INVESTMENT RULES AND COMPETITION PATTERNS IN LNG SHIPPING: A GAME THEORY APPROACH

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Abstract

The LNG market is experiencing a tremendous growth. It is expected that competition will increasingly develop especially in the shipping segment of the LNG chain, which at least in its first phases will have the characteristics of an oligopolistic market. The LNG shipping market is appropriate for the application of a (non-cooperative) game theoretic framework. This paper reviews the basic insights that game theory can offer to the analysis of the LNG shipping market and presents relevant game theoretic structures regarding competition and strategic investments. Game theory is a useful supplement to the intuition of a market player in the LNG shipping business, as it helps in identifying right strategies given certain conditions.

Key words:

LNG Shipping, Competition & Strategic Investments, Game Theory

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1. INTRODUCTION

For many years, world gas markets consisted of isolated pipeline or LNG short-haul trade. The LNG market was served by ships dedicated to specific routes (Jensen, 2004). These rigid patterns began to break up in the late 1990s. New structures in the LNG market have contributed to the development of a "world gas market" and LNG is playing a growing role in providing competitive gas supply.

The LNG market is experiencing a tremendous growth. It is expected that competition will increasingly develop especially in the shipping segment of the LNG chain, which at least in its first phases will have the characteristics of an oligopolistic market. Investments are capital intensive and relatively few and large players will be 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.

Because of its distinctive idiosyncrasies, methodologies applicable to other shipping markets fail to support decision-making in the LNG shipping business. A gap exists in the literature regarding the analysis of the newly developed LNG market. 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 has been extensively used for competition analysis in oligopolistic markets among other topics[2]. 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 paper reviews the basic insights that game theory can offer to the analysis of the LNG shipping market. In Section 2, some basic concepts of game theory and their relevance to the construction of appropriate models regarding strategic interactions in LNG shipping are discussed. In Section 3, game theoretic structures for the analysis of competition and strategic investments in LNG shipping are presented. Section 4 concludes this paper with the main suggestions derived from the previous discussion.

[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, the same prize was awarded again for contributions to game theory and specifically to T. Schelling and R. Aumann for their analyses of conflict and cooperation.

2. BASIC CONCEPTS OF GAME THEORY, AND LNG SHIPPING

Game theory started as a branch of applied mathematics. It could be called the Science of Strategy. It is particularly effective when there are many interdependent decision-makers. Game theory focuses on "finding the right strategies and making the right decisions" and to achieve this, it utilises an appropriate analysis framework built around the following dimensions: players, added value, rules, perceptions – tactics, scope, and rationality (Brandenburger & Nalebuff, 1996).

2.1 Players

The players around a given company in a business game can be distinguished in customers and suppliers, competitors and complementors. The Value Net helps in understanding how players interact in a business game.

A player can occupy more than one role in the Value Net. Customers and suppliers play symmetric roles, while competitors and complementors play mirror-image roles. A player is a competitor to a company, if customers value the company's product less when the competitor's product is offered in the market as well. On the contrary, a player is a company's complementor, if customers value the company's product more when the complementor's product is offered in the market as well. Overall, there are complementary opportunities as well as competitive threats. Companies are complementors in making markets and competitors in dividing them up.

In order to identify the players in the LNG shipping business, the value net of an independent LNG shipping company is drawn (Figure 1).

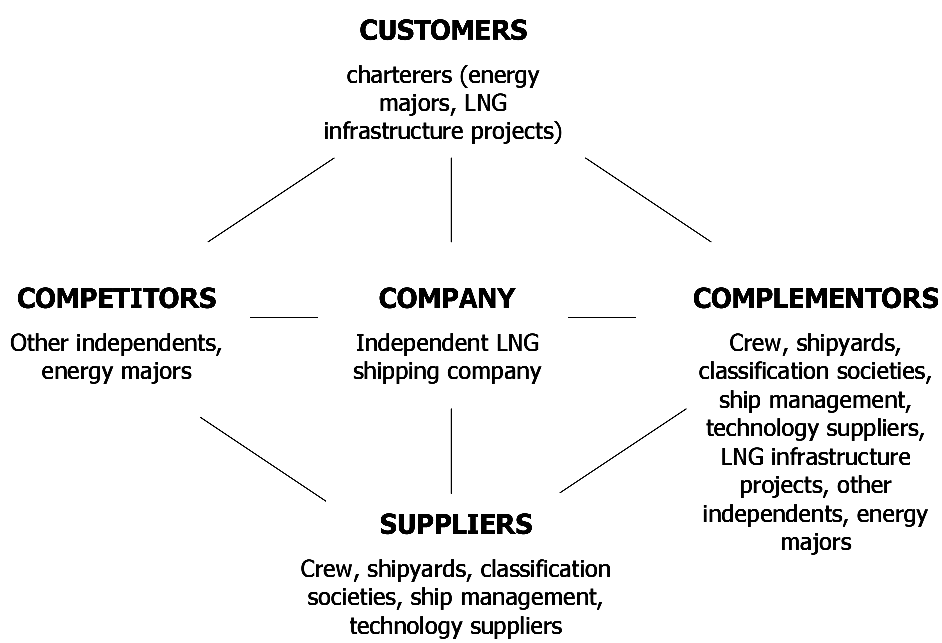

Figure 1: The Value Net of an LNG shipping company

The customers of the company are the charterers. These can be either major energy companies wishing to transport their LNG cargoes within their integrated chain of interests or LNG liquefaction / regasification stand-alone projects.

The suppliers of the company are the crew, ship management, classification societies, shipyards, and technology suppliers. The availability of specialised crew, ship management, and classification services is restricted at the current phase of the LNG market. The availability of shipyards possessing the required expertise is also paramount in newbuilding and repairs. The technology developers introduce new technologies to the market.

The competitors are obviously other independent LNG shipping companies or energy majors owning a fleet. They can provide the same service (i.e. the LNG-cargoes shipment service) in a competitive market.

Complementors of the company can actually be all the abovementioned players. The product or availability of crew, ship management, classification societies, shipyards, and technology suppliers, all enhance the product - service of the LNG shipping company. The construction of LNG liquefaction / regasification projects also increases the value of the company's product in a competitive market. Finally, other independents and energy majors act as complementors in the phase of creating the market, although they act as competitors when it comes to sharing it.

2.2 Added value

The added value of a player can be defined as the size of the market when the player is in the game minus its size when he is out of the game. It is unlikely for a player to receive more from a game than his added value, which represents his relative strength. An interesting observation is that getting a sufficiently large slice of a "pie" can more than compensate for a possible reduction in the size of the pie. In other words, it is the relative position in the market that is often more important than the absolute size of the market.

An LNG shipping company has a higher added value at the early stages of the market development, than later on. In the early stages, it may act as a complementor in creating the "pie" with other companies providing the same service. The "pie" is a functional, versatile and competitive LNG shipping market offering quality and reliable services.

The LNG shipping market is currently at a stage of development. The added value of a company entering the market should therefore be high. However, market analysts are suggesting that energy majors possessing a fleet do not favor the entrance of competitors in the market. This could be interpreted either as strategic miscalculation or as a sign of a coming oversupply in LNG vessels. But as it was suggested above, it could be argued that getting a sufficiently large slice of a pie can more than compensate for keeping the pie small.

2.3 Rules

There are many rules governing business and originating in customs, contracts or law. Rules are an important source of power in games. Rules are an important element in the shipping business as well. The contract defining the services that a shipping company provides is such a rule. So far, contracts in the LNG shipping business tended to be too much detailed and complicated leaving little space for flexibility. Recent demands by market players ask for simpler contracts allowing the development of an operationally flexible and liquid market.

The LNG shipping market has also been characterised by long-term relationships between shipowners and charterers. LNG vessels would be dedicated to specific trade routes for 20 or more years with a likely possibility of extension. These rules are changing and LNG carriers increasingly switch trade routes and redirect their cargoes according to market conditions.

The above changes in the market rules also change the nature of the LNG shipping game. They are translated into an increased ability of the players to make regular choices regarding their counterparts, the disposal of their vessels, and the level and length of their involvement in a specific market. They also signify market relations that are assessed on a continuous basis, rather than solid long-term relations. Reputation will play an increasing role, as well as the quality of the provided services, the ability to adapt to current demands and the level of commitment to the requirements of a project.

These changes are suggesting a switch from one-off games to repeated game structures. The LNG shipping business model changes from a static to a dynamic one. Taking rules into account, one needs to look forward into the game and then reason backwards to figure out which initial move will lead him where he wants to end up.

2.4 Perceptions - tactics

The way players perceive the business game influences the way they make their decisions. What matters isn't just what one thinks of the game, but also what he thinks that the other players think. It is important to look at a game from different perspectives and this is one basic insight of game theory. The devices used to shape perceptions are called tactics.

As the LNG shipping business is an oligopolistic one, inevitably a decision-maker needs to take into account the decisions and responses of other players. Consider for example the technical aspects of the world LNG fleet. The world LNG fleet is still quite limited in number, and so are the LNG shipbuilding capacity of shipyards and their orderbooks. Ordering ships of established, or rather compatible with the interests of other players, technology may be a preferable strategy for a shipowner.

A shipowner placing orders of a certain size should also take into account the size of orders of other shipowners. As the total capacity of the world LNG market, and even more of specific trade routes, is restricted, orders of considerable size have a direct effect on employment, availability, and usage rates of the LNG fleet. Crew availability issues are also of rising importance. In the end, charter rates are considerably influenced in such an oligopolistic market and so are the returns on investments.

Players in a game can often shape perceptions through techniques that are called tactics. For example, a player may want to suggest to the market that he acts in a certain way (create a reputation). This could be the result of a signalling tactic, which however has to be credible to be believed by other players.

2.5 Scope

A game without boundaries is too complex to analyse. On the other hand, the analysis may miss many important parameters, when a game is reduced to a much simpler one. Moreover, a move in one game can affect other linked games.

In the previously depicted value net, a game has been defined with the LNG shipping company at the centre of it and an analysis can be performed at the suggested level of depth and breadth. Some notional boundaries have actually been set. These boundaries make the analysis easier to perform and more specific, but on the other hand may restrict it to the point of neglecting some important parameters. For example, the analysis can be taken further by extending the game or by actually forming related games, such as the one referring to the shipyards and their business within the steel market.

In other words, defining the "correct" game is decisive for the modelling success of a game theoretic approach.

2.6 Rationality

Rationality considerations are important, because in games where players are interdependent, a player acting irrationally can greatly influence (especially in a negative way) the other players with his decisions.

Defining rationality is not easy. Differences in information can lead to different perceptions and misperceptions. Players may have wrong perceptions, without being irrational. Again, it is important to look at a game from different angles.

In the LNG shipping business, the rationality of players can be interpreted as the degree of their understanding of the market dynamics. This is also related to the amount of information they have in hand and their experience in the market. Also, rationality could also be understood as the degree of following the market trends, unwritten rules and way of doing business in the market.

The LNG market history is short and, moreover, it is going through a restructuring or one could say revolution (Jensen, 2004). Established rules do not exist and the older ones are changing. New players are entering the market with no previous experience of it and the old ones need to adapt to the new conditions. The lucrative prospects of the market also attract opportunists. Also, market information is not easily diffused or publicly disclosed. In general, this is rather a "club" market with limited liquidity and transparency.

All these characteristics of the LNG shipping market favour, at least occasionally, "irrational" behaviour by its players. Opportunistic behaviour, limited understanding of the market and limited information can all lead to irrational market moves that the prudent player must take into account in his planning and decision-making process.

3. GAMES AND THE LNG SHIPPING BUSINESS

When a firm makes a strategic investment decision, it is important 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 supports the analysis of strategic investment decisions. First, it reduces complex strategic problems to 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.

In the previous section, some important aspects that need to be considered before analysing a game were discussed. Next, some simple strategic interaction situations in LNG shipping are introduced inspired by classical games. In such models of interacting decision-makers, one needs to specify a) the players, b) the available actions for each player, and c) the resulting payoffs for each player, which express his preferences over the available actions.

The classification of games in two broad categories, namely Static Games (discussed in Section 3.1) and Dynamic Games (Section 3.2), is suggested. The importance of information in games is discussed separately (Section 3.3).

The following analysis is based on several game theory textbooks and mainly: Romp (1997), Rasmusen (2001), Osborne (2004), Gibbons (1992), and Smit and Trigeorgis (2004), except where otherwise mentioned.

3.1 Static Games

In static games the players make their moves in isolation, without knowing what other players have done. Decisions do not have to be made at the same time, but it is rather ***as if*** they were made at the same time. In other words, time is absent from the model (a "simultaneous-move game").

Such games are addressed using the concepts of ***Dominance*** (strict / weak, iterated strict / weak) and ***Equilibrium*** (Nash equilibrium / Mixed Nash equilibrium). Examples of static games that can represent simplified strategic contexts in the LNG business are discussed next.

Panic equilibrium in the face of uncertainty

The ***Prisoners' Dilemma*** is a classical illustration in game theory. Two suspects are arrested for a crime and are kept in different cells, making communication impossible. One suspect will be released and the other will receive severe punishment, if the first confesses and the second does not. If neither confesses, they will both receive a lower punishment, than if they both confess. The fear of the other prisoner's confessing puts pressure on each to confess, even though it is preferable for both not to confess. The paradox of the Prisoners' Dilemma is that the equilibrium outcome (where both prisoners confess) is worse for both of them to the outcome where neither confesses.

In a hypothetical LNG business strategic investment context, two shipowners (S1 and S2) are considered who have to choose between either ordering 2 LNG vessels now (as a slot for 2 vessels currently exists in a shipyard where they can both place an order) or waiting until market uncertainty clears. It is supposed that the Net Present Value (NPV) value of ordering 2 LNG vessels now and capturing a share in the LNG market is USD 500 million. So, if they both order now (1 vessel each), they will receive a payoff of USD 250 m. each. If one places both orders, he will receive USD 500 m. while the other will receive 0. Also, it is supposed that the additional NPV value of the flexibility to wait and see is USD 100 m. This means that the total value of the option to wait and see is USD 600m. If both shipowners exploit this option, the payoff is USD 300m. for each.

The above strategic situation is represented in ***normal form*** in Table 1.

Table 1: Panic Equilibrium

Pay-offs		Shipowner 2	
		Order	Wait
Shipowner 1	Order	**(250, 250)**	(500, 0)
	Wait	(0,500)	(300, 300)

It is obvious that each shipowner has a dominant strategy: that of ordering now. The action "Order" gives a shipowner a higher (underlined) payoff, no matter what the other shipowner does. The result is a Nash equilibrium outcome, where both shipowners choose to order (neither shipowner can improve his position by making a unilateral move) and the payoff is of USD 250 m. for each. This payoff is lower than the USD 300 m. they could achieve if they coordinated actions and exploited the option "wait and see"[1]. So, the two shipowners fail to coordinate their investment strategies and to avoid the "panic" equilibrium of rushing to place an order.

Flooding the market as an inferior choice

An asymmetric strategic investment situation as the one depicted in Table 2 is now examined. Here, each shipowner can choose between ordering 1 vessel or taking a leading position compared to the other shipowner and exercising the option for the order of a 2nd vessel as well.

Table 2: An asymmetric investment situation

Pay-offs		Shipowner 2	
		Order 1 vessel	Exercise option for 2nd vessel
Shipowner 1	Order 1 vessel	(400, 300)	**(200, 400)**
	Exercise option for 2nd vessel	(300, 200)	(-50, -50)

The asymmetric payoffs signify that S1 is better off when both players choose to restrain orders (as S1 may be in position to exploit a more profitable trade route). However, the market requires extra shipping capacity and rates are high.

[1] Note that this is the only Pareto efficient outcome, where no player can be made better off without making the other worse off.

If both players choose to exercise their options, then they both experience losses, as they oversupply shipping capacity in a restricted market[1].

When only one shipowner exercises the option for a 2nd order, the market is supplied with 3 vessels. Hire rates are lower than in the case where the market is supplied with 2 vessels, but higher than in the case where it is supplied with 4 vessels. S2 can maximize his payoff if he assumes a leading position, while S1 has more limited ability to arrange high profit employment for both his vessels.

The Nash equilibrium in this game corresponds to S2 assuming a leading position. Indeed, no player would unilaterally deviate from this strategy combination (or using iterated strict dominance: S1 has a strictly dominant strategy of ordering only 1 vessel and, given this, S2 exercises his option).

This is an ***asymmetric "grab the dollar"*** interaction (after the name of a classical game). Both players loose if they rush to "grab the dollar" simultaneously. It is also an asymmetric one, as S2 is better off by assuming a leading position, while S1 cannot exploit a leading position in the market (according to the suggested payoffs). It is also interesting that S2 achieves his best payoff, while S1 only his 3rd best payoff. This outcome will be totally reversed later on, when the same game will be approached as a dynamic one.

Appreciating the competitor's preferences is important

The following game is inspired from a classical game called ***"The Battle of the Bismarck Sea"*** , dealing with the choices of two enemy generals in World War II regarding the deployment of their forces in the Bismarck Sea (Pacific), such as North or South. The first one wished to confront the enemy forces (i.e. would prefer to make the same choice as the other), while the other to avoid them.

In the following illustration, two shipowners (S1 and S2) are considered who have to decide in which of two shipyards (Y1 or Y2) to place an order. The payoffs related to this choice are shown in Table 3.

Table 3: Anticipating the competitor's preferences

Pay-offs		Shipowner 2	
		Shipyard 1 (Y1)	Shipyard 2 (Y2)
Shipowner 1	Shipyard 1 (Y1)	**(50, -50)**	(50, -50)
	Shipyard 2 (Y2)	(25, -25)	(100, -100)

The above payoffs suggest that S1 would prefer that both players' orders are placed in the same shipyard (Y1 or Y2), because e.g. he has priority in the orderbooks of both of them

[1] Assuming that 4 vessels cannot be accommodated by the market, and so both S1 and S2 face difficulty in finding employment for their 2nd vessel. Hire rates significantly drop and the 4th vessel remains idle while the 3rd one is chartered.

and thus can launch his vessel in the market first. Overall he has a marketing advantage, so in all cases he has positive payoffs, while S2 has the exact negative in all cases[1].

S1 would choose Y1 if he knew S2 would choose Y1, but Y2 if he knew S2 would choose Y2. On the other hand, S2 would choose Y1, if he knew S1 would choose Y2, and is indifferent between Y1 and Y2, if S1 chooses Y1.

An equilibrium can be found using the concept of iterated weak dominance. Indeed, S2 has a weak dominant strategy, that of placing his order in Y1. Taking into account this weak dominant strategy of S2, S1 will delete Y2 as an inferior option for S2 (because it is weakly dominated). The strategy set of player S2 is reduced to Y1 and so S1 will also place his order in Y1 and the outcome will give as payoffs (50, -50).

Dealing with uncertainty

"The Battle of the Sexes" is another classical illustration where the two players are a woman and a man wishing to coordinate their preferences. In a similar fashion, two shipowners are considered, who are placing an order for a new LNG vessel in a shipyard. They have two options regarding the tanks design: spherical or membrane.

The "extra" payoffs due to the design choice are shown in Table 4. These payoffs signify that both shipowners prefer to order the same type (e.g. to achieve a lower price from the shipyard due to economies of scale), while each has a preference for a different type (e.g. in order to match the rest of the fleet and have benefits in terms of repair and maintenance costs and trained crew availability).

Table 4: Uncertainty faced with mixed strategy

Pay-offs		Shipowner 2	
		Membrane	Spherical
Shipowner 1	Membrane	**(100, 50)**	(0, 0)
	Spherical	(0, 0)	**(50, 100)**

This is again a static game as the two shipowners cannot coordinate their actions and have to decide "simultaneously". The two pure Nash equilibriums are highlighted in the payoff matrix. However, no player is certain about what the other player will choose. Playing a mixed strategy is the response to this uncertainty. Each player randomises over his pure strategies according to an appropriate probability distribution. Every pure strategy played as part of the mixed strategy must have the same expected value, i.e. the player should be indifferent between the two (otherwise he would always choose the one with the higher value).

Next, it is examined how the mixed-strategy equilibrium is determined in the above case. Let $P_{(S1)M}$ and $P_{(S1)S}$ be the probabilities that Shipowner 1 (S1) orders Membrane (M) and Spherical (S) respectively ($P_{(S1)M} + P_{(S1)S} = 1$). Similarly, it will be $P_{(S2)M}$ and $P_{(S2)S}$ for S2 ($P_{(S2)M} + P_{(S2)S} = 1$).

[1] This is a zero-sum game, because the sum of the payoffs of the players is zero no matter what strategy they choose.

The expected payoff for S1, if he chooses "Membrane" is:

$$\Pi_{(S1)M} = 100\ P_{(S2)M} + 0\ P_{(S2)S} = 100\ P_{(S2)M}$$

The expected payoff for S1, if he chooses "Spherical" is:

$$\Pi_{(S1)S} = 0\ P_{(S2)M} + 50\ P_{(S2)S} = 50\ P_{(S2)S}$$

The expected values of these two strategies must be the same so:

$$100\ P_{(S2)M} = 50\ P_{(S2)S} \Rightarrow$$

$$100\ (1-P_{(S2)S}) = 50\ P_{(S2)S} \Rightarrow$$

$$P_{(S2)S} = 2/3 \text{ and } P_{(S2)M} = 1/3$$

This means that in the mixed strategy equilibrium, S2 will order S with probability 2/3 and M with probability 1/3. Similarly, S1 will order M with probability 2/3 and S with probability 1/3. They will both order the same type with probability 2/9 (for each type) and they will order different types with a total of probability 5/9.

The combination of mixed strategies constitutes a third mixed Nash equilibrium as no-one has an incentive to deviate from it. It is a rational response to the element of uncertainty.

Although this game may be suggesting that the two players could interact on a repeating basis, it is not a dynamic one. It is actually the solution approach that is suggesting this, in order to derive the probabilities of the mixed-strategies. Even when this game is repeated, no experience is gained from previous outcomes (the probabilities are independent of previous outcomes).

Coordination of actions – the usefulness of mediation

Sometimes players can be better off, if they coordinate their actions to a Pareto-efficient equilibrium[1], such as in the situation shown in Table 5. This is similar to the previous case, however both shipowners gain more if they make the same specific choice (order "membrane" type, rather than "spherical"). The coordinated choice of "spherical" is also a Nash equilibrium, but not Pareto-efficient. Multiple Nash equilibriums exist which are Pareto ranked. This is why such coordination games can be referred to as cases of ***ranked coordination***.

Table 5: Ranked coordination

Pay-offs		Shipowner 2	
		Membrane	Spherical
Shipowner 1	Membrane	**(<u>100</u>, <u>100</u>)**	(0, 0)
	Spherical	(0, 0)	**(<u>50</u>, <u>50</u>)**

[1] An outcome or equilibrium is Pareto-efficient when, by choosing another strategy, no player gains without another player loosing. In other words, when a player is made better-off, someone else is always made worse-off.

The actual outcome is not necessarily the Pareto-efficient one, if it is assumed that this is a simultaneous move game (no pre-game communication between the players). The adoption of an inferior technology ("spherical" in this example) by a large majority of shipowners is a plausible outcome.

Rasmusen (2001) discusses a situation as the one in Table 6, which he characterises as a case of Dangerous coordination.

Table 6: Dangerous coordination

Pay-offs		Shipowner 2	
		Membrane	Spherical
Shipowner 1	Membrane	**(<u>100</u>, <u>100</u>)**	(-1000, 0)
	Spherical	(0, 0)	**(<u>50</u>, <u>50</u>)**

One would suggest that the Pareto-dominated outcome is more likely, if S1 fears that S2 may be "irrational" (e.g. poorly informed about the outcomes of the game). In this case S1 will choose "spherical" as a safer choice, because in the contrary case even a small probability of mistake by S2 (i.e. choosing "spherical") will result in a major loss for S1. However, it can be argued that the game in Table 6 is not well-modelled, rather than that one of the two Nash equilibriums is a bad prediction. A game of incomplete information (discussed later) would better describe such a situation.

The theory of Nash equilibrium is neutral about the equilibrium that will occur in a game with many equilibriums. The solution is sometimes given by ***focal points*** (a term used by Schelling, 1960). These are strategy combinations (e.g. one of the available Nash equilibriums), which for some reason are more compelling and give a more likely prediction of the actual outcome among numerous Nash equilibriums. The focal points may be provided by past history or some special characteristics of the specific combination [1].

In the absence of focal points, mediation and communication are important (Rasmussen, 2001). If the players cannot communicate, a mediator may be able to suggest an equilibrium. In the above example, a well-informed mediator could provide this service to the shipowners and charge for it. This idea could justify the existence of such professional agents in the LNG market.

"Cheap talk" is a term to describe costless communication before a game. Many rounds of announcements before the final decision increase the chances of the shipowners' coming to an agreement and can help reduce inefficiency, even if the two players are in conflict. In ranked coordination above, cheap talk might allow the players to make the desirable outcome a focal point.

[1] Such as psychological reasons especially in social sciences' applications.

3.2 Dynamic Games

Dynamic games have the element of timing, so that players are able to observe the actions of competitors before deciding upon their optimal response. Dynamic games can also be one-off games repeated a number of times, so that players observe the outcome of previous rounds. Dynamic games are represented in ***extensive form***.

Dynamic one-off (or one-shot) games are addressed using the concepts of ***subgame perfect Nash equilibrium*** and of ***backward induction***. Infinitely repeated games allow Pareto-efficient outcomes different from an expected Nash equilibrium. In finitely repeated games, the so-called backward induction paradox suggests that a non-cooperative collusion outcome is not possible. Several concepts are used to overcome this paradox, such as bounded rationality, the existence of multiple Nash equilibriums, uncertainty about the future and about other players in the game. The introduction of the ***Bayesian subgame perfect Nash equilibrium*** is often required.

A commitment that eliminates flexibility as a source of advantage

Consider again the strategic context depicted in Table 2 in normal form. This time, however, the situation is modelled as a dynamic or sequential game, where S1 (player 1) chooses his action first, while S2 (player 2) observes this action and responds next. This dynamic game can be represented in extensive form as in Figure 2.

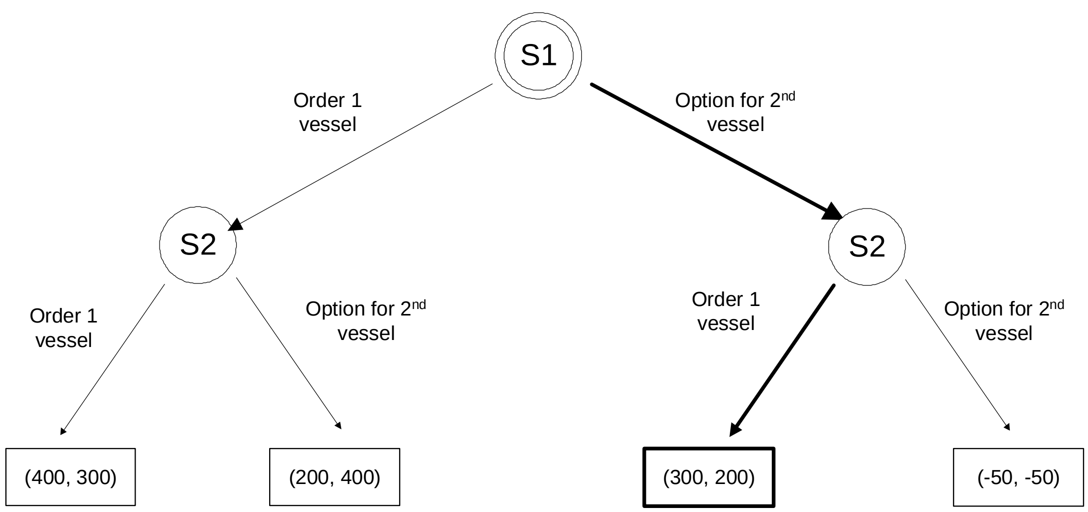

Figure 2: Eliminating flexibility can be good

Since S1 has two possible actions (and so does S2), S2 has four (2 x 2) strategies. These can be coded as: a) always exercise option for 2nd vessel, b) always order 1 vessel, c) same action as S1, and d) opposite action than S1. Then the extensive game can be represented in normal form as in Table 7.

Table 7: The dynamic game in normal form

Pay-offs		Shipowner 2: always exercise option for 2^{nd} vessel	Shipowner 2: always order 1 vessel	Shipowner 2: same action as S1	Shipowner 2: opposite action than S1
Shipowner 1	Order 1 vessel	(<u>200</u>, <u>400</u>)	(<u>400</u>, 300)	(<u>400</u>, 300)	(200, <u>400</u>)
	Exercise option for 2^{nd} vessel	(-50, -50)	(300, <u>200</u>)	(-50, -50)	(<u>300</u>, <u>200</u>)

In the above normal form representation of the game, the Nash equilibriums can be identified. First, for each player the optimal strategy (action) in response to what the other player might do (the relevant pay-off is underlined) is identified. A Nash equilibrium exists when both players play their optimal strategies simultaneously. Therefore the two Nash equilibriums are:

1. S2 threatens to always exercise option for 2^{nd} vessel. In response to this, S1 orders 1 vessel.
2. S2 promises to choose the opposite action than S1 (this is a conditional strategy on S1's strategy). S1 chooses to exercise the option for 2^{nd} vessel.

However, not all promises or threats made by S2 are credible. The issue of credibility arises when a player makes a threat or promise. A strategy is credible only if a player has an interest in carrying it out, when the time comes. For example, in the above example the threat of S2 of always exercising the option for 2^{nd} vessel is not credible, because if S1 chooses to exercise the option for 2^{nd} vessel, S2 will prefer to order 1 vessel (and have a pay-off of 200, rather than -50). This idea is incorporated in the concept of subgame perfect Nash equilibrium.

Subgame perfect Nash equilibrium requires that the predicted solution to a game is a Nash equilibrium in every subgame, that is every player must act in his own interest in every period of the game. This concept rules out equilibriums that involve incredible threats or promises. In the above example, the only subgame perfect Nash equilibrium is the one where S1 chooses to exercise option for 2^{nd} vessel and S2 responds with the opposite action.

The same result can be reached by using the concept of backward induction, which is the application of iterated strict dominance to dynamic games in extensive form. Starting from the last period in Figure 2 and working backwards through successive nodes until the beginning of the game, actions that players would not play because other actions give higher pay-offs are ruled out.

The equilibrium outcome is (300, 200) i.e. the 2^{nd} best payoff for S1 and the 3^{rd} best payoff for S2. Compared to the static game of Table 2: An asymmetric investment situation, S1 achieves a better payoff by ***"burning the bridge"***: his move to exercise his option is a commitment that eliminates his flexibility, yet forces the outcome of the game (as it leaves S2 with no actual option). So, the elimination one's own flexibility can become the source of advantage.

Moving first can create an advantage or give away information

If one of the players has the opportunity to move first, then the outcome of a game can be greatly influenced. If in the static game depicted in Table 3: Anticipating the competitor's preferences, a player had the opportunity to choose first (a dynamic game), then he would clearly have a first-mover advantage. His commitment would force the choice of the other player.

On the other hand, in the static game depicted in Table 2: An asymmetric investment situation, if S1 could move first (i.e. a dynamic game), then the outcome (Y1, Y2) would also become an equilibrium outcome. In this case, the player who moves first gives away valuable information to the other player, before the latter acts.

Repeated games

The above-discussed can be categorised as one-off dynamic games. Another category of dynamic games are repeated games. Game theory discusses both infinitely and finitely repeated games.

Infinitely repeated games are a rather theoretical concept. A relevant discussion could possibly apply to a more flexible LNG shipping market. Instead, the current initial stages of the LNG market involve large scale investments and strategic positioning of the players. The main theoretical conclusion regarding infinitely repeated games suggests that it is possible for the involved players to coordinate their actions on the Pareto-optimal outcome (e.g. in a Prisoner's Dilemma interaction repeated infinitely). By adopting credible punishment strategies, the players can learn to coordinate their actions in non-cooperative collusive outcomes and avoid inferior outcomes (Romp, 1997).

Paradoxically, the above conclusion cannot be reached in finitely repeated games, such as a game with a unique Nash equilibrium, which is repeated a finite number of times. Using backward induction, in the last period the outcome will be the unique Nash equilibrium (exactly as in a one-off game). In the penultimate game, players will again play the unique Nash equilibrium, as there is no threat of punishment in the last game. In a similar fashion, the first period is reached and in all stages the unique Nash equilibrium will have been played. The subgame perfect Nash equilibrium for the entire game is the Nash equilibrium of the stage game played in every period. This argument suggests that a non-cooperative collusive outcome is not possible.

The above result is known as the paradox of backward induction, as it is in contrast with what infinitely repeated games suggest. The reason is that a finitely repeated game is qualitatively different from an infinite game (Romp, 1997). The structure of a finite game changes as the final period is approached, which does not happen in an infinite game.

A number of ways have been suggested to overcome the paradox of backward induction. The introduction of bounded rationality allows players to be rational, but only within certain limits. The existence of multiple Nash equilibriums in the stage game can also overcome the backward induction paradox, as there is no unique prediction about the last period of play. Uncertainty about the future, such as uncertainty about when the game will actually end, can also overcome the paradox. In this case, players can place credible threats and promises because there is only a possibility and not a certainty that the game will end in the next period.

Uncertainty about other players in the game exists when at least one player does not know how the other players in the game are like in terms of their pay-off functions (a game of incomplete information). Such games of incomplete information can be transformed into games of complete but imperfect information by introducing the player "Nature", which determines each player's type according to a probability distribution. Because information is an important element in games, relevant concepts are discussed separately in the following section, where the relevance of incomplete information to overcoming the backward induction paradox is also explained. It will be shown that a new concept is required, namely the Bayesian Subgame Perfect Nash Equilibrium.

3.3 Information – Bayesian Games

The previous strategic situations are modelled as cases of complete information, where all players know everything about each other. However, in the real world this is not usual. In game theory, games of imperfect information are distinguished from games of incomplete information.

In games of imperfect information, at least one player is not aware of all the moves of other players in past or current periods (i.e. at which node of the game he is situated)[1]. In an incomplete information game, the pay-offs of the game are not common knowledge to all players. Incomplete information games can be modelled as complete but imperfect information games by introducing "Nature" as a player. A strategic game with imperfect information is called a Bayesian Game.

Static games of incomplete information

First, the above concepts are illustrated by considering static games of incomplete information. Players move simultaneously, so no player has the opportunity to react to another's move (the inferences made by players about their opponents' types are not of concern, because all actions are taken before any actions are observed) (Tirole, 1992).

It is considered that Shipowner (2) does not have a clear picture of the market potential of Shipowner (1) i.e. of his payoffs (an incomplete information game). Referring to Table 8 (based on the strategic interaction depicted in Figure 2), S2 may be able to achieve the payoffs shown in the top table (Type A) or the ones in the bottom table (Type B).

[1] In this sense, static games are by definition imperfect information games.

Table 8: A Bayesian Game

"Nature" → q → Shipowner 1 Type A; 1-q → Shipowner 1 Type B

Pay-offs		Shipowner 2: Order 1 vessel	Shipowner 2: Exercise option for 2nd vessel
Shipowner 1 Type A	Order 1 vessel	(400, 300)	(200, 400)
	Exercise option for 2nd vessel	(300, 200)	(-50, -50)
Shipowner 1 Type B	Order 1 vessel	(200, 300)	(100, 400)
	Exercise option for 2nd vessel	(300, 200)	(150, -50)

In this game of incomplete information, S2 is not aware of S1's type (or in other words, S2 does not know which game he is playing). This game can be transformed into an imperfect information one by introducing "Nature" as a player who assigns the type of S1 with a certain probability (q for type A and 1-q for type B).

Finding the solution to this game is easy, as both types A and B of S1 have a dominant strategy: "Order 1 vessel" and "Exercise option for 2nd vessel" respectively. The expected payoff of S2 for each of his possible actions is:

1. for "Order 1 vessel": q x 300 + (1-q) x 200 = q x 100 + 200 and
2. for "Exercise option for 2nd vessel": q x 400 + (1-q) x (-50) = 450 x q - 50

Therefore, S2 will follow the "Order 1 vessel" strategy, only if q x 100 + 200 > 450 x q - 50 => q < 5/7. If q>5/7, S2 will prefer the "Exercise option for 2nd vessel" strategy and if q=5/7, he will be indifferent between the 2 actions.

The expected payoff for each of S2's action when e.g. q=50% is estimated as:

1. For "Order 1 vessel": 0.5 x 300 + 0.5 x 200 = 250 and
2. for "Exercise option for 2nd vessel": 0.5 x 400 + 0.5 x (-50) = 175.

Therefore, S2 will follow the "Order 1 vessel" strategy and the resulting outcome of the game will be (400, 300) or (300, 200) with probability 50% each i.e. the expected payoffs are (350, 250).

The above equilibrium is often called Bayesian equilibrium and constitutes a generalisation of Nash equilibrium for games of incomplete information. In a Bayesian equilibrium a player anticipates an appropriate strategy in response to the possible types of the other player.

Players in games of incomplete information with Bayesian equilibrium may achieve Pareto-efficient solutions. This is demonstrated in the following game that overall has two Nash equilibriums, of which only one is Pareto-efficient.

Table 9: A Bayesian Game leading to a Pareto-efficient outcome

"Nature"	Pay-offs		Shipowner 2: Increased presence	Shipowner 2: Limited presence
q	Shipowner 1 Type A	Increased presence	(400, 400)	(600, 300)
		Limited presence	(300, 400)	(500, 500)
1-q	Shipowner 1 Type B	Increased presence	(0, 400)	(200, 300)
		Limited presence	(300, 400)	(500, 500)

S1 and S2 have to decide on the level of their presence in a certain geographical area. For type A of S1 a Prisoner's Dilemma game is played[1]. Type B of S1 has a competitive disadvantage in capturing a market share in this geographical area (lower table of Table 9). Both types A and B of S1 have a dominant strategy: "Increased presence" and "Limited presence" respectively. However, S2 is not aware of the type of S1.

The expected payoff of S2 for each of his possible actions is:

1. for "Increased presence": q x 400 + (1-q) x 400 = 400 and
3. for "Limited presence": q x 300 + (1-q) x 500 = 500 – 200 x q

Therefore, S2 will follow the "Increased presence" strategy, only if 400 > 500 – 200 x q => q > 50%. For q < 50% and type B of S1 the Pareto-efficient outcome (500, 500) can be achieved.

Dynamic games of incomplete (or imperfect) information - Bayesian Subgame Perfect Nash Equilibrium

In dynamic games of incomplete (or imperfect) information, a player who reacts to another player's move can first extract information from that move. If an incomplete information game is repeated a finite number of times, a Pareto-efficient outcome will not necessarily be achieved in every stage because of two basic complications (Romp, 1997):

1. In dynamic games of incomplete information, players may be able to learn what other players are like by observing their past actions. Given this, a player might seek to conceal his true identity by playing accordingly, so as to create a reputation for something he is not. This may be costly in the short-run, but may bring higher future pay-offs.
2. Players are aware of the above complication and this influences how they update their probability assessment of the other player's type conditional on his actions.

These complications are addressed using the notion of Bayesian Subgame Perfect Nash Equilibrium, which satisfies two conditions:

[1] It is suggested that a limited presence of both shipowners results into a Pareto-efficient outcome, as the availability of LNG shipping services are constrained and higher charter rates can be achieved.

1. Only credible threats or promises are acceptable (subgame perfect)
2. Players update their beliefs rationally according to Bayes' Rule.

Under the Bayesian subgame perfect Nash equilibrium, players hold prior beliefs about the other players' types and as they see them take actions, they update their beliefs according to Bayes's Rule[1] (under the assumption that they are following equilibrium behaviour). Small amounts of uncertainty regarding the type of the other player can be greatly magnified in repeated games and this leads to the prediction that the Pareto-efficient solution will only be reached in the early stages of a game. Such an approach allows overcoming the backward induction paradox, at least partially i.e. in the initial stages.

This concept suggests that the assumption of common knowledge of rationality may be inappropriate. Instead, it introduces incomplete information in the form of uncertainty regarding the rationality of other players. Players are unsure whether their opponent is rational.

Illustration: Signalling in a two-period reputation game

The above concepts are illustrated in the following simplified two-period reputation game (adapted from Tirole, 1992). Two shipowners S1 (the incumbent) and S2 (a recent entrant) are offering LNG shipping services in the same geographical area (e.g. exploiting opportunities in a growing short-term market in the Atlantic Basin).

Their interaction takes place in two periods. In the first period, S1 only moves by either fighting[2] S2, or accommodating the presence of S2 (taking no action). S1 can be of two types, Type 1 ("rational") with probability p and Type 2 ("irrational") with probability 1-p. Type 2 always decides to fight (several interpretations of "irrationality" were earlier discussed). In the second period, S2 responds by either staying in the market or exiting the market.

The game is represented in extensive form in Figure 3. Regarding the pay-offs, it is M1>H1>L1 and H2>0>L2, with a discount factor d between the two periods. If S1 chooses to accommodate, S2 will stay in the market. The question is what happens when S1 chooses to fight. The dotted line, connecting S2's decision nodes in this case, signifies that S2 cannot distinguish in which node he is actually situated after S1 plays "fight" (an

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[1] Bayes's Rule (or Theorem): $E_1, \ldots, E_N$ are N possible states and an event F is a signal. Bayes' rule can be used to find the probability P of a state E_K given the observed signal F (probability of E_K conditional on F), as:

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

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

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

incomplete information game, modelled as an imperfect information game by introducing Nature as a pseudo-player at the beginning).

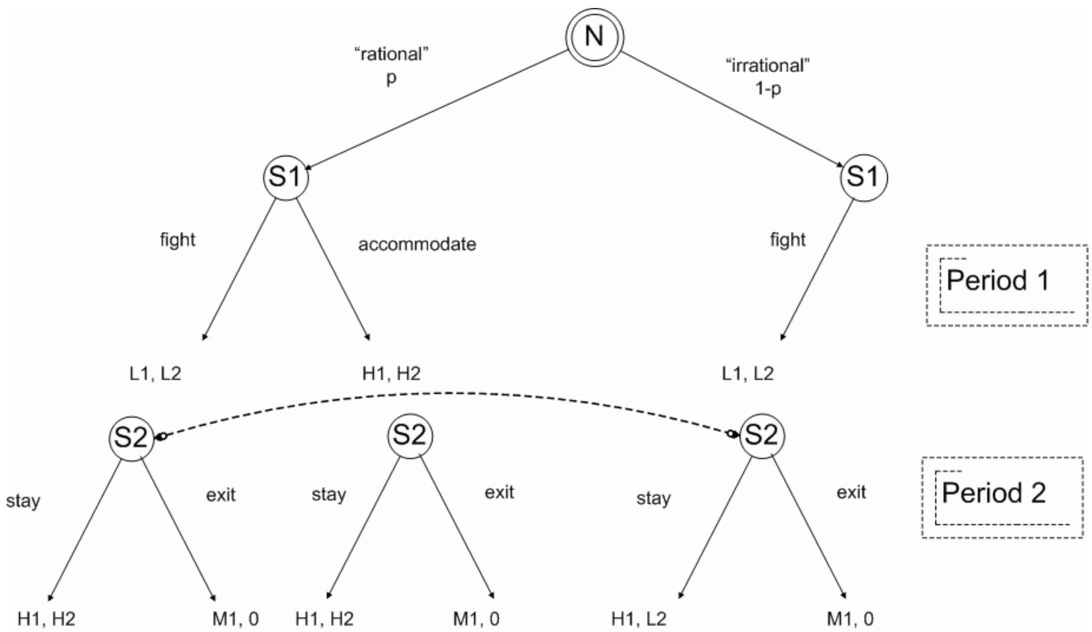

Figure 3: A two-period reputation game

In the first period, a rational S1 prefers to accommodate (H1>L1). However, most of all S1 would prefer to be a monopolist and gain M1 in the second period. So, a rational S1 by fighting in the 1st period can send a "signal" that may convince S2 that he is irrational (S1 creates a "reputation") and make S2 exit the market in the 2nd period (as L2<0, on the right bottom side of Figure 3), while S1 increases his profit to M1.

In period 2, if S2 stays, he gets H2 if S1 is rational or L2 if S1 is irrational. The reason is that if S1 is rational, he will not pursue a predatory strategy in period 2, as there is no point in building or preserving a reputation then. Next, the possible equilibriums are considered.

In a ***separating equilibrium***, S1's two types would choose a different action in the 1st period (a rational S1 chooses accommodate only for example). In this case, S2 has complete information in the 2nd period. If P is S2's posterior (2nd period) belief about S1's type, then:

- P(rational | accommodate) = 1
- P(irrational | fight) = 1

In a ***pooling equilibrium***, S1's two types choose the same action in the 1st period (the rational S1 fights too). In this case, S2 does not update his beliefs, when observing S1's equilibrium action:

- P(rational | fight) = p

In a ***hybrid or semi-separating equilibrium***, a rational S1 randomises (or places a probability) between the two available actions to him and P is given by Bayes' Rule:

- $P(\boldsymbol{rational} \mid \boldsymbol{fight}) = \dfrac{P(\boldsymbol{fight} \mid \boldsymbol{rational})\ \boldsymbol{p}}{P(\boldsymbol{fight} \mid \boldsymbol{rational})\ \boldsymbol{p} + P(\boldsymbol{fight} \mid \boldsymbol{irrational})\,(1-\boldsymbol{p})} < \boldsymbol{p}$

  as P(fight | irrational) = 1

- P(rational | accommodate) = 1

Using Bayes' Rule, S2's belief (prior) about S1's type is updated following S1's move (the posterior belief is P < p after the choice "fight" by S1).

In the separating equilibrium of the game, S1 accommodates when rational and reveals his type. S2 responds by staying in the market. S1's total pay-off is H1(1+d). If S1 fights, then he convinces that he is irrational and S2 exits. S1's total pay-off is L1+d M1. For S1 to decide to accommodate, the necessary condition is:

$$\boldsymbol{H}1(1+\boldsymbol{d}) \geq \boldsymbol{L}1 + \boldsymbol{d}\,\boldsymbol{M}1 \Rightarrow \boldsymbol{d}\,(\boldsymbol{M}1 - \boldsymbol{H}1) \leq \boldsymbol{H}1 - \boldsymbol{L}1 \qquad \text{(a)}$$

So if (a) holds and S1 fights then S2 realises that S1 is irrational and exits the market.

In the case of a pooling equilibrium, both types of S1 choose to fight. The probability that S1 is rational is p, as it was explained. A rational S1 will fight and loose H1-L1 in period 1, hoping to make S2 exit the market and have an equilibrium pay-off of L1+d M1. For S2 to decide to exit the market, the necessary condition is:

$$\boldsymbol{p}\,\boldsymbol{H}2 + (1-\boldsymbol{p})\,\boldsymbol{L}2 \leq 0 \qquad \text{(b)}$$

So, if (b) holds and S1 fights, then S2 exits the market (moreover if (a) is violated, a pooling equilibrium occurs).

If both (a) and (b) are violated, then, under a hybrid or semi-separating equilibrium, S2 updates his belief about S1 according to Bayes' Rule, when observing "fight", and randomises his responses accordingly.

4. CONCLUSIONS

In this paper, a conceptual introduction to a game theoretic analysis of competition in LNG shipping was attempted. The purpose was to familiarise the reader with an approach of giving to a strategic interaction in the LNG shipping business the form of an appropriately defined game, rather than produce readily exploitable results.

The elements of this game that need to be identified are first of all the involved players. From the view of a LNG shipping company, some players at some stage will complement it, while may compete with it at another stage. The players' added value determines their competitive position in the overall game. The rules define the balance of power between players, and it was suggested that the LNG shipping business model changes from a static to a dynamic one. The beliefs of players (their perceptions of the game) determine their tactics. The game-theoretic model must remain simple enough to reach conclusions of practical nature. Finally, the rationality of players can be interpreted as the degree of their understanding of the market dynamics, opportunistic behaviour, or limited information.

By analysing static game situations, it was shown how investors in LNG shipping can be trapped in a panic equilibrium; the reasons they may have to let a competitor assume a leading position in a market; the importance of appreciating the preferences of the competitors and how to face uncertainty; the possible existence of multiple equilibriums and the importance of mediation or communication in this case.

Extending the discussion to dynamic games, it was demonstrated how less flexibility can be advantageous, the first-mover advantages and disadvantages and the basic concepts underlying repeated interaction.

The parameter of information and the concepts of incomplete and imperfect information were later introduced. Static games of incomplete information can lead to efficient outcomes, while in dynamic games, the beliefs of players are updated by the signals other players send when they take actions. Reputation becomes important and can be used by players to their advantage. Some useful concepts that help decision-making in such occasions were developed.

The above illustrations of a game theoretic approach to LNG business strategic interactions demonstrate some useful insights. First, it is important to take into account the reaction of other market players when making a strategic investment. Decisions cannot be evaluated in isolation, when they have a significant impact on other market players and change their strategic positioning in the market. In this case, decisions will cause a strategic reaction which is quite likely to totally alter the strategic setting.

Second, it is equally crucial to understand the competitive setting of a given strategic interaction. Is the given interaction a case of a "Prisoners' Dilemma" or does a "Grab the Dollar" model better describe the competitive setting? Is this a simultaneous decision process or is a dynamic interaction possible, where "Burning the Bridge" advantages can be exploited? These are fundamental distinctions that require market understanding and knowledge.

Finally, information availability regarding the "types" of the involved players is important. Incomplete information games can be modelled as imperfect information games, but again the outcome of the analysis depends on the values to be assigned to the probability parameters of player "Nature". Knowledge of the market reality and dynamics are again of decisive importance for a reliable prediction by the strategic model.

The game theoretic treatment of the LNG shipping business that has not been covered in the present paper, yet has been developed in the context of the present research, addresses oligopolistic competition over continuous decision variables, namely quantity and price. The Cournot / Stackelberg and Bertrand competition models have been used respectively and the possibility of non-cooperative collusion have been examined. Also, the strategic value of early commitment (or why ordering uncommitted vessels in the LNG market may be justifiable) and entry deterrence strategic interactions in the LNG shipping market have been analysed.

Overall, game theory can be a useful supplement to the intuition of a market player in the LNG shipping business, as it helps in identifying right strategies given certain conditions. This is a required step towards making right decisions.

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