Early Commitment and Entry Deterrence in an LNG Shipping Market

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Abstract

The LNG (Liquefied Natural Gas) trade is one of the most promising sectors in energy shipping. An important characteristic of the LNG shipping market is its oligopolistic structure. The market actors make their decisions independently, yet knowing that these decisions are likely to influence the strategic positioning of the other players. This context is appropriate for the adoption of a (non-cooperative) game theoretic analysis framework to support decision-making. Two topics of strategic decision-making in LNG shipping are investigated in this paper, namely Early Commitment and Entry Deterrence.

Early Commitment has to do with the rationale that may justify an early strategic investment commitment (it may also be encountered as "pre-commitment"). In an LNG shipping market such a pre-commitment could be an order of (uncommitted) LNG vessels to be launched in the market in a future point in time.

Entry Deterrence is a strategic interaction between a monopolist LNG shipowner in a specific market (the incumbent) and a potential entrant or entrants in that market. The entrants offer identical or close substitute products (services), i.e. the LNG cargoes shipping service. If they enter the market, then the incumbent's profits are reduced, so the incumbent - monopolist tries to prevent other firms from entering the market. First, a traditional approach to such a strategic interaction is discussed and it is explained why it is unsatisfactory. Then, it is presented how game theory provides a more sophisticated treatment of the subject, and the previously developed early commitment concepts are also utilized for this purpose.

Keywords

LNG Shipping, Strategic Decision-Making, Game Theory, Early Commitment, Entry Deterrence

1. Introduction – the LNG Market and its Dynamics

The Liquefied Natural Gas (LNG) trade is without doubt one of the most interesting areas in energy shipping, which dominates the world bulk maritime transport. Its recent dynamics have attracted companies and investors who are only now discovering its special characteristics.

Meeting the world's energy demands is one of the greatest challenges for the 21st century and, in many respects, natural gas is considered as the successor of oil. While for many decades natural gas markets were localized and isolated, the LNG trade (that is the transport of natural gas by sea) has contributed to the development of a global competitive market (Foss, 2005) which presents similarities to the oil market, yet many differences as well.

A gap exists in the literature regarding the analysis of the newly developed LNG market. Methodologies applicable to other shipping markets fail to support decision-making in the LNG shipping business, because of its distinctive idiosyncrasies. The LNG shipping market context is appropriate for the adoption of a (non-cooperative[1]) game theoretic analysis framework. What is important is to anticipate the reactions of competitors, as these may have a direct impact on the value of the firm. Taking into account the responses of other players in the business game and their positive or negative effects on a firm's value can greatly benefit strategic decision-making.

Game theory reduces complex strategic problems into simple analytical structures. Then it assigns values to strategic decisions and finds equilibrium strategies using solution techniques that help in understanding or predicting how competitors will behave. Game theory is an established field in economics[2]. It has been extensively

[1] The players are unable to enter into binding and enforceable agreements. In *cooperative* game theory such agreements are possible.

[2] In 1994, the Nobel Prize in Economic Sciences was awarded to J. Harsanyi, J. Nash, and R. Selten for their pioneering analysis of equilibriums in the theory of non-cooperative games. In 2001, it was awarded to G. Akerlof, M. Spence and J. Stiglitz for their work in the field of "information economics", which has significantly built upon game theory. In 2005, it was awarded again for contributions to game theory and specifically to T. Schelling and R. Aumann for their analyses of conflict and cooperation. Finally, in 2007 the same

used for competition analysis in oligopolistic markets among other topics. Game theoretic approaches to the analysis of competition patterns in energy shipping (and relevant markets) and to investment decision-making in the transportation of natural gas can be found in the literature. Yet, similar analyses for the LNG market do not exist.

This section (section 1) introduces the reader to the developments taking place in the LNG market and its dynamics (based on Gkonis & Psaraftis, 2007b &c). The paper focuses on early commitment and entry deterrence in an LNG shipping market, which are covered in sections 2 and 3 respectively. Section 4 concludes this paper.

1.1 Basic information

Natural gas (NG) is a fossil fuel consisting mainly of methane. As a primary energy source, it has been increasing its share in world energy consumption faster than any other source in the recent years (with the exception of coal, mainly because of its use in China) and it now accounts for about 25% of world energy consumption.

Natural gas is traditionally transported from producing to consuming countries through pipelines. An alternative and direct way (without passing through third countries) to transport natural gas is by sea using the LNG technology. Natural gas is liquefied under very low temperatures (-161^{o}C) and, with its volume reduced by about 600 times under atmospheric pressure, is contained in cryogenic tankers. The LNG chain also includes liquefaction plants located nearby the exporting ports, and regasification units located at the import terminals. A system of pipelines is of course required to transport natural gas to and from the latter (see also Fig. 1a).

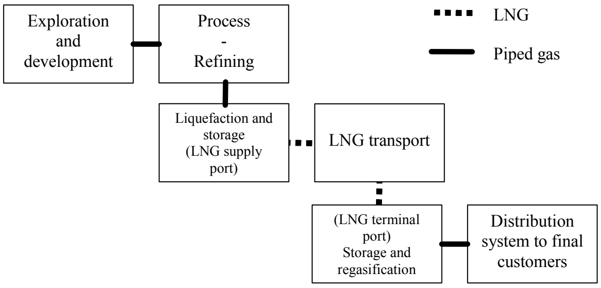

Fig. 1a: Schematic LNG chain

The largest reserves of natural gas are found in Russia, Iran and Qatar. The biggest producers are Russia, USA and Canada, followed by Iran, Norway, and Algeria. The biggest consumers of natural gas are USA and Russia.

Two large LNG markets can be distinguished, namely the Asia-Pacific and the Atlantic Basin ones (see Fig. 1b). In the former, predominantly Japan and South Korea (the world's greatest importers of LNG) are supplied with LNG mainly from Indonesia, Malaysia, and Australia. In the Atlantic Basin market, USA and Europe import LNG mainly from Africa (Algeria, Nigeria, Egypt), and Trinidad & Tobago (BP, 2007). The Middle East acts a swing supplier to both the above markets.

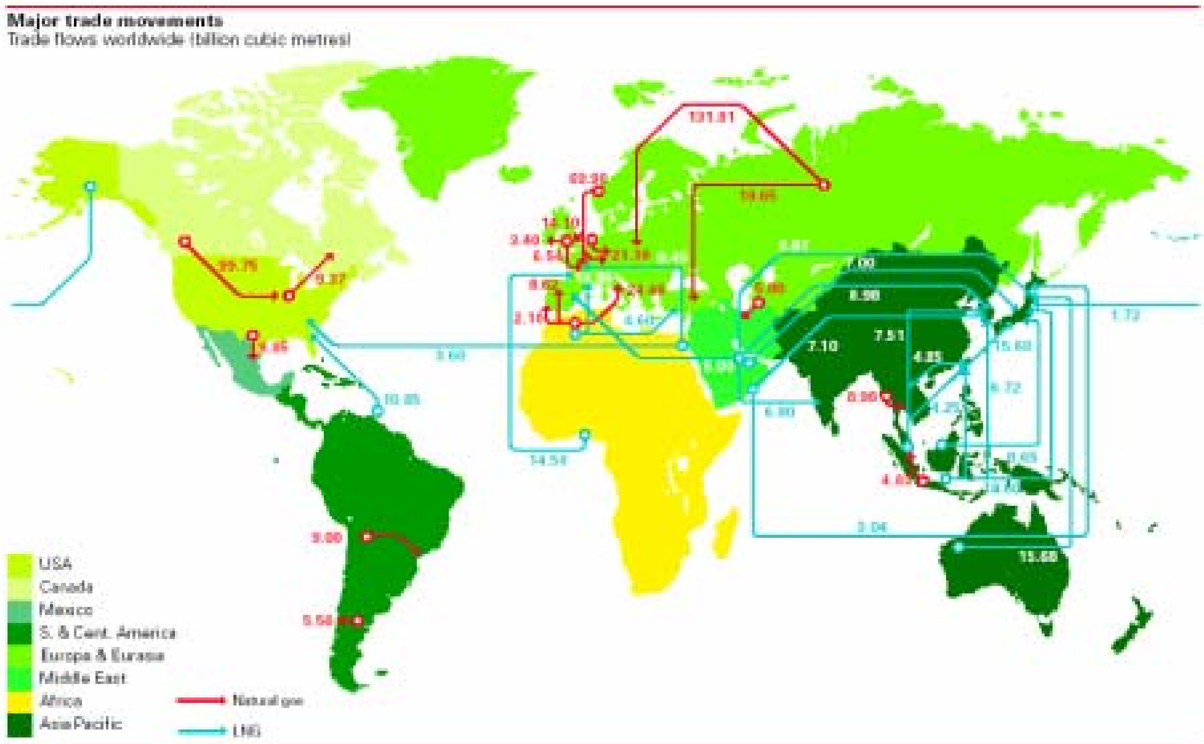

Fig. 1b: Global LNG– natural gas trade (source: BP, 2007)

prize was awarded to L. Hurwicz, E. Maskin, and R. Myerson for having laid the foundations of mechanism design theory based on game theory.

1.2 Motives for the development of the LNG trade

The reduction in the volume of natural gas by 600 times, when liquefied, allows its transport as LNG on economically competitive terms compared to pipelines. Especially for transport over long distances (above around 3,000 miles – Jensen, 2004), LNG is the advantageous option. Moreover, LNG allows the trade among areas which otherwise would be technically or politically impossible to connect (IELE, 2003).

In its first stages, the LNG trade was taking place in specific routes where the ships were dedicated under long-term contracts. These attributes started changing in the end of 1990s.

The development of the international LNG trade was favoured by the turn to natural gas for electricity production, in order to meet the ever growing demand across developed and developing countries. Natural gas powered stations present economic advantages, are faster to build and are more environmentally friendly, when compared to electricity production from other fossil fuels. Moreover, natural gas can be burned directly as a fuel in the industrial and the household sectors with very high efficiency and minimal losses.

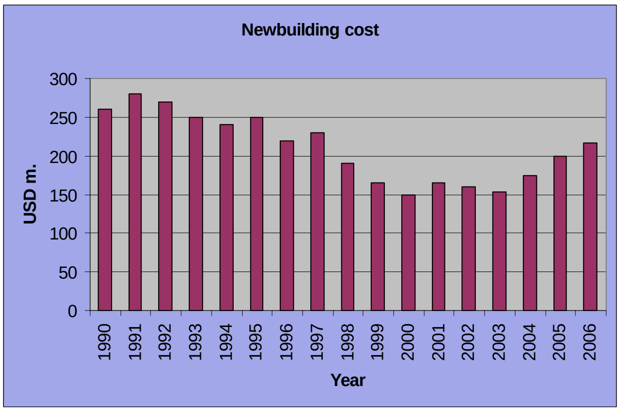

Fig. 2: Typical LNG vessel newbuilding cost (source: Drewry Shipping Consultants data provided in LNG One World, 2007)

Also, significant cost reductions were achieved in all stages of the LNG chain with technological improvements (in Fig. 2, the evolution of the newbuilding cost for a typical LNG vessel is shown). Moreover, the contract terms had to become more elastic, in order to accommodate the need for greater flexibility in meeting the increasing demand. Gradually, a part of the market started to operate on competitive terms and to promise increased returns. Last, but not least, LNG fits well in the security of supply considerations of national energy plans through the diversification of energy supply and sources.

1.3 Characteristics and evolution of the LNG trade

The LNG trade started in the 1960s with a limited number of sailings towards European markets, while soon it moved to the Asia-Pacific area. In these first stages, it consisted of ships dedicated to specific trade routes under long-term contracts. This rigid structure started to break in the late 1990s.

Although most of the LNG trade is still taking place on "inelastic" terms, a growing short-term market currently represents 10% of the total market (PE, 2007a). It is not unusual for cargoes to be diverted from their original destinations to take advantage of arbitrage opportunities, according to market conditions and prices. The natural gas prices (traditionally linked to oil prices) are increasingly indexed to reference gas prices, as gas-to-gas competition develops around the globe.

An LNG carrier is a sophisticated technology ship, with double-hull special design and insulated storage tanks (independent or prismatic type) with metallurgical properties that allow them to withstand very low temperatures. LNG ships are going through many technological developments concerning on-board equipment (e.g. reliquefaction units) and propulsion.

The standard size of an LNG vessel has increased in the last years and it currently corresponds to about 150,000 cu.m. of natural gas (i.e. about 60,000 tonnes of LNG). Its building cost is about USD 225 million. The world fleet counts 233 ships and is experiencing a dramatic growth in the last years; the current orderbook counts 139 ships (SE, 2007a). Fig. 3 shows the dramatic increase in the number of LNG vessels of the world fleet and the proportionally significant and increasing size of the orderbook from 1990 to the end of 2006.

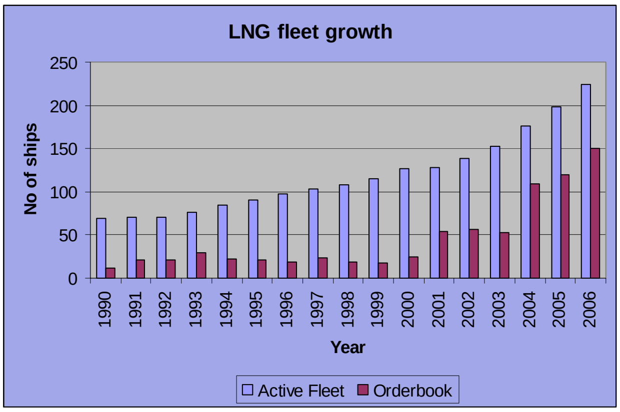

Fig. 3: LNG fleet development (source: adapted from LNG One World, 2007)

1.4 The LNG market prospects

The long-term contracts between suppliers and importers will continue to dominate the international LNG trade, but they will increasingly become more flexible allowing cargoes to be traded in a growing short-term market.

In the traditional market model, the basic players in LNG shipping were integrated energy majors and national companies. The cost reductions and the versatility required by the market, in response to increased demand and new conditions in the international energy scene, opened up the "LNG club" to independent shipowners and other investors. Especially the oil tankers independents showed great interest. The newcomers to the market currently own 10% of the world fleet. Their share is expected to rise as they represent 25% of orders (SE, 2007b), many of which are uncommitted vessels to be launched in the short-term / high-returns market. Although the integrated structures in the LNG trade will remain, the market will further open up to a whole new range of investors and players.

The market projections for an oversupply of LNG shipping capacity in the next years (SE, 2007b) and the recent rebound of investment costs (e.g. see Fig. 2) and operational costs should be considered as parentheses in the growth trend of the LNG trade in the coming decades (as an example see Fig. 4 for a projection of LNG demand in the Atlantic basin – similar growth rates are expected for the Asia-Pacific market). Moreover, technological innovations, e.g. onboard regasification and FSRUs – Floating Storage Regasification Units (PE, 2007b), are expected to give a further boost to the market.

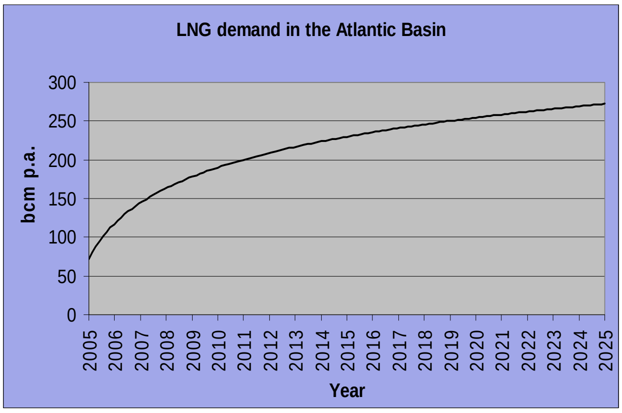

Fig. 4: Atlantic basin LNG demand (in billion cu.m. per annum) (market estimations)

The LNG trade is growing rapidly in the Atlantic Basin market which is likely to overtake the Asia-Pacific market. Large natural gas fields are to be exploited in the Arctic zone by Russia and Norway (LL, 2007). Russia, also with the development of its fields in Siberia, may play in the natural gas market a role similar to that of Saudi Arabia in the oil market (Chevalier, 2004). The Middle East (especially Qatar) will enhance its exporting role to both the Atlantic and Asia-Pacific market (PE, 2007b). Moreover, the energy demand in China and India will create new challenges. Security of supply considerations, through the diversification of sources, will influence the choices for the supply of energy to markets around the globe in the coming future.

In this dynamic environment, the traditional players in energy shipping, the independent oil tanker companies, are trying to fit in. Investments in LNG shipping are capital intensive and relatively few and large players are able to enter and stay in the market. Consequently, the decisions of a market player are likely to influence to a significant degree the position of other players; therefore strategic decision-making is crucial at this stage.

It is expected that competition will increasingly develop especially in the shipping segment of the LNG chain, which however at least in its first phases will have the characteristics of an oligopolistic market. The LNG shipping market context is therefore appropriate for the adoption of a (non-cooperative) game theoretic analysis framework, as it has been argued in Gkonis & Psaraftis (2007a). The following discussion relies on the oligopolistic characteristics of LNG shipping markets.

2. The Strategic Value of Early Commitment in an LNG shipping market

The discussion in this section is based on Smit and Trigeorgis (2004)[1].

2.1 The Value of Early Commitment

The rationale that may justify an early strategic investment commitment (it may also be encountered as "pre-commitment") is discussed next. In the LNG shipping market, such a pre-commitment could be an order of uncommitted LNG vessels (without any contract guaranteeing business for them when they are launched in the market). Indeed, such an order has the characteristics of strategic commitment, because it can substantially influence the supply of shipping capacity in a market (given its oligopolistic structure) and is difficult to reverse without considerable cost[2].

Such an early strategic investment commitment may seem unattractive or totally unacceptable based on its direct cash-flows. However, it may entail substantial strategic value from improving a firm's long-term strategic position.

When considering an early strategic investment commitment, it is crucial to understand the competitive setting of the market and in which way a rival will respond. It is shown in another paper of the authors (Gkonis & Psaraftis, 2007b) that capacity competition in the LNG shipping market implies that an expansion of capacity forces a rival to build less capacity (the possibility that it may even deter entry under some circumstances is discussed in section 3 of this paper).

In general, a competitor's response to a strategic investment decision is likely to depend on the type of competitive reactions (strategic substitutes or complements[3]) and whether the strategic investment is tough or accommodating (i.e. whether it hurts or benefits the competitor).

In a competitive setting with two firms, firm A can make an early (first-stage) capital investment K_A, resulting in subsequent (second-stage) profits of value V_A (V_B for firm B). The second-stage action of firm B (in terms of capacity supply) in response to the first-stage investment K_A of A is $\alpha_B(K_A)$ or $\alpha^*_B(K_A)$ when optimal. V_A depends on both K_A and the optimal actions of both firms. In this case, the impact of the incremental investment dK_A on firm A's value of its subsequent profits (V_A) is:

[1] who refer to Fudenberg and Tirole (1984).

[2] A strategic commitment will be credible, if it is costly to reverse. If it can be reversed at little cost, it will not have much impact and it will hardly change the strategies of the players. In game theoretic terms, the best response curves will not move (see the Appendix for more details).

[3] The difference is explained in the Appendix.

$$\frac{dV_A}{dK_A} = \frac{\partial V_A}{\partial K_A} + \frac{\partial V_A}{\partial a_B}\frac{da_B^*}{dK_A} \tag{1}$$

This expression suggests that:

(commitment effect) = (direct effect) + (strategic effect)

Whether firm A's strategic investment will have a positive result (commitment effect $dV_A / dK_A > 0$) is a function of two components, i.e. the sum of the direct and the strategic effects). The first term on the right-hand side of Eq. 1 captures the direct effect of the incremental investment dK_A on A's own value V_A. The strategic effect (the second term) results from the impact of firm A's strategic investment on firm B's optimal second-stage action ($d\alpha^*_B / dK_A$) and the latter's indirect impact on firm A's profit value.

So, whether firm A should make the early strategic investment (commitment) or not depends not only on its direct effect on its own profit value, but also on the positive or negative indirect strategic effect related to the competitor's reaction, as illustrated below, where the direct effect is negative for the assumed order of uncommitted LNG vessels.

$$\frac{dV_A}{dK_A} = \underbrace{\frac{\partial V_A}{\partial K_A}}_{\text{negative direct effect}} + \underbrace{\frac{\partial V_A}{\partial a_B}\frac{da_B^*}{dK_A}}_{\text{negative / positive strategic effect}}$$

Therefore, an order of LNG shipping capacity, which constitutes by nature an early strategic investment commitment, should be assessed by taking into account the above parameters. It has been recently observed that quite a few shipowners have placed orders for LNG vessels, which are uncommitted. Such a strategic investment can hardly be justified by considering only its direct effects (e.g. direct cash-flows or NPV analysis). It is the strategic effect of such a pre-commitment that justifies the decision and introduces a game theoretic element to the analysis. This strategic effect is further elaborated next.

2.2 The strategic effect

A commitment by firm A can either hurt or benefit the competitor firm B (tough or accommodating action). On the other hand, the response of firm B will depend on the competitive setting prevailing in the market. The competitive setting will determine what kind of initial commitment to make. In price competition, reactions are reciprocating, while in capacity competition reactions are contrarian.

Overall, the strategic effect depends on both the type of the competition (reciprocating or contrarian / players act as strategic substitutes or complements respectively) and. the type of the commitment (tough or accommodating). Specifically:

[sign of the strategic effect]

(positive + or negative -)

=

[sign of the type of the competition]

(+ for reciprocating or - for contrarian)

X

[sign of the type of the strategic investment commitment]

(+ for accommodating or - for tough)

Ordering vessels in an LNG shipping market is an interaction of capacity competition, where reactions are contrarian (sign -). So referring to the strategic effect in Eq. (1), a tough commitment (-) by A will result in a positive (+) strategic effect for A (the strategic effect term is positive as both its factors are negative). On the contrary an accommodating commitment (+) would result in a negative (-) strategic effect. An aggressive behavior is met with soft response. This signifies that supplying more capacity to the market in question forces the competitor to restrict his own.

In a strategic case where the competitor firm B is a potential entrant to the market, it may be forced to restrict its supply of capacity to a level, where it is unprofitable for it to enter the market. Consider the impact of the incremental investment dK_A on firm B's second-stage profits (V_B):

$$\frac{dV_B}{dK_A} = \frac{\partial V_B}{\partial K_A} + \frac{\partial V_B}{\partial a_A}\frac{da_A^*}{dK_A} \tag{2}$$

Referring to Eq. (2), the direct effect of A's investment on B's value is negative, but also its strategic effect is negative. Indeed the strategic effect term is negative, as its first factor is negative and the second is positive. So, firm A may achieve to deter entry of B to the market by making such an entry unprofitable ($dV_B / dK_A < 0$).

2.3 Conclusions

The main conclusion from this discussion is that the value of strategic investments can be under- (or over-) estimated if one considers only their direct effect (e.g. NPV analysis of direct cash-flows). The strategic effect taking into account the competitors' moves may instead determine whether the strategic move is beneficial or not.

Moreover, it is important to know when to compete aggressively and when to coordinate actions with rivals. Understanding whether a strategic move is tough or accommodating for competitors and knowing whether they act as strategic substitutes or complements helps in predicting their reaction to it. In this way, profitable opportunities based on common interests can be exploited and harmful reactions can be avoided.

In the case of LNG shipping, these concepts help in better appreciating the strategic value of ordering uncommitted vessels (without any contract guaranteeing business for them when they are launched in the market). The direct effect may not justify such an investment, however the latter may be suggested by the strategic effect on the shipping firm's own strategic position related to the position of its adversaries.

The nature of LNG shipping competition signifies that building more capacity forces the competitors to restrict their own. In a strategic case where the competitors are the potential entrants to a market, under circumstances they may be forced not to enter the market at all. Entry deterrence is analyzed in the following section.

3. Entry Deterrence in an LNG shipping market

In this competitive setting, strategic interaction situations are considered between a firm already active in a specific market (the incumbent) and a potential entrant or entrants in that market (they may choose to enter or not in the market). The entrants offer identical or close substitute products (services). If they enter the market, then the incumbent's profits are reduced, so the incumbent - monopolist tries to prevent other firms from entering the market.

This approach is viewed through similar strategic interactions in the LNG shipping market. The incumbent is the monopolist LNG shipowner in a market, where the potential entrants wish to enter. The substitute product they offer is the LNG cargoes shipping service.

First, a traditional approach to such a strategic interaction is discussed and it is explained why it is unsatisfactory. Then, it is presented how game theory provides a more sophisticated treatment of the subject. Finally, the main conclusions regarding the LNG shipping market are reviewed, which significantly advance the understanding of how firms may strategically interact over time.

3.1 The traditional Approach to Monopoly - Entry Deterrence and the Game Theory perspective

The current discussion is adapted from Romp (1997)[1]. In the *static theory of monopoly*, the prospect of competition is ignored. It is rather examined how the monopolist firm can maximize its profits (supernormal profits). This is achieved by supplying the capacity where the marginal costs equal the marginal revenues. It is assumed that significant barriers prevent other players from entering the market.

However, in the absence of barriers to entry, the presence of supernormal profits will attract other players. In this case, the monopolist could increase his output to an appropriate level and decrease the price accordingly, so that the potential entrants believe that their sales will not earn them a normal profit.

The highest price charged by the incumbent (yet still below the monopoly price and corresponding to a higher level of output than the monopoly state) at which entry is deterred is called the *limit price*. The *limit price strategy* will be followed by the incumbent, if the present value of the profits it will bring is higher than the value of maximizing current profits.

The *limit price theory* assumes that the incumbent will continue to produce the same level of output even after any other firm has entered the market. This is not realistic, except in cases where some sort of inescapable commitment has been made by the incumbent. Normally, after the entrance of a competitor in a market, the monopolist will change his output / price and compete in a duopoly market accordingly.

This is illustrated by considering a two stage game. In the first stage, the monopolist sets his level of output. In the second stage, a potential entrant decides whether to enter or not. If he enters, Cournot competition takes place[2]. It is also assumed that there is no possibility of pre-commitment by the incumbent, and that there is complete information. Obviously, the entrant will enter in the second period depending on whether he can make a profit under Cournot competition. This decision will not be influenced by what the incumbent does in the first period (e.g. limit price strategy). Realizing this, the incumbent will maximize current profits in the first period (will act as a monopolist, instead of adopting a limit price strategy), as he cannot affect the potential entrant's decision.

In the case of LNG shipping, the incumbent firm may similarly choose to supply its market with such a level of shipping capacity at competitive charter rates, that the potential entrants will not find it profitable to enter the market.

From the perspective of game theory, the threat by the incumbent of producing the same level of output even after a competitor has entered the market is not credible and therefore the limit price strategy is not a subgame perfect Nash equilibrium[3]. Accordingly, the entrant is not justified to believe it. The theory of limit pricing is based on irrational behavior by firms.

3.2 Game Theoretic Analysis of Entry Deterrence

It was explained above how game theory rejects limit price strategy as incapable of achieving entry deterrence in oligopolistic interaction, since it is based on irrational behavior by the involved players. Instead, game theory makes entry deterrence possible by relaxing i) the previous assumptions of limited interaction between the incumbent and the potential entrants, ii) the inability of the incumbent to pre-commit to a certain action, and iii) the existence of complete information. These three relaxations are discussed in the following three subsections respectively.

3.2.1 Repeated interaction

The incumbent in a market can deter entry only in

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[1] who refers to Bain (1956), Modigliani (1958) and Sylos-Labini (1962).

[2] See the Appendix for a brief description of Cournot competition.

[3] According to subgame perfect Nash equilibrium, the solution to a game must be a Nash equilibrium (see the Appendix) in every subgame of it. A subgame of a game is defined as a smaller part of the whole game starting from any point and ending to the end of the entire game. It suggests that each player must act in his own self-interest in every period of the game.

credible ways. Such a credible strategy can be predatory pricing or a price war. While in limit price theory the incumbent sets a low price before entry occurs, in predatory pricing he does so afterwards.

Predatory pricing may make both the entrant and the incumbent worse-off compared to an accommodating strategy. If this is the case, then the incumbent cannot be credible when threatening with a price war in a one-off game. However, if the incumbent faces an infinite number of possible entrants in separate markets, predatory pricing can deter entry in equilibrium (Milgrom and Roberts, 1982a).

In the case of LNG shipping, competition is capacity-based rather than price-based (as argued in Gkonis & Psaraftis, 2007b). The "predatory pricing" strategy can be replaced by a "fighting" strategy in an LNG shipping interaction.

A dominant LNG firm may enjoy a better positioning through its established relationships with the customers, that it can take advantage of after the entrance of a competitor in the market. These advantages can be identified in administrative, contractual and logistical facilitations, apart form the importance of the relationship itself.

The case is considered where the incumbent LNG firm faces a potential entrant in each one of an infinite number of markets (assumed to be "identical"). The incumbent has to choose between accommodating or fighting. The potential entrants make their decisions to enter or not sequentially. If the potential entrant stays out, the incumbent earns monopoly profits. If the potential entrant enters and the incumbent accommodates, both earn positive profits, while if he chooses to fight, then both loose. This game - which is also known as the "chain-store" after a classic game (Selten, 1978) - is illustrated in Table 1, where M>H>0>L and EH>0>EL.

Table 1: The "chain-store" game

Pay-offs		Entrant	
		Enter	Stay out
Incumbent	Fight	L, EL	M, 0
	Accommodate	H, EH	M, 0

If in the above game the incumbent accommodates in the first period (market), then with the expectation of accommodation, entry will occur in all periods (markets). The present value of pay-offs for the incumbent will therefore be:

$$H + dH + d^2 H + ... = \frac{H}{1-d} \quad (3)$$

where d=1/(1+r) is the discount factor (r is the discount rate). If, however, the incumbent chooses to fight in the first period (market), then the potential entrants in the next markets will prefer to stay out expecting the same behavior (as a rational response from the incumbent in identical strategic interactions). The present value of the pay-offs for the incumbent will then be:

$$L + dM + d^2 M + ... = L + \frac{dM}{1-d} \quad (4)$$

For the incumbent to choose the "fighting" strategy, it must be:

$$L + \frac{dM}{1-d} > \frac{H}{1-d} \Rightarrow d > \frac{H-L}{M-L} \quad (5)$$

So, the incumbent will follow a "fighting" strategy, if he does not discount the future too much (i.e. the discount rate r is small enough to satisfy Eq. 5, which means future profits are not discounted a lot).

The result is that with the prospect of infinitely repeated interaction, the incumbent's threat of "fighting" becomes credible and thus he achieves entry deterrence. However, if the number of markets is finite, the threat is not credible, as it can be shown by backward induction (this is the so-called "chain-store paradox"). Indeed, in the last game the incumbent will have no reason not to accommodate and so on moving backwards. As a result, entry deterrence is not possible in this case.

3.2.2 Credible pre-commitment

Finitely repeated interaction under complete information fails to explain entry deterrence because the incumbent cannot credibly pre-commit to a certain action. An action of the incumbent in the present period that can affect competition in the future and deter entry must be irreversible. If it is instead easily reversible, it will not be credible.

Romp (1997)[1] demonstrates how investing in capital can be such an action of pre-commitment. A two-period strategic interaction is considered. In the 1st period the incumbent controls the market, while in the 2nd period a potential entrant may choose to enter the market and compete in terms of Cournot competition. The incumbent may invest in capital in the 1st period in an irreversible way (in the 2nd period this expenditure is considered as a sunk cost i.e. cannot be recovered). This could be an investment in physical infrastructure that lowers for example the firm's marginal costs.

The strategic value of early strategic investment, which can otherwise be translated as pre-commitment, was discussed in section 2. In the case of LNG shipping, the 1st period could be when the incumbent LNG shipping firm chooses to place an order for LNG vessels. This is a capital investment of irreversible nature. The 2nd period is when the vessels become available at around the same time that a potential competitor considers entering the market.

[1] who refers to a model presented by Dixit (1981).

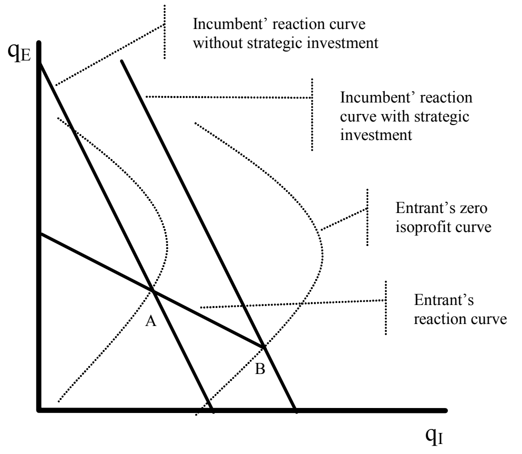

Fig. 5: Entry deterrence under Courmot competition

Referring to Fig. 5, point A is the Nash equilibrium under Cournot competition[1], when the entrant enters the market and the incumbent has a given reaction curve without pre-commitment. Under this equilibrium, the entrant receives the profit indicated by the respective isoprofit curve passing from A.

If the incumbent LNG firm makes an irreversible capital investment in the 1st period as suggested above, its reaction curve will move to the right, as with a larger fleet and enjoying economies of scale, it can supply more capacity for each level of supply by the entrant. In the general model, the reaction curve moves to the right as a result of a reduction in marginal costs, that allows the incumbent to optimally produce more output for each level of output of the entrant.

The new equilibrium point is B, which corresponds to an isoprofit curve of lower profit for the entrant. This can actually be the isoprofit curve that corresponds to zero profits for the entrant, if the reaction curve of the incumbent moves sufficiently to the right (in this case the reaction curve of the entrant stops there, as beyond point B he would earn negative profits).

The result of the pre-commitment by the incumbent in the 1st period is that he competes from a stronger strategic position in the 2nd period (a new reaction curve). The potential entrant does not enter the market, if the Cournot equilibrium suggests that he does not gain from entry.

As Romp (1997) discusses, entry deterrence can be achieved by various in nature strategic investments. It could be research and development that changes the strategic position of a firm in the future. Also, successful advertising or long-term contracts may deter a competitor from entering a market by fear of finding himself in competitive disadvantage. Increasing current production may also lower the future costs of a firm through a learning-by-doing process and increase switching costs by creating a loyal customer base (switching costs are incurred by consumers when switching to another firm's products). A firm that is established in a wide customer base may put a future entrant at a competitive disadvantage.

[1] see the Appendix.

Similarly, in the LNG shipping business, the importance of long-term contracts and market relationships has already been stressed. Loyal market relationships can be translated into increased switching costs that bring a potential competitor to a disadvantageous position. Also, technological superiority in the form of a fleet that is modernized or even exhibits technical innovations can be seen as a source of competitive advantage that may achieve entry deterrence.

3.2.3 Incomplete information

Entry deterrence in a finitely repeated game can also be supported in game theoretic terms by introducing incomplete information. Specifically, the potential entrant may not know the type of the incumbent he is facing i.e. the actual pay-offs of the incumbent.

"Signaling" that deters entry in a single market

Continuing the discussion based on Romp (1997)[2] and Fudenberg & Tirole (1993), a two-period game is considered between an incumbent and a potential entrant. In the first period, the incumbent chooses a market policy[3]. The entrant observes it and decides whether to enter or not in the second period.

In the case of an LNG shipping interaction, the incumbent is assumed to be of two possible types: R_H i.e. with a "High" capabilities profile and a strong position in the market (this could be based on a good financial standing, favorable cost characteristics, good reputation and strong relationships with the customers) or R_L i.e. with a "Low" capabilities profile and a weak position in the market. The potential entrant will enter only if he believes that the incumbent is of type R_L. In any case, the incumbent has an interest in "signaling" that he is R_H (creation of a "reputation") in the 1st period, so as to deter entry in the 2nd period. However, the signal must be credible.

Complete information

Under complete information, the type of the incumbent is common knowledge. If he is of type R_H, the entrant will stay out. The incumbent will supply to the market the same level of shipping capacity in a monopoly state (denoted by superscript M) in both periods and the present value of his total profits will be[4]:

$$\pi(Q_H^M \mid R_H) + d\ \pi(Q_H^M \mid R_H)$$

If the incumbent is of type R_L, the entrant will enter the market in the 2nd period and compete in a Cournot duopoly. The incumbent will supply his R_L type-compatible monopoly capacity in the 1st period, knowing that he cannot deter entry. In the second period, the two firms will compete in a duopoly (denoted by super-

[2] who refers to Milgrom & Roberts (1982b) and Fudenberg & Tirole (1986).

[3] A limit price strategy in the model discussed by Romp. A capacity-setting policy in considered in this illustration.

[4] π(Q|R) stands for the payoff (or profit) of a type R player when supplying capacity Q. d is the discount factor.

script D). The present value of the incumbent's total profits will be:

$$\pi(Q_L^M \mid R_L) + d\ \pi(Q_L^D \mid R_L)$$

If the incumbent is of type R_H or R_L with probabilities ProbH and ProbL respectively, then the entrant will stay out or enter the market with the same probabilities.

Incomplete information

In the case of incomplete information, the entrant does not know the incumbent's type. The action of the incumbent in the 1st period sends a signal to the entrant about the incumbent's type. Such a game will have a Bayesian equilibrium[1], which can be either separating or pooling. In a separating equilibrium, a player's actions reveal his type, contrary to a pooling equilibrium.

As in a separating equilibrium the incumbent's actions reveal his type, in the first period a type R_L incumbent must have no reason to imitate an R_H one. This will happen if the following inequality holds:

$$\pi(Q_L^M \mid R_L) + d\ \pi(Q_L^D \mid R_L) > \pi(Q_H \mid R_L) + d\ \pi(Q_L^M \mid R_L) \quad (6)$$

Q_H is the capacity that an R_H firm would supply in the first period to deter entry.

Accordingly, in the first period a type R_H incumbent must have no reason to imitate an R_L one. This will happen if the following inequality holds:

$$\pi(Q_H \mid R_H) + d\ \pi(Q_H^M \mid R_H) > \pi(Q_L^M \mid R_H) + d\ \pi(Q_L^D \mid R_H) \quad (7)$$

The right-hand side suggests that an R_H firm supplies in the first period the monopoly capacity an R_L firm would supply.

The above inequalities (6) and (7) suggest the capacity Q_H to be supplied by an R_H incumbent so as to guarantee a separating equilibrium (typically Q_H will be higher than Q_H^M, so that an R_H incumbent clearly distinguishes himself from an R_L incumbent, in order to deter entry). It is a strategy[2] that signals to the entrant the actual type of the incumbent. The entrant correctly understands the incumbent's type based on his action in the first period.

In the case of a pooling equilibrium, both types of the incumbent firm supply the same capacity in the first period, so that the entrant learns nothing about the incumbent's type. For the entrant to be deterred from entering the market, the capacity supplied in the first period must suggest negative profits if he enters the market. An R_L incumbent will supply in the first period what an R_H would supply. In this way, entry is deterred.

[1] Bayesian equilibrium is a generalization of Nash equilibrium for games of incomplete information. Players must correctly anticipate the types of the other players, based on their actions. More specifically, players hold prior beliefs about the other players' types and as they see them take actions, they update their beliefs according to Bayes' Rule.

[2] Comparable to a limit price strategy.

"Signaling" that creates a "reputation" and deters entry in a repeated interaction

In a different model of incomplete information[3], the incumbent may demonstrate an irrational behavior in the form of fighting (after entry has occurred), even if this involves reduced profits for him. A model is considered as the one previously described when discussing repeated interaction, but the entrant does not know whether the incumbent has a preference for behaving irrationally. The greater this possibility is, the more likely it is for entry to be deterred.

In this context, a rational incumbent has an incentive to fight entry in the first markets where interaction takes place (send a "signal") and develop a "reputation" of being irrational, which deters future entry and raises the present value of future profits. In the latter markets of the game, the benefits of gaining future profits decreases and the incumbent will accommodate entry.

Before this final stage, the incumbent will play a mixed strategy. If an entrant decides to enter at this stage and is accommodated, then entry will occur in all succeeding markets. If entry is fought, the entrants will revise their perceived probability that the incumbent is irrational according to Bayes' Rule[4], which delays entry. From the side of the incumbent, during the mixed-strategy stage the probability of fighting decreases as long as there is no entry.

As a result, entry is deterred in the initial markets of this finite incomplete-information game because the potential entrants realize that the incumbent has an incentive to follow a fighting strategy after entry has occurred (as opposed to signaling in the previous model, which takes place before entry to the market).

3.3 Conclusions

In this section, strategic interactions of entry deterrence with application to LNG shipping were examined. The incumbent player is a monopolist LNG shipping firm in a market, where the potential entrants wish to enter. The main conclusions of this section can be summarized as follows.

Initially, the static theory of monopoly and the limit price theory were discussed. It was explained why such a traditional approach is unsatisfactory, as it assumes irrational behavior by firms.

[3] Romp (1997) refers to Kreps and Wilson (1982).

[4] Suppose that $E_1, \ldots, E_N$ are N possible states and an event F is a signal. We can use Bayes' rule to find the probability P of a state E_K given the observed signal F (probability of E_K conditional on F), as:

$$P(E_K \mid F) = \frac{P(F \mid E_K)\ P(E_K)}{\sum_{j=1}^{N} P(F \mid E_j)\ P(E_j)}$$

where:

$P(E_K)$ is the prior belief about the probability of E_K (all probabilities on the right-hand side of the above expression are prior probabilities determined before F occurs)

$P(E_K|F)$ is the posterior (updated) belief about the probability of E_K modified by the evidence F.

Next, a game theoretic discussion of entry deterrence was examined. First, it was demonstrated that under repeated interaction, the incumbent's threat of "fighting" the potential entrants after they have entered the market can be credible and deter entry. However, when this repeated interaction is finite, entry deterrence was not supported.

This obstacle was overcome by introducing the possibility of credible pre-commitment by the incumbent LNG firm. This is usually a capital investment of irreversible nature, such as an order of LNG vessels to be launched in the market. The effect of such a commitment in the form of strategic capital investment can be entry deterrence. Long-term contracts, loyal market relationships and technological superiority can have similar strategic effects.

Next, incomplete information was introduced as another realistic market characteristic that can be the source of successful entry deterrence. Specifically, the entrant may not know the type of the incumbent he is facing. In this case, the incumbent will send a signal regarding his type, which may deter the potential entrant from entering the market.

Alternatively, an incumbent LNG shipping firm that is active in many markets can create a reputation of fighting entry once it has occurred, even if this is harmful for it (reputation of irrational behavior). Entry deterrence can be achieved until the point, where the incumbent decides to accommodate entry, because he can expect no further gain from developing this reputation.

Overall, the sophisticated treatment of entry deterrence that game theory offers was demonstrated in this section. These game theoretic concepts significantly advance the understanding of how shipping firms may strategically interact in LNG shipping.

4. Overall Conclusions

In this paper, an introduction to and an overview of the LNG market was provided and, more specifically, the dynamics of its shipping segment were discussed. LNG shipping is a specialized bulk trade with great prospects in energy shipping. Compared to its parent markets, the oil trade and the onshore gas markets, it differentiates substantially, because of its limited fluidity. It is not expected to reach in the near future similar levels of mature competition. However, its growth rate and the opening up to new players with the adoption of more flexible terms of operation makes it a most promising field in the shipping industry.

The context of LNG shipping is appropriate for the adoption of a (non-cooperative) game theoretic analysis framework to support decision-making. The focus in this paper was placed on two topics of strategic decision-making in LNG shipping, namely Early Commitment and Entry Deterrence.

The discussion on early commitment showed that the value of investments can be under- (or over-) estimated if one considers only their direct effects, while neglecting their strategic effects. Moreover, that it is important to know when to compete aggressively and when to coordinate actions with rivals. In the case of LNG shipping, these concepts help in better appreciating the strategic value of ordering uncommitted vessels and the rationale that supports entry deterrence strategies that were analyzed next.

Entry deterrence strategic interactions involve an incumbent (monopolist) LNG shipping firm in a market, where potential entrants wish to enter. A game theoretic analysis demonstrated that under infinite repeated interaction, the incumbent's threat of "fighting" the potential entrants after they have entered the market can be credible and deter entry. In finite interactions, a credible pre-commitment, such as an order of LNG vessels, can deter entry. Incomplete information can also be the source of entry deterrence, in which case the incumbent may send a signal regarding his type, which can deter a potential entrant from entering the market. Alternatively, an incumbent LNG shipping firm can create a reputation of irrational behavior.

In the dynamic environment of LNG trade, new entrants to the market such as the independent oil tanker companies, want to capture a share. Strategic decision-making is crucial at this stage and game theoretic concepts significantly advance the understanding of how shipping firms may strategically interact in LNG markets. Overall, game theory can be a useful supplement to the intuition of market players, as it helps in identifying right strategies given certain conditions.

References

Bain, J. (1956), Barriers To New Competition, Cambridge, Mass.: Harvard University Press

BP (2007), Statistical Review of World Energy, June 2007.

Chevalier, J-M. (2004), *Les grands batailles de l'énergie*, Gallimard.

Dixit, A. (1981), "The role of investment in entry deterrence", Economic Journal, 90:95-106

Foss, M. (2005), "Global natural gas issues and challenges: a commentary", The Energy Journal, 26:2.

Fudenberg, D. and J. Tirole (1984), "The Fat-Cat Effect, the Puppy-Dog Play and the Lean and Hungry Look", American Economic Review, 74:361-366

Fudenberg, D. and J. Tirole (1986), Dynamic Models of Oligopoly, New York: Harwood

Fudenberg, D. and J. Tirole (1993), Game Theory, MIT Press

Gkonis, K.G. and H.N. Psaraftis (2007a), "Investment rules and competition patterns in LNG shipping: a Game Theory approach", Proceedings of IAME 2007 Annual Conference, Athens, Greece, June 27-29, 2007.

Gkonis, K.G. and H.N. Psaraftis (2007b), "The LNG Market and a Game Theory Approach to Competition in LNG Shipping", Working paper, Laboratory for Maritime Transport, National Technical University of Athens.

Gkonis, K.G. and H.N. Psaraftis (2007c), "The LNG shipping market and its prospects" (in Greek),

NAYTIKA XPONIKA magazine, December 2007.
Institute for Energy, Law and Enterprise (2003), Introduction to LNG, University of Houston Law Center.
Jensen, J. (2004), The Development of a Global LNG Market, Oxford Institute for Energy Studies.
Kreps, D. and R. Wilson (1982), "Reputation and imperfect reputation", Journal of Economic Theory, 27:253-79
Lloyd's List (2007), "LNG" special report, 21/09/2007.
LNG One World (2007), http://www.lngoneworld.com
Milgrom, P. and J. Roberts (1982a), "Predation, reputation and entry deterrence", Journal of Economic Theory, 27:280-312
Milgrom, P. and J. Roberts (1982b), "Limit pricing and entry under incomplete information: An equilibrium analysis", Econometrica, 50:443-59.
Modigliani, F. (1958), "New Developments on the Oligopoly Front", Journal of Political Economy, 66:215-32
Petroleum Economist (2007a), "Liquefied Natural Gas" analysis, April 2007.
Petroleum Economist (2007b), "Shipping" analysis, March 2007.
Romp, G. (1997), Game Theory – Introduction and Applications, Oxford University Press.
Selten, R. (1978), "The Chain-Store Paradox", Theory and Decision, 9:127-159
Shipping Economist (2007a), "Gas Carriers" data, September 2007.
Shipping Economist (2007b), "LNG Shipping" report, July 2007.
Smit, H. and L. Trigeorgis (2004), Strategic Investment – Real Options and Games, Princeton University Press.
Sylos-Labini, P. (1962), Oligopoly and Technical Progress, Cambridge, Mass.: Harvard University Press

Appendix: Cournot competition

In Cournot competition, companies simultaneously compete in terms of the capacity supplied to the market.

In a simplified model of Cournot competition, two LNG shipping companies A and B compete (i.e. a duopoly, the so-called *Cournot Duopoly*). The two shipping companies supply the same product: the LNG cargoes shipping service, in terms of capacity e.g. thousands of cu.m. miles.

The strategies (decisions) available to the two companies are the capacities supplied by each, q_A and q_B respectively. The supply level decisions are taken simultaneously (companies do not observe the competitor's level of supply before setting their own). The payoffs are their profits, π_A and π_B, which they wish to maximize.

A solution technique to approach this game is the concept of *Nash equilibrium*. This involves determining for each company the optimal strategy dependent on the other company's move. The so-called *reaction function* (also known as *best response* function) shows a company's optimal capacity for every capacity supplied by the other company.

The reaction functions for companies A and B represent downward sloping *best response curves*, as the optimal supply for each company is negatively related to the expected level of supply of the other one (see Fig. 6). For this reason the two companies are called *strategic substitutes* (if the correlation was positive, they would be *strategic complements*).

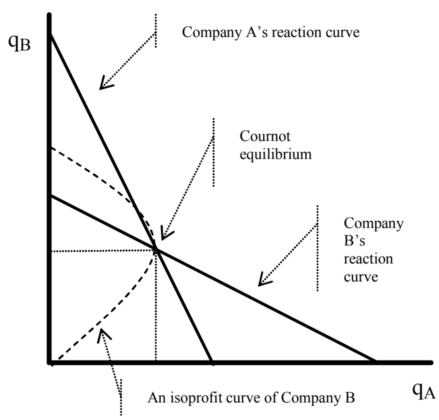

Fig. 6: Cournot competition

In Nash equilibrium, both companies must be maximizing profits simultaneously (given the other company's capacity supply), which means that they must be on their reaction curves simultaneously. Thus, the reaction curves' intersection corresponds to the unique Nash equilibrium for this model.

An *isoprofit curve* of a company depicts the different combinations of both companies' supply that yield the same level of profit for that company (in general it is a hyperbolic curve).