycles in this variable seems to decrease as simulation advances. This is more evident in the capacity under construction in Figure 4 (b), which shows an increasing trend with cycles. This happens because investors continue adjusting their investment even when prices are high.

As it was explained in Section 3, cycles have been studied in electricity systems [27], [28], [29], [46], and other industries such as oil tankers [31]. According to Green [47], in the electricity industry, insufficient coordination causes investors to overreact to high price signals, ignoring the actions of other players. This increases the margin between capacity and demand and lowers prices. Prices begin to rise again when capacity is retired or demand increases, which lowers the capacity/demand margin. On the other hand, the mechanism proposed by [31] to explain the periods of under capacity and overcapacity of oil fleet tankers is the 'market sentiment', which is related to expectations of short run profits.

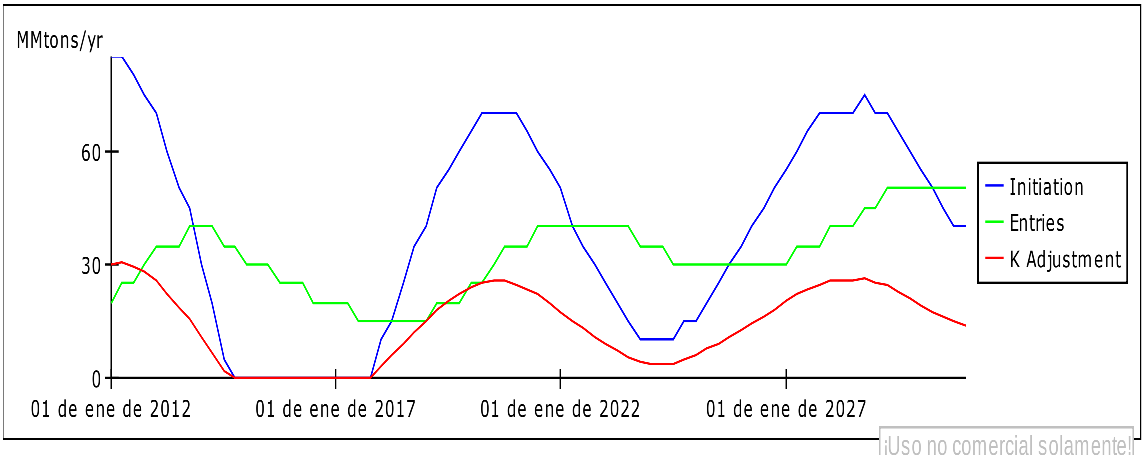
The model we present includes similar mechanisms: investors assess future capacity needs and adjust their investment according to their short run expectations on profits (price signals). However, the low number of LNG producers and the magnitude of investments make coordination easier than in electricity industries, and we model this by adding a long-run adjustment based on the number of projects under construction. In the model we present, investors are able to foresee future competition and to adjust their decision accordingly. Cycles observed in Figure 4(a-d) result from using only a short-run mechanism for adjusting investment. As the actual behavior of the industry is closer to what is observed in Figure 3, one can conclude that investors on liquefaction of natural adjust their behavior according to their perception of future market saturation.



(a) Capacity under operation (red) surpasses forecast of future demand (green)



(b) Fluctuations of capacity under construction



¡Uso no comercial solamente!

(c) *Investment adjustment induce cyclicality to projects that enter to planning stage (blue), which in turn induces cycles to Capacity needed (red). Cycles induce booms and busts in, projects that start operation (green).*

Figure 4.*Simulation results assuming investor only take into account the current profits of the industry when adjusting their investments.*

As it is important to ensure the robustness of the model and to make it trustable, several validation tests were applied to the model. Tests correspond to those presented by Sterman [39] and seek to validate model's structure and behavior separately. The behavior of the model when its boundaries and structure were tested was consistent, and results were correct when extreme conditions were applied to the model. In addition, the model does not present significant changes when time step and integration method are varied.

Nonetheless, we will perform a further sensitivity tests to assess the robustness of the model. We will test calibrated parameters (*u*, *h*, *m*, *a*, *b0* and *b1*) and other assumptions such as weights of the expectation factor, costs, life time of capacity (for obsolescence), reference profitability and growth rate (for future demand), using the Risk Assessment Tool from Powersim Studio 8.

8.3. Extreme price scenarios

The price for the base scenario is a weighted average of USA (Henry Hub) and Japan price, which is indexed to oil prices. Considering that oil price is volatile and depends on several exogenous variables such as geopolitical issues and economic growth, we calculate Japan LNG prices for high and low oil-price scenarios given by [38] as *Figure 5* shows.

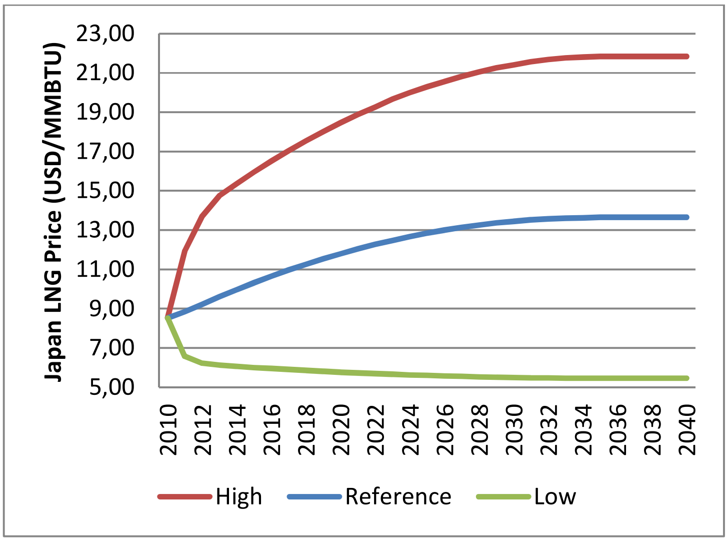


Figure 5. *Japan LNG prices forecast under three scenarios for oil prices.*

Figure 6 shows that capacity built in the high oil-price scenario is similar to the capacity built in the reference scenario. Although there is little difference between both scenarios, capacity grows more rapidly in the high price scenario than in the low price scenario. While capacity in the reference and high scenarios surpasses 570 mmtpy in 2030, in the low scenario it is about 555 mmtpy by then. The model seems to be more sensitive to low prices than high prices.

In the reference scenario high oil prices keep LNG prices high, LNG costs are recovered and total LNG supply grows.LNG supplies decrease under a low oil price scenario and because of low LNG prices industry profits and incentives for entering decrease too. Prices for both the reference (base) and high-price scenarios, lead to similar supplies. The S-shaped curve smooths the adjustment of new projects when profitability is very high. Even when a market is growing rapidly, investments are not proportional to market profitability because firms know that excess of investment can create a bubble that would eventually burst. Also, if there is no gap to meet, firms do not invest in new capacity as the follow future demand expectations.

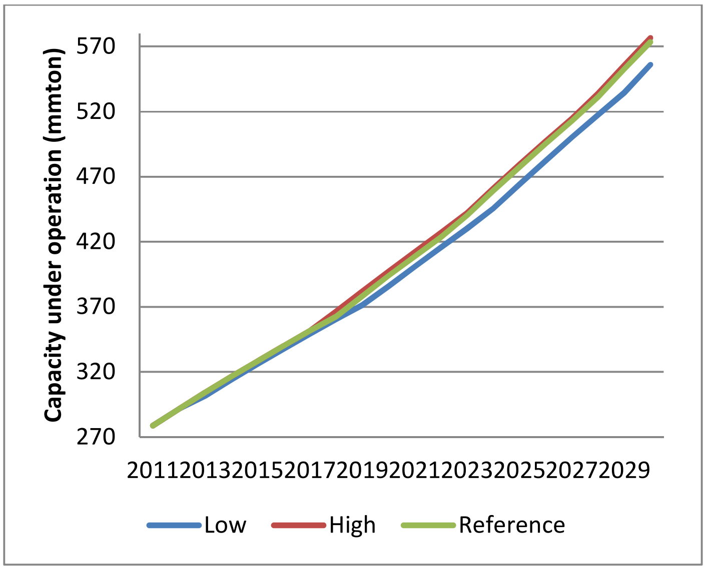


Figure 6. *Simulation results: Capacity under operation under three oil prices scenarios.*

9. CONCLUDING REMARKS

Capacity additions in the LNG industry are larger and less frequent than in other industries. The result is a complex decision making process in which it is necessary to understand the dynamic of capacity expansion, especially in the liquefaction segment. The model we propose is a first approach to explain how the investments are made and what factors encourage or discourage them.

The results validate our hypothesis that investors assess capacity needs depending on future expected demand and the current projects under operation. Then, the "market sentiment" amplifies or reduces the amount of projects needed before they begin to be built. 'Market sentiment' is increased by profitability and is decreased by projects under construction as investors would find stronger competition for allocate its supply, leading to lower profits because of low prices or low capacity utilization.

Results suggest that capacity cycles appear (even when there are no price cycles) when investor base their decision on market profitability only. Cycles result from the myopic view of investors, who try to meet future demand without taking into account delays and accumulation of projects under construction that arises from them. As long as the gap between the future expected demand and current capacity decreases, firms decrease their investment but projects keep entering to the market as they correspond to previous commitments. This result, however, contradicts the evidence of LNG industry in which historical data show no presence of cycles, suggesting that LNG investors are moderate. Indeed, actual behavior is more consistent with investors balancing their price expectations with their expectations regarding the possible saturation of the market in the near future.

Although results are consistent with our dynamic hypothesis, it is necessary to make further assessment tests and to calibrate functions regarding the investors' behavior. Further work should include expansion in LNG shipping and the presence of substitutes. Also, it is necessary to study if this model could fit other capital intensive industries such as petrochemical, pulp and paper, agriculture chemicals and steel.

10. APPENDIX

As it was explained, we assessed LNG price using a combination of USA and Japan LNG import prices. As there was not forecast for both prices, we used Henry Hub and oil price forecast for estimating them. Hence, following regressions were done: Henry Hub vs. Price of US LNG imports and Oil price vs. Japan LNG cif.

Data from Japan LNG import price belongs to 1984-2010 term and was taken from BP [48]. Other data was taken from [38]. In the case of US data, regression was made with data from 1989 to 2010. All data is annual and was transformed to 2010 USD using CPI from USA and Japan [49], as it corresponds. We supposed a linear regression as follows.

$$P_{LNG} = \beta + \alpha * P_{substitute} \qquad (19)$$

Where $P_{substitute}$ is the oil price for Japan regression and the Henry Hub price for USA regression and α, β are estimation parameters. Results and validation are presented in *Table 3*.

Table 3. *Regressions' parameters for USA and Japan prices of LNG imports.*

	Param.	Estimate	Pr*	R^2
Japan	β	0,63477	0,087	0,8879
	α	0,10737	2,20e-13	
USA	β	1.03853	0.00264	0,9137
	α	0.86141	4.19e-12	

*Pr is P-value of a null hypothesis. In this case, null hypothesis refers whether *parameter= 0*and Pr's lower than 0,05 means *parameter≠0*with a 95% confidence.

11. REFERENCES

[1] J. K. Thomas, "Is lumpy investment relevant for the business cycle?," Federal Reserve Bank of Minneapolis, Staff Report 302, 2002.

[2] S. Rüster and A. Neumann, "Corporate Strategies along the LNG Value Added Chain - An Empirical Analysis of the Determinants of Vertical Integration." Globalization of Natural Gas Markets Working Papers, 2006.

[3] S. Engelen and W. Dullaert, "Designing a decision support model for the LNG market," *Transportation Planning and Technology*, vol. 33, no. 8, pp. 719–731, 2010.

[4] P. A. J. Berends and A. G. L. Romme, "Cyclicality of capital-intensive industries: a system dynamics simulation study of the paper industry," *Omega*, no. 29, pp. 543–552, 2001.

[5] D. Besanko, U. Doraszelski, L. X. Lu, and M. Satterthwaite, "Lumpy Capacity Investment and Disinvestment Dynamics," *Operations Research*, vol. 58, no. 4-Part-2, pp. 1178–1193, Jul. 2010.

[6] T. Kadoya, T. Sasaki, S. Ihara, E. Larose, M. Sanford, A. K. Graham, C. A. Stephens, and C. K. Eubanks, "Utilizing System Dynamics Modeling to Examine Impact of Deregulation on Generation Capacity Growth," *Proceedings of the IEEE*, vol. 93, no. 11, pp. 2060–2069, 2005.

[7] S. Ruester and A. Neumann, "Linking alternative theories of the firm – a first empirical application to the liquefied natural gas industry," *Journal of Institutional Economics*, vol. 5, no. 01, pp. 47–64, 2009.

[8] S. Engelen and W. Dullaert, "Transformations in gas shipping: Market structure and efficiency," *Maritime Economics and Logistics*, vol. 12, no. 3, pp. 295–325, 2010.

[9] J. T. Jensen, "The LNG Revolution," *The Energy Journal*, vol. 24, no. 2, Apr. 2003.

[10] M. Greaker and E. Lund Sagen, "Explaining experience curves for new energy technologies: A case study of liquefied natural gas," *Energy Economics*, vol. 30, no. 6, pp. 2899–2911, 2008.

[11] T. Phalen and J. Scotti, "Update on LNG Facility Construction," in *Offshore Technology Conference*, 2008.

[12] BP, "Statistical Review of World Energy 2012 | BP," 2012.

[13] M. Dailami and R. Hauswald, "Risk shifting and long-term contracts : evidence from the Ras Gas Project," The World Bank, Policy Research Working Paper Series 2469, 2000.

[14] S. Cornot-Gandolphe, “LNG cost reductions and flexibility in LNG trade add to security of gas supply,” *ENERGY PRICES & TAXES*, vol. 2005, no. 1, pp. 29–36, 2005.

[15] Oil & Gas Journal, “Worldwide Construction Update,” *Oil & Gas Journal*, Various issues.

[16] C. Driver, “Capacity utilisation and excess capacity: Theory, evidence, and policy,” *Review of Industrial Organization*, vol. 16, no. 1, pp. 69–87, 2000.

[17] G. Pasaoglu Kilanc and I. Or, “A decision support tool for the analysis of pricing, investment and regulatory processes in a decentralized electricity market,” *Energy Policy*, vol. 36, no. 8, pp. 3026–3034, 2008.

[18] K. G. Gkonis and H. N. Psaraftis, “Investment rules and competition patterns in LNG shipping. A game theory approach,” Laboratory for Maritime Transport, School of Naval Architecture and Marine Engineering, National Technical University of Athens, 2007.

[19] J. A. Van Mieghem, “Capacity Management, Investment, and Hedging: Review and Recent Developments,” *Manufacturing and Service Operations Management*, vol. 5, no. 4, pp. 269–302, 2003.

[20] J. Huang and Y. Lan, “Research on vertical integration under overcapacity,” in *IE and EM 2009 - Proceedings 2009 IEEE 16th International Conference on Industrial Engineering and Engineering Management*, 2009, pp. 491–495.

[21] A. Dixit, “The Role of Investment in Entry-Deterrence,” *Economic Journal*, vol. 90, no. 357, pp. 95–106, 1980.

[22] C. F. Mason and C. Nowell, “Entry, Collusion, and Capacity Constraints,” *Southern Economic Journal*, vol. 58, no. 4, pp. pp. 1002–1014, 1992.

[23] S. Dorigoni, C. Graziano, and F. Pontoni, “Can LNG increase competitiveness in the natural gas market?,” *Energy Policy*, vol. 38, no. 12, pp. 7653 – 7664, 2010.

[24] S. Rajagopalan and J. M. Swaminathan, “A coordinated production planning model with capacity expansion and inventory management,” *Management Science*, vol. 47, no. 11, pp. 1562–1580, 2001.

[25] S. M. Ryan, “Capacity expansion for random exponential demand growth with lead times,” *Management Science*, vol. 50, no. 6, pp. 740–748, 2004.

[26] J. Henderson and K. Cool, “Corporate governance, investment bandwagons and overcapacity: An analysis of the worldwide petrochemical industry, 1975-95,” *Strategic Management Journal*, vol. 24, no. 4, pp. 349–373, 2003.

[27] A. Ford, “Cycles in competitive electricity markets: A simulation study of the western United States,” *Energy Policy*, vol. 27, no. 11, pp. 637–658, 1999.

[28] A. Ford, “Waiting for the boom: : a simulation study of power plant construction in California,” *Energy Policy*, vol. 29, no. 11, pp. 847–869, 2001.

[29] D. W. Bunn and E. R. Larsen, “Sensitivity of reserve margin to factors influencing investment behaviour in the electricity market of England and Wales,” *Energy Policy*, vol. 20, no. 5, pp. 420–429, 1992.

[30] M. Liehr, A. Größler, M. Klein, and P. M. Milling, “Cycles in the sky: understanding and managing business cycles in the airline market,” *System Dynamics Review*, vol. 17, no. 4, pp. 311–332, 2001.

[31] J. Randers and U. Goluke, “Forescasting turning points in shipping freight rates: Lessons from 30 years of pratical effort,” *System Dynamics Review*, vol. 23, no. 2–3, pp. 253–284, 2007.

[32] A. J. Taylor, “System Dynamics in Shipping,” *Operational research quarterly*, vol. 27, no. 1, pp. 41–56, 1976.

[33] Reuters, “Gas liquefaction terminal projects,” 2007. [Online]. Available: http://uk.reuters.com/article/2007/09/24/lng-liquefaction-idUKL2886631920070924. [Accessed: 30-May-2011].

[34] H. Kotzot, C. Durr, D. Coyle, and C. Caswell, “LNG Liquefaction - Not All Plants Are Created Equal.” .

[35] BP, “Energy Outlook 2030 | BP,” 2013.

[36] A. V. Banerjee, “A Simple Model of Herd Behavior,” *Quarterly Journal of Economics*, vol. 107, no. 3, pp. 797–817, 1992.

[37] Y. Olaya, “World liquefied natural gas (LNG) trade model,” PhD. Thesis, Colorado School of Mines, Colorado, 2006.

[38] EIA, “U.S. Energy Information Administration.” [Online]. Available: http://www.eia.gov/. [Accessed: 13-Mar-2012].

[39] J. D. Sterman, “Business Dynamics: Systems Thinking and Modeling for a Complex World,” 2000.

[40] Poyry, “Global Gas & LNG Markets & GB’s Security of Supply.” 2010.

[41] International Energy Agency, “Are we entering a golden age of gas?” 2011.

[42] I. G. U. IGU, “World LNG Report 2011,” Jun. 2012.

[43] Yahoo! Finance, “Business Finance, Stock Market, Quotes, News.” [Online]. Available: http://finance.yahoo.com/. [Accessed: 24-Oct-2011].

[44] S. Rüster and A. Neumann, “Economics of the LNG Value Chain and Corporate Strategies - An Empirical Analysis of the Determinants of Vertical Integration,” in *10th Annual ISNIE Conference*, 2006.

[45] EIA, “International Energy Outlook 2011.” 2011.

[46] S. Arango and E. Larsen, “Cycles in deregulated electricity markets: Empirical evidence from two decades,” *Energy Policy*, vol. 39, no. 5, pp. 2457–2466, 2011.

[47] R. Green, “Investment and generation capacity,” in in *Competitive Electricity Markets and Sustainability*, F. Lévêque, Ed. Edward Elgar Publishing, 2007.

[48] BP, “Statistical Review of World Energy 2011 | BP,” 2011.

[49] RI, “Consumer Price Index (CPI).” [Online]. Available: http://www.rateinflation.com/consumer-price-index/. [Accessed: 13-Mar-2012].