A cooperative game approach applied to the furniture supply chain of clusters for improving its competitive value: a case study[*]

by

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Abstract: The paper studies a cooperative game, which is being played among the firms, involved in furniture industries, belonging to the same cluster. Due to the increased competition at the local and global levels, cooperation among the business entities is practically the only way to survive in the cluster. Consequently, a cooperative game model is proposed for the firms, associated in a vertical channel, where its performance indices are measured by one of its indicators of competitiveness at an entrepreneurial level versus the value of the cluster itself. As a case study, a competitive value analysis is done for the Colombian furniture cluster by indicating the characteristics and existing conditions of the cluster in the department of Atlantico in Colombia. Moreover, this paper analyzes and establishes an optimal feasible solution of cooperative game among the principal firms using Shapley value method.

Keywords: cooperative games, industrial cluster, supply chain, Shapley value

1.   Introduction

In competitive business environment, the organisation of a cluster, involving a group of companies operating in design, production, distribution, marketing and consumption of goods and services, aims to improve productivity through the articulation of the sectoral advantages and the competitive development of their products and processes. Clusters influence mainly the competitiveness of the organizations belonging to a given sector and increase the productivity and the effectiveness of the channel members, who enhance and stimulate marketing as well as the creation of new businesses and ability to innovate with regard to effective strategies (Valderrey et al., 2012). Garnica and Rivero (2004) mention that clusters arise by associative factors, including the cooperation among small enterprises, highlighting especially the context, in which neither factor dominates permanently. Being a part of a cluster, allows the respective companies to operate in a more productive way and encourages competition and cooperation. As a result, each member is able to benefit at a larger scale. However, it is necessary to implement strategic analysis to strengthen the entire chain, which leads to the generation of competitive advantages.

A supply chain (SC) is defined as multiple interrelated transactions among companies (Cardenas-Barron and Porter, 2013; Trevino-Garza et al., 2015; Panda, 2014; Sarkar, 2013; Sarkar and Majumder, 2013; Modak et al., 2016). Generally, in fact, an SC integrates its suppliers and providers with the customers (Lin and Hsieh,2012). An integrated SC includes among its effects cost reduction, improved processes, better quality and an increased value added scheme (Richey et al., 2008). This paradigm emphasises the transfer of information among the members of the SC, which helps to enhance and increase information sharing, demand, inventory, order status and production programmes. Then, the cooperative game theory studies the relationships in the chain (Slickker and van der Nouweland, 2001), while pursuing three issues, namely: (1) the forming coalitions, (2) how they should divide the expected result, and (3) whether this relationship is stable and robust (Nagarajan and Sosic, 2008). Cooperative game theory studies the selection, identification, adoption and assignment of the expected results, and can be also classified into coalitional alliances or negotiation games. The interest of our proposed research is to focus on coalitional games. It is currently observed that the value of a coalition in an environment of supply chain depends on its interaction, with the resulting competitive outcomes being compared to other chains. In this context, the members of an SC evaluate their objective function and participate in the chain only when the payoff is not less than the target level of the expected profit within the coalition. Now, the following questions are pertinent in the field: which is the minimum expected value? how could it be determined from an existing competitive dynamics in business today?

The proposed study corresponds to the need of clusters to cooperate effectively among the members and to propose the strategies for the companies that conform to accession to and taking advantage of such cooperation agreements,

without leaving aside the competitive dynamic behavior that characterizes the entities here considered. To achieve this goal, a cooperative game among the companies along the vertical dimension of the value chain is proposed here. It uses the Shapley value as the solving methodology for improving the competitiveness of the cluster, in which the respective companies belong. A case study presents the analysis of competitiveness of the furniture cluster in Atlantico, Colombia, this case study demonstrating that it is possible to measure feasibility of cooperation between the member companies of a definite cluster in order to strengthen them at the individual as well as group level.

The rest of the paper is organized as follows. Section 2 reviews the issues of business competitiveness and clusters, and cooperation in the SC. Then, the general model of cooperative game theory is applied to supply chains, especially for the case of clusters. Section 3 proposes the concrete model, which is implemented in the case study. Section 4 provides the description of the case study. Numerical evidence is presented in Section 5. The results show the conditions, under which it would be possible to cooperate, and the contributions of the respective companies within the cluster, using the Shapley value. Conclusions are provided in Section 6.

2.   Literature review

Game theory is mainly classified into theory of non-cooperative and cooperative games. Both kinds of models have been used in the context of the SC. Various tools of game theory have been applied to the SCM (Supply Chain Management: Bartholdi and Eda, 2004; Cachon, 2004; Cachon and Lariviere, 2001; Cachon and Kok, 2007; Cachon and Netessine, 2004) where the newsboy problem is used mainly to demonstrate the applicability of the game theory to the SCM for both static and dynamic environments. The importance of game theory for such analysis of SCM arises from the very nature of relations among the members of the chain, in which they are independent and none of them has a completely controlling power over the chain. Padula and Dagnino (2007) have applied cooperative approaches to optimize the SCM games considering competition. A coalitional game considers n players with 2^n-1 coalitions. Each coalition member takes part in the overall result of the coalition, which is independent of the results generated by the other players, who are not a part of the coalition. In this system, the players are included into the coalition, in which they desire to belong. It is a dynamic process and provides a better result than the respective non-cooperative situations. The set of feasible coalitions depends on the problem, with appropriate consideration of the restrictions that specify the concrete problem conditions.

Now, let $N = 1, 2, \ldots, n$ be the set of n players, and S_i, where $i = 1, \ldots, (2^n - 1)$, be the set of coalitions, while $v_i(S_i)$ represents the value for each coalition S_i. The function v is referred to as the characteristic function of the cooperative game, and is identified with the pair of (N, v). The coalition structure $S = \{S_1, S_2, \ldots, S_m\}$ is formed out of the possible coalitions, which obey the

following conditions (Owen,1995):

$$S_j \neq \emptyset \tag{1}$$
$$S_i \cap S_j = \emptyset \tag{2}$$
$$\bigcup S_j = N. \tag{3}$$

Besides these three conditions, a fourth condition is contemplated, implying that the value of an empty set is 0, $v(\emptyset) = 0$. Then, upon applying the super additive function, Eq. (4) provides the fourth condition

$$v(S \cup T) \geq v(S) + v(T) \ \forall \ S, T \subseteq N, \tag{4}$$
$$\text{such} \quad \text{that} \ S \cap T = \emptyset.$$

The above restriction is important for determining the total payoff of a coalition called a *grand coalition*. Given that x_i is a vector coalition of player i, which belongs to a coalition of N players, there must be three important principles that are satisfied by the coalition formation: the principle of efficiency (Eq. 5), the principle of individual rationality (Eq. 6), and the principle of collective rationality (Eq. 7). The Equations (5), 6 and 7 are as follows:

$$\sum_{i \in N} x_i = v(N) \tag{5}$$
$$x_i \geq v(\{i\}) \forall \ i \in N \tag{6}$$
$$\sum_{i \in S} x_i = v(S) \text{ for } S \subset T_k \in T. \tag{7}$$

The well known solution concepts in cooperative game theory are, first of all, the core of the game (Gillies, 1959), the stable set (von Neumann and Morgenstern, 1944), the kernel value (Davis and Maschler, 1965), the trading value, the Aumann-Maschler (Aumann and Maschler, 1964), and the Shapley value (Lutz et al., 2012), just to quote the most important ones. Although the first two solution concepts are easier to model, they involve a definite difficulty. Namely, they do not always reach the settlement of a non-empty set as the game analysis is framed in a relationship of dominance. However, the value of the coalitional game, proposed by Shapley, leads to an equilibrium and a balance of the game, enabling to determine whether or not the game has a feasible solution. The following Eq. (8) presents the Shapley equation as follows:

$$\varphi_i = \sum_{\{S \in N : i \in S\}} \frac{(S-1)!(n-S)!}{n!} (v(S) - v(S - \{i\})). \tag{8}$$

In the literature, these solutions are applied to cooperative supply chain games in multiple ways under several models and methods of solution. In the model

of Granot and Soste (2005), a multi-stage decentralized system among multiple retailers to share inventory information at the stage of cooperation suggests that the Shapley value encourages retailers to share their surplus earnings. Raghunathan (2003) considered a chain composed of one manufacturer and n retailers with correlated demand and applied the Shapley value to analyze the expected value of manufacturers and retailers to share information on demand. Lin and Hsieh (2012) studied a cooperative game between chains in an environment of perfect competition under a duopolistic market, using an algorithm called iterative diagonalization algorithm. Leng and Parlar (2009) addressed the three layer supply chain, comprising the manufacturer, distributor and retailer, through a cooperative game, for the allocation of the cost savings in a scheme in which information is shared. Huang et al. (2012) investigated an integrated model of multiple levels, in which the optimal provider is selected, where decisions, regarding sales prices and the quantity in inventory are taken into account. Zamarripa et al. (2012) improved the SCM by considering the competitive behavior as a source of uncertainty in decision-making at the tactical level, in the SC, in which players compete for demand in various scenarios.

In summary, there exists a significant volume of research on SC, where game theory is applied for both cooperative and non-cooperative schemes. However, there are only few studies that involve the value of competitiveness and analysis tools in decision making. This same concept relates to the measure of competence of individual firms, implying non-cooperation among them. At the cluster level, competitiveness inevitably involves cooperation among entities. This provides an opportunity to of filling a gap in the literature, and proposing a novel cooperative game approach for cluster formation and evolution in supply chains.

3.   The proposed model

In the proposed model, cooperation among the entities in the supply chain can be studied along the vertical or horizontal dimension, as shown in Fig. 1. In the case of a cluster, the management of the supply chain is performed by a central decision maker, who proposes improvement strategies at any level of the chain. In this case, each member of the chain is aligned according to the same objective, and takes part in the competition as an independent agent.

In order to achieve competitiveness in the chain, it is necessary to establish the objective or objectives that need to be reached in terms of the cluster. It is possible for a cluster to be competitive and this calls for the development of a project or strategies that are appropriately embedded in the international market. In this context, the performance indicators or utilities must be reflected as an objective. In cooperative game theory this objective is modelled as the characteristic function (v) of the game. Here, strategies are generated in the chain by the contribution from each company. This model includes a model of cooperative game that manages the structure of these contributions to the cluster. In clustering, the companies are able of getting involved as a coalition within the same link and of contributing to the competitiveness of the link. Also, the
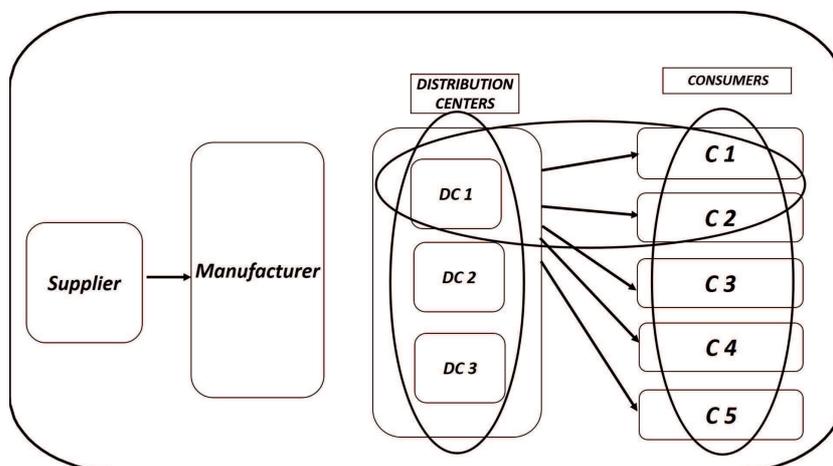
Figure 1. Cooperation schemes in the supply chain

link must be aligned with the objective of the cluster to secure competitiveness. Let n_i $(i = 1, \ldots, n)$ be the number of enterprises belonging to a link i in the supply chain of a cluster. A cooperative game (n_i, v_i) is defined for each link i, and cooperation among the agents represents each of the links. This is achieved through the centralized optimization of the supply chain, whose overall objective translates into one or more indicators of the competitiveness of the cluster, and is directly related to the overall objective of the cluster. Such a model is dubbed the multi-link cooperation in the supply chain, and it is presented in Fig. 2.

In order to solve this model, Shapley value is applied according to Eq. (8), owing to which calculation is done of the contributions of each company to the characteristic function of the respective game (v_i) and the feasibility of cooperating in the chain is validated.

4. Case study of competitiveness in furniture industry

4.1. Global analysis

In furniture industry, there are many units that design, manufacture, market, distribute and install the respective objects. These objects serve comfort or household needs, and include such items as beds, tables, chairs or armchairs, dining room furniture, bedrooms, desks, garden furniture, etc. These utensils are made out of different materials, such as wood, metal or plastic. Also, input suppliers of accessories that complement the manufacture of furniture, include producers of such items and materials as foams, fittings, upholstery, etc. In this system, conditioned wood sawmills are of relevance for the respective industries. According to the statistics, given by CSIL (Center for Industrial Studies), inter-
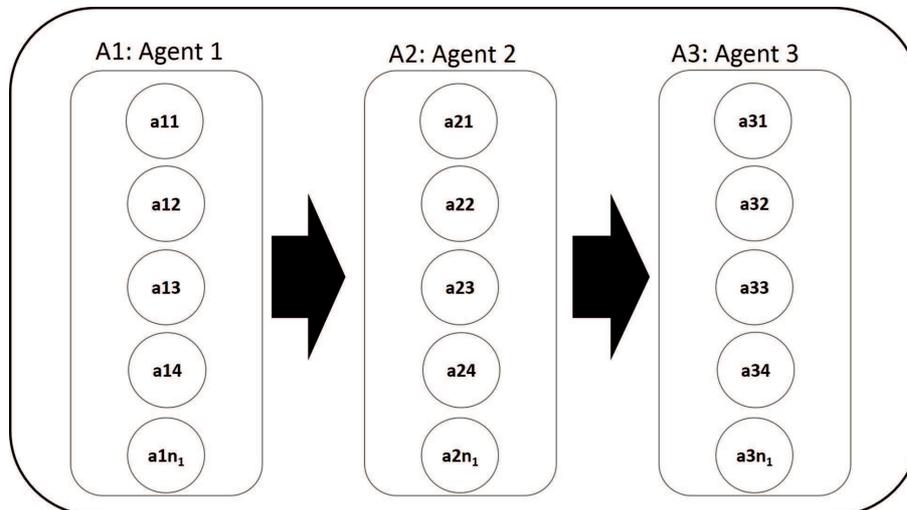
Figure 2. Multi-echelon model of cooperation in the supply chain

national trade in furniture represents about 1% of world trade in the processing industry and consumption today totals approximately $ 410 billion at factory gate, this figure having doubled in the last 10 years. Among the major producing countries are China with 31% of the global value, followed by the United States, Italy and Germany. Reports from the Research and Development Laboratory - NOSIS, in 2012 China has increased its exports to US up to $ 45 billion, compared to $ 25 billion in 2011 (Tian et al., 2014). On the other hand, total import value in the furniture industry worldwide exceeds $ 190 billion. The industry has the experience of many important changes worldwide, especially in the late 1990s, when the distribution and marketing of furniture was so fragmented that many manufacturers would sell their products to many stores by relatively small quantities (see Fig. 3). Here, rivalry between competitors was relatively low, and there was a higher distribution margin. By early 2000s, the emergence of structured network stores left behind many small establishments. Since then, today's businesses focus on the distribution channels and marketing. Therefore, departmental stores have become more important. Today, the marketing power of the big stores has driven down the manufacturer's margins (Fig. 3) and increased competition in the industry.

4.2. Cluster analysis for Atlántico, Colombia

The Atlantico Department is located in the northern region of Colombia, South America, on the west bank of the Magdalena River, 15 km from its mouth in the Caribbean Sea. Having the capital city of Barranquilla, the department consists of 23 municipalities with the total population of 2,344,140 inhabitants.
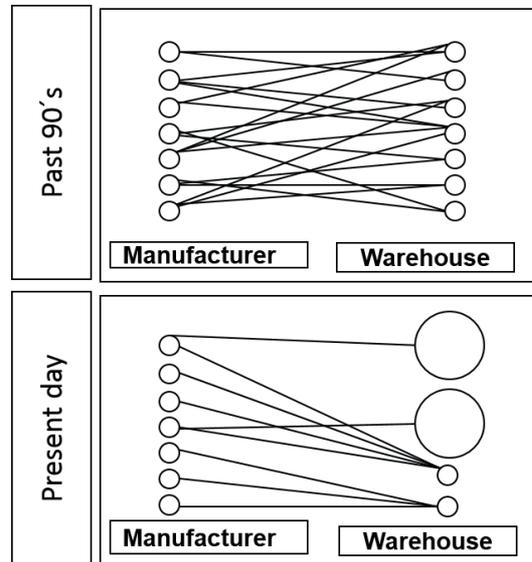
Figure 3. Global changes in the furniture industry

Today, it is the most populous department in the Colombian Caribbean Coast (Fig. 4).

The cluster of furniture industries of the Atlantico department is composed of more than 150 companies, which carry out design, production, distribution, marketing, and consumption of goods and services, related to furniture supply chain. As a cluster, they have the objective of improving the productivity through collaborative industrial activities, competitive product development and processes. According to the database of the Barranquilla Chamber of Commerce, these companies, 186 in number, can be classified into the following economic activities:

- Wood Manufacturers and Suppliers: 9
- Furniture Manufacturers: 94
- Marketers: 62
- Specialised Training and Research Centers: 5
- Services: 6
- Governmental Bodies: 2
- Promotion Agencies: 3
- Regulatory Bodies: 2.

As a way to improve the current operation of the furniture business in the Atlantico, an analysis has been conducted, following the work of Malawski (2002). Most of the respective technical material is strictly confidential, yet an overall analysis can be made public to disseminate the bigger picture of the cluster's role in the furniture business around the world. After obtaining information
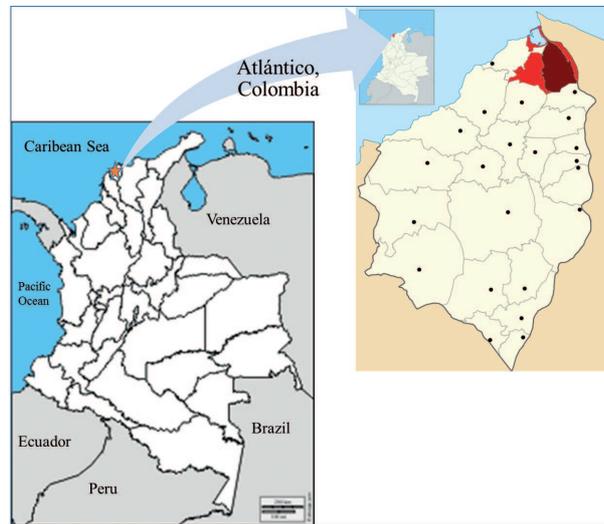
Figure 4. Atlántico department, Colombia

from all of the businesses in this cluster with the help of the Chamber of Commerce, analysis was performed. As a part of the analysis, the supply chain is visualized in detail in Fig. 5.

In this cluster, most of the furniture is made up of wood. Yet, its geographical area is not specialized in the production of the raw material. In the case of the accessories of the final product, most of the suppliers are not locals. They are from other regions of the country or can even come from the global market. Here, China is the leading supplier for most of the accessories used in the furniture of Atlantico. It has also been observed that the manufacturing processes in the cluster are conducted under informal or craft techniques. This depends largely on the work and expertise of carpenters, joiners and painters. However, there is little use of large machinery and technology, involving a very low participation of this link in the furniture supply chain.

5. Numerical example

On the basis of information, compiled by the Chamber of Commerce of Barranquilla, the data on the major suppliers and manufacturers have been obtained. For better convenience in evaluating the cooperation within the chain in this article, only the results of cooperation related to the vertical dimension are presented and an analysis of the possible cooperation along the horizontal dimension is considered. In Tables 1 and 2 the data collected from the leading suppliers and manufacturers, making up the cluster, are presented.

In the context of assessing the level of cooperation among the companies, which form each of the links, a strategy to strengthen the link is identified.
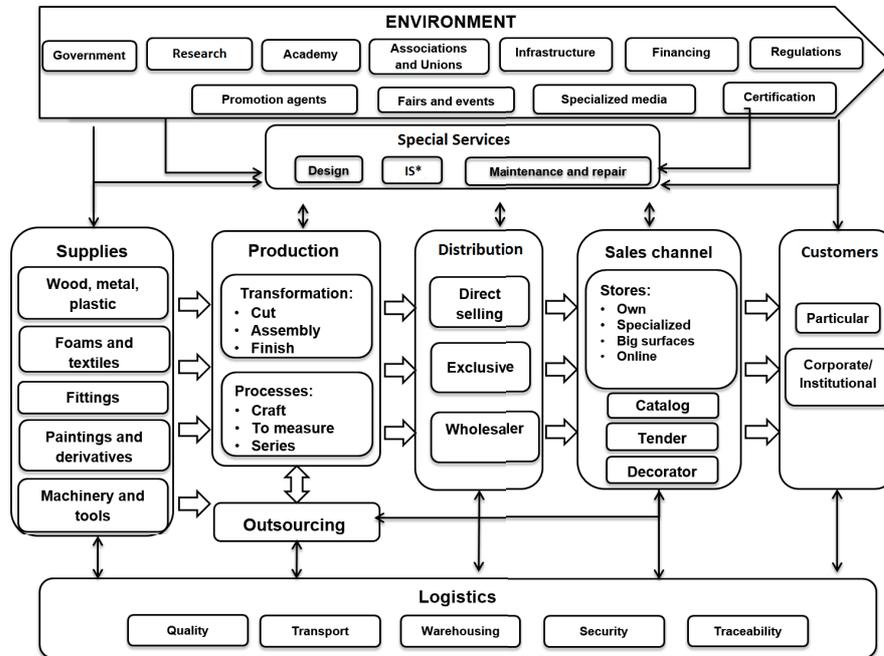
Figure 5. Supply chain in the Atlántico department cluster *Information Systems

In the case of the providers, it is necessary to calculate the maximum money amount, expected to be invested in the production process of each company, so that the prices offered to their clients (manufacturers) could be competitive. In the case of the manufacturers, investment in skilled labour is essential for taking part in the competition as to offering the world-class furniture. An opportunity to use the state funds to strengthen the cluster is analyzed for both these links. So as to follow the strategy of using the state funds, companies must meet the following requirements:

- Net working capital: it must be at least equal to 10 % of the total project value.
- Liquidity ratio (LR): it must be greater than or equal to 1.
- Debt Ratio (DR): it must be less than or equal to 70 % (in the case of suppliers) and 80 % (in the case of the manufacturers).

To leverage higher revenue, companies need to cooperate. The level of cooperation, measured in millions of Colombian Pesos, corresponds to the amount of funding received, which is 10% of the net working capital of all companies, involved in the coalition. This would be the characteristic function of each game. The characteristic values for the suppliers (v_1) and manufacturers (v_2) are as follows:

Table 1. General information on the suppliers in the furniture cluster (million of Colombian Pesos). Source: Database of the Chamber of Commerce of Barranquilla 2013

	Current Assets	Current liabilities	Total liabilities	Equity
P1	632	106	475	156
P2	1,033	410	513	278
P3	34,153	9,804	16,849	3,302
P4	7,824	920	3,063	4,762
P5	749	270	428	321
P6	10,752	4,889	4,889	5,862

Table 2. General information of the manufacturers in the furniture cluster (million of Colombian Pesos). Source: Database of the Chamber of Commerce of Barranquilla 2013

	Current Assets	Current liabilities	Total liabilities	Equity
F1	3,853	1,111	3,011	841
F2	1,004	682	682	321
F3	1,590	945	1,245	346
F4	9,107	3,387	5,680	796
F5	1,756	954	1,020	736
F6	871	377	377	236

$$v_1 = \begin{cases} 0.1 * Net\,working\,capital\,(S_j), & \text{if } LR \geq 1 \text{ and } DR \leq 0.7 \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

$$v_2 = \begin{cases} 0.1 * Net\,working\,capital\,(S_j), & \text{if } LR \geq 1 \text{ and } DR \leq 0.8 \\ 0, & \text{otherwise} \end{cases}. \tag{10}$$

These indicators for suppliers and manufacturers, calculated for the actual local conditions, are shown in Tables 3 and 4, respectively.

Note that in the case of suppliers, companies P1 and P3 would not be able to apply the state support funds by themselves, because of the high levels of debt. Later, coalitions, which are generated among different companies, must also meet the conditions set forth above. In the case of manufacturing companies, the results show that only one company, F3, could not participate with their own resources. At a general level, one can also see that companies are not competitive as individuals, and so it is necessary to consider cooperation.

Table 5 shows the results for the suppliers. Here, the Shapley value indicates the amount of investment that would correspond to each entity in an investment project, financed by the state. Results indicate that P6 has the largest share

Table 3. Financial indicators of suppliers

	Net working capital (millions of pesos - Colombian currency)	Liquidity ratio	Debt ratio
P1	525	5.94	0.75
P2	623	2.52	0.65
P3	24,349	3.48	0.84
P4	6,904	8.51	0.39
P5	479	2.77	0.57
P6	5,862	2.20	0.45

Table 4. Financial indicators of manufacturers

	Net working capital (millions of pesos)	Liquidity ratio	Debt ratio
F1	2,741	5.94	0.75
F2	321	2.52	0.65
F3	646	3.48	0.84
F4	5,720	8.51	0.39
F5	802	2.77	0.57
F6	494	2.20	0.45

Table 5. Suppliers' contribution based on Shapley value (in millions of Colombian Pesos)

	Shapley Value (net working capital)	Contribution	Uncooperative contribution	Cooperative benefit %
P1	350,09	35,01	0	100%
P2	536,72	53,67	62,31	-7%
P3	9,979,21	997,92	0	100%
P4	5,771,08	577,11	690,43	-9%
P5	1,124,63	112,46	47,86	40%
P6	20,898,06	2,089,81	586,25	56%

Table 6. Manufacturers' contribution based on Shapley value

	Shapley Value (net working capital)	Contribution	Non-cooperative contribution	Cooperative benefit %
F1	2,424,12	242,41	267,12	-5%
F2	435,75	43,57	28,51	21%
F3	438,31	43,83	44,59	-1%
F4	2,143,28	214,33	0	100%
F5	4,083,15	408,31	50,15	78%
F6	526,21	52,62	39,37	14%

in the cooperation scheme and would be willing to cooperate with the smaller companies. The strategic condition for this company does not exclude it from the coalition. On the contrary, P6's contributions are enhanced when entering the coalition with 56 %. The total sum of the Shapley value in terms of the net working capital would correspond to the grand coalition value (the coalition among all the players, i.e. the entities belonging to the link). This involves sharing a total of 38,659,789,320 Colombian Pesos in net working capital. Assuming funds are available, the companies would be able to finance the total of 3,865,978,932 Colombian Pesos (10% of the total net working capital). For manufacturers, a similar situation is observed. The results, presented in Table 6, indicate that companies F4 and F5 are the most competitive, having an incentive to cooperate, which finds a reflection in the distribution of the funded capital. This demonstrates weak stability of these channel members, with the exception of company F1, which is also competitive, but its contribution is not improved by the coalition. The total amount of the contributions reaches the value of 1,005,081,409 Colombian Pesos, which would be exploited to achieve technical training and innovation regarding the production process for each company of the cluster. In making this a reality, manufacturers could be just one step away from becoming the world class in the furniture industry.

The results of implementation of the cooperative game model provide the companies with a hint on the fair share concerning their participation in a cooperative setting, but further studies could indicate the actual degree of their willingness to participate in such a cooperation scheme. With the exception of a few businesses, results suggest that cooperation is the right way to go on, both for the suppliers and the manufacturers, in order to ensure competitiveness of the cluster at the national and international levels.

6.   Conclusions and future research

Cooperation in clusters is an interesting topic among researchers as well as practitioners around the globe, because of its utility in industrial business. As a supporting framework, game theoretic models aim to address the strategic alliances and coalitions among the companies, aiming to generate significant additional benefits among the channel members. The proposed cooperation model is validated through the implementation of one of the strategies encountered in the cluster analysis of furniture industries. This strategy involves the use of the state funds, which are invested in innovation practices for both the manufacturers and suppliers. A selected number of companies from among both manufacturers and suppliers are considered to definitely profit in the game theoretic model, as shown by the calculation of the Shapley value for the possible coalitions of the channel members.

Our findings show that cooperation is needed at the levels of both manufacturers and suppliers in the supply chain. If manufacturers and suppliers decide to collaborate, then all members of the cluster will win. This win-win situation is achieved if the shares are fairly distributed. Thus, Shapley value provides a way for the companies to improve their current situation, and implies a positive impact on their supply chain. In the competitive marketing environment, it is quite difficult for a company (smaller or bigger) to compete independently with other companies across the globe. The high debt indicators and low cash fluidity of at least some of the companies considered are the obstacles to any form of innovation in improving their business operations. Establishing cooperation agreements among the different members of the chain will allow the cluster to strengthen and eventually increase their joint competitive value.

The proposed model may be extended further by incorporating other performance indicators that would likely increase the cluster's competitive value. Evaluation of both the quantitative and qualitative factors, which affect the competitive value of the chain, can be incorporated in the future, so as to make a complete analysis of cooperation throughout the entire cluster.

7.   Acknowledgements

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