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Research Article
Measurement of Dyadic Supply Chains Efficiency under New Assumptions Using DEA Models

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Abstract
Background: Relationships between members who constitute a supply chain are mainly based on cooperation in order to achieve better joint performance. Hence, the evaluation of supply chains performance usually depended on the existence or absence of cooperation between its members. However, this should not deny in any way the presence of another type of relationship which also could affect the supply chain performance namely, the dominance relationship. Indeed, each member seeks to dominate other actors in the chain to which it belongs in order to achieve better individual performance. **Objective:** Knowing that technical efficiency is considered as the main attribute of performance, the purpose of this study is to introduce new assumptions consisting in distinguishing between cooperation concept and dominance concept when measuring the efficiency of supply chains. **Methodology:** Based on what was suggested, new models using Data Envelopment Analysis (DEA) technique are developed and then applied. **Results:** Obtained models and results are relevant and show that technical efficiency is sensitive to dominance relationship which could be present between members within their supply chain. **Conclusion:** Although, the configuration of supply chains considered in this study is limited to a dyadic supply chain, the authors share the conviction that this study provides a basis for the development of models that deal with more complex chains, it also allows a more realistic research of best practices and strategies in order to have better joint and individual efficiencies.

Key words: Data envelopment analysis, dyadic supply chains, efficiency, cooperation, dominance

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INTRODUCTION

Global competition have led firms to increasingly focus on building cooperative relationships with their supply chains partners in order to achieve better performance. However, these kinds of relationships cannot hide some sort of egoism of each of these firms which consists in seeking satisfaction for its own good. Infact, in a supply chain relation each firm (member) tries naturally to hold power in order to dominate its partner's actions. Meehan and Wright[1] who have studied the origins of power in buyer-seller relationships, indicated that dominance was defined by Emerson[2] as the ability of an actor to influence another to act in the manner that they would not have otherwise. They added that this definition is the commonly-held operationalization of power in inter-organizational studies. According to Ogbonna and Wilkinson[3], the concept of dominance could be present in all kinds and levels of a given relationship.

Focusing on supply chains, one of the criteria for effective supply chain management is to have a clear idea about its actual performance allowing the determination of targets and goals to achieve. Then, measuring the performance of a supply chain is an important step considered as a basis for the evaluation of its performance in order to finally act on the system by undertaking corrective actions to restore a proper functioning in correlation with the fixed objectives. In this regard, Bond[4] has identified performance measurement as having the advantage of stabilizing the process and identifying areas needed to be improved in a given system. The author further stated that performance measurement can also indicate whether an organization will need to continue with its current methods or adopt a reconfiguration of the units found deficient. Neely[5] has defined the performance measurement as a process of quantifying efficiency and effectiveness of actions. The author has stated that when one can measure something and express it in numbers, he/she will have good basic knowledge about it. Kaplan and Norton[6] have argued this in their statement "what you measure is what you get."

In this study, the performance of a supply chain is considered as an objective, but first it is necessary to think about how this performance can be measured so that it can be then evaluated, specifically with the focusing on the measurement and evaluation of technical efficiency which considered as an attribute of performance. This is equivalent to judging whether a supply chain has well allocated its resources to achieve maximum possible production without resorting to additional investments. Among the best known methods to evaluate technical efficiency of a set of Decision Making Units (DMUs), Data Envelopment Analysis (DEA) is found to be very popular. It is a non-parametric approach which in presence of multiple inputs and outputs uses mathematical programming to compare the efficiency of each unit only with those of the best units found in the considered sample. Seeking better units for each unit of the sample is at the center of the DEA methodology. If the found unit is better than the observed unit (either because it produces more outputs using the same amount of inputs or because it produces the same amount of outputs with less inputs) then the observed unit is considered inefficient. Charnes *et al.*[7] were the first who developed the DEA following the pioneering study of Farrell[8]. The CCR model proposed initially by these researchers assumes constant returns to scale. Later proposed the BCC model which enables to relax this assumption and considers variable returns to scale, Banker *et al.*[9].

Considering these two concepts namely, dominance representing power relationship between members who constitute the chain and technical efficiency, the main objective of this study is to provide consistent DEA models allowing an improved measure of global as well individual supply chain's efficiencies. Noting that among the different configurations that a supply chain could take, this study only focus on dyadic chains (Fig. 1) which are defined as linear minimal chains composed only by two units (firms, members,....). In fact, given its simplicity, authors often advise to use it first for the performance evaluation then to iterate the reasoning to more complex chains.

MATERIALS AND METHODS

Standard DEA methodology: The DEA technique is considered as a non-parametric study to measure technical efficiency of a given DMU within multiple inputs and multiple outputs. Indeed, it consists in using mathematical programming to build a frontier in fragments (piece-wise surfaces) starting from production units data. Indeed, to get the relative efficiency of a DMU Charnes *et al.*[7], proposed to treat weights of inputs and outputs as variables and maximizing the unit efficiency while maintaining other efficiencies less than or equal to an arbitrary limit usually set to one.

This way is generally applicable in cases where each DMU represents a single unit consuming a given amount of inputs to produce a given quantity of outputs. However, in cases where this DMU is composed of atleast two sub-units and each sub-unit can perform its own efficiency, this model could be not valid anymore to measure individual efficiencies of these sub-units and that of the relative DMU. Specifically, the structures of supply chains are the best known among these cases.

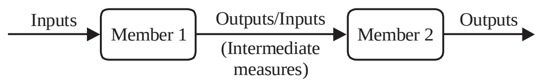

Fig. 1: Conventional structure of a dyadic supply chain

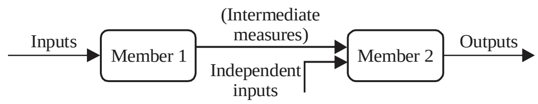

Fig. 2: Dyadic supply chain with independent inputs

The CCR and BCC models representing the standard DEA approach have experienced a wide variety of extensions[10]. Among these extensions, there are those dealing with dyadic supply chains. For the last decade, several studies have examined the efficiency of this type of chains with the DEA technique. Infact, the majority of these studies could be grouped into two major families. The first contains studies dealing with the case where dyadic chains take a structure with independent inputs (Fig. 2) and a second group of studies dealing with the conventional structure of a dyadic supply chain (Fig. 1).

It is clear that the difference between the two structures lies in the fact that in the former (Fig. 2), there are inputs of the second member (the right one) which are not generated by the first member (the left one). While, in the second structure (Fig. 1) only outputs generated by the first member become inputs to be consumed by the second member. Inputs of member 2 which are also outputs of member 1 are usually called "Intermediate measures".

Problem description: In order to measure dyadic chains' efficiency while considering intermediate measures, studies which have adopted the game theory in their modeling[11,12] have considered two main cases; a first case assuming that relationship between the first member (stage 1) and the second member (stage 2) is based on a non-cooperative game, a second case assuming that the first and second members are operating in a cooperative context. For the first situation, the authors used a leader-follower structure where the dominant member's efficiency is measured first then based on what is found as optimal relative efficiency, the dominated member's efficiency is then measured. Thus, two situations are assumed to represent the non-cooperative game. On the other hand, the cooperative game was formulated by a single model forcing the two members to assign the same set of weights to their intermediate measures. Thus, only the situation of absence of dominance is considered in order to reflect the cooperative game. In summary, three main deduced assumptions on which these studies were based to build their models allowing the measurement of the efficiency of a dyadic supply chains:

A1: Non-cooperative game necessarily implies the existence of dominance between chain members
A2: Existence of dominance necessarily reflects dominance of one of the two chain members
A3: Cooperative game necessarily implies the absence of dominance between chain members

Based on definitions dedicated to cooperation and dominance within a supply chain, these assumptions will be considered too restrictive and do not allow us to make a clear distinction between these two concepts in the procedure of measuring the efficiency of dyadic supply chains. Indeed, cooperation is usually defined as an agreement drawn in a perspective of time, involving interaction between members of independent organizations that combine intangible and hardware assets to achieve the agreement purpose as well as common and individual goals[13]. Thus, it represents the type of relationship that may exist between chain members. However, dominance is defined as the ability to influence others so, it reflects the power relationship that may exist between these two members. Consequently, in what follows a new methodology will be presented for measuring efficiency of dyadic chains in order to make these three hypotheses more flexible.

New methodology: As for as the cooperation concept is concerned and as already reported in studies that have used game theory to assess the efficiency of dyadic chains or two-stage production processes by DEA methodology, the authors have often distinguished between non-cooperative game and cooperative game. This same procedure is preserved so that a chain is said to be operative in a cooperative context if its members seek to maximize their joint profit or minimize their joint cost. By analogy in DEA, they seek to measure their joint efficiency. However, in the non-cooperative context, each member of the chain is more interested in maximizing its own benefit or minimizing its own cost without considering the consequences on the overall profit or on the overall cost for the chain. By analogy in DEA, they measure their efficiencies separately without worrying about the entire chain's efficiency.

Concerning dominance, the proposed approach is to incorporate this concept in modeling efficiency will not be the same neither in way nor in form. Regarding the form, it is distinguished by two points. First, based on the assumption that this concept could be applied to all types and levels of relationship[3], assuming that even when supply chain actors seek to maximize their joint efficiency, there may be different characterizations of their power relationship. Thus, when modeling dyadic supply chain's efficiency, that dominance should be present in the cooperative as well as in the non-cooperative contexts. The second point is that in addition to the two situations of dominance introduced in previous studies, it will be useful to consider two other situations which will be helpful for analyzing the effect of dominance on the efficiency of a given chain as well as that of its members; one situation that could be located in the middle of the two others and reflecting egalitarian dominance and another situation of absence of dominance. By doing so, four different situations of dominance that could be incorporated in the modeling of dyadic supply chain's efficiency are obtained namely: (1) Absence of dominance, (2) The first member who dominates, (3) The second member who dominates and (4) Egalitarian dominance.

At this point, the authors are inspired by Crozier and Friedberg[14] that the member holding the resource "information" and the ability to circulate it effectively within the chain has a decisive leadership. In this study, conflicts that may exist between chain members are supposed to be related to intermediate measures. Therefore, the member which controls and shares information regarding these measures is assumed to be the dominant one. Thus, absence of dominance is equivalent to the case where there is no information related to intermediate measures circulating among members, while the case of egalitarian dominance assumes that members agree to have the same amount of these measures.

These new assumptions will be formulated into models that take into account the four different situations which have been proposed to the consideration of dominance.

Let's consider a set of Z supplier-producer chains ($j = 1, ..., Z$), x_{isj} is the quantity of input i ($i = 1, ..., I$) consumed by the supplier S_j, v_i is the weight given to the input i, x_{pMj} is the quantity of independent input p ($p = 1, ..., P$) consumed by the producer M_j, v_p is the weight given to the input p, y_{qMj} represents the output q ($q = 1, ..., Q$) produced by the producer M_j, μ_q is the weight given to the output q, w_{rSCj} is the quantity of intermediate measures r ($r = 1, ..., R$) produced by the supplier S_j and consumed by the producer M_j, S_j and M_j together compose the chain SC_j and μ_r is the weight given to the intermediate measures r.

Non-cooperative framework models: Recall that the non-cooperation reflects a situation where each chain member is concerned only with maximizing its own efficiency regardless of the consequences that may be generated on the whole chain efficiency.

Situation 1: Absence of dominance: Mathematically, the technical efficiency of a supplier-producer chain is assessed in this case by measuring the supplier and the producer efficiencies separately while keeping away any restriction that could represent their power relationship. For a given chain k, these efficiencies are given respectively by the following two CCR-DEA models:

$$\text{Max}\sum_{r=1}^{R}\mu_r w_{rSC_k} = E_{S_k}$$

$$\begin{aligned}&\sum_{i=1}^{I}\vartheta_i x_{iS_k} = 1;\ \sum_{r=1}^{R}\mu_r w_{rSC_j} - \sum_{i=1}^{I}\vartheta_i x_{iS_j} \le 0;\\&j = 1,\ldots,Z;\ \mu_r,\ \vartheta_i \ge 0;\ r = 1,\ldots,R \text{ and } i = 1,\ldots,I\end{aligned} \quad (1)$$

$$\text{Max}\sum_{q=1}^{Q}\mu_q\, y_{qM_k} = E_{M_k}$$

$$\begin{aligned}&\sum_{r=1}^{R}\mu_r w_{rSC_k} + \sum_{p=1}^{P}\vartheta_p x_{pM_k} = 1;\ \sum_{q=1}^{Q}\mu_q\, y_{qM_j} - \sum_{r=1}^{R}\mu_r w_{rSC_j}\\&-\sum_{p=1}^{P}\vartheta_p x_{pM_j} \le 0;\ j = 1,\ldots,Z;\ \mu_q, \mu_r,\ \vartheta_p \ge 0;\\&r = 1,\ldots,R;\ p = 1,\ldots,P \text{ and } q = 1,\ldots,Q\end{aligned} \quad (2)$$

Overall efficiency could be generated in two ways; either by considering the mean of individual efficiencies or by their products. These two methods have one principle in common which is that a dyadic chain is considered efficient, if and only if, its members are both efficient. In this study, it is the first method that will be adopted thus, the chain's efficiency is given by:

$$E_{SC_k} = \frac{1}{2}\left(E_{S_k} + E_{M_k}\right)$$

Situation 2: Dominance of the supplier: After relaxing the assumption of equal weights related to intermediate measures, a restriction, allowing minimal consumption of intermediate measures to be equal to the quantity of these variables produced by the supplier and which guarantees an optimal efficiency of this latter is added to the standard producer model 2. Formally, this restriction is given by the following constraint:

$$\sum_{r=1}^{R}\mu_r^{M}\, w_{rSC_k} \ge \sum_{r=1}^{R}\mu_r^{S*} w_{rSC_k} \quad (3)$$

When measuring producer efficiency, this constraint forces the producer to take into account the fact that weights related to its intermediate measures should not negatively affect the supplier's optimal efficiency obtained by solving model 1.

Situation 3: Dominance of the producer: In contrast with the previous situation, the producer efficiency is measured first, then on the basis of obtained optimal value of intermediate measures, the supplier efficiency is determined. Thus, producer efficiency remains the same as given by model 2 presented in the situation of absence of dominance.

To measure its efficiency knowing that the producer is dominant, the supplier will have to consider that the efficiency given by maximizing its outputs must not degrade the producer's optimal efficiency. In order to have atleast an efficiency equal to that obtained by solving model 2, the producer would have to ensure minimum consumption of intermediate measures which are the supplier outputs and which also represent the supplier efficiency. So, this can be made by relaxing the assumption of equal weight and introducing a constraint into the standard supplier model 1 reflecting the producer dominance.

$$\sum_{r=1}^{R}\mu_r^S\, w_{rSC_k} \leq \sum_{r=1}^{R}\mu_r^{M*}\, w_{rSC_k} \qquad (4)$$

The constraint (4) introduced to the supplier model requires the latter to produce a quantity of intermediate measures equal to the relative amount considered as part of the producer inputs allowing the latter to have an efficiency atleast equal to that found by the resolution of model 2.

Situation 4: Egalitarian dominance: The presence of egalitarian dominance is assumed to deny the absence of dominance as it denies the existence of dominance of one of the members operating within a given chain. Indeed, equal power could be interpreted as a situation where no member of the chain could exert power over the other member even if it holds the information on intermediate measures.

Therefore, egalitarian dominance requires the establishment of a compromise between the supplier and the producer reflecting an agreement between them that the amount of intermediate measures produced by the supplier is the same as that consumed by the producer. In this situation the efficiency of a given chain and that of its members are proposed to be the average of efficiencies generated, respectively in the two previous situations (supplier dominance and producer dominance).

Cooperative framework models: This section is devoted to trying to formulate DEA models where the two members of the same chain seek simultaneously to maximize their efficiencies with taking into account all possible cases generated by the association of proposed situations of dominance.

Situation 5: Absence of dominance: Mathematically, the efficiency of a supplier-producer supply chain can be assessed in this case by simultaneously maximizing outputs of these members while putting away any restriction that could refer to dominance of one of them or to egalitarian dominance. To achieve this, the starting point will be the cooperative model proposed by Liang *et al.*[11] who proposed in their model to maximize the average of member's outputs and at the same time, to assume that weights assigned to intermediate measures are the same. According to these authors, when considering different the relative weights of these measures as supplier outputs and their relative weights as producer inputs, it is like considering the two members constituting the chain as independent.

However, a different point of view could be considered. Indeed, if maximizing efficiency ratios of chain members while, setting equal the weights of intermediate measures when they play the role of outputs or inputs, this would mean that cooperation reflects necessarily the absence of dominance between members. This leads to confusion between the concept of cooperation and that of dominance. Therefore, following the strategy of distinguishing between these two concepts, herein is proposed to treat the problem differently; the same cooperative model proposed by Liang *et al.*[11] is kept, but weights assigned by the supplier to its intermediate variables μ_r^S will be considered as different from those assigned by the producer to these same variables μ_r^M. Thus, the following model is obtained:

$$\text{Max}\ \frac{1}{2}\left[\frac{\sum_{r=1}^{R}\mu_r^S\, w_{rSC_k}}{\sum_{i=1}^{I}\vartheta_i x_{iS_k}} + \frac{\sum_{q=1}^{Q}\mu_q\, y_{qM_k}}{\sum_{r=1}^{R}\mu_r^M\, w_{rSC_k} + \sum_{p=1}^{P}\vartheta_p x_{pM_k}}\right]$$

$$\begin{aligned}&\frac{\sum_{r=1}^{R}\mu_r^S\, w_{rSC_j}}{\sum_{i=1}^{I}\vartheta_i x_{iS_j}} \leq 1;\ j=1,\ldots,Z;\ \frac{\sum_{q=1}^{Q}\mu_q\, y_{qM_j}}{\sum_{r=1}^{R}\mu_r^M\, w_{rSC_j} + \sum_{p=1}^{P}\vartheta_p x_{pM_j}} \leq 1;\\ &j=1,\ldots,Z;\ \mu_r^S,\ \mu_r^M, \vartheta_i, \mu_q,\ \vartheta_p \geq 0;\ r=1,\ldots,R,\ i=1,\ldots,I,\\ &p=1,\ldots,P \text{ and } q=1,\ldots,Q\end{aligned} \qquad (5)$$

Furthermore, model 5 can generate only the efficiency score of the chain under evaluation. So, there is a need to improve this model so that it can yield, after its resolution, the chain's as well as the supplier's and the producer's efficiency scores.

Inspired by Cook *et al.*[12] and Kao and Hwang[15], a model equivalent to model 5 which allows us to obtain all these scores simultaneously is proposed. Infact, these studies intended to measure overall dyadic supply chain's (two-stage production process) efficiency by involving all the two member's efficiency ratios. In their model's objective functions, they considered outputs of the second member as outputs of the entire chain. However, by doing so the supplier's concerns to maximize its efficiency will be ignored. Therefore, apart from the weighted sum of supplier inputs, the weighted sum of producer inputs should be equal to 1. Thus, the following linear model as an improved version of model 5 is proposed.

$$\text{Max } \frac{1}{2}\left(\sum_{q=1}^{Q}\mu_q\, y_{qM_k} + \sum_{r=1}^{R}\mu_r^S w_{rSC_k}\right)$$

$$\begin{aligned}&\sum_{i=1}^{I}\vartheta_i x_{iS_k} = 1;\ \sum_{r=1}^{R}\mu_r^S\, w_{rSC_j} - \sum_{i=1}^{I}\vartheta_i x_{iS_j} \le 0;\ j=1,\ldots,Z;\ \sum_{r=1}^{R}\mu_r^M\, w_{rSC_k} + \\ &\sum_{p=1}^{P}\vartheta_p x_{pM_k} = 1,\ \sum_{q=1}^{Q}\mu_q\, y_{qM_j} - \sum_{r=1}^{R}\mu_r^M w_{rSC_j} - \sum_{p=1}^{P}\vartheta_p x_{pM_j} \le 0;\ j=1,\ldots,Z; \\ &\mu_r^S,\ \mu_r^M,\ \vartheta_i, \mu_q,\ \vartheta_p \ge 0;\ r=1,\ldots,R;\ i=1,\ldots,I;\ p=1,\ldots,P \text{ and } q=1,\ldots,Q\end{aligned} \tag{6}$$

Compared to model 5, this model allows after its resolution to yield, for a given chain, all needed relative efficiencies. The supplier's, the producer's and the entire chain's efficiencies are given respectively by:

$$\sum_{r=1}^{R}\mu_r^{S*}w_{rSC_k},\ \sum_{q=1}^{Q}\mu_q^{*}\,y_{qMk} \text{ and } 1/2\left(\sum_{q=1}^{Q}\mu_q^{*}\,y_{qMk} + \sum_{r=1}^{R}\mu_r^{S*}w_{rSC_k}\right)$$

Situation 6: Dominance of the supplier: Back to situation 2 where the supplier is assumed be dominant in a non-cooperative context, this latter should measure its efficiency in the first place (before the producer) in order to transmit information that reflects its dominance resulted from this measure. However, in a cooperative context, this advantage is no longer available because the order of measurement is not involved. Indeed, joint efficiency of the two members is assumed to be generated by a single model. Therefore, incorporation of supplier dominance in the cooperative model should be modeled differently.

By agreeing to cooperate with the producer, the supplier wants to maximize its efficiency through maximizing its outputs that are also intermediate measures of the chain while, trying to minimize or keep its inputs constant. Since it is considered dominant, it will then use these variables in a way that does not negatively affect its efficiency. This could lead us to treat these variables from a different perspective to that considered in the non-cooperative context.

Indeed, although intermediate measures represent profit to be maximized for the supplier, they could be also considered in some cases as a charge having an adverse effect on its efficiency. To avoid such charge, the supplier is assumed to will require the producer to consume a quantity of intermediate measures greater than or equal to that it produced. Formally, this can be expressed by adding a constraint to the model 6, reflecting the information transmitted by the supplier which is as follows:

$$\mu_r^M\ w_{rSC_k} \ge \mu_r^S\ w_{rSC_k} \text{ and } r=1,\ldots,R \tag{7}$$

This restriction forces the producer to use an amount of intermediate measures greater than or equal to that produced by the supplier. Thus, this latter guarantees that all its outputs will be consumed. In this way, it ensures there will be no loss of income on unsold production and no extra charges on stock.

Situation 7: Dominance of the producer: In order to express its dominance and since intermediate measures are part of its inputs, the producer is assuming to will have to prevent a stock out which may expose it to production problems. Therefore, it will require the supplier to produce a quantity of intermediate variables just bit greater than or equal to that it (the producer) will need. Mathematically, this can be expressed by adding a constraint in (6), reflecting this information transmitted by the producer to the supplier which is as follows:

$$\mu_r^S\ w_{rSC_k} \ge \mu_r^M\ w_{rSC_k} \text{ and } r=1,\ldots,R \tag{8}$$

Situation 8: Egalitarian dominance: In the non-cooperative context, specifically in situation 4, the average is used because the order of the efficiency measurement differs following the member who dominates. However, in a cooperative context, efficiencies are all provided by a single model, that's why it will be necessary to find another alternative to model egalitarian dominance.

If the supplier is assumed to express its dominance by imposing the constraint (7) and the producer expresses its dominance by imposing the constraint (8) then the position of egalitarian dominance, where the two members seek to have a common agreement (compromise) on intermediate measures should be located between these two situations of dominance. As a result, this situation could be represented by the following constraint:

$$\mu_r^S \; w_{rSC_k} = \mu_r^M \; w_{rSC_k} \text{ and } r = 1,\dots,R \qquad (9)$$

This constraint ensures that the amount of intermediate measures produced by the first member is the same used by the second member.

RESULTS AND DISCUSSION

To achieve the main objective of this study that is obviously studying the DEA efficiency of a dyadic chain and those of its members when taking into account the difference between cooperation and dominance, the illustration considered in this work is the same adopted by Liang *et al.*[11] (Table 1). Table 2 presents results obtained in the first four situations of dominance considered in the non-cooperative context while, Table 3 displays results yielded in those same situations considered in the cooperative context.

Obtained results allow highlighting important remarks which can be summarized as the follows:

- The chain's efficiency scores obtained in a non-cooperative context where there is absence of dominance (situation 1) are higher than or equal to those obtained in the presence of dominance (situations 2 and 3), it follows that dominance, regardless of its origins, does not improve chain's efficiency levels
- Compared to supplier dominance in a non-cooperative context (situation 2), the producer dominance (situation 3) has a more negative effect on the efficiency score of the chain to which it belongs
- Efficiency scores obtained in a cooperative context with dominance (situations 6 and 7) are lower or equal to those obtained in the same context without dominance (situation 5). Thus, dominance regardless of its origins, has a negative or neutral impact on chain's and member's efficiency levels
- Among all situations where dominance exists in a cooperative context, namely, supplier dominance, producer dominance and egalitarian dominance (situations 6, 7 and 8) this latter has the most negative effect on chain's and member's efficiency scores

By comparing results generated in a cooperative context with those obtained in a non-cooperative context, efficiency scores relative to chains and members are found the same in

Table 1: Illustrative example

	Supplier inputs			Intermediate measures			Independent inputs	Producer outputs	
Chain	X_{1S_k}	X_{2S_k}	X_{3S_k}	W_{1SC_k}	W_{2SC_k}	W_{3SC_k}	X_{1M_k}	Y_{1M_k}	Y_{2M_k}
1	9	50	1	20	10	5	8	100	25
2	10	18	10	10	15	7	10	70	20
3	9	30	3	8	20	2	8	96	30
4	8	25	1	20	20	10	10	80	20
5	10	40	5	25	20	5	15	85	15
6	7	35	2	35	10	5	5	90	35
7	7	30	3	10	25	8	10	100	30
8	12	40	4	20	25	4	8	120	10
9	9	25	2	10	10	5	15	110	15
10	10	50	1	20	15	9	10	80	20

Table 2: Suppliers, producers and supply chains efficiencies yielded in the non-cooperative context

	Situation 1			Situation 2			Situation 3			Situation 4		
SC	S. Eff.	P. Eff.	SC. Eff.	S. Eff.	P. Eff.	SC. Eff.	S. Eff.	P. Eff.	SC. Eff.	S. Eff.	P. Eff.	SC. Eff.
1	1.000	1.000	1.000	1.000	1.000	1.000	0.642	1.000	0.821	0.821	1.000	0.911
2	1.000	0.805	0.903	1.000	0.805	0.903	1.000	0.805	0.903	1.000	0.805	0.903
3	0.800	1.000	0.900	0.800	1.000	0.900	0.800	1.000	0.900	0.800	1.000	0.900
4	1.000	0.628	0.814	1.000	0.548	0.774	0.350	0.628	0.489	0.675	0.588	0.631
5	0.676	0.604	0.640	0.676	0.604	0.640	0.676	0.604	0.640	0.676	0.604	0.640
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	0.833	0.917	1.000	0.833	0.917	0.627	0.833	0.730	0.814	0.833	0.823
8	0.770	1.000	0.885	0.770	0.945	0.858	0.519	1.000	0.759	0.644	0.973	0.808
9	0.500	1.000	0.750	0.500	1.000	0.750	0.390	1.000	0.695	0.445	1.000	0.722
10	1.000	0.668	0.834	1.000	0.650	0.825	0.626	0.668	0.647	0.813	0.659	0.736

Table 3: Suppliers, producers and supply chains efficiencies yielded in the cooperative context

	Situation 5			Situation 6			Situation 7			Situation 8		
SC	S. Eff.	P. Eff.	SC. Eff.	S. Eff.	P. Eff.	SC. Eff.	S. Eff.	P. Eff.	SC. Eff.	S. Eff.	P. Eff.	SC. Eff.
1	1.000	1.000	1.000	0.770	1.000	0.885	1.000	0.894	0.947	0.726	1.000	0.863
2	1.000	0.805	0.903	0.943	0.801	0.872	0.922	0.784	0.853	0.922	0.784	0.853
3	0.800	1.000	0.900	0.800	1.000	0.900	0.722	1.000	0.861	0.673	1.000	0.836
4	1.000	0.628	0.814	1.000	0.548	0.774	1.000	0.628	0.814	1.000	0.548	0.774
5	0.676	0.604	0.640	0.676	0.566	0.621	0.676	0.597	0.637	0.676	0.559	0.617
6	1.000	1.000	1.000	0.995	1.000	0.997	1.000	1.000	1.000	0.995	1.000	0.997
7	1.000	0.833	0.917	1.000	0.808	0.904	1.000	0.833	0.917	1.000	0.808	0.904
8	0.770	1.000	0.885	0.728	0.907	0.818	0.766	1.000	0.883	0.728	0.907	0.818
9	0.500	1.000	0.750	0.500	1.000	0.750	0.500	1.000	0.750	0.500	1.000	0.750
10	1.000	0.668	0.834	0.860	0.650	0.755	0.956	0.656	0.806	0.851	0.657	0.754

the situation of absence of dominance (situations 1 and 5), when the supplier is considered dominant (situations 2 and 6), efficiency scores obtained in a cooperative context (situation 6) are lower while, in the case of producer and egalitarian dominance (situations 3, 4, 7 and 8) to determine which context (cooperation or non-cooperation) is more beneficial for chain's and member's efficiency scores cannot be done.

After comparing the results of this study with those of other studies by Liang *et al.*[11], Cook *et al.*[12], Kao and Hwang[15], Chen *et al.*[16], Wu *et al.*[17] and Yang *et al.*[18] following improvements could be derived.

Conceptual improvements: Researchers such[12,15] have emphasized the fact that dyadic chain could be considered efficient if and only if its members are found both efficient. However, based on the four situations proposed for considering dominance, two new definitions could be introduced; (1) Semi-efficiency of a dyadic chain in situations where dominance is absent or egalitarian (definition 1) also strong semi-efficiency and weak semi-efficiency of a dyadic chain where one of its two members is considered dominant (definition 2).

- **Definition 1:** A dyadic supply chain is called semi-efficient if and only if one of its two members is efficient and the other is not
- **Definition 2:** A dyadic supply chain, dominated by one of its two members, is called strongly semi-efficient if and only if the dominant member is efficient and the other is not and it is called weakly semi-efficient if the dominated member is technically efficient and the other is not

The usefulness of these two definitions is essentially the ability, after compute efficiency scores, to point out the sources of inefficiency and hence, allow the manager to detect quickly member's that should be reconfigured or replaced in order to improve global efficiencies of chains under evaluation.

Analytical improvements: Contrary to studies such[11,16,17], DEA models proposed in this study have the advantage of being all non-parametric and linear programs therefore, they do not require extra effort for linearization as the transformation of variables to be solved.

Also, the proposed new methodology gives the possibility of using other methods of efficiency measure such, non-parametric methods namely the Free Disposal Hull (FDH) or parametric methods like the Deterministic Frontier Analysis (DFA) and the stochastic Frontier Approach (SFA). By focusing on DEA method, extensions related to its basic models could be as well used. Among these extensions, this study mention the cross efficiency score and the least distance projections[10].

Decision aid improvements: By comparing efficiency scores obtained in the different proposed situations, a decision maker will have a kind of sensitivity analysis enable him to detect and analyze plausible changes on results generated from each situation. Therefore, this study will be able to deduce the best situation allowing to achieve better efficiency and to advice on the best combination allowing maximum efficiency for a chain and its members.

CONCLUSION

In this study, researchers have provided new Data Envelopment Analysis (DEA) formulations allowing the measurement of supply chain's efficiency based on distinguishing between cooperation concept (reflecting the relationship that could exist between chain actors) and dominance concept (reflecting the power relationship that could be present between these same actors). Also, they have studied the impact of dominance on global as well on individual efficiencies of dyadic supply chains. Proposed models are all linear and non-parametric therefore, they are easier to solve. In addition, two new definitions of semi-efficiency and strong/weak semi-efficiency were introduced, they help in quickly detecting the sources of inefficiency in any dyadic supply chain even more, in any two members/stages structure. Obtained results will certainly help to improve future studies of more complex supply chains performance especially in term of available resource's using.

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