Coordination and return uncertainties in closed loop supply chains

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***Abstract*— In this article we analyze quantitatively the gains of coordination in a closed loop supply chain context for different levels of uncertainty about returns. The novel characteristic of this study is to evaluate quantitatively the value of coordination for operational decisions (in the context of inventory management decisions). Thus, we find it interesting to verify its validity in the reverse logistics setting. We observe principally that the works in this area, according to some authors, use approaches such as game theory or contracting. This leads us to believe that there is a gap in the studies on the influence of coordination in relation to operational decisions such as inventory management. One of the more important characteristics of the closed loop supply chain context is the addition of uncertainties about returns. This heightens our interests on the analysis of this topic. We show through a numerical experiment the convenience of global coordination in a closed loop supply chain for different levels of uncertainty. Finally, we observe that the value of coordination, as uncertainty increases, slightly decreases.**

Index Terms-Coordination; information sharing; uncertainty; closed loop supply chains

I. Introduction

In the last several decades there has been an increased interest in the impact of the economic activities in natural resources. The legislation, each time more demanding, has obligated companies to take care of products after the end of their life (cars, mobile phones, photocopiers, etc.). In addition to these restrictions at the end of the product's life, the companies must also manage the return flow of products with warranty, and with defects which do not meet the client requirements, in excess in the retail stores, etc. These flows are partially increasing due to e-commerce. All these return flows represent an important impact in the company's performance. For example, big stores such as Home Depot, may have return rates near 10% [1]. In the computers industry, more than 700 million dollars of return products, which continue to function, have been destroyed [1]. Hewlett – Packard estimates that the cost of returned products is 2% of the total sales [2].

It is possible to create value from returned products by remanufacturing operations (leave the returned products as good as new), from the reutilization of some components for the manufacturing of new products, from the materials recycling, etc. Some authors estimate that the production cost of remanufactured products is 40% to 60% cheaper than brand new products [3].

Reference [4] affirms that the production cost reduction due to the reutilization of components and materials is between 40% and 65%. Eastman Kodak Company receives from their retail stores the cameras returned by the clients. On average, the 76% of the components are reused in the production of a new one [4].

This paper is focused on coordination problems imposed by the flows of returned products and therefore, in the reverse logistic framework. In particular, we want to analyze the benefits expressed in the precedent paragraphs remain, decrease or increase in presence of coordination and return uncertainties among the actors of the supply chain. The approach of this paper is focused on operational decisions. Some authors state that there is a lack of research about coordination in closed loop supply chains [5]. According to [1] principally the works about coordination in the reverse logistics context use approaches such as game theory or contracting, thus leading us to believe that there is a gap in the studies on the influence of coordination and return uncertainties on operational decisions like inventory management.

Inventory management problems present an interesting approach to analyze the value of coordination at the operational level. Game theory approach, according to our knowledge, is more focused at the strategical or tactical level.

According to [6], the different quantitative models proposed in the area can be classified as distribution planning models, inventory management models and production planning models. In this article we will focus on inventory management models. In order to have suitable mechanisms of control and management of the inventories it is fundamental to integrate correctly the return flows of disuse products in the production planning of the company. If the products in disuse are returned to the producer of origin, this gives him another source of resources for the manufacture of new products. For example, in the manufacturing of cars, the replacements can often be made from parts in disuse or in the electronic industry where the returned products can be used in new ones [6].

In order to gain a deeper understanding of this context, we present the approach of [6]. In their article, they propose a general framework to analyze the inventory management in this area, see Fig.1.

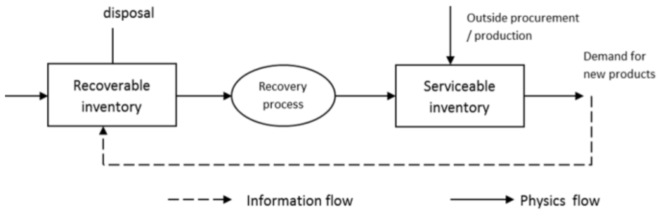

Fig. 1. Framework for inventory management with returns. Source: [6].

The producer satisfies the demand for new products. We put in the case where the producer receives products in disuse from the market. It has two alternatives to satisfy the demand. To order the supplies to an external supplier and make the new products or to repair the products in disuse received to leave them in the same conditions as new products. The objective of the inventory management is to control the orders of materials to external suppliers and to control the process of recovered products in disuse, in order to guarantee a suitable level of service while fixed and variable costs are minimized.

In this article we will use a modified version of the Fleishchmann's framework. In particular we will include coordination and information sharing among the supply chain actors in a centralized and decentralized setting in the presence of return uncertainties.

In the next section we review the literature, where we present issues of coordination in forward supply chains in order to better our understanding of the gains in this setting. Then, we will compare whether or not the gains change once in a closed loop supply chain. In the same section we will analyze pieces of literature about coordination in the reverse logistics setting, and finally we will study some specific inventory management models. Later, we will present the section on materials and methods. In this section, we present the test cases to analyze the value of coordination, we define the coordination scenarios, and we present the linear programming model and the used data. Finally, we have a section with the results, conclusions and perspectives of this paper.

II. Literature Review

A. Coordination in Forward Supply Chains

A great part of the literature in this area is interested in the value of downstream information in supply chains. This is the information nearest to the final customer. Principally, in studies such as these, the used information is the customer's demand in the form of realized demand or forecast of the demand.

In the work of [7], the gains on the costs in the centralized information case have an average value of 1,75%. Some other results of this study are: the value of information seems to be more important when the number of stages in the supply chain increase, or the lead time increases or the coefficient of variation of the demand increases. Indeed, [7] showed with its results that if the variability of the demand increases, information sharing about customer demand becomes more important.

Reference [8] stated that information sharing is beneficial only if the capacity is not restrictive and if the "system" has the flexibility to respond to the additional information. In his numerical example, information sharing reduces the costs between 1% and 35%. The objective of the work of [9] is to measure quantitatively the gains of information sharing in a supply chain with a retailer and a factory. The principal results show that information sharing is important for the factory when the correlation and the variance of the customer demand is high and the lead times are long. Reference [9] showed that if the variance of the demand is high, the gains due to information sharing are more important. In the work of [10], there is a comparison between a policy of inventory management with and without information sharing for a supply chain with a factory and N identical retailers. In their numerical example, they found profits of 2.2% on average with a maximum of 12.1%. The conjecture of the authors to explain this relative small improvement is that the orders of the retailers have a great part of the information necessary for the factory. On the other hand, they led an analysis to determine the importance of the reduction of lead times and the reduction in batch sizes. They found profits of 21% on average due to a reduction of the lead times and 22% due to smaller batch sizes and high frequencies of deliveries. The conclusion of these results is that the information sharing becomes more useful if it is used to accelerate and smooth the physical flows of products through the supply chain (to smooth and to accelerate physical flows implies a reduction of lead times and an increase in the frequencies of the deliveries because smaller batch sizes). The authors anticipate that isolated information sharing (without reduction of lead times or the batches sizes) is more important in an environment with uncertain demand, for example, new products.

Reference [11] analyzes the benefit of information sharing and the strategy VMI (Vendor Managed Inventory). The results showed gains between 0% and 9,5%. They also found that these profits improve if the demand is correlated with time, if the lead times are long or if there are restrictions of capacity.

In a different context, [12] measure the bullwhip effect in a supply chain with two members (a retailer and a factory). The authors noted that the increase in the variability of the orders of the retailer towards the factory is the result of 3 elements: the number of observations used to make the forecast of the demand (the moving average), the lead time, and the correlation factor of the customer's demand. The results showed that if all information is centralized and that each member of the supply chain uses the same forecast technique and the same policy of inventory management, the variability is reduced, but the bullwhip effect still exists. That means that it is difficult to eliminate this effect completely.

Reference [13] found in their work that information sharing is not the only strategy to improve performance in supply chains. They stated that there are also greater benefits through decision-making coordination, which aligns all information and incentives to support global system objectives.

In the same context we found the work of [14]. They study the value of anticipated information for a production/distribution system with restricted capacity. The authors show that the profits of anticipated information are reduced if the studied system is rather charged (an utilization ratio of the server close to 100%). If the final customer accepts to be delivered in advance, the profits of anticipated information are important. On the other hand, if the final customer does not accept the delivery in advance of the orders, the value of information anticipated is rather modest.

In a similar context there are studies that analyze the impact of coordination in supply chains when there are different levels of uncertainty. References [7] and [9] states that information sharing is more valuable when the customer demand variance is high. Reference [9] adds demand correlation and long leads times to his analysis.

Similarly, [10], present some results about the importance of information sharing in this context. In a one supplier and N retailers setting they make a comparison between inventory management policies with and without information sharing. Wer observe the same kind of results, i.e., information sharing is more important in uncertain environments. They mentioned the case of early sales of new products.

We have noted that all the authors often compared a centralized approach (with full information sharing in the chain) with a decentralized approach (with only local information). In these works the used models are often of inventory management. However, assumptions, resolution approaches, and mathematics tools differ from one study to another.

The common results of these works are: restrictions of capacity, lead times, structure of the chain, and characteristics of the customer's final demand, can influence the value of shared information.

B. *Coordination in Closed Loop Supply Chains*

Reference [15] analyze alternative prioritization and coordination strategies for replenishing serviceable items in hybrid (manufacturing/remanufacturing) systems, where their major result is that coordination in the first echelon of the hybrid system eliminates the benefits of prioritization. As [1] mention, the works about coordination in closed loop supply chains are principally in the game theory and contracting area. We find works like [4], [16], [17], [18] and [19].

Reference [5] explores the value of information in the context of a firm that faces uncertainty with respect to demand, product returns, recovery yield, and capacity utilization. He measures and evaluates the value of information through three information cases. He found that there is no dominance in value amongst the different types of information.

References [5] and [20] used four different scenarios that reflect capabilities with respect to supplier lead-time and yield information; this work compares the value of information to improvements in supplier responsiveness. Reference [21] extends this work to the case of remanufacturing multiple components parts. Reference [22] also addresses the value of yield information in the context of a mixed assembly-disassembly operation for remanufacturing.

Finally, [23] address a supplier that satisfies demand with new product, recovered product or a mix. There are uncertainties about demand, product returns and recovery yield. They showed that the value of one type of information does not dominate any other type and that there is an additional pay-off from investing in more than one type.

Reference [24] investigates the impact of imperfect information with respect to the return process on inventory management performance. They analyzed four methods to forecast lead-time net demand. Their results showed that in the case of imperfect information the most informed method does not necessarily lead to best performance.

Reference [25] states four procedures to forecast lead-time returns of reusable containers. Each procedure has a different level of information requirement.

We observe, like [24], that there is not much literature concerning the value of information for inventory management in reverse logistics settings. In addition the literature about this topic assumes “perfect” information. Therefore the gains of coordination in the reverse context are not so evident as in the forward case.

C. *Reverse Logistics Inventory Models*

In the context of deterministic models (all the information is known), one of first models presented is from [26]. This model, considers that there does not exist backlogs and supposes infinite capacity of external supplier and recovery process. The aim of this model was to find the optimal order lots from the external supplier and from recovery process (similar to the EOQ model, Economic Order Quantity). Reference [27] treats an extension of the Schrady’s model to the case in which backorders exists. Reference [28] considers a model with gradual arrival of products from the recovery process to a rate of P units / year. This model is an extension of the EPQ model (Economic Production Quantity) to reverse flows. It is assumed that the recovery process has a limited capacity.

In the context of the stochastic inventory models, the demand and the return flows can be uncertain. Several cases can be considered: returns independent from the demand or not, instantaneous returns or not, possibility of rejecting the returned products or not, etc. The work of [29] analyzes an inventory model with return flow where they found the policies that determine optimal manufacturing, remanufacturing and disposal through a dynamic optimization problem. Another study related to the topic is the work of [30]. They explore different policy decisions in a manufacturing system by obtaining the optimal policy of sourcing and comparing it with those obtained by heuristic procedures.

Reference [31] conducted an analysis of an inventory dynamic management system through simulation models that contain recovery processes. He analyzes different scenarios in order to characterize the effects in considering the return flow of end of use products in relation to the traditional inventory models.

To our knowledge, it is possible to observe in the literature about reverse logistics inventory models that quantitative comparisons do not exist between traditional inventory management and ones that consider return flows. We also observe that there is no consideration of the impact of uncertainties in the performance of reverse inventory management models. On the other hand, the majority of the proposed models are for one product of one component. Naturally, in practice there exist many situations in which the product is constructed from several components, therefore the extension to these cases is natural and desirable.

III. Material and methods

A. Test Cases

To study the influence of coordination and uncertainty in closed loop supply chains we propose a test case that considers a simple structure of a reverse supply chain, see Fig. 2.

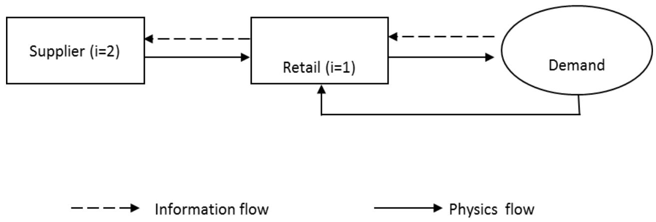

Fig. 2. Structure for the reverse supply chain analysis.

The supply chain has two entities: a single retailer and a single supplier. The capacity is infinite for each supply chain member. There are fixed lead times for order information and supply. And there is no information sharing between them (except the order of the retailer). Each week the supply chain members have to meet the downstream demand (customer demand for the retailer and the retalier order for the supplier). In addition, each week the retailer receives returned products from the market. These products are as good as new, thus the products are added to the serviceable inventory. If an order cannot be meet, is recorded as backorder. This order must be satisfied as soon as possible. For each week, there is a backorder cost of $2 per item and a holding cost of $1 per item.

The objective for each member is minimize the supply chain costs, either individually or globally. This setting is very similar to the MIT Beer Game in an operational way. But the difference is that we explore different coordination scenarios. For example, in our work the retailer may share demand and forecasting information to the supplier. Next the supplier schedules his production with this information. After that, we analyze two alternatives of perimeter decision. A centralized and a decentralized decision making. In the former case, the planned orders may or not be share to the upstream member. We called that decision making (DM) information sharing. Finally, each member plans his production with the available information.

For this structure we are interested in the minimizations of the total supply chain cost composed of holding and backlog costs. There is no information about the future and initially there is no coordination. In this setting, we make a comparison of the reverse supply chain performance according to two coordination scenarios for different levels of uncertainty. Therefore, we compare a coordinated case (global optimization with demand and decision making (DM) information sharing) with a less coordinated case (local optimization with demand and decision making (DM) information sharing). For each comparison, we evaluate different levels of uncertainty about returns. More details in next section.

B. The Coordination Scenarios

Reference [32] characterizes the supply chain coordination scenarios in two dimensions of analysis: the perimeter of decision making and information sharing.

The perimeter of decision making (DM) considers two extreme approaches. Initially, each supply chain member optimizes his operations in a myopic way. Namely, there is no interest in the impact of his policy on the other members of the chain (we have a sum of local optimizations). The second approach is a global optimization that implies the identification of an optimization criterion for the whole system. Naturally we can have intermediate scenarios to analyze.

We distinguished, for this research, tree types of information sharing: demand, decision making and reverse flow (opportunity, quality and quantity of returns) information sharing.

This work proposes several levels of uncertainty for each coordination scenario. Some characteristics of both coordination scenarios are: the customer demand is known by the retailer and shared with the supplier at t=0 (we have therefore "demand" information sharing), the forecast of returns is shared too by the retailer at t=0. The first scenario is a supply chain global optimization and the second one is a local optimization for each member. In this former scenario, we have additionally decision making (DM) information sharing between the members. To resume we have full information sharing between the scenarios and the difference is that in one case we have a global coordination and in the other one we have a local optimization (scenarios 1 and 2 in table 1).

One important remark is that our local optimization scenario is different compared with the well-known decentralized case studied in the literature. Principally, because we allow information sharing among the members (scenarios 3 and 6 in Table 1).

Table 1. The coordination scenarios.

Information sharing		DM perimeter	
Demand	***DM***	***Global optimization***	***Local optimization***
Yes	Yes	Scenario 1	Scenario 2
	No	-	Scenario 3
No	Yes	Scenario 4	Scenario 5
	No	-	Scenario 6

C. *The Model*

We developed linear programming (LP) models to solve the global and local coordination scenarios (scenario 1 and scenario 2 in table 1). We minimize the total cost for both scenarios. Each supply chain member incurs in holding and backlog costs for each period.

Each member solves a LP model in the local coordination case (scenario 2). Here we suppose additionally that there is infinity capacity of the supplier. In the global case, we minimize the total supply chain cost (scenario 1).

We used CPLEX© 12.1 to solve both coordination scenarios. The linear programming (LP) models for the global and local coordination cases are presented in Fig.3.

$HC_{i,t}$ is the unit holding cost for member 'i' in period 't'
$BC_{i,t}$ is the unit backlog cost for member 'i' in period 't';
$S_{i,t}$ are the inventory units for member 'i' at the end of period 't' (the orders in transit are not included here)
$b_{i,t}$ are the units in backlog for member 'i' at the end of period 't'
i is equal to 1 (Retailer),and 2 (Supplier)
N is the number of planning periods (N=36 periods)
L_i is the information lead time
L_p is production and transport lead time
$Sh_{i,t}$ are the units sent by member 'i' in period 't'
$X_{i,t}$ is the order of member 'i' in period 't'
R_t are the returned quantities from the customer to the retailer in period t.
D_t is the final customer demand in period 't'
The LP model for the global optimization case is:

$$Min\ TC = \sum_{t=1}^{N} \sum_{i=1}^{2} HC_{i,t} * S_{i,t} + BC_{i,t} * b_{i,t} \quad (1)$$
s.t.

Retail (i=1):
$$S_{i,t} = S_{i,t-1} + Sh_{i+1,t-L_p} - Sh_{i,t} + R_t \quad (2)$$
$$Sh_{i,t} \le S_{i,t-1} + Sh_{i+1,t-L_p} + R_t \quad (3)$$
$$Sh_{i,t} \le D_t + b_{i,t-1} \quad (4)$$
$$b_{i,t} = D_t + b_{i,t-1} - Sh_{i,t} \quad (5)$$

Supplier (i=2):
$$S_{i,t} = S_{i,t-1} + X_{i,t-L_p} - Sh_{i,t} \quad (6)$$
$$Sh_{i,t} \le S_{i,t-1} + X_{i,t-L_p} \quad (7)$$
$$Sh_{i,t} \le X_{i-1,t-L_i} + b_{i,t-1} \quad (8)$$
$$b_{i,t} = X_{i-1,t-L_i} + b_{i,t-1} - Sh_{i,t} \quad (9)$$

The LP model for the local optimization case is:

Retail (i=1):

$$Min\ TC = \sum_{t=1}^{N} HC_{1,t} * S_{1,t} + BC_{1,t} * b_{1,t} \quad (10)$$
s.t.
$$S_{i,t} = S_{i,t-1} + X_{i,t-(L_p+L_i)} - Sh_{i,t} + R_t \quad (11)$$
$$Sh_{i,t} \le S_{i,t-1} + X_{i,t-(L_p+L_i)} + R_t \quad (12)$$
$$Sh_{i,t} \le D_t + b_{i,t-1} \quad (13)$$
$$b_{i,t} = D_t + b_{i,t-1} - Sh_{i,t} \quad (14)$$

Supplier (i=2):

$$Min\ TC = \sum_{t=1}^{N} HC_{2,t} * S_{2,t} + BC_{2,t} * b_{2,t} \quad (15)$$
s.t.
$$S_{i,t} = S_{i,t-1} + X_{i,t-(L_p+L_i)} - Sh_{i,t} \quad (16)$$
$$Sh_{i,t} \le S_{i,t-1} + X_{i,t-(L_p+L_i)} \quad (17)$$
$$Sh_{i,t} \le X_{i-1,t-L_i} + b_{i,t-1} \quad (18)$$
$$b_{i,t} = X_{i-1,t-L_i} + b_{i,t-1} - Sh_{i,t} \quad (19)$$

Fig. 3. LP models for global and local coordination.

It is important to notice that the supplier's forecast of the retail order is equal to the demand in period t minus the retailer forecast of the returns for period t. We believe that it is the closest intuitive approach of the supplier. Thus, there is demand information, forecast of returns information, and decision making sharing between the members.

D. *Used Data and Experiment Design*

For all the supply chain members, the unit holding and backlog costs are 1($/week) and 2 ($/week) respectively. Lp and Li are equal to 2 weeks and the optimization horizon is N=36. The customer demand follows a normal distribution with a mean of 200 (units/week) and a standard deviation of 150 (units/week). We use a customer demand with a high variability because we want to analyze the results in relation with those obtained for the forward supply chains. The return quantities are a fraction of the demand and follow a normal distribution. Namely, the return quantities follow a normal distribution with a mean of p200 and a standard deviation of p150 (we analyze the value of coordination for different return rates (p), where p can be 10%, 30%, 50% and 70%).

For the first four weeks, for all the supply chain members, the values of some variables are: customer demand (D_t) is equal to 4(units/week); inventory ($S_{i,t}$) for each member is equal to 12 (units/week), shipments ($Sh_{i,t}$) and quantity orders ($X_{i,t}$) are equal to 4 (units/week).

Next, we made the forecast for the returns. The uncertainty is measured like the accuracy of the forecast. For example, if the forecast is not accurate at all, we have a bigger level of uncertainty. We define 6 levels of uncertainty, where an increasing value of the standard deviation indicates a bigger uncertainty. In table 2 we present the levels of uncertainty, where for example, level 1 is less uncertain than level 2.

TABLE 2. LEVELS OF UNCERTAINTY.

Level of accuracy	**Forecast of returns (Ft)**
0	Exact
1	N(p200;1.2p150)
2	N(p200;1.4p150)
3	N(p200;1.6p150)
4	N(p200;1.8p150)
5	N(p200;2p150)

We recall that we are looking for the value of coordination for different levels of uncertainty about returns. For both coordination scenarios, we have full information sharing.

The forecast of return quantities are known for all the supply chain members at t=0. We don´t make a stochastic optimization. We used a realization from the normal distribution of return quantities. This realization is the forecast.

For each coordination scenario we have tested the six levels of uncertainty through the LP models over the entire time horizon (N=36 weeks).

For the analysis, we used a rolling planning horizon. That is, for each coordination scenario, we optimize over the 36 periods with the forecast. Next, when the real value of the return quantities becomes known for a particular time $t=t_0$, we actualize the stock ($S_{i,to}$), the shipments ($Sh_{i,to}$) and the units in backlog ($b_{i,to}$) and we re-optimize for the (N- t_0) remaining periods. It is important to mention that we do not update the forecast. We actualize the variables of the model and re-optimize the rest of the periods. Therefore, we adjust the decision variables for the remaining periods based on the real value of the return quantities.

We want to clarify the use of the levels of uncertainty. For example, if the real return quantities follow a normal distribution with parameters N(20;15) , then a forecast of the return quantities with parameters N(20;27) is more uncertain than a forecast with parameters N(20;21).

Each level of uncertainty remains constant during the 36 weeks. In further studies, we can study the effect of decreasing uncertainties for the closest periods.

Finally, we have tested 100 instances of customer demand. For each instance of customer demand we have tested the 6 levels of uncertainty, as we already know each level of uncertainty represents a forecast. For each level of uncertainty, we generated instances of the forecast (100 instances). Therefore, the performance measure of the reverse supply chain for each coordination scenario and level of uncertainty was obtained through the average of 10.000 combinations of instances.

IV. RESULTS

In Fig. 4, we give the average of the performance measure for the two coordination scenarios (global and local optimization with demand, forecast of returns and DM information sharing) for a return rate of 10% of the customer demand.

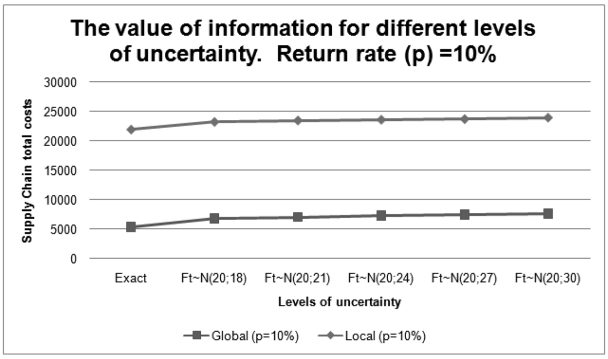

Fig. 4. The value of information for different levels of uncertainty. Return rate (p)=10%.

We observe an important difference between the global and local coordination scenarios. On average, the global costs represent a 30% of the local coordination costs for different levels of uncertainty. If we compare the performance without uncertainty (exact on Fig. 4), the global costs represent a 25% of the local coordination costs. If we make the same analysis for the other return rates, we have in table 3 a summary of these results.

TABLE 3. GLOBAL COSTS AS A PERCENTAJE OF LOCAL COSTS

Return Rate	**Without Uncertainty**	**With Uncertainty**				
	0	***1***	***2***	***3***	***4***	***5***
10%	25%	30%	30%	31%	31%	32%
30%	23%	36%	38%	39%	40%	41%
50%	22%	41%	42%	42%	43%	44%
70%	24%	43%	44%	44%	44%	47%

For the different returns rates we always observe an important difference between the global and local coordination scenarios. We also found that a global optimization remains better than the local one if the uncertainty increases. Apparently, the difference between the curves remains almost constant with uncertainty. Let us note that in the deterministic case (called exact in Fig. 4) the global optimization is better than the local one, which is not surprising, and in addition, the supply chain performance is better than in those cases with uncertainty.

If we analyze the global coordination costs for different return rates (see Fig. 5) we observe that as the return rates increase the global coordination performance is worse and this behavior is very clear. We are also able to observe that if the level of uncertainty increases (for each return rate). However the increase is very little. In fact, we can say that as uncertainty increase (for each return rate) the global cost remains almost constant.

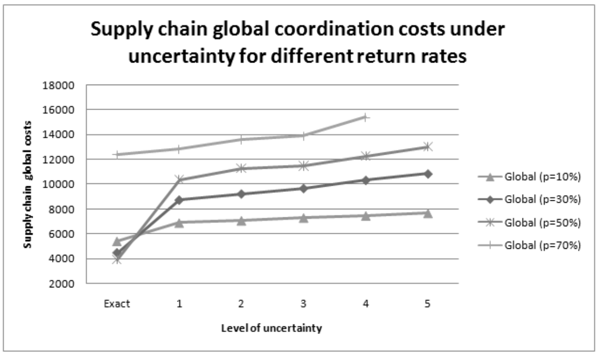

Fig. 5. Supply chain global coordination costs under uncertainty for different return rates.

These results are similar if we analyze the local coordination case (see Fig. 6). In addition, we observe that for global and local coordination scenarios in the presence of perfect information (see exact in Fig. 5 and Fig. 6) there is almost no difference in the supply chain performance for the different return rates (except for the global coordination case when the return rate is 70%).

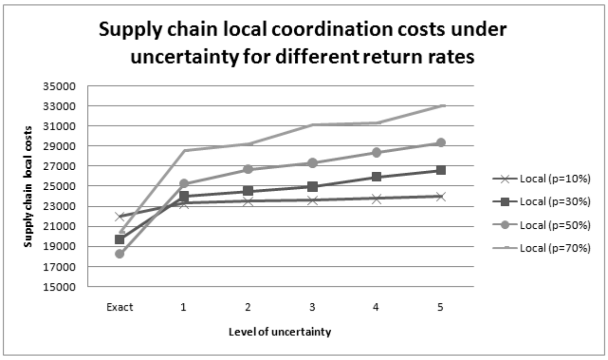

Fig. 6. Supply chain local coordination costs under uncertainty for different return rates.

Finally, we observe another way of the relationship between global and local coordination costs through Fig. 7. In this figure we present the supply chain global coordination costs as a percentage of local coordination cost for different return rates. The results are that the global coordination has a worse performance (in relation to the local coordination) if the return rate is higher.

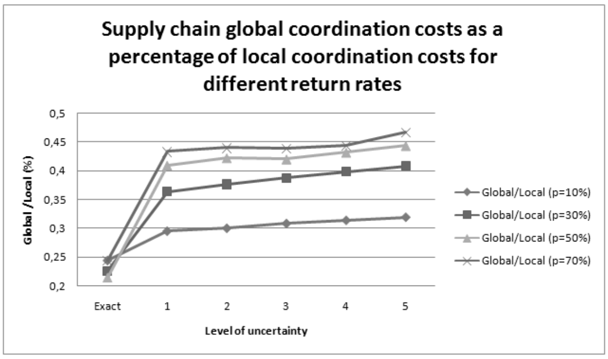

Fig. 7. Supply chain global coordination costs as a percentage of local coordination cost for different return rates.

V. CONCLUSIONS

This paper deals with the value of coordination in a supply chain with uncertainty about returns. We defined two coordination scenarios characterized by information sharing and the decision-making perimeter.

We show through a numerical experiment the convenience of global coordination in a supply chain with return flows for different levels of uncertainty. This is an interesting result because we present that even if there is a huge uncertainty, a global coordination remain as the better strategy. Therefore, if a supply chain member wants to decrease the impact of uncertainties about the return quantities, a global coordination can lead to better performances compared with the local one.

Finally, we observe that the value of coordination (a global coordination case in this paper), as uncertainty increases, slightly decreases. This outcome is interesting and consistent with the results with the reverse logistic literature where we observe that the gains of coordination are not very clear in the reverse logistic framework.

These outcomes are an advance in the studies about the value of coordination in a closed loop supply chain setting. Particularly when there are uncertainties about the return quantities. We noted in addition the consistence with another results of the literature.

Furthermore, we present several LP models that can be useful for real applications.

The next steps of this research are to analyze these models with forecast updates and to analyze the decrease of uncertainty for the closest planning periods. Another alternative is to analyze different types of information sharing (demand information sharing and decision-making).

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