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Coopetitive Games for Management of Marine Transportation Activity: A Study Case

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Abstract: In this paper, we will use coopetitive game theory to analyze a case of real coopetition among port companies, for what concerns loading and unloading of goods, within a competitive management scenario of marine transportation activities. Our research consists of the analysis of a study case involving coopetition between two real companies from which we obtained the financial and contractual data allowing us to define two modeling payoff functions, both of them based on real agreements and tariffs. We recognize actual coopetition and an asymmetric R&D alliance in this type of agreement, where a bigger enterprise deals with a smaller competitor, in order to capture more value from their activities. In particular, our model will show a precise coopetitive bi-dimensional trajectory within which we suggest, after a quantitative analysis, different kinds of solutions: the purely coopetitive solution, a Kalai-Smorodinsky solution and, finally, a transferable utility Kalai-Smorodinsky solution. Our methods provide specific strategy procedures determining win-win solutions for both.

Keywords: game theory; non-cooperative games; coopetition; management of marine transportation activity; R&D asymmetric alliance

1. Introduction

The complexity of reality brought the economic and competitive research to the analysis of new forms of competition. One of these phenomena (appeared in reality before research) is the so-called Coopetition. Many studies have been conducted [1–4] in a range of almost twenty years, and this particular relationship has become an attractive field for researchers ranging from game theory studies, to economics, to business administration, and so on.

1.1. Scope of the Paper

This study uses game theory to analyze a very specific case of marine transportation coopetition; however, the analysis itself and the methodology used here could help in more general contexts. The scope in our research consists in the study of a real coopetition interaction between two marine transportation companies, which needed a clear quantitative analysis of the possible agreement scenarios, a clear understanding of how much that coopetition agreements would have been capable to enlarge the pie of possible profits and, finally, a clear acceptable quantification of the fair distribution of gains through a binding contract.

We interviewed the two CEOs companies, in order to obtain the financial and contractual possible data that allowed us to formulate a game model and to define two payoff functions, both of them based on possible real agreements and tariffs. We will recognize a case of asymmetric coopetition in this possible agreement, where a bigger enterprise deals with a smaller one, and in which the small company needs a contractual incentive in order to stipulate the contract. This contractual incentive should guarantee, for the smaller company, a final payoff exceeding—of a certain amount to be determined—the gain offered by the best possible coopetitive Nash equilibrium.

We desire to recap the necessity of our quantitative intervention in order to determine:

- the set of all possible payoff scenarios;
- the set of all Nash equilibria in those possible scenarios;
- the best possible Nash equilibrium with associated payoff;
- a fair possible division of the gains, guarantying the incentive to the smaller enterprise in order to sign the contract and the maximum collective gain obtainable from the coopetitive agreement.

1.2. Structure of the Paper

This paper can be divided into five main sections:

- the first one where we review the literature on coopetition and management of port activities and we explain the scope of the paper and the scientific relevance also for other fields of applications;
- the second one where we remind the game theory methods used in our quantitative analysis;
- the third one where we describe the study case (the agreement, the enterprises involved), and we study the associated coopetitive game and possible commercial policy implications;
- the fourth one where we discuss about the use of transferable utility selection;
- the last one, where we recapitulate and explain the results of the coopetitive game.

1.3. Literature Review on Coopetition

The concept of coopetition has been studied from several points of view by a variety of authors [1–4]. Even though the literature on this subject is recent and also very fragmented in several flows of study, the first time that the term appeared was in an article written by Cherington in 1913 [5]. However, it was brought to public discussions and research by the book "Co-opetition" written by Brandeburger and Nalebuff (B/N from now on) in 1996 [6]. The purpose of the book was to use the concepts of competition and cooperation in business networks using the tools of game theory. Even if this publication is of pivotal importance for the research on coopetition, it was written for non-professional readers. Even so, it had a big resonance on the literature on the subject, giving birth to the stream of literature that uses game theory to analyze this phenomenon.

Bengtsson and Kock distinguished the existing literature on coopetition using the aggregation level as a discriminant [7]. They individuated individual level, organization level, inter-organizational level, and inter-network level.

Studies on the individual level focus on how individual motivations stimulate actors to compete, even if they actually trust each other [8]. At this level, the heart of the discussion on the outcome of the coopetitive relationship is the knowledge sharing and the group performance [9,10].

Research on the organizational level study the impact of coopetition on the business units or teams, highlighting how knowledge sharing varies within the organization. In this context, Luo [11] argues that various infrastructural systems permit units to collaborate, while simultaneously competing with each other.

The inter-organizational level is the most interesting and studied of all. The outcomes of coopetition in this case are multifaceted and there are four possible outcomes that can be found in this research stream [12]: increased competitiveness and competitive advantage, developments in technology innovation, examination of international opportunities, and access to needed resources.

This level of analysis is the most interesting because it involves the study of the cases where the players in the coopetitive relationship are competitors in the most restrictive definition of the term (on the contrary, B/N for example, gave a broader definition of "competitor" in their study, in order to comprise more cases).

At last, according to Bengtsson and Kock [7], only a few studies have been conducted on the network level.

Another important distinction in the literature on coopetition regards the dynamic view of the subject. Authors showed two different points of view: the contextual argument and the process view.

The contextual argument focuses on how the competitive and cooperative dynamics in the environment influence the organizations' behavior, determining whether or not they will engage in coopetitive relationships [13]. In this view, competitors could cooperate with each other to compete with a third party, so that coopetition is one of the contextual characteristics that influence firms' behaviors.

The process view, on the other side, define coopetition as the "paradoxical relationship between two or more actors simultaneously involved in cooperative and competitive interactions, regardless of whether their relationship is horizontal or vertical" [2]. This perspective could be classified into two different approaches based on whether coopetition should be considered a process happening on a single continuum (ranging from competition to cooperation), or on two separate continua [14]. The single-continuum approach takes not into account the interactions involved in any coopetitive inter-relation, while the two-continua approach shows how competition and cooperation can be considered as two different types of interactions running together within a coopetitive relationship [15]. This line of thinking points out that different levels of competition and cooperation can exist in a coopetitive relationship.

1.4. Literature Review on Management of Transportation Activities in Ports

Various papers deal with competition among ports for port policy and their management [16]. We have considered also scientific works about value creation in ports [17] and about game theoretical approaches to competition between multi-user terminals and related impacts of dedicated terminals [18]. We have also considered literature about the following: societal costs and benefits of cooperation between port authorities [19]; cooperation and competition in international container transport and decision strategies for ports [20]; competition and cooperation between Shanghai Port and Ningbo-Zhoushan Port [21].

In the above cases, the game theory models reveal no simultaneous management of competition and cooperation. On the contrary, here, we propose a possible generalization of non-cooperative games in order to contain, within a competitive structure, a sufficiently flexible, manageable, and efficient idea of cooperation, with all the necessary modifications at the level of analysis and solutions. In our study, we enlarge the capacity of classic game theory by allowing the simultaneous dynamical coexistence of competition and cooperation.

We have also analyzed some papers about examinations of operational loading and unloading equipment in sea transport [22], with relative cargo loading and unloading efficiency study in transportations [23] and, finally, we studied some reports about optimal operations of transportation fleet for unloading activity at container ports [24].

For what concerns the use of coopetition in marine transportation, we refer also to [25–27]. In the above models, we see a wide field of applications. Our approach is new with respect to the above models because it uses a specific structure of coopetitive game defined as a continuous family of non-cooperative games labeled by a cooperative parameter. In particular, we observe a main difference between our solutions and the solution found in paper [27], where the authors are searching for a form of equilibrium by optimization, while our method suggested a transferable utility solution determined by a Kalai-Smorodinsky selection procedure.

1.5. Possible Developments of the Model Proposed

We wish to emphasize that the present model, and its immediate generalizations, can design and solve different questions for cooperation at individual and social levels. The mathematical model of coopetition we propose (a continuous family of non-cooperative games indexed by a cooperative parameter) is capable of addressing various general problems such as health problems in a human population, environmental problems, economic crisis, problem of crimes and conflicts, and the problem of green energy developments and uses, as we will specify better in Section 2.2.

2. Methods

In this study, we consider the coopetition as a complex quantitative relationship between competition and cooperation. A formal game structure will permit the above antipodal behavioral ways to co-exist and interact dynamically; therefore, our mathematical modeling considers and manages those behavioral strategies simultaneously in a game extended architecture.

2.1. Quantitative Methods and Classic Decision Theory in the Applications: A Critical View

We desire to underline the importance of quantitative methods and game theory in the applications to economic studies, and not only. In our paper we follow a line similar in philosophy to a wide literature using quantitative methods, statistical physics and decision theory, to analyze situations of conflicts, social dilemmas and socio-economic interactions. In terms of applications of classic game theory and statistical physics, without coopetition, recent works have demonstrated applicability:

- for human cooperation in social physics [28];
- for human cooperation in statistical physics [29];
- for optimal vaccination strategies [30];
- in the combating of crime and improving human lives in general [31];
- in saving human lives [32];
- in conceiving speculative and hedging decision models in financial markets [33];
- in optimal dosage of drugs [34,35].
- in financial market transactions [36–39].

In all the above cases mathematical and statistical physics models (also based on game theory and decision theory), have played a pivotal role in the application to the specific problem and have offered a rich history of applications.

Nevertheless, classic game theory and decision theory (also theory based on statistical physics) reveals a bit unprepared in the simultaneous management of two antipodal ideas along which a game could be analyzed and solved [40]. The two opposite approaches are competition and cooperation. Indeed, the two fundamental approaches have generated two different mathematical definitions of game, the non-cooperative games and the cooperative games.

The two decision structures reveal completely different, from a mathematical point of view, and both hardly capture the reality of an economic and social interaction.

In the following subsection, we propose a possible generalization of non-cooperative games in order to contain, within a competitive structure, a sufficiently flexible, manageable and efficient idea of cooperation, with all the necessary modifications at the level of analysis and solutions.

2.2. Coopetitive Game Theory in Applications

In our study, we enlarge the capacity of classic game theory by allowing the simultaneous dynamical coexistence and design of competition and cooperation at the same time. Effective examples of this new—more comprehensive and complex—approach, applied in several fields of economics, are listed below, where the coopetitive games are conceived for:

- general management [41];
- sustainability of natural resources [42];
- green economy and green technologies [43,44];
- mitigating climate change [45,46];
- political economics [47,48];

- industrial ecology [49];
- biopharmaceutical industry management [50];
- financial market transactions [51,52];
- social interactions [53];
- supply chains [54].

We will use the new model of coopetition, as a generalized normal form game, introduced by David Carfì [55,56].

3. The Case Study: A General Analysis and Resolution

3.1. General Presentation of the Players

We consider the case of two existing stevedores operating on the same market in the same territory. A stevedore deals with every activity concerning with the loading and unloading operations of cargo ships arriving in port, both for the import and export phases.

In particular, these enterprises manage the sequent operations in the import and export phases respectively (see Table 1):

Table 1. Operations of import and export of the two enterprises.

Import	Export
Notice of ship's arrival	Request to ship
Clearance	Cargo availability
Handling board-quay	Stowage of the finished products on transports
Stowage of the goods on transports	Forwarding of the goods to the quay
Forwarding of the goods to the factory	Receptions of the goods and storage in the quay
Delivery to the factory	Handling quay-board, lashing and stowage
Issuing of Documentation	Issuing of Documentation
Billing	Billing
File closing	File closing

These two Stevedore Companies we analyzed, are naturally competitors for the same market, but at a certain point, they decided to cooperate in order to manage the demand from a big foreign client that they would have not be able to accept individually. It is important to notice that the first company (Enterprise A from now on) is bigger and with a greater financial power than the second one (Enterprise B from now on). Thus, we can consider this a case of asymmetric coopetition.

Enterprise A has a developed commercial division, and has a higher degree of correlated diversification of the activities than Enterprise B. A has the capacity to attract and retain this kind of client, while B is smaller and less structured with low commercial competences.

Enterprise A cooperates with the competitor B to maintain higher flexibility in the port sector, in order to reduce the risk concerning this activity.

Enterprise B, on the other side, cooperates with the competitor A to take advantage of its commercial and bargaining power on the market, to obtain part of the organizational and managerial know-how of A that has more experience in the field.

3.2. Specific Decription of the Two Enterprises

Our two enterprises, Free-lines & co S.r.l. (Enterprise A) and Planet Transport Company Mediations S.r.l. (Enterprise B), work in the areas of Milazzo (Sicily/Italy) and Messina (Sicily/Italy), respectively.

In particular, the first one is located in the north of Sicily about 60 km west of the Messina Strait (harbour position: Lat. 38°13′00″ N, Long. 015°14′30″ E) and the company counts around 100 employees, operates mainly in Italy with some occasional assignments out of the Country. One of the activities that are part of this enterprise is stevedoring, the one involved in this study. Principal activities are fast ferry connections with the Aeolian Islands, break bulk cargo, principally steel products, liquid petrochemical products. Moreover, the Enterprise A offers the services of: port agency; crew change; customs clearance; documentation storage; stores and provision; bunkering; launch services; de-slopping; repairs; supplies of bunker fuels, lubricants and chemicals; communications assistance; in/outward clearing of ships and loading and unloading cargos. The average cost of loading and unloading cargos is 10 euros per 1 ton (it depends on the transported good).

The Planet Transport Company Mediations S.r.l. was formed in 1995 by a group of professionals in the maritime sector with the purpose of the production of all services related to maritime activities, mobility of goods and people in general, both nationally and internationally. The company counts around 20 employees including administrative personnel. Planet is the first enterprise for handling of goods at the port of Messina and Milazzo, but, as write above, is smaller and less structured than Free-lines & co S.r.l., with low commercial competences. With the experience and expertise gained from years of activity is able to provide a wide range of specialized services, performed with advanced machines and equipment.

Enterprise B is located in Messina (harbour position: Lat. 38°11′38″ N, Long. 15°33′09″ E) and its principal activities, certified by RINA, are service delivery management of marinas, service delivery management cruise terminal, service delivery of multimodal logistic operator, shipping customs, domestic and international shipments, service delivery management platform RO-RO vessels. Moreover, the Enterprise B operates as port company, managers of stores and bonded warehouses, customs agents, shipping agency, management docks, commercial and tourist, management passenger terminal, multimodal logistic operator, international shipping, maritime, land, aerial, railway, multimodal intermodal. The average cost of loading and unloading cargos is 10 euros per 1 ton (it depends on the transported good).

3.3. Agreement

Enterprise A, shipping enterprise and stevedore operator, acquires an important and international client, whose needs requires taking huge investments, so it stipulates an agreement with B, that is also a stevedore operator (and competitor) and with its support A is able to maintain the necessary flexibility to stay competitive on the market, avoiding to employ new staff and the investment in long-term assets whose cost should be amortized in several years, risking to come in the position of selling the assets under unfavorable conditions.

For what concerns the specifics of the agreement, it establishes that B provides:

- Labor and cranes for the traffic of raw materials
- Labor, cranes and handling on the quay for the traffic of finished products.

A buys these services from B at a determined price, and then bill them to the client as cost items that contribute to the rate composition for the client, with a mark-up for B. The mark-up for these services will be the only source of income in the operation for Enterprise B.

Enterprise A will handle, instead, the providing of: transport on trucks, marking of raw materials, cuts, custom operations and dunnage for storage, for the raw materials traffic; dunnage use, transport on trucks, custom operations and assistance and issuing of custom documents, for the finished products traffic.

Remark 1 (Convenience considerations). *The main issue that Enterprise A had to face in the agreement was the need for additional workforce in order to satisfy the request of the client that would have burden it with additional employees (which would have had a big impact on liquidity and financial flows). The main issue that Enterprise B had to face was its ability to reach and negotiate with big international clients, and competition from bigger companies (like Enterprise A) that was able to set better tariffs on the market. Compared to 2011 (year of the study), Enterprise A is still operating as before. Enterprise B had needed a restructuring to ensure operations and continuity of the business. The agreement we have proposed by our model is still in place, since 2011, in the same terms.*

The convenience of collaboration is evident for both the enterprises:

Enterprise A is able to manage the client anyway, but with high costs whose sustaining would make the use of borrowed capitals necessary;

Enterprise B would not have the commercial and organizational strength to manage the client on its own, because the annual traffic of raw materials and finished products would make its acquisition impossible without a proper supervision of both operations and customer care.

3.4. Coopetitive Model for Management

3.4.1. General Assumptions

Consider the enterprises A and B; each of them has a payoff function, denoted by f_1 and f_2, respectively. We shall specify the domains $\boldsymbol{E}$, $\boldsymbol{F}$ of these functions and their association law definitions, very soon. Each of the two enterprises practices an own stevedore activity; we shall consider the respective strategies of the two enterprises A and B, respectively, x in $\boldsymbol{E}$ and y in $\boldsymbol{F}$, and we shall assume these two possible strategies sets $\boldsymbol{E}$, $\boldsymbol{F}$ to be compact intervals of the real line.

Economic interpretation. $\boldsymbol{E}$ and $\boldsymbol{F}$ represent the set of possible annual tonnage of material traffic, of A and B respectively.

The two enterprises decide to collaborate for a client, and the cooperative strategy is a real number z belonging to $\boldsymbol{C}$, which represents the annual tonnage of material traffic of the common client, to be managed together, and the strategy set $\boldsymbol{C}$ will be assumed to be a compact interval of the real line.

3.4.2. Payoff Functions

We define the payoff functions of the game, in unit of 100,000 tons. 10 euros/tons, as follows.

Enterprise A. We assume the payoff function f_1 of the first enterprise defined on the compact interval $\boldsymbol{E}$ by the sum of the net gains (we consider the costs inside) deriving from the two activities minus an erosion coefficient times any strategy y of enterprise B, more specifically:

$$f_1\,(x, y, z) = \alpha_1 x - \beta_1 y + \gamma_1 z \qquad \text{(in unit 100,000 tons} \cdot \text{10 euros/tons)} \tag{1}$$

for any x in the strategy set $\boldsymbol{E}$ of enterprise A, for any y in the strategy set $\boldsymbol{F}$ of enterprise B, and for any strategy z in the compact, convex common strategy set $\boldsymbol{C}$ of the two enterprises, where:

(1) $\alpha_1 > 0$ is the net gain of the enterprise A on 1 ton of material, measured in euros/tons;
(2) $\beta_1 > 0$ is an erosion coefficient of the enterprise B versus the enterprise A, for any ton of material;
(3) γ_1 is the net gain of the enterprise A on one ton of material of the common client.

Enterprise B. Analogously we have:

$$f_2\,(x, y, z) = -\beta_2 x + \alpha_2 y + \gamma_2 z \qquad \text{(in unit 100,000 tons} \cdot \text{10 euros/tons)} \tag{2}$$

for any x in the strategy set $\boldsymbol{E}$ of enterprise A, for any y in the strategy set $\boldsymbol{F}$ of enterprise B, and for any strategy z in the compact, convex common strategy set $\boldsymbol{C}$ of the two enterprises, where:

(1) $\alpha_2 > 0$ is the net gain of the enterprise B on 1 ton of material;
(2) $\beta_2 > 0$ is an erosion coefficient of the enterprise A versus the enterprise B for any ton of material;
(3) γ_2 is the net gain of the enterprise B on one ton of material of the common client (coopetitive activity).

3.4.3. Coopetitive Game

We have so constructed a coopetitive game G = (f, >) with payoff vector-function defined by:

$$\begin{aligned} f\,(x, y, z) &= (\alpha_1 x - \beta_1 y + \gamma_1 z - \beta_2 x + \alpha_2 y + \gamma_2 z) \\ &= (\alpha_1 x - \beta_1 y - \beta_2 x + \alpha_2 y) + z\,(\gamma_1, \gamma_2). \end{aligned} \tag{3}$$

We now consider the parametric curve defined by

$$v\colon \boldsymbol{C} \to \boldsymbol{R}^2\colon v(z) = z\,\gamma = z\,(\gamma_1, \gamma_2).$$

We observe that the trajectory of the above parametric curve is the segment of extreme points

$$v(0) = (0, 0) \text{ and } v(5) = 5\gamma.$$

Moreover, we observe that the game G(z), defined by the payoff function $f(\cdot, \cdot, z)$, is the translation of the initial game G(0), defined by payoff function $f(\cdot, \cdot, 0)$, by the vector $v(z)$.

3.5. Complete Study of the Coopetitive Game

3.5.1. Strategy Sets

We shall consider the following strategy sets:

- the compact interval $\boldsymbol{E} = [0, 2]$, with its conventional unit 1 representing 100,000 tons;
- the compact interval $\boldsymbol{F} = [0, 1]$, with its conventional unit 1 representing 100,000 tons;
- the compact interval $\boldsymbol{C} = [0, 5]$, with its conventional unit 1 representing 100,000 tons.

So the bi-strategy space $\boldsymbol{E} \times \boldsymbol{F}$ (set of all profile strategies x, y decided by enterprise A and B, individually) is the rectangle with four vertices:

$$A\colon = (0, 0),\ B\colon = (2, 0),\ C\colon = (1, 1),\ D\colon = (0, 1).$$

Figure 1 shows its representation.

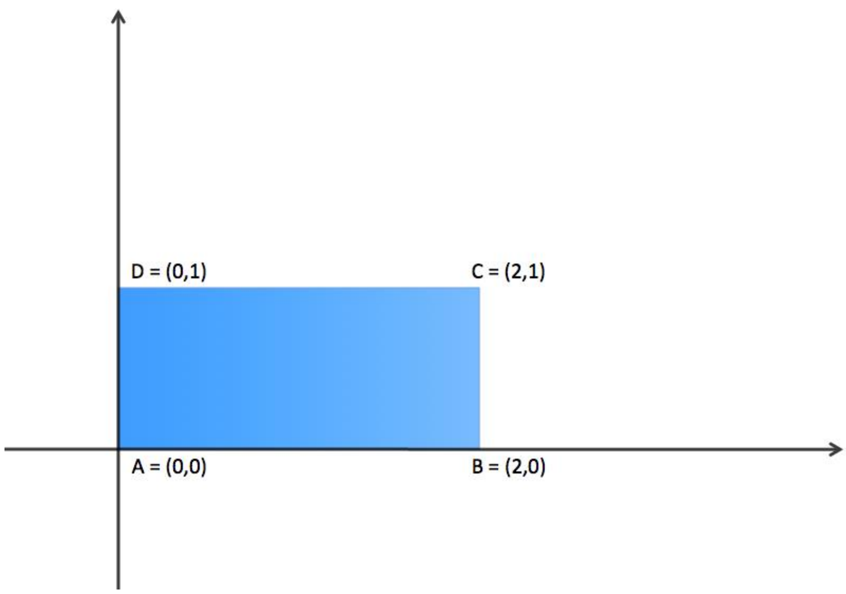

Figure 1. Bi-strategy space of any game G(z), with z belonging to $\boldsymbol{C}$. Any point (x, y) of the above strategy space represents a combination of two possible actions of the players: x represents the tons of materials chosen to manage by enterprise A for the considered year in a competitive scenario and analogously for the action y chosen by enterprise B.

3.5.2. Economic Meaning of the Payoff Function Coefficients

All the coefficients of our game are deduced from the real agreement and policy of the two enterprises, as we have learned from the CEOs of the two enterprises themselves. We have considered only the real values because we needed to find a fair agreement just for that situation.

We have deduced:

$$\alpha_1 = 1, \beta_1 = 0.1, \gamma_1 = 1.8$$

for enterprise A, and

$$\beta_2 = 0.2, \alpha_2 = 1, \gamma_2 = 0.2$$

for enterprise B, where:

1. α_1 and α_2 represent the medium market price for a ton, decided by A and B respectively in competition. 1 unit equals 10 euros, the medium price for one ton of material in this context;
2. β_1 and β_2 represent two erosion coefficients (dimensions ton^{-1}), applied by the two enterprises, respectively, in a competitive fashion. More precisely, enterprise A adopts a reaction function

   $$r_1\colon \boldsymbol{F} \to \boldsymbol{R},$$

   from the strategy set $\boldsymbol{F}$ to the real line, defined by

   $$r_1(y) = \beta_1 y,$$

   for every y belonging to the strategy set $\boldsymbol{F}$. The number $r_1(y)$ represents the money variously invested by enterprise A (commercial ads, bonus for clients, improvements of the services, costs of commercial politics), in order to maintain a certain level of demand, when the second enterprise chooses and adopts its strategy y. Symmetrically, also enterprise B applies the same kind of reaction function

   $$r_2\colon \boldsymbol{E} \to \boldsymbol{R},$$

   from the strategy set $\boldsymbol{E}$ to the real line, defined by

   $$r_2(x) = \beta_2 x,$$

   for every x belonging to the strategy set $\boldsymbol{E}$. For example, if y is equal to $\frac{1}{2}$, that is enterprise B manages 50,000 tons, then enterprise A will react with an investment of

   $$0.1\ (\text{ton}^{-1}) \cdot (\frac{1}{2}) \cdot 100{,}000\ (\text{tons}) \cdot 10\ (\text{euros}) = 50{,}000\ \text{euros};$$

3. the difference between the erosion coefficients depends upon the different commercial power of enterprise A with respect to enterprise B;
4. γ_1 and γ_2 are two coefficients proportional to the contract prices for a ton of the common special client, decided by the enterprises together, and communicated to us during the interview. The two coefficients are calculated in the following way. By contract, the client will pay 20 euros for any ton of its good to enterprise A (z belonging to the interval [0, 5], which means possible transportation from 0 to 500,000 tons of material). Of the total

   $$z \cdot 100{,}000\ \text{tons},$$

   the quantity

   $$(4/5) \cdot z \cdot 100{,}000\ \text{tons},$$

   of the good, will be managed by enterprise A and the quantity

   $$(1/5) \cdot z \cdot 100{,}000\ \text{tons},$$

   of the good, will be managed by enterprise B. Enterprise A will pay 10 euros to enterprise B, for any ton of client material managed by enterprise B, while retaining for itself 22.50 euros per ton, for any ton of client material managed by itself. Therefore, the profit of enterprise A, for z. 100,000 tons is

$$\gamma_1 z = 4/5 \cdot 22.5 \cdot z/10 = 1.8z \text{ (100,000 tons. 10 euros).}$$

The profit of enterprise B, for z. 100,000 tons is

$$\gamma_2 z = 1/5 \cdot 10 \cdot z/10 = 0.2z \text{ (100,000 tons. 10 euros).}$$

So we can write down the payoff functions:

$$f_1(x, y, z) = x - 0.1y + 1.8z \qquad \text{(in unit 100,000 tons} \cdot \text{10 euros/tons),}$$

$$f_2(x, y, z) = -0.2x + y + 0.2z \qquad \text{(in unit 100,000 tons} \cdot \text{10 euros/tons).}$$

3.5.3. Payoff Space of the Initial Game

We see the following transformations, for the initial game G(0):

$$A' := f(A,0) = f(0,0,0) = (0, 0)$$

$$B' := f(B,0) = f(2,0,0) = (2, -0.4)$$

$$C' := f(C,0) = f(2,1,0) = (1.9, 0.6)$$

$$D' := f(D,0) = f(0,1,0) = (-0.1, 1).$$

So that, we obtain the payoff space of the initial game G(0) in Figure 2.

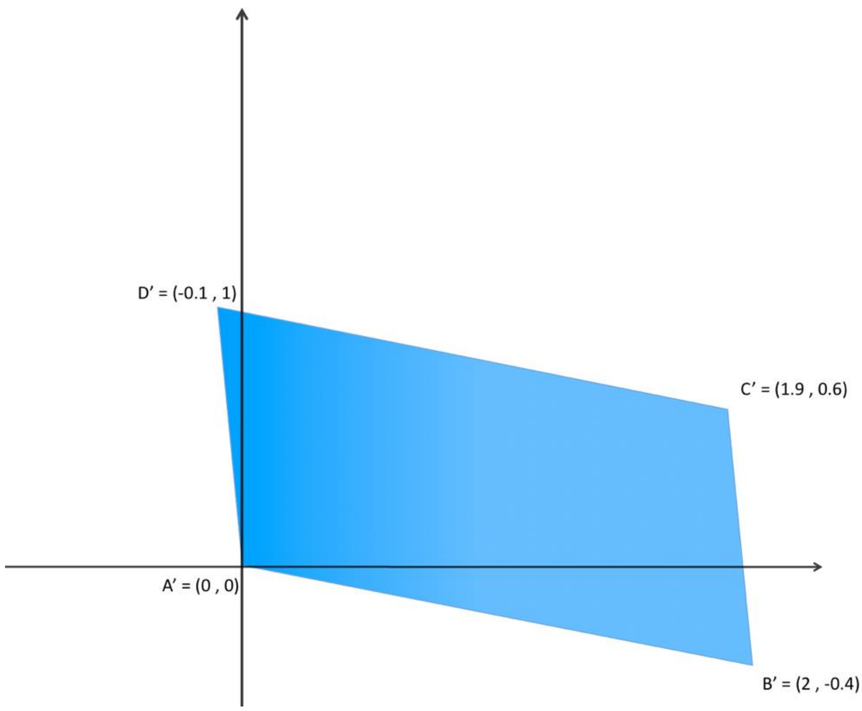

Figure 2. Initial payoff space: collection of all possible payoff scenarios, in a purely competitive framework, with $z = 0$.

3.5.4. Payoff Space and Pareto Boundary of the Coopetitive Game G

To the payoff space of the initial game G(0) we need to add all possible vectors $v(z)$, with z belonging to [0, 5], in order to obtain the coopetitive payoff space. We, therefore, obtain the convex envelope of six points A', B' B'', C'', D'', D' and the relative Pareto maximal boundary P which equals the bi-segment of vertices D'', C'', B'', as you can see in Figure 3.

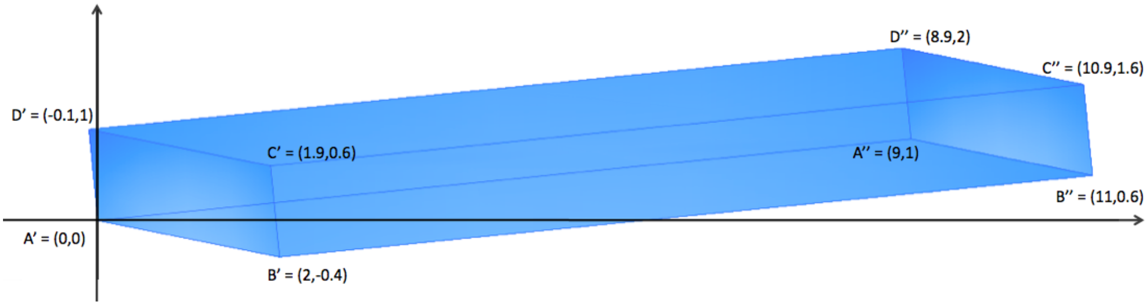

Figure 3. Payoff space of the entire coopetitive game: collection of all possible payoff scenarios, in a full coopetitive framework, with the tonnage z varying in [0, 5].

3.5.5. Conservative Analysis

Concerning the conservative (or defensive) values of the initial game G(0), we obtain:

$$v_1^{\#} = sup_{\ x \in E}\ inf_{\ y \in F}\ (\alpha_1 x - \beta_1 y) = (x - \beta_1) = (2 - 0.1) = 1.9$$

Therefore, the unique conservative strategy of enterprise A is the strategy 2.
Moreover, we obtain:

$$v_2^{\#} = sup_{\ y \in F}\ inf_{\ x \in E}\ (-\beta_2 x + \alpha_2 y) = (-\beta_2 x + y) = (-0.4 + 1) = 0.6.$$

Therefore, the unique conservative strategy of enterprise B in the initial game G(0) is strategy 1.
The conservative cross is the point

$$i^{\#} = (x^{\#}, y^{\#}) = (2, 1) = C.$$

3.5.6. The Conservative Bi-Value of the Game G(0)

The conservative bi-value of the game G(0) is

$$v^{\#} = (v_1^{\#}, v_2^{\#}),$$

that is the point

$$C' = (1.9, 0.6).$$

The point C′ belongs to the maximal boundary of the initial game G(0), therefore, the initial game is a so-called inessential game. From the initial game, by $v(z)$-translation, we try the conservative bi-value

$$C' + v(z)$$

of the game G(z), for every z in $\boldsymbol{C}$.

3.5.7. Nash Payoff Coopetitive Path

Let us analyze the best reply multifunction $B_{1,z}$: $\mathbf{F} \to \boldsymbol{E}$ of the enterprise A. We need to find, fixed any z in $\boldsymbol{C}$ and for every strategy y of the enterprise B, the strategies of enterprise A maximizing the partial function $f_1(\cdot, y, z)$. Since the derivative

$$f_{1,1}(x, y, z) = \alpha_1 = 1$$

is positive, we obtain

$$B_{1,z}\ (y) = 2 = \max \boldsymbol{E},$$

for every y in strategy set $\boldsymbol{F}$ and any z in $\boldsymbol{C}$. Analogously, the best reply multifunction $B_{2,z}$: $\mathbf{E}\rightarrow\boldsymbol{F}$ of the enterprise B is obtained by maximizing the partial gain function $f_2(\mathrm{x}, \cdot, z)$. After considering that the partial derivative

$$f_{2,2}(x, y, z) = \alpha_2 = 1$$

is positive, we obtain

$$B_{2,z}(x) = 1 = \max \boldsymbol{F},$$

for every x in the strategy space $\boldsymbol{E}$.

Therefore, the **unique Nash equilibrium** (of any partial game G(z)) reveals the point (common to both the best reply graphs)

$$C = (2, 1).$$

The Nash payoff of the initial game G(0) is the conservative bi-value:

$$C' = (1.9, 0.6).$$

Consequently, the conservative bi-value of any game section G(z) equals the Nash payoff

$$C' + v(z).$$

The Nash path is the segment $[C', C'']$ and it's the union of all the Nash Equilibria of the infinite games G(z), between G(0) and G(5). Therefore, we can immediately infer that the maximum of the Nash path exists and it is the point C''.

3.5.8. Coopetitive Solutions: Payoffs

From the above discussion about the Nash path, we can immediately propose our first coopetitive solution, the ***purely coopetitive solution***, which is defined to be any compromise solution belonging to the maximal boundary of the Nash path. In the present case, the maximal boundary of the Nash path equals the single point C'' and then we can conclude that the unique purely coopetitive solution is C'' itself. At this point, in order to find other possible coopetitive solutions, we draw in the payoff universe the fairness line

$$r = inf\, P + \mathbf{R}(2.1, 1.4) = \inf P + \mathbf{R}(sup\ P - \inf P),$$

where

$$\inf P = (-0.1, -0.4)$$

and

$$\sup P = (2, 1)$$

are the infimum and the supremum of the Pareto boundary and **R** represents the real number line, and the "straight-line of maximum collective gain"

$$s = C'' + \mathbf{R}(-1, 1).$$

We have represented the above two lines as two affine subspaces of the Cartesian plane. This algebraic representation requires two elements, a point belonging to the line and a vector directing the line. In our case, the so-called fairness line (or Kalai-Smorodinsky line) reveals the set of all points in the Cartesian plane obtain as sum of the inf of the Pareto boundary plus any vector proportional to the vector/point (2.1, 1.4). The second line is the unique line passing through the point C'' and directed by the vector $(-1, 1)$.

We propose some solutions (see Figure 4):

1. The ***best compromise solution***, with respect to the fairness line r, is the point K', the unique Pareto boundary point, of the payoff space of G, belonging to the Kalai-Smorodinsky line r.
2. The **purely coopetitive solution** C'', already considered above.
3. The ***transferable utility Kalai-Smorodinsky solution*** K, with respect to the fairness line r, comes from the intersection of the Kalai-Smorodinsky line

$$r = \inf P + \mathbf{R}(2.1, 1.4),$$

with the line of collective gain

$$s = C'' + \mathbf{R}(-1, 1).$$

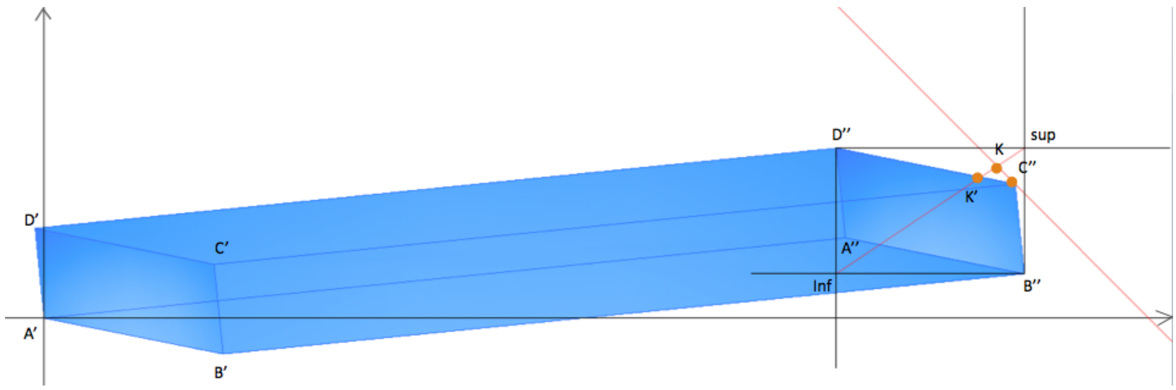

Figure 4. Coopetitive solutions: K′ (best compromise solution); C'' (purely coopetitive solution); K (transferable utility Kalai-Smorodinsky solution).

3.5.9. Coopetitive Solutions: Strategies

To define more specifically the possible practical implications of our model, let us consider the three solutions in the payoff space C'', K' and K. We easily obtain such payoff compromise solutions as the result of well-defined possible profile strategies.

We need to use the profile strategies:

- $(C, 5) = (2, 1, 5)$ in order to obtain the payoff C'';
- $(1.9 - 21^2/910, 1, 5)$ in order to obtain the payoff K';
- $((2, 1), 5, (C'' + \boldsymbol{R}(-1, 1), \inf P + \boldsymbol{R}(2.1, 1.4)))$ in order to obtain the payoffs K.

The first components above of the profile strategies represent the quantity of annual tonnage of material traffic of the enterprise A in the set $\boldsymbol{E} = [0, 2]$ for its usual activities.

The second components represent the quantity of annual tonnage of material traffic of the enterprise B in the set $\boldsymbol{F} = [0, 1]$ for its usual activities.

The third components represent the quantity of annual tonnage of material traffic, to be accepted and managed, of the common client in the set $\boldsymbol{C} = [0, 5]$.

Remark 2. *The tri-strategy*

$$H = (1.9 - 21^2/910, 1, 5)$$

is the unique anti-image of the payoff K' by means of the function f; in other terms, the strategy point H is the unique profile strategy such that

$$f(H) = K'.$$

We observe also that the selection rule of the third point K can be considered as an actual additional by-strategy defined by the two lines r and s, so that the final strategy profile needed to obtain the payoff K is the triple strategy profile

$$((2, 1), 5, (r, s)),$$

that means, in real terms, that: enterprise A manages 200,000 tons of ordinary goods in a competitive market; enterprise B manages 100,000 tons of ordinary goods in a competitive market; enterprises A and B manage a total common order of 500,000 tons of special goods in a cooperative fashion; by contract, the two enterprises share the total gain of 12.5 million euros, according to the rule determined by the intersection of the two lines, that is 10 million euros for A and 2.5 million euros for B.

4. Discussion and Considerations

According to the general coopetitive agreement, the enterprises would end up, naturally, at the payoff point C'', the purely coopetitive solution.

Nevertheless, the transferable utility Kalai-Smorodinsky solution K, which is out of the payoff space of the enterprises interaction game, reveals an important point because it represents the fair distribution of the gains and it is, however, reachable because it belongs to the maximum collective gain line, of equation

$$X + Y = \Sigma C'' = 10.9 + 1.6 = 12.5.$$

As we already observed, the two enterprises will arrive naturally at the payoff scenario C'', but they should decide, by contract, to distribute their gains differently. Specifically, instead of 10.9 for the enterprise A and 1.6 for the enterprise B, they should re-distribute 10 for A and 2.5 for B, respectively (the coordinates of K). This situation would be the fair payment where A should renounce only to 0.9, but B would gain, in percentage, a lot more than the purely coopetitive scenario.

5. Conclusions

In this paper, we used coopetitive game theory to analyze a case of real coopetition among port companies, for what concerns loading and unloading of goods, within a competitive management scenario of marine transportation activities.

Our research consisted in the analysis of a study case involving coopetition between two real companies from which we have previously obtained the financial and contractual data, allowing us to define the modeling payoff functions, both of them based on real agreements parameters and tariffs.

We recognized an actual form of coopetition superposed to an asymmetric R&D alliance—a type of agreement in which a bigger enterprise deals with a smaller competitor in order to capture more value from their activities.

In particular, our model has shown:

- a precise coopetitive bi-dimensional trajectory of payoffs;
- within that coopetitive path, we have suggested, after an "ad hoc" quantitative analysis, many kinds of possible solutions:
    - the purely coopetitive solution C'';
    - a proper Kalai-Smorodinsky solution K' (best compromise), with respect to a certain selection rule (fairness line r, obtained joining sup and inf of the Pareto boundary);
    - a transferable utility Kalai-Smorodinsky solution K, with respect to a certain selection rule (according to the fairness line r, obtained joining sup and inf of the Pareto boundary).

Our methods provide specific strategy procedures for determining the above win-win solutions.

We desire to recap the necessity of our quantitative intervention in order to determine:

- the set of all possible payoff scenarios;
- the set of all Nash equilibria in those possible scenarios;
- the best possible Nash equilibrium with associated payoff;
- a fair possible division of the gains, guarantying the incentive to the smaller enterprise in order to sign the contract and the maximum collective gain obtainable from the coopetitive agreement.

We have suggested to the companies the solution K (transferable utility Kalai-Smorodinsky solution) with the associated profile strategy to obtain it. Our choice has represented the right incentive inducing enterprise B to sign the contract.

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