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Collaborative shipping under different cost-sharing agreements

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Abstract. We study collaborative shipping where two shippers bundle their shipments to share the same transportation vehicle (also known as co-loading). The goal of such a collaboration is to reduce the total number of transports, thereby reducing transportation costs and CO_2 emissions. To synchronize the replenishment of both companies, we adopt a can-order joint replenishment policy for both companies, and we analyze how the costs of each individual company are impacted by the collaboration. In our analysis, we not only look at the impact on transportation costs, but we also study how collaborative shipping impacts each company's inventory costs. We consider different agreements to redistribute the costs (or the gains) of the collaboration, ranging from no cost redistribution at all, sharing the transportation costs (or its gains) only, to sharing the total logistics costs (or its gains) that are impacted by the collaboration, i.e., transportation plus inventory costs. We show that the stability of the collaborative agreement strongly depends on the cost-sharing agreement, in combination with the allocation mechanism used to share the costs (or gains) of the coordination. Whereas most companies focus on the redistribution of transportation costs, it may not necessarily lead to a win-win situation where each company benefits from collaboration.

Keywords: "Horizontal supply chain collaboration", "Joint replenishment", "Gain sharing", Cost allocation"

1 Introduction

Collaborations in the supply chain have proven to be a successful means to reduce the logistics costs within one and the same supply chain. This type of *vertical* supply chain collaborations are typically established between suppliers and buyers. *Horizontal* collaborations, on the other hand, are established between companies that operate at the same level in different supply chains, i.e., between suppliers or between buyers. Sharing transportation capacity when moving freight is an example of this type of horizontal collaboration, an option that benefits the environment and yields substantial network efficiencies [1, 2, 7].
These horizontal collaborative shipping agreements are gaining traction in today's business world. By bundling or co-loading transport shipments, the available space in transportation vehicles can be utilized more efficiently. A 2009 World Economic Forum report indicates that 24% of "goods vehicles kms" in the EU are running empty. When carrying a load, vehicles are typically loaded for only 57% of their maximum gross weight [3]. The problem of low utilization rates is getting worse. After optimizing internally, companies now look for opportunities outside their own borders. That is why companies have started co-loading or bundling their shipments, by setting up partnerships with other shippers, be it direct competitors or not, with the objective to further reduce transportation costs and CO_2 emissions. Vanovermeire et al. [8] report on some recent (successful) horizontal logistics alliances.
A collaboration agreement is usually set up to maximize the gains of the partnership. However, in order to have a stable collaboration, each company should be able to reduce its individual costs, otherwise there is no incentive to participate. This means that not only the total logistics cost of the coalition should be reduced, equally important is the individual cost performance of each company, compared to the stand-alone situation where there is no collaboration. Therefore, an agreement can be made to either redistribute the (joint) costs in the collaboration to each company according to a partition rule, or to allocate the gains of the collaboration among each participating company. A wide range of possible cost or gain sharing allocation mechanisms are available to do so. Besides the selected allocation mechanism, the companies

also need to agree on which set of costs (or gains) will be redistributed. In most horizontal logistics alliances, the primary focus has always been on (gains and allocations of) the transportation costs. However, the synchronization of shipments also impact each company's inventory holdings. To maximize the gains of collaborative shipping, the collaborating partners are required to be flexible: they have to replenish their inventories either sooner or later than originally planned in order to benefit from joint transport. This flexibility may have an impact on a company's inventory holdings. It may thus occur that a company reduces its transportation costs, at the expense of higher inventory levels. Therefore, one should look at the total logistics costs resulting from the cost-sharing agreement, as both transportation and inventories are impacted by the collaboration.
In this article, we analyze each company's transportation and inventory cost performance when they set up a collaborative shipping agreement that maximizes the coalition gains (i.e., minimizes the total joint logistics costs). We consider four types of cost-sharing agreements:

1. Each company pays for its own transportation and inventory costs, and no costs or gains are redistributed. When the other company joins your transport, they don't have to pay for it, and when you join the other company's transport, you don't pay for it neither.

2. When multiple companies share space on the same truck (or any other transportation mode), they can decide to share the costs of the trucks, which we denote as the *major* transportation costs. Alternatively, both companies can also decide to share the gains that result from joining their major transportation costs. When the shipments have not exactly the same origin or destination, they may be consolidated using multi-stop truckloads. Under this agreement, each shipper pays for its own handling and *minor* transportation costs to accommodate for its individual pick-up and/or drop-off. Each company also pays for its own inventory holding costs.

3. As the benefits in joint major transportation costs are not possible without the multi-stop pick-ups, companies may agree to share and redistribute the total transportation costs, which is the sum of both major and minor transportation costs. Also here, it is to be decided whether the joint transportation costs are shared, or whether the gains in the joint transportation costs are shared. Each company pays for its own inventory holding costs.

4. Finally, we consider the case where all logistics costs that are impacted by the coordination are redistributed. This means that both transportation as well as inventory holding costs are observed in the partnership, and either the total logistics costs or its gains are redistributed among the participating companies.

The objective of this article is to investigate how the stability (and thus the long-term viability) of the collaborative shipping agreement is impacted by the cost-sharing agreement and the allocation mechanism that is used to share the costs or gains of the collaboration. We study a simplified setting with two companies. We assume that both companies sell a single item and the demand for each item follows an independent Poisson process. A can-order policy is used to synchronize the orders and to enable joint replenishment of both companies. Assuming zero lead times, a Markov model is used to quantify the individual cost performance under the can-order policy.
We contribute to the existing literature in the following ways: (1) we analyze the individual (transportation and inventory) cost performance when a can-order policy is adopted in a multi-company setting; (2) we analyze the redistribution of the gains and costs of the coordination under different agreements, each one characterized by a different set of costs to be allocated, and different cost-allocation and gain-sharing mechanisms; (3) we evaluate when a collaborative shipping agreement is stable, and which allocation mechanism is to be used for each type of cost-sharing agreement.

2 Inventory replenishment policy

We study a single-item inventory model under continuous review, in which two companies (shippers), $N = \{1,2\}$, want to set up a collaborative shipping agreement to minimize logistics costs. Each company's demand is generated from an independent Poisson process with rate λ_i for each $i \in N$. We assume zero lead times, which means that the inventory is replenished immediately after an order is placed. As a result, there are no shortages nor backlog.

We assume the following costs in our model. For each item in inventory, company i incurs a holding cost h_i per unit of time. When a company i initiates the placement of a replenishment order Q_i, it incurs a transport cost $K + k_i$ per replenishment, where K is the major fixed cost per replenishment (e.g., the transportation cost of the truck or train to transport the goods) and k_i the minor fixed cost of this replenishment (e.g., the handling cost, or the cost of the last mile for company i to reach company i's origin or destination). If company $j \neq i$ joins the order (and the transport) of company i with order Q_j, it incurs only its minor fixed order cost k_j. Company j may decide to not join company i's transport, for instance when it has sufficient inventory and does not want to pay the minor order cost. In a second phase, the logistics costs can be redistributed among the companies, depending on the cost-sharing agreement, as will be discussed later.

When there is no collaboration, the inventory dynamics of the companies are independent, and each company replenishes inventory following the (Q_i, s_i) policy. For zero lead times, the reorder point $s_i = 0$. When the inventory is depleted to zero, it is immediately replenished to the level of Q_i, and the average inventory over time is thus $(Q_i+1)/2$. By balancing the cost of inventory with the cost of ordering transport, the optimal order quantity corresponds to the EOQ: $Q_i = EOQ_i = \sqrt{2\lambda_i(K+k_i)/h_i}$, with Q_i rounded to the integer that minimizes total costs. The expected costs of company i in the stand-alone model, C_i^{nc} (the superscript nc denoting *no collaboration*) are given by:

$$\begin{aligned} C_i^{nc} &= (K+k_i)\,\eta_i^{nc} + h_i \pi_i^{nc} \\ &= (K+k_i)\,\frac{\lambda_i}{Q_i} + h_i \frac{Q_i+1}{2}, \end{aligned} \tag{1}$$

where η_i^{nc} denotes the expected number of orders placed, and π_i^{nc} is the expected inventory of company i. The total joint costs of the stand-alone model is then the sum of each company's stand-alone costs, or $C_N^{nc} = \sum_{i \in N} C_i^{nc}$.

If both companies set up a collaborative shipping agreement to share the same transport, they need to adopt an inventory policy that synchronizes their replenishments. This can be done by installing a joint replenishment policy to both companies. A natural extension of the (Q_i, s_i) policy is the can-order (S_i, c_i, s_i) joint replenishment policy. The can-order policy is a popular joint replenishment policy that is often used in the literature and it is shown to perform well. Moreover, we see three additional benefits to adopt the can-order policy in a collaborative shipping context. First, it allows placing joint orders, yet at the same time maintains the flexibility for each company to place an individual order even when the other company is not joining. Second, it allows synchronization of orders without having to reveal explicit demand information to its partners. Finally, as the can-order policy has one additional degree of freedom compared to the (Q_i, s_i) policy (if $c_i = s_i$, the can-order policy reduces to the (Q_i, s_i) policy), the total expected cost performance under collaboration will never be worse than the total joint costs in the stand-alone model.

The can-order policy for firm i is defined using three parameters $S_i > c_i \geq s_i$. Any order placed raises the inventory level up to its respective base-stock level (S_i or S_j). The company first reaching its reorder point is the one triggering the order – let's say it is i: so inventory-on-hand I_i reaches its reorder point s_i while $I_j > s_j$ where $j \neq i$. Then i places an order of size $Q_i^s = S_i - s_i$ (we use superscript s for "self-initiated" and c for "collaborates"). The other company $j \neq i$ also replenishes (and joins the transport) if its inventory position I_j is at or below its can-level c_j; if $I_j > c_j$, firm j has sufficient stock and will not join the order. Hence, $Q_j^c = S_j - I_j$ if $I_j \leq c_j$ and $Q_j^c = 0$ if $I_j > c_j$. Given that lead times are zero, we have $s_i = s_j = 0$.

Let η_i^s denote the expected number of self-initiated orders of company i, and η_i^c the expected number of orders that company i joins company j's replenishment. Then, the expected costs of company i under collaboration are given by:

$$C_i(S_i, c_i, s_i) = K\eta_i^s + k_i(\eta_i^s + \eta_i^c) + h_i \pi_i, \tag{2}$$

and the total joint costs under collaboration is $C_N = \sum_{i \in N} C_i(S_i, c_i, s_i)$. The values of S_i and c_i (for zero lead times, we have $s_i = 0$) are set to minimize the expected joint costs of the collaboration, C_N.

The individual cost performance under collaboration can be analyzed by characterizing the replenishment cycle under a can-order policy by an advanced Markov process. This allows to derive the expected cost performance of company i for a given set of parameters (S_i, c_i). The optimal values of (S_i, c_i) that minimize C_N can then be found by an enumeration procedure.

3 Cost-sharing agreements

The objective of collaborative shipping is to minimize the expected joint costs of both companies. The parameters of the can-order policy are thus optimized to minimize the total joint costs $C_N = \sum_{i \in N} C_i$, with C_i the expected costs of company i in collaboration. However, even when the partnership may gain (i.e., $C_N \leq C_N^{nc}$), for each company i it is critical that its *individual* cost performance is lower compared to the stand-alone model (i.e., $C_i \leq C_i^{nc}$). Otherwise there is no incentive to participate. Therefore, an agreement can be made between the participating companies to redistribute (a part of) the joint costs of the collaboration, or to allocate (a part of) the collaboration gains to each company. In most collaborative shipping partnerships, the focus is on the quantification of the gains in transportation costs, so that each company can improve its transportation cost performance. However, that does not take into account the impact of collaborative shipping on inventories. To maximize the gains of freight bundling, the collaborating partners are required to be flexible and they have to replenish their inventories either sooner or later than originally planned in order to benefit from joint transport. This may come at the expense of increased inventory holdings.
We analyze the expected cost performance, being transportation plus inventory costs, of each company under four different types of agreements, where a different set of costs $X_N = \sum_{i \in N} X_i$ may be redistributed between the participating companies. The four agreements considered are as follows:

1. Either there is no redistribution of the costs:
$$X_N = \emptyset. \tag{3}$$
This means that the company placing the order (and organizing the transport), pays for the transport, regardless whether the other company joins or not. If the other company joins the order, it is free-riding on that transport.

2. Both companies can decide to share the payment of the (joint) major transport costs:
$$X_N = \sum_{i \in N} K\eta_i^s. \tag{4}$$
Under this agreement, each company still pays their own minor transport costs and inventory holding costs.

3. As the benefits in joint major transportation costs are not possible without the multi-stop truckloads, companies may agree to share and redistribute the total transportation costs, which is the sum of both major and minor transport costs:
$$X_N = \sum_{i \in N} \left(K\eta_i^s + k_i(\eta_i^s + \eta_i^c)\right). \tag{5}$$
In this case, the companies still pay for their own inventory costs.

4. Finally, companies may agree to share and redistribute all the logistics costs that are impacted by the collaborative shipping:
$$X_N = C_N = \sum_{i \in N} \left(K\eta_i^s + k_i(\eta_i^s + \eta_i^c) + h_i\pi_i\right). \tag{6}$$
The rationale behind this agreement is that this redistributes all costs that are impacted by the collaboration.

We make a distinction between the allocation of costs vs. the allocation of gains. Cost allocation refers to the redistribution of the set of joint costs X_N to each company i according to a proportional rule: $\rho_i X_N$, where ρ_i denotes the proportion of the costs incurred by company i. As not all costs are allocated (depending on the agreement), company i additionally carries its complementary costs, $X_i^{\complement}$. The total costs for company i after allocation of the joint costs, denoted by $\widetilde{C}_i$, are then given by:

$$\begin{aligned} \widetilde{C}_i &= X_i^{\complement} + \rho_i X_N, \\ &= C_i - \rho_j X_i + \rho_i X_j. \end{aligned} \tag{7}$$

Gain sharing, on the other hand, allocates the gains in X_N resulting from collaboration, which we denote by $\nu(X_N) = \sum_{i \in N} \nu(X_i)$, with $\nu(X_i) = X_i^{nc} - X_i$ the respective gains of company i in that particular set of costs (prior to any cost redistribution). Similarly, we denote the gains of the set of complementary costs under collaboration (which can be positive or negative) for company i as $\nu\left(X_i^{\complement}\right) = X_i^{\complement,nc} - X_i^{\complement}$.
If the fraction ρ_i of the gains in X_N is allocated to company i, company i's costs reduce from X_i^{nc} to $X_i^{nc} - \rho_i \nu(X_N)$, and additionally it carries its complementary costs, $X_i^{\complement}$.
Hence, the total costs for company i after allocation of the gains, are given by:

$$\begin{aligned} \widetilde{C}_i &= X_i^{\complement} + [X_i^{nc} - \rho_i \nu(X_N)] \\ &= C_i^{nc} - \nu\left(X_i^{\complement}\right) - \rho_i \nu(X_N), \end{aligned} \tag{8}$$

as $X_i^{nc} = C_i^{nc} - X_i^{\complement,nc}$, and $X_i^{\complement,nc} - X_i^{\complement} = \nu\left(X_i^{\complement}\right)$.

The allocation rule determines the fraction ρ_i that can be used to allocate the costs X_N or the gains $\nu(X_N)$ to each company i. The allocation rule should distribute the entire set of costs X_N considered in the collaboration agreement, or alternatively it should share all gains in the considered set of costs. However, to ensure a stable collaboration, it is vital that after allocation of the costs/gains, each company should be able to reduce its total cost performance:

$$\widetilde{C}_i \leq C_i^{nc}.$$

This implies that the benefits are obtained at the level of the *total* cost performance, and not only the costs considered in the cost-sharing agreement. For instance, a cost-sharing agreement may be *individually rational*, but not stable if the individual complementary losses are larger than the gains observed in the cost-sharing agreement.

In the literature, a wide range of possible allocation mechanisms exist (ranging from game-theoretic mechanisms to simple allocation rules). We refer to Guajardoa and Ronnqvist [5] for a recent overview on the cost allocation methods used in collaborative transportation.
Gain sharing methods belong to the stream of cooperative game theory and are founded in the bargaining problem of J.F. Nash. If only two companies participate in the collaboration, these mechanisms all result in the same allocation: the gains of the collaboration are divided in two equal parts: Let ρ_i^G be the portion of the gains allocated to company i, then

$$\rho_i^G = \frac{1}{2}. \tag{9}$$

Instead of sharing the gains $\nu(X_N)$, one can alternatively allocate the joint costs X_N to each company according to a proportional rule. There are different rules to allocate the costs of the coordination, X_N. [4] proposes to allocate the costs under collaboration based on the ratio of each company's costs in the stand-alone model. We denote this rule the "Linear rule". The proportion of the costs X_N that is allocated to company i under the Linear rule, denoted by ρ_i^L, is then:

$$\rho_i^L = \frac{X_i^{nc}}{\sum_{j \in N} X_j^{nc}}. \tag{10}$$

The Linear rule is the most frequently used rule in the literature[5]. Note than in case of two identical companies, also the cooperative gain sharing mechanisms (Eq.(9)) reduce to the linear rule, where half of the gains or half of the costs is allocated to each company.
Meca et al. [6] introduce the *distribution-rule* to allocate the (joint) major ordering costs to each company according to the ratio of each company's squared order frequencies in the stand-alone model (η_i^{nc}). Even when each company pays for its own inventory costs, they show that this rule is stable, meaning that collaboration will always reduce each company's total (transportation plus inventory) costs after allocation according to the distribution rule. Note that in their analysis, there are no minor order costs. Whereas Meca et al. [6] use this rule to distribute the major ordering costs only, we adopt the rule to distribute the costs X_N (with X_N depending on the type of agreement). We denote this rule the "Order rule', and denote ρ_i^{η} the

proportion of X_N that is allocated to company i under the Order rule:

$$\rho_i^{\eta} = \frac{(\eta_i^{nc})^2}{\sum\limits_{j \in N} \left(\eta_j^{nc}\right)^2}. \tag{11}$$

Finally, we extend the distribution rule to allocate the joint costs based on the ratio of its respective squared stand-alone costs X_i. We denote this rule the "Square rule". Denote ρ_i^S the proportion of the costs X_N that is allocated to company i under the Square rule:

$$\rho_i^{S} = \frac{(X_i^{nc})^2}{\sum\limits_{j \in N} \left(X_j^{nc}\right)^2}. \tag{12}$$

Observe that when only the major transportation costs are shared, the Square rule reduces to the Order rule.

4 Numerical experiment

We performed an extensive numerical experiment to understand the dynamics of the cost performance under collaborative shipping when the can-order policy is used to synchronize the shipments. Our goal is to provide guidelines under which conditions the collaboration is stable and thus viable on the long-term. In our numerical experiment, we evaluate three different runs with varying combinations of the major transport cost K, the minor transport costs k_i, the holding cost h_i, and different combinations of demand λ_i. We refer to our full working paper for more details on the numerical experiment. For the purpose of this conference paper, we restrict to the main conclusions of our numerical experiment.
We first analyze the individual cost performance of each company under collaboration, prior to redistribution of any costs. Our results reveal that:

- The major transportation costs for each company are always lower than in the stand-alone model. On the other hand, its minor transportation costs are always higher compared to the stand-alone model. The total (of major and minor) transportation costs may increase or decrease compared to its stand-alone performance, depending on the value of K and k_i. The higher the major transport cost K, the higher the individual savings and also the higher the likelihood that each company gains in total transportation costs.

- Each company's individual inventory costs may increase or decrease compared to the stand-alone model. Also here, the gains (and the likelihood of a positive gain) in inventory holding costs increase with larger K.

- The total logistics cost performance of each company will always improve in collaboration compared to the stand-alone model. The total cost savings will be higher for larger values of K.

These results can be explained by the dynamics of the can-order policy. Recall that the collaborative (S_i, c_i, s_i) can-order policy reduces to the stand-alone (Q_i, s_i) policy if $c_i = s_i$. In other words, the can-order parameter c_i provides an additional degree of freedom to reap benefits in the major transport costs, which allows to reduce the major transport costs in the collaborative model, and the number of self-initiated orders under collaboration will be smaller than the number of orders placed in stand-alone ($\eta_i^s \leq \eta_i^{nc}$). However, because c_i increases with increasing values of K (there is more reason to join replenishment), the order quantities themselves decrease and as such the total number of replenishment orders increases compared to the stand-alone model ($\eta_i^s + \eta_i^c \geq \eta_i^{nc}$). This explains the increase in minor transport costs (and a potential increase in total transportation costs) under collaboration. The impact of the can-order policy on inventories is two-fold: on the one hand, decreasing order quantities result in lower base-stock levels and hence a decrease in cycle inventories. However, as $c_i \geq s_i$, the probability of having inventory levels lower than c_i, decreases, and the inventory distribution is no longer uniform over $I_i \in [s_i, c_i[$, leading to average inventory levels higher than $\frac{S_i - s_i + 1}{2}$. As a result, the impact of the can-order policy on inventory is a mixed effect and can be both positive or negative.

After allocation of the costs X_N, or after allocation of the gains in X_N, we find that not only the game-theoretic gain sharing mechanisms (which satisfy individual rationality by definition), but also as the linear cost allocation rule always satisfies the axiom of individual rationality. When the major transportation costs are shared, the order rule (which is in that case identical to the square rule), fails to satisfy individual rationality in 16 out of the 2430 instances tested. More specifically, we find that this only happens when the demands of both companies are not identical, and the larger the discrepancy between both companies, the more likely that the axiom of individual rationality fails. When both companies have identical demands, the order rule always satisfies individual rationality when the major transportation costs are shared. When more costs are shared (i.e., including minor and/or inventory costs), we find that both the order rule and square rule fail the axiom of individual rationality more often, both for identical and non-identical demands.

We finally evaluate each company's *total* cost performance under collaboration after allocation of the costs/gains, $\widetilde{C}_i$, compared to its stand-alone costs, C_i^{nc}. Only when $\widetilde{C}_i \leq C_i^{nc}$, the collaboration is stable. Recall that the total costs include the allocated costs, as well as the complementary costs. Hence a collaboration may be individually rational, but not stable when its complementary losses outweigh the collaboration gains in X_N.

- First, we observe that when no costs are redistributed, the axiom of stability is always satisfied: under collaboration, each company will always reduce its costs compared to the stand-alone model, even when no costs are redistributed. This result is interesting, as it represents the "easiest" type of agreement. It could be argued whether this type of agreement is considered to be *fair* to both participating companies, as it means that you never have to pay for joining the truck of your coalition partner, but it clearly does lead to a stable collaboration where each company wins.

- Second, as more costs are shared, the stability (and thus the success) of the collaboration is very sensitive to the allocation mechanism. The game-theoretic gain sharing approaches clearly dominate, yet they are not perfect. In our experiment we find that the collaboration is not stable in two instances (one per company) when the gains in the total transportation costs are shared. In those cases the increase in inventory holding costs for an individual company outweigh its gains in total transportation costs.

- The Linear rule always satisfies the axiom of stability when the total logistics costs are shared. In that case, the axiom of individual rationality and stability coincide, and the linear rule leads to a stable collaboration. However, when only the transportation costs are shared, the Linear rule still performs very well, but it does not always lead to a win-win situation where each company wins. There are some instances where the companies after allocation perceive a gain in transportation costs, but it incurs losses due to increased inventory holding costs, which outweigh the transportation savings.

- Finally, the Order rule and the Square rule fail to be stable in many instances, either when the major transportation costs, the total transportation costs, or the total logistics costs are shared. Clearly, these rules may not lead to a stable collaboration. In general, we find that using the Square rule leads more often to stability than when the Order rule is used, except when the difference in demand rates between both companies is high. Also, as the value of K increases, we find that the axiom of stability is more likely to be satisfied (which confirms our intuition).

5 Conclusions

In this article, we study the setting where two companies set up a collaborative shipping agreement to share the same transport vehicle. The shipments are synchronized by jointly replenishing inventories using the can-order policy. We assess how this synchronization impacts transportation and inventory holding costs, both at the level of the coalition as well as the level of each individual company. The individual cost performance under the can-order policy is evaluated using a Markov chain approach. The parameters of the can-order policy of both companies are optimized to minimize the total joint costs of both companies.
We find that collaboration always leads to a reduction in each company's major transportation costs, but also to an increase in its minor transportation costs. The flexibility may also require companies to keep higher inventory holdings. However, we find that when a company experiences losses in inventories (resp.

transport), the gains in transport (resp. inventories) will always outweigh these losses (it also means that a company never experiences losses in inventory and transportation costs simultaneously). In other words, each company always improves its cost performance under collaboration, even where there is no redistribution of the costs.

When the joint costs are redistributed, we can make use of gain sharing methods (which share the gains of the collaboration) or cost allocation rules (which partition the joint cost under the collaboration based on a given indicator). When only the joint major transportation costs are shared, the Linear allocation rule (allocating the joint costs proportionally to its respective stand-alone costs) leads more often to a stable collaboration than the Order rule (which allocates the joint costs proportionally to the squared number of orders placed in the stand-alone model), however stability is not always guaranteed. The same holds when the total (minor and major) transportation costs are shared. This means that it may happen that a company perceives gains in transportation efficiency, but it comes at the cost of increased inventory holdings, which may even outweigh the savings in transportation costs.

When all joint logistics costs are shared (i.e., both transportation and inventory costs), the Linear rule always leads to a stable coordination, but the Order and Square rule (allocating the joint costs based on the ratio of its respective squared stand-alone costs) often do not. The game-theoretic gain sharing approaches (allocating half of the gains to each company) almost always lead to a stable solution, regardless which costs are shared (we only found two instances where stability was not met when the total transportation costs were shared).

We conclude that, before redistribution, the total logistics costs of each company under collaboration are always smaller than (or equal to) those of the stand-alone setting. After redistribution, however, it is possible that the shipping agreement does not lead to a win-win situation because an improper choice was made with respect to the redistribution mechanism and/or the set of costs to redistribute. In this research we have not only shown that these choices are of extreme importance, but we have also shown under which conditions a particular choice has to be made in order to ensure a stable shipping agreement.

Although we acknowledge that our findings strongly depend on the use of the can-order policy to synchronize orders, we believe that our insights extend to other joint replenishment policies as well. This is subject to further research.

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