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The impact of product characteristics and innovativeness on the benefits of collaboration

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Abstract

Horizontal collaboration is a promising avenue to improve the efficiency of logistical operations. However, the benefits strongly depend on the degree of fit between partners. In this paper, we analyze the impact of the partners' product characteristics on those benefits, focusing on their innovativeness. Companies supplying functional versus innovative products have different requirements in supply chain efficiency and responsiveness, which impacts the benefits that can be reached with a given partner. To assess the collaborative benefits, we use a location–inventory model accounting for the partners' individual interests and the costs revealing the responsiveness level of the supply chain (facilities, transportation, cycle inventory, safety stocks and stock-outs). The model offers a set of Pareto-optimal solutions balancing the partners' costs to support the selection and negotiation process. Finally, we perform numerical experiments in which the partners supply products with identical or different levels of innovativeness and with various demand volumes, leading to valuable managerial insights on the impact of product characteristics on collaborative benefits.

Keywords: horizontal collaboration; collaborative benefits; product characteristics; functional/innovative products; supply chain network design; stock-out costs

1. Introduction

The way in which companies organize themselves is closely related to the product or service they provide and the market they operate in. Acting independently, however, often leads to inefficiencies due to strong restrictions to what the individual company can achieve. For example, the need for

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frequent transport of limited volumes along certain connections might prevent companies from reaching high loading rates. A promising opportunity for creating synergies—impossible to seize on an individual basis—is considering supply chain collaboration (Audy et al., 2012).

In this research, we focus on horizontal collaboration, defined as a collaboration between two or more companies that are active at the same level of the supply chain. Initiating such a collaboration can be a means to share risk, save costs through the sharing of resources, increase investments, pool know-how, enhance product quality and variety, and launch innovation faster (European Commission, 2011). More specifically, the exploitation of a joint supply network in which companies share vehicles as well as distribution centers (DCs) can create significant gains for all partners involved, by sharing fixed costs, reducing distances from DCs to retailers, and improving the vehicle loading rate (Hacardiaux and Tancrez, 2018; Jouida et al., 2021).

Although working together clearly provides benefits, the failure rate of starting partnerships is high (Raweewan and Ferrell, 2018; Basso et al., 2019). A potential mismatch between individual partner and coalition objectives may jeopardize the long-term stability of the collaboration. The success of achieving collaborative benefits strongly depends on the degree of fit between all collaboration participants (Martin et al., 2018). According to Van Breedam et al. (2005), trust, and engagement, as well as the level of operational, strategic, and cultural complementarity between partners, influence collaborative performance. While a limited number of papers analyze the impact of partner characteristics on attainable collaborative savings (Palhazi Cuervo et al., 2016; Verdonck et al., 2019), the numerical relationship between the partners' product characteristics and the performance of their collaborative supply network both in terms of cost and customer service has not been investigated yet.

In this context, the main contribution of this paper is to provide insights on the impact of the partners' product characteristics and cost structure on the performance of the collaboration. Specifically, in line with the product characterization proposed by Fisher (1997), we distinguish two types of products based on their level of innovativeness: functional and innovative products. Functional products are associated with a stable demand and a low profit margin. They require a physically efficient supply chain where cost reduction is the absolute priority (e.g., realized through economies of scale and high truck loading rates). Innovative products are characterized by a highly unpredictable demand and a short life cycle. Low competition for this type of products allows for a higher profit margin. Consequently, these products require a more responsive supply chain layout with low lead times, as stock-outs and obsolete inventory are expensive (Fisher, 1997). Since functional and innovative products exhibit a different cost structure and require different levels of supply chain responsiveness (Langenberg et al., 2012), the challenge is to design a collaborative supply chain network that balances the individual interests of each partner, accounting for the innovativeness level of its product.

To assess the cost reduction reached from collaboration, we propose a location–inventory model that accounts for the product type as well as the individual priorities of the partners. From our computational experiments, we derive managerial insights on the compatibility of companies based on their product type, market size, and individual preferences. In contrast to existing work on collaborative logistics—typically limited to the minimization of the total logistics costs of the entire supply network—this paper also quantitatively analyzes the favorable impact of horizontal collaboration on customer service level and the reduction of stock-outs. With increasing competition and rising expectations of customers, companies can stimulate profit by satisfying customer needs better than their competitors, which is especially true for those supplying innovative products (Basso et al., 2021).

The remainder of the paper is structured as follows. Section 2 contains a literature review and positions the contribution of our paper. In Section 3, we present the multipartner collaborative location–inventory model, integrating stock-out costs, and the product innovativeness level of each partner. Also, this section discusses the construction of a set of Pareto-optimal solutions using the weighted sum method. In Section 4, various collaboration settings are numerically analyzed to assess the impact of all considered partner and product characteristics on the collaborative benefits. These experiments allow us to provide decision support on how to select the right partner, based on product characteristics and demand levels. Finally, Section 5 concludes our paper and outlines some ideas for future research.

2. Related literature

In this section, an overview is provided of the state-of-the-art literature related to the different research domains covered by this paper. First, we focus on horizontal collaboration and the cooperative location–inventory problem. Second, we discuss the problem of selecting the right supply chain partner to initiate a horizontal logistics collaboration, as well as the allocation of costs among partners. Special attention is given to the consideration of product characteristics of potential collaboration partners.

Through partnering with fellow organizations, companies may extend their resource portfolio, reinforce their market position, and create a more efficient transport and inventory planning (Krajewska et al., 2008). Given the fact that collaborative logistics has been identified as one of the most effective approaches to improve transportation efficiency and sustainability, horizontal collaboration has gained increasing research attention in the past decade (Pan et al., 2019). Pan et al. (2019) state that research on horizontal collaboration can be classified according to both the collaborative solution that is proposed and the implementation aspect that is analyzed. In terms of the first classifier, horizontal collaboration may range from single carrier collaboration (e.g., Buijs et al., 2016) to the hyperconnected physical internet (e.g., Pan et al., 2017). As for implementation aspects, seven classes can be distinguished, including, among others, collaborative network design (e.g., Pan et al., 2013), transport planning optimization (e.g., Sohrabi et al., 2016), mechanisms for exchanging requests (e.g., Lafkihi et al., 2020), and gain sharing (e.g., Verdonck et al., 2016).

In terms of implementation, existing studies on horizontal collaboration mainly focus on transport planning optimization, where the main incentive for companies to cooperate is an increased efficiency of their vehicle fleet routes and operations (Verdonck et al., 2016; Gansterer and Hartl, 2020). Despite the potential benefits, the sharing of DCs, which can be classified within the collaborative network design category, or joint inventory management policies have received limited attention from the collaborative research community (Pan et al., 2019). While the amount of studies on location–inventory problems is significant (Melo et al., 2009; Farahani et al., 2015; Daskin and Maass, 2019), their application in a horizontal collaboration context is novel. In Verdonck et al. (2016), the facility location problem is extended to a collaborative environment in which multiple companies jointly open a set of facilities with the aim of minimizing the sum of total facility opening and distance-based travel costs. Similarly, Tang et al. (2016) study the collaboration synergy that results from installing a joint supply chain network that consists of a centralized consolidation and DC, as well as multiple regional DCs in a less than truckload environment. Makaci et al. (2017) empirically study the sharing of warehouses among different companies to identify, among others, its KPIs and uncertainty sources. Quintero-Araujo et al. (2019) consider different degrees of collaboration for the location-routing problem. The study focuses on the scenario in which only route decision is jointly taken through the sharing of existing facilities and vehicle capacity (referred to as the semicooperative scenario) or its extension in which also facilitation location decisions are jointly taken. These authors do not account for inventory costs and decisions. Hacardiaux and Tancrez (2018) analyze the collaborative location–inventory problem and demonstrate savings in terms of facility opening, transportation, cycle inventory, ordering, and safety stock costs. A multiobjective, multipartner extension of their model is developed in Hacardiaux et al. (2021), which accounts for partner preferences in terms of logistical costs and CO_2 emissions. Jouida et al. (2021) study the joint supply chain network design problem with shared DCs as a coalition formation problem based on cooperative game theory.

Although the overall goal of a horizontal collaboration is to increase participants' logistics efficiency, it should not be ignored that companies that engage in such a collaboration remain independent entities that might show individualistic behavior with respect to their individual aims and goals (Defryn et al., 2019). Existing collaboration research, however, typically relies on the assumption that all partners agree on a unique objective. The consideration of multiple objectives in a horizontal collaboration context is a novel research domain. Moreover, except for the paper by Defryn et al. (2019) and our previous work (Hacardiaux et al., 2021), existing papers (e.g., Soysal et al., 2018; Wang et al., 2018) consider multiple objectives on the coalition level but aggregate, and thus ignore, individual partner preferences. Besides considering conflicting partner goals when optimizing the collaborative supply chain, dividing the coalition gains in a fair manner between the participants also constitutes a key issue to improve cooperation stability (Verdonck et al., 2016). The literature on collaborative logistics has devoted attention to the identification of efficient allocation mechanisms. For the location-routing problem, Osicka et al. (2020) investigated subadditivity, convexity, and nonemptiness in more than 10,000 instances and different cost allocation methods. Although game theoretical methods (such as Nucleolus and the Shapley value) outperform proportional methods, they tend not to be applicable in practice due the need for (typically unknown) information. This is also acknowledged by Verdonck et al. (2016) who distinguish and review three categories, namely, proportional sharing mechanisms, allocation mechanisms using game theory, and allocation techniques designed to cope with additional cooperation properties. As each method has its specific benefits and drawbacks, it remains unclear which mechanisms could guarantee stability and sustainability in a cooperative location–inventory setting. However, in line with the results described in Verdonck et al. (2016), for a limited number of partners, operationally simple sharing mechanisms may well be utilized, reducing alliance complexity and enforcing the strength of partner relationships.

A large part of the literature on horizontal logistics collaboration mainly focus on demonstrating and allocating the collaborative cost benefits of sharing resources. It has been revealed that the amount of attainable collaborative savings is largely dependent on the degree of fit between the collaboration participants (Hacardiaux and Tancrez, 2018; Martin et al., 2018; Verdonck et al., 2019). According to Brouthers et al. (1995), cooperating with an unsuitable partner is even more damaging to an organization than not collaborating at all. Although multiple researchers acknowledge the importance of selecting the right collaboration partner, the number of papers that quantitatively measure the degree of fit and investigate the relationship between specific company traits and the performance of the partnerships these companies are involved in is limited. Lozano et al. (2013) identify the most profitable logistics collaborations by varying the number of companies involved in the collaboration, the number of cities to which shipments are made, and the homogeneity of the participating companies, measured by their shipment volume. Palhazi Cuervo et al. (2016) study the effect of three company characteristics (the number of orders, average order size, and the maximum number of days an order can be delayed) on the cost performance of two-partner shipper collaborations. In Guajardo et al. (2018), the coalition configuration problem is analyzed within the forest fuels industry, where the goal is to minimize the total cost by varying the number of companies involved, the geographical distribution of supply and demand points, and the coverage of companies in different areas. Similarly, Verdonck et al. (2019) compare cost savings for horizontal carrier collaborations differing in terms of number of partners, demand volume per partner, geographical coverage of the coalition, customer order time windows, and customer order size. Finally, Hacardiaux and Tancrez (2020) analyze the impact of several partner characteristics, such as vehicle capacity, facility opening cost, inventory holding cost, order cost, demand variability, distances, and the number of partners, on the level of cost and CO_2 emission reduction.

To the best of our knowledge, the impact of partners' product characteristics, whether the partners are supplying functional or innovative products, on collaborative performance has not been studied. Differences in product characteristics require, however, a different view on the design of the supply network (Langenberg et al., 2012). When companies with different product characteristics collaborate, the challenge is to design a cooperative supply network that balances the individual interest of each partner coinciding with the product type this partner offers. The predictable demand and low profit margins of functional products force companies to strive for the highest efficiency by cutting total logistics costs as much as possible. Innovative products, on the other hand, benefit from a responsive supply chain, with a strong focus on customer satisfaction and low lead times to avoid expensive stock-out and obsolescence costs.

Following the research gaps identified in the current literature, the main academic contribution of our work is to analyze how collaborative benefits are impacted by the individual product characteristics and cost structure of the partners involved. For this purpose, a cooperative location–inventory model is developed and solved, which accounts for the innovativeness level of the partners' products and the individuality of partners in terms of their influence to adapt the collaborative supply chain according to their preferences. In addition, the proposed model and associated numerical experiments provide quantitative decision support and managerial insights for practitioners implementing and managing horizontal partnerships in terms of supply chain network design and forming the most beneficial partnerships.

3. Multipartner location–inventory model

3.1. Problem setting

In this section, we present a multipartner location–inventory model, which will be applied in Section 4 to assess the benefits of collaborating for a given set of partners, depending on their characteristics. In this sense, our model supports the partner selection process by helping to identify the most promising partnerships. All considered partnerships can be tested (separately) to identify those that lead to the highest benefits. To assess the potential of a given collaboration, we will compare the stand-alone situation with the collaborative case, supposing that the supply chain network is optimized in both cases. The model accounts for the characteristics and individual preferences of each partner in the objective function. It integrates the cost structure of the partners' products to allow us to represent their innovativeness level. More specifically, we account for the demand variability, the penalty cost for stock-outs reflecting the profit margin, the product value, and the holding cost associated with varying product innovativeness levels.

In the stand-alone case, we are given a supply chain network configuration in which a company supplies a single product from a central plant to regional DCs from which they are shipped directly to the retailers. A fixed cost is incurred when a DC places an order with the plant, reflecting the cost for manufacturing and shipping a batch of products. It may reflect the transportation cost from the central plant to a particular DC (and be proportional to the distance between those two). Inventory is held at DCs in the form of cycle inventory proportional to the order size and in the form of safety stock. To balance the fixed ordering cost and the cycle inventory costs at DCs, we decide on the optimal order quantities to ship from the central plant to each DC. Safety stocks are kept at all DCs to cater the fluctuations in demand during the lead time, to ensure a given service level. Furthermore, one of the goals is to find the optimal number of DCs as well as the location of each DC. We assume single sourcing, that is, all products that need to be delivered to a specific retailer come from a single DC. Transportation costs from DCs to retailers are proportional to the number of vehicles (so that the improved loading rate of the vehicles when collaborating is accounted for). Inventory at retailers is also included (supposing vendor managed inventory) in the form of cycle inventory proportional to the shipment size, and in the form of safety stock. The delivery frequency and shipment size from the DCs to each retailer is optimized considering the trade-off between the transportation cost and the cycle inventory cost at retailers. Safety stocks at every retailer cater the fluctuations in demand during the transportation lead time. When a retailer runs out of stock, the company incurs a penalty cost for the lost sales and loss of goodwill.

When forming a collaboration, we assume that all companies share a joint distribution network, which is specifically designed for the collaboration as whole, and optimized with the same assumptions as in the stand-alone case. This means that each partner has access to all opened DCs in the joint network and that all vehicles are shared. Therefore, each vehicle will transport a mix of different products belonging to different companies. Although products from different companies are stored in the same DCs, companies keep their own inventory and incur their own out-of-stock penalty costs, as demand and product type are directly linked to a single company.

3.2. Mathematical model

The design of the collaborative supply network is optimized by solving the mathematical model introduced in this section. The model decides on the number and the locations of the joint DCs, the allocation of flows to transport connections, the shipment sizes and the safety stock levels. We note that including the location of each DC as well as the shipment sizes is important to evaluate core benefits of collaboration: the reduction of the number of DCs and the improvement of the vehicles

Table 1
Overview of mathematical notations

Sets and indices:	
D	Set of potential distribution center (DC) locations, indexed by d.
R	Set of retailers, indexed by r.
I	Set of companies, indexed by i.
Parameters:	
F	Opening cost for one DC, in € /period.
T	Transportation cost per kilometer for a vehicle, from DCs to retailers, in € /(km·vehicle).
D_{dr}	Distance between potential DC d and retailer r, in km.
H_r^i	Unit inventory holding cost at retailer r for a product of company i, in € /(item·period).
h_d^i	Unit inventory holding cost at potential DC d for a product of company i, in € /(item·period).
p_r^i	Penalty cost for unsatisfied demand of a product of company i at retailer r.
K_d^i	Fixed cost at DC d for placing an order to the plant of company i, in € /order.
C_{dr}	Vehicle capacity from potential DC d to retailer r, in items/vehicle.
z_α^i	Standard normal deviation associated with service level α^i at DCs, for company i.
LT_{dr}	Transportation lead time between potential DC d and retailer r, in periods.
LT_d^i	Order lead time between the central plant of company i and potential DC d, in periods.
λ_r^i	Mean demand for products of company i at retailer r, in items/period.
Λ_r	Mean demand for all products at retailer r, in items/period, i.e. $\Lambda_r = \sum_i \lambda_r^i$.
Λ^i	Mean demand for products of company i for all retailers, in items/period, i.e. $\Lambda^i = \sum_r \lambda_r^i$.
σ_r^i	Standard deviation of the demand for products of company i at retailer r, in items/period.
$F_{dr}^i(\cdot)$	Cumulative distribution function of the demand for a product of company i during the lead (transportation) time from potential DC d to retailer r.
$n_{dr}^i(\cdot)$	Unit normal loss function of the demand for a product of company i during the lead (transportation) time from potential DC d to retailer r.
Q_{dr}	Shipment size from potential DC d to retailer r in items/vehicle.
R_{dr}^i	Reorder point for a product of company i at retailer r when the order comes from potential DC d.
Decision variables:	
y_d	$\begin{cases} 1, & \text{if DC } d \text{ is opened,} \\ 0, & \text{otherwise.} \end{cases}$
x_{dr}	$\begin{cases} 1, & \text{if DC } d \text{ serves retailer } r \text{ (for all products),} \\ 0, & \text{otherwise.} \end{cases}$
v_{1d}^i, v_{2d}^i	Auxiliary variables for company i and potential DC d.

loading rate. The model aims to minimize the total logistics cost, comprising the DC facility costs, the transportation costs, the fixed ordering costs to the central plant, the cycle inventory and safety stock costs at DCs and retailers, and the stock-out costs. The inclusion of the holding, safety stock and stock-out costs in particular allows to account for the innovativeness level of the products (the demand uncertainty, obsolescence rate and profit margin in particular). The proposed inventory-location model bears similarities with those introduced by Atamtürk et al. (2012) and by Puga and Tancrez (2017). Moreover, it is close to the collaborative model presented by Hacardiaux and Tancrez (2018), but adds multiple objectives (associated with the different partners) and stock-out costs.

The multipartner inventory–location model is formulated below with the mathematical notation defined in Table 1.

$$\min \ \frac{\Lambda^i}{\Lambda}\sum_d F y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r}\sum_d TD_{dr}\frac{\Lambda_r}{Q_{dr}}x_{dr} \tag{1a}$$

$$+\sum_d \sqrt{2K_d^i h_d^i}\, v_{1d}^i + \sum_d h_d^i z_\alpha^i \sqrt{LT_d^i}\, v_{2d}^i \tag{1b}$$

$$+\sum_{d,r} H_r^i\left(\frac{Q_{dr}}{2}\frac{\lambda_r^i}{\Lambda_r} + R_{dr}^i - \lambda_r^i LT_{dr}\right)x_{dr} + \sum_{d,r} p_r^i n_{dr}^i(R_{dr}^i)\frac{\Lambda_r}{Q_{dr}}x_{dr} \qquad \forall i \tag{1c}$$

s.t.

$$\sum_r \lambda_r^i (x_{dr})^2 \leq (v_{1d}^i)^2 \qquad \forall d, i \tag{2}$$

$$\sum_r (\sigma_r^i)^2 (x_{dr})^2 \leq (v_{2d}^i)^2 \qquad \forall d, i \tag{3}$$

$$\sum_d x_{dr} = 1 \qquad \forall r \tag{4}$$

$$x_{dr} \leq y_d \qquad \forall d, r \tag{5}$$

$$v_{1d}^i, v_{2d}^i \geq 0 \qquad \forall d, i \tag{6}$$

$$x_{dr}, y_d \in \{0, 1\} \qquad \forall d, r. \tag{7}$$

For each collaborating partner in the coalition, the objective function is defined as its total logistics cost. Part (1a) allocates the *DC opening cost* and the *transportation cost* to the corresponding company by applying a proportional volume-based allocation rule. Such an allocation approach is common in practice as it does not require a substantial amount of data, is rather intuitive, transparent and predictable (Guajardo and Rönnqvist, 2016). The fixed costs for opening the joint DCs in the collaboration, proportional to F, are shared among the partners proportionally to the volume they are occupying in the DCs, that is, each company pays a fraction Λ^i/Λ of the opening costs. As the total logistics cost is accounted for per period, which is commonly done for the facility location problem, the fixed cost F per period represents the amortized cost for opening the DC plus the cost for operating the DC during one period. The transportation cost (from a DC) to a given retailer r is allocated to a company i proportionally to the volume it is transporting in the vehicles to retailer r, that is, each company pays a fraction λ_r^i/Λ_r of the transportation cost to retailer r. The transportation cost is proportional to the number of shipments per period to the retailer (and thus to the loading rate of the vehicles), given by Λ_r/Q_{dr}.

Given the proportional allocation mechanisms applied for these DC opening and transportation costs, a partner could decide to reject a given solution because it violates rationality principles (Zolezzi and Rudnick, 2002). Individual rationality means that a partner will not accept a solution that is worse than its stand-alone situation, and thus not viable for this partner and the collaboration in the long run. If a cooperative solution is rejected by at least one of the partners, this solution is inaccessible to the other partners even if acceptable for them individually.

Contrary to DC opening cost and transportation costs, each company holds its own inventories and incurs the corresponding costs. Part (1b) gives the inventory costs for company i at the DCs. The first term, which corresponds to $\sum_d \sqrt{2\, K_d^i\, h_d^i\, (\sum_r \lambda_r^i\, x_{dr})}$, includes the *cycle inventory and fixed ordering costs*, assuming an Economic Order Quantity (EOQ) control policy. The second term, which corresponds to $\sum_d h_d^i\, z_\alpha \sqrt{\sum_r LT_d^i(\sigma_r^i)^2 x_{dr}}$, gives to the safety stock costs at DCs, where we suppose a service level (i.e., probability of no stock-out) equal to α.

Part (1c) of the objective function corresponds to the inventory-related costs for company i at the retailer's location. We suppose that the inventory at retailers is managed using a (Q,R) inventory control policy with a penalty cost for stock-outs. The first term gives the cost for holding the *cycle inventory* and the *safety stock*. The average cycle inventory is half the number of product i in each delivery. The proportion of product i in a vehicle is equal to the retailer's demand for this product divided by the sum of all its demands, λ_r^i/Λ_r. The safety stock is computed as the difference between the reorder point R_{dr}^i and the expected demand during the lead time, $\lambda_r^i LT_{dr}$. The second term of part (1c) defines the *stock-out cost* for retailers of company i. The penalty cost for unsatisfied demand p_r^i integrates the loss of margin and the loss of goodwill (Nahmias and Olsen, 2015). The penalty cost is multiplied by the expected number of stock-outs incurred in a cycle, $n_{dr}^i(R_{dr}^i)$, times the number of cycles per period, Λ_r/Q_{dr}.

Constraints (2) and (3) define the auxiliary variables v_{1d}^i and v_{2d}^i. They allow to have a linear objective and move the nonlinearity caused by the cycle inventory and safety stock costs at DCs to the constraints (Atamtürk et al., 2012). The resulting model is a conic quadratic mixed integer program (as Q_{dr} and R_{dr}^i can be computed separately, see Section 3.3), which has the advantage to be solvable using commercial solvers. Constraints (4) ensure that each retailer is assigned to exactly one DC (i.e., single sourcing) and constraints (5) ensure that a retailer can be served only by a DC that is open. Constraints (6), impose nonnegativity on the auxiliary variables, while constraints (7) enforce the binary nature of decision variables x_{dr} and y_d.

3.3. Solving the multipartner inventory–location problem using a weighted sum approach

Our multipartner inventory–location model (1a)–(7) model has multiple objectives, one for each partner, as it aims to minimize the logistics cost of each company in the collaboration. To solve it, we make use of a weighted sum approach, as it allows us to compute the values of variables Q_{dr} and R_{dr}^i prior to solving the mathematical program (see Equations (9) and (10)). With this method, the objective functions (1a)–(1c) are rewritten and all objectives are summed with a weight γ^i representing their relative importance, as follows (constraints (2)–(7) are unchanged).

$$\min \sum_i \gamma^i \Bigg[\frac{\Lambda^i}{\Lambda} \sum_d F y_d + \sum_r \frac{\lambda_r^i}{\Lambda_r} \sum_d TD_{dr} \frac{\Lambda_r}{Q_{dr}} x_{dr} + \sum_d \sqrt{2K_d^i h_d^i v_{1d}^i} + \sum_d h_d^i z_\alpha^i \sqrt{LT_d^i} v_{2d}^i + \sum_{d,r} H_r^i \left(\frac{Q_{dr}}{2}\frac{\lambda_r^i}{\Lambda_r} + R_{dr}^i - \lambda_r^i LT_{dr}\right) x_{dr} + \sum_{d,r} p_r^i n_{dr}^i(R_{dr}^i) \frac{\Lambda_r}{Q_{dr}} x_{dr} \Bigg]. \tag{8}$$

The weight γ^i represents the influence of partner i to adapt the collaborative supply chain to its own preferences and product characteristics. The influence of a partner can, for example, be quantified based on the volume that the company ships through the network or whether it possesses assets or resources that are valuable to the coalition. By varying these weights for each partner, we gain insight into the outcome of different scenarios, given by the set of Pareto-optimal solutions. This information is valuable to managers during the negotiation process.

We note that the weighted sum approach does not allow to generate the complete Pareto frontier, but rather a set of points on the supported subset of the Pareto frontier, which are Pareto-optimal solutions. This set of points can be considered sufficient for our purpose: guiding the negotiation process of companies considering collaboration. Some specific points are of particular interest. When weights γ^i are identical for each partner (e.g., all equal to 1), the resulting objective function (8) corresponds to the total logistics cost of the coalition. This particular case thus corresponds to minimizing the logistics cost of the collaboration as a whole and maximizing the total collaborative benefits (that can then be shared among partners, see Fig. 2b). Dissimilar γ^i between partners gives more influence to a specific company on the design of the collaborative supply chain. The extreme situation where the weights γ^i are equal to 0 for all partners except for one company corresponds to this latter company deciding for the entire collaboration. These different scenarios will be analyzed in Section 4.

Regarding the computation of the shipment size Q_{dr} and the reorder level R^i_{dr}, it can be seen in Equation (8) that they only appear in the transportation costs, the cycle inventory costs at retailers and the stock-out costs. As a result, Q_{dr} and R^i_{dr} can be computed *a priori*, so that they are not variables of the optimization model, which can be solved as a conic quadratic mixed integer program. As detailed in the Appendix, we find the following closed-form formulas, similar to the optimal (Q,R) policy (Nahmias and Olsen, 2015), by differentiating expression (8) according to Q_{dr} then R^i_{dr}, equaling the resulting expressions to 0, and accounting for the vehicle capacity.

$$Q_{dr} = \min\left(C_{dr}, \sqrt{\frac{2\sum_i \gamma^i (TD_{dr}\lambda^i_r + p^i_r n^i_{dr}(R^i_{dr})\Lambda_r)}{\sum_i \gamma^i H^i_r \frac{\lambda^i_r}{\Lambda_r}}}\right) \qquad \forall d, r \tag{9}$$

$$1 - F^i_{dr}(R^i_{dr}) = \frac{H^i_r\, Q_{dr}}{p^i_r\, \Lambda_r} \qquad \forall d, r, i. \tag{10}$$

Note that the formula for Q_{dr} depends on the weight γ^i and, therefore, the ability to compute Q_{dr} (and thus R^i_{dr}) prior to the mathematical problem resolution is tied to the use of the weighted sum method. The system of Equations (9) and (10) can be solved exactly, iterating between the two equations. In the following, in our computational experiments, we solve Equation (9) neglecting the stock-outs (second part of the numerator) as the EOQ has been shown to be a high-quality approximation for Q_{dr} for the (Q,R) policy (Nahmias and Olsen, 2015).

4. Computational experiments

In this section, we illustrate and discuss how the product characteristics of the partners influence the benefits of horizontal collaboration. The parameters and the cost structure for two product

Table 2
Parameter values for functional and innovative products

	Functional product	Innovative product
Selling price	€ 50	€ 100
CV	0.2	0.5
Penalty	10%	40%
$h_d^i = H_r^i$	20%/year	50%/year

types, functional and innovative, are presented in Section 4.1. Then, in Section 4.2, we elaborate on the stand-alone scenario, as it will be used as the benchmark to compare our collaborative results with. In Section 4.3, we focus on the scenario in which all collaborating companies have a similar demand volumes for their respective products. We vary the demand for the different product types and study the effect on the collaborative benefits in Section 4.4.

4.1. Experimental setting

To allow for relevant insights, we focus on two product types: a functional and an innovative product (Fisher, 1997). A product type is defined regarding its characteristics such as the selling price, the variability in its demand, the costs of stock-out (related to the profit margin), and the cost to store it. As described in Section 1, each product type requires either a physically efficient or a responsive supply chain. The parameter values in our experiments[1] for both product types are summarized in Table 2.

First, we assume a price difference for both product types. A functional product is sold for € 50, whereas an innovative product is sold for € 100 per unit. This price difference arises from the fact that it is more expensive to produce, store, and deliver innovative products (Martí et al., 2015). Second, according to their definition (Fisher, 1997), the functional product has a lower coefficient of variation of the demand ($CV = 0.2$) and a smaller profit margin (penalty cost of 10%), compared to the innovative product ($CV = 0.5$ and penalty cost of 40%). The higher penalty cost for the innovative product is also due to a stronger expectation from customers, leading to a significant loss of goodwill (Martí et al., 2015). For both product types, we assume that the demand is normally distributed. The inventory holding cost includes storage, opportunity and obsolescence costs and are, therefore, higher for an innovative product (annual rate of 50%) compared to a functional product (annual rate of 20%) (Langenberg et al., 2012).

The experiments are set up so that they mimic collaborations between pairs of companies operating in the U.S. market. The retailers' locations are taken from the 49-node U.S. data set by Daskin (2011), commonly used in the facility location literature (Jeon et al., 2006; Santiváñez and Carlo, 2018). Also common in this literature (Shen et al., 2003; Atamtürk et al., 2012), we assume that all retailers' locations are potential locations for the DCs. Similar to Atamtürk et al. (2012) and Schuster Puga et al. (2019), we use the city's population size given in Daskin (2011) divided by 1000

[1]The complete data for our experimental setting can be found following this link: https://doi.org/10.14428/DVN/DRLCBX.

as the baseline for the retailers' daily demand, denoted by π_r. To allow for variance in the data set, a deviation of 25% is considered for the demand (i.e. randomly generated within the intervals [$0.75\pi_r$; $1.25\pi_r$]).

The opening of a DC involves a running cost F_d of € 2500 per week. The service level (α^i) is fixed at 97.5% at DCs, for all partners. From the central plant of each partner to the DCs, we suppose that both companies have similar settings and that production constraints dominate transportation in this stage, so that the order cost and the lead time are not impacted by distances. The order cost K_d^i is € 250 per order for all partners and DCs. The order lead time LT_d^i is supposed to be the same between the central plant of each partner i and each DC d, and is fixed to the average lead time from all potential DCs to all retailers (Puga and Tancrez, 2017). The transportation cost from DCs to retailers, T, is set to € 1/km, and each vehicle has a maximum capacity C_{dr} of 1200 items. The vehicle capacity is chosen to reflect consistent shipment size decisions for each product type characteristics: in our experiments, the average vehicle loading rate is 98.6% and 58.3% for functional and innovative products, respectively. Lead times between DCs and retailers, LT_{dr}, are directly proportional to the distance, assuming an average speed of 50 km/h.

The model is implemented in CPLEX and run on a 3.2 GHz computer with 16 GB of RAM. All problems are solved to optimality for the stand-alone as well as for the collaboration cases.

4.2. Stand-alone scenario

To assess the potential benefits of horizontal collaboration depending on the product types of the partners, we need to compare the collaborative scenario with the stand-alone situation. To compute the stand-alone scenario, we assume that each company optimizes its individual supply chain (i.e., number and location of facilities, delivery network, and inventory decisions) based on its product type. For this, we solve the mathematical program presented in Section 3.2 for each company separately (i.e., with $|I| = 1$). The different components of the logistics cost for partners with each product type are presented with full black and grey bars in Fig. 1 and summarized in the columns labeled as "stand-alone" in Table 3.

In Fig. 1, we observe that the cost distribution is different depending on the product type, impacting the supply chain design. In the stand-alone case, companies that offer functional products favor an efficient supply chain, seeking to strongly minimize costs at the expense of supply chain responsiveness. Figure 1 also reveals that the transportation and facility opening costs represent a large part of the logistics cost for this company (41.6% and 26.1%). In our experiments, the functional product provider opens three DCs and has a high loading rate of 98.6%, minimizing the number of deliveries. Functional products are supplied to the retailers every 17.1 days (compared to 10.4 days for the innovative products, see Table 3) leading to significantly higher inventory costs at the retailers, accounting for about 19% of the total logistics cost. Finally, safety stocks costs at the retailers and DCs (1.2% and 0.8%, respectively), as well as stock-out costs (1.6%), are low for the functional product provider as the variability in demand and the penalty costs for lost sales are low.

Table 3 reveals that, even if companies have similar demand volumes, the stand-alone cost of the company supplying innovative products is more than twice larger (around 62k compared to 29k). As their unit holding costs are higher, innovative products are ordered more

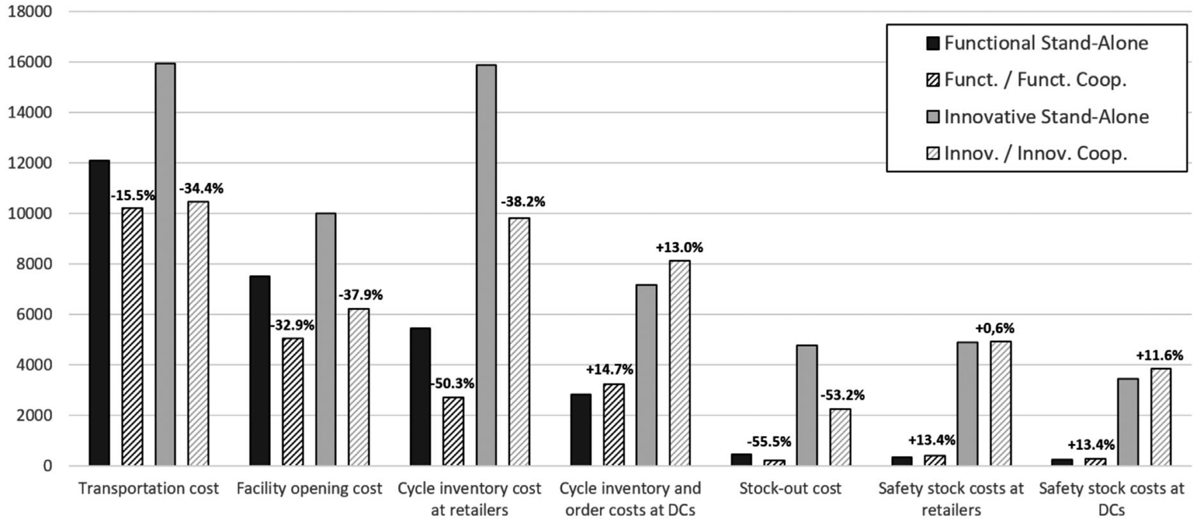

Fig. 1. Cost components for two reference companies, one with functional products (two first bars for each cost) and one with innovative products (two last bars). For each company, cost components are given when the company is working in stand-alone and when it collaborates with a partner supplying products of the same type.

Table 3
Numerical results for two reference companies, one with functional products and one with innovative products. For each company, performance measures are given when the company is working in stand-alone and when it collaborates with a partner supplying products of the same type

	Functional products			Innovative products		
	Stand-alone	Collab.	Difference	Stand-alone	Collab.	Difference
Logistics cost, Partner 1	28,911	22,054	−23.7%	62,046	45,542	−26.6%
Logistics cost, Partner 2	28,616	21,514	−24.8%	62,606	46,325	−26.0%
Logistics cost, Total	57,527	43,568	−24.3%	124,652	91,867	−26.3%
Total number of DCs	6 DCs (3+3)	4 DCs	−2 DCs	8 DCs (4+4)	5 DCs	−3 DCs
Avg. distance DC-retailer	580 km	487 km	−16.0%	533 km	436 km	−18.2%
Avg. loading rate	98.6%	99.2%	+0.6%	58.3%	75.3%	+29.2%
Avg. delivery window	17.1 days	8.6 days	−49.7%	10.4 days	6.6 days	−36.5%
Probability of no stock-out	90.8%	95.5%	+5.2%	96.6%	97.9%	+1.3%

often and in smaller quantities than the functional ones. In our experiments, products are delivered every 10.4 days and vehicles loading rate is only 58.3% on average, leading to transportation costs 34% higher than for functional products. Also, the demand is more variable and the penalty cost for a lost sale is more expensive for an innovative product. Therefore, the safety stock costs at DCs and at retailers and the stock-out costs are much higher, representing 5.5%, 7.9%, and 7.7% of the logistics cost, respectively. Related to the larger safety stocks, the probability of no stock-out (i.e., the service level) is equal to 96.6%, against 90.8% for functional products.

4.3. Collaboration between partners with similar demand volume

We now consider the collaboration between two companies with equal demand volumes. We distinguish between two scenarios, based on whether both partners offer the same product type or not, to analyze the impact of product types on the cost reductions.

4.3.1. Identical products type

When companies have a comparable demand volume and offer the same product type, they face the same needs in terms of supply chain responsiveness. As a result, they are likely to easily agree on the configuration of the collaborative distribution network and show similar usage of the network. This relates to the statement by Verstrepen et al. (2009) advising that it is better to select partners of approximately similar size in order to avoid unilateral dominance within the collaboration. The individual cost components for both scenarios are presented by the dashed bars in Fig. 1 and summarized in the columns labeled with "Collab." in Table 3.

In Table 3, we see that a collaboration between companies offering the same product type leads to substantial logistics cost reductions (24.3% and 26.3%, on average, for functional and innovative products, respectively). The following three sources of benefits have been identified.

1. *Collaborating companies benefit from sharing facilities*. Each partner has access to more DCs while the total number of DCs in the joint supply network is lower than in the stand-alone case, reducing the facility costs (as observed in Fig. 1). The shared DCs are also better geographically distributed, reducing the average distances to the retailers by 16% for functional products and by 18.2% for innovative products (see Table 3), impacting positively the transportation cost. These benefits of the increased number of accessible DCs clearly outweigh the increase in ordering costs to the plant, which are due to the fact that orders are smaller and more frequent (see Fig. 1).
2. *Collaboration allows to improve the average vehicle loading rate*. As the coalition has roughly twice as much products to carry, it has more possibilities for bundling, thereby reducing the total number of required vehicles and, consequently, lowering the transportation cost. As the loading rate of vehicles carrying functional products is already high in the stand-alone case (98.6%), it does not allow a significant improvement when cooperating (to 99.2%, see Table 3). In that case, nearly full vehicles are sent twice more frequently to the retailers, impacting positively their stock level and reducing their holding costs (−50.3%, see Fig. 1). For the innovative products, the small quantities sent more often in the stand-alone case lead to a low loading rate (58.3%), which can be improved significantly when collaborating (75.3%, see Table 3). This is in accordance with experimental results of Vanovermeire (2014) and Verdonck et al. (2019) demonstrating that the larger the pool of joint orders, the larger the potential to find a profitable distribution plan for the collaboration. As a consequence, the transportation cost is further reduced (by 34.4% compared to 15.5% for functional products, see Fig. 1). While the distance reduction coming for the sharing of DCs is similar for both product types, the companies supplying innovative products also benefit from an improved delivery efficiency with better loaded vehicles. As the loading rate increases, the reduction in inventory level for the innovative product (38.2%, see Fig. 1).

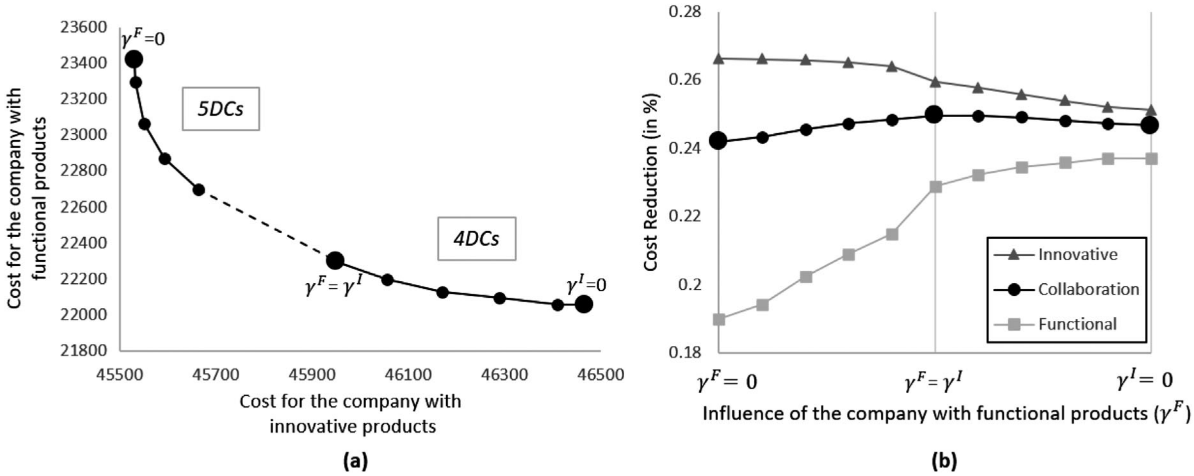

Fig. 2. Set of Pareto-optimal solutions, that is, when the influence weights (γ_i) in the collaboration vary, for a coalition of two companies supplying different product types: (a) costs allocated to each individual company in the coalition and total number of joint DCs; (b) collaborative benefits for each partner and for the collaboration as a whole, with the influence of the company supplying functional products (γ^F) increasing.

3. *Shortened lead times from joint DCs lead to a reduction in lost sales*. The shortened distances to retailers, coming from the sharing of DCs, also induces reduced lead times. By sharing (more) DCs, the inventories are located closer to the customers. As a result, lost sales are reduced significantly (more than 50% for both product types) while the safety stock level is kept similar (see Fig. 1). As the stock-out cost represents a much larger part of the logistics cost for innovative products, its reduction is significantly more impactful for this product type.

In conclusion, companies with identical products type easily agree on the optimal collaborative solution and benefit from substantial logistics cost reductions, coming from sharing facilities, more efficient transportation and reduced stock-outs. Regarding the impact of product characteristics on collaborative benefits, we show that these reductions are even larger for companies supplying innovative products as the room for improving vehicle loading and the impact of stock-outs reduction are higher.

4.3.2. Different product types

We now assess the benefits of a collaboration between companies supplying products with different innovativeness levels but similar demand volumes. In this case, the companies have different priorities for their supply network. To accommodate this, we generate a set of Pareto-optimal solutions, applying the weighted sum approach (see Section 3.3) and varying the weights of the partners with functional (γ^F) and innovative products (γ^I). The set of Pareto-optimal solutions, which are on the supported subset of the Pareto frontier, is illustrated in Fig. 2a. This figure shows the cost allocated to both partners for each alternative solution, and also shows how the number of joint DCs evolves depending on the influence of the partners. The corresponding benefits for the collaboration as a whole as well as for each partner are presented in Fig. 2b. Table 4 provides more details on three

Table 4
Impact on individual performance for a collaboration between one company supplying functional products and one company supplying innovative products. Three cases are distinguished: all decision power is with the innovative company ($\gamma^F = 0$), equal decision power between both partners ($\gamma^F = \gamma^I$), and all decision power is with the functional company ($\gamma^I = 0$)

	$\gamma^F = 0$		$\gamma^F = \gamma^I$		$\gamma^I = 0$	
	Functional	Innovative	Functional	Innovative	Functional	Innovative
Logistics cost reduction	−18.9%	−26.6%	−22.9%	−25.9%	−23.7%	−25.1%
Change in no. of accessible DCs	3 → 5	4 → 5	3 → 4	4 → 4	3 → 4	4 → 4
Change in Avg. distance to retailers	−24.8%	−18.3%	−16.0%	−8.7%	−16.0%	−8.7%
Change in loading rate	−22.6%	+17.3	−6.3%	+33.6	+1.1%	+41.0%
Change in delivery window	−61.4%	−36.5%	−53.8%	−24.0%	−49.7%	−17.3%
Change in safety stock at DCs	+29.1%	+11.6%	+13.3%	−1.4%	+13.3%	−1.4%
Change in safety stock at retailers	+5.3%	+0.3%	+15.0	+9.9%	+13.2%	+8.5%
Probability of no stock-out (%)	96.6%	97.9%	95.8%	97.4%	95.5%	97.2%
Change in stock-out cost (%)	−58.2%	−53.1%	−56.1%	−50.3%	−55.5%	−49.7%

specific solutions (highlighted in Fig. 2a and b by larger points): when the company with innovative products decides alone for the collaboration ($\gamma^F = 0$), when partners exert the same influence on the decisions ($\gamma^F = \gamma^I$), and when the company with functional products decides alone on the supply network ($\gamma^I = 0$).

We observe that the total benefits from collaboration (see black circles in Fig. 2b) are highest when the partners share the decision power equally ($\gamma^F = \gamma^I$), reaching 24.9%. When the decision power becomes unbalanced, the deciding company will tend to shape the joint supply network to its own needs, to the detriment of its partner and of the overall collaboration. Hacardiaux et al. (2021) confirm this by stating that a discrepancy in influence might create an incentive for partners to behave opportunistically. Second, we observe in Fig. 2b that the company with the innovative products (see triangles in Fig. 2b) always benefits the most from collaborating. Whatever its weight in the joint supply network design decisions, this company should be particularly incentivized to cooperate as its collaborative benefits are relatively stable, varying from 25.1% to 26.6% (see Table 4). The benefits for the company supplying functional products (see squares in Fig. 2b) are always significantly smaller. An equal benefit solution for both partners does not exist in our experiments. Moreover, we observe in Table 4 that those benefits are markedly more hurt when the company is not able to influence the design of the joint network (i.e., when γ^F is low), as the benefits go from 23.7% to 18.9%.

As a reminder, in the stand-alone scenario, three DCs were used by the company with functional products and four DCs by the company supplying innovative products (see Section 4.2 and Table 3). Looking at three specific collaborative solutions ($\gamma^F = 0$, $\gamma^F = \gamma^I$, and $\gamma^I = 0$) in Table 4, we observe first that when the company with innovative products decides unilaterally ($\gamma^F = 0$), five joint DCs are opened to reduce lead times and improve the responsiveness of the supply chain (also see Fig. 2a). This increases the DC opening costs but allows to significantly decrease stock-out costs while limiting the safety stocks at retailers. It also reduces the average distance to the retailers, and the low loading rate of the company supplying innovative products in the stand-alone case is improved by 17.3%, reducing its transportation cost. As stock-out and safety stock costs represent a much larger share of the cost for the company with innovative products (see Fig. 1), this company benefits more from the collaboration (−26.6%). On the contrary, the company supplying functional products incurs larger facility opening costs, as two additional DCs are now opened compared to its stand-alone situation, and sees its average loading rate deteriorated by 22.6%, leading to a lower collaborative benefit of −18.9% (see Table 4).

When both companies have equal decision power ($\gamma^F = \gamma^I$), they compromise to design a supply chain that balances cost efficiency and responsiveness, and we observe in Fig. 2b that they reach the maximum possible benefit from collaborating. Compared to when the company supplying innovative products decides alone ($\gamma^F = 0$), the joint supply network becomes more cost-efficient and less responsive: only four joint DCs (see Fig. 2a) are opened and the loading rate of vehicles improves (to 92.3%), but the delivery frequency and the service level deteriorate. The positive impact for the company with functional products (+4%) is clear as facility and transportation costs reduction is its priority. The negative impact for its partner with innovative products (−0.7%) is limited as it also benefits from those costs reductions and manages to balance the increases in safety stocks at retailers and in stock-outs to mitigate the impact of increased lead times. These changes are expanded when the weight γ^F increases, up to the collaborative solution decided unilaterally by the company with functional products ($\gamma^I = 0$). To design an even more cost-efficient joint supply network, the number of DCs is not modified anymore but the vehicles are only sent once they are nearly full (99.7%). Even in that case, the benefit for the company supplying innovative products, presented in Table 4, is higher (25.1%) than for the one providing functional products (23.7%), as observed in Table 4.

To conclude, in line with the nascent literature looking at collaborating partner preferences, companies supplying products with different innovativeness levels have different priorities for their supply network, and thus need to compromise (choosing one of the Pareto-optimal solutions). The highest benefit for the cooperation as a whole is achieved when both partners have the same influence on the decision ($\gamma^F = \gamma^I$), but the individual priorities of each company incentivize them to diverge away from it. Regarding the influence of the innovativeness level, we find that the potential benefits for the company with innovative products are larger and more stable, whatever its influence on the network design decisions.

4.4. Collaboration between partners with dissimilar demand volumes

In line with the operational fit concept described by Van Breedam et al. (2005), most of the literature in horizontal collaboration claims that a collaboration has more chance to succeed when partners are similar in size due to an easier cost (or profit) allocation (Cruijssen et al., 2007; Vanovermeire, 2014). However, this statement needs to be expounded upon in the setting under study in this paper, with products of different types. In Section 4.3, we saw that the concept of size is unclear as similar demands for products do not lead to the same costs when products have different types.

In the following, we thus propose a set of experiments to assess the benefits of a collaboration between companies with different demand volumes. We consider two companies of reference with a fixed demand volume as benchmarks. One supplies functional products and the other supplies innovative products. Their characteristics follow the experimental setting introduced in Section 4.1.

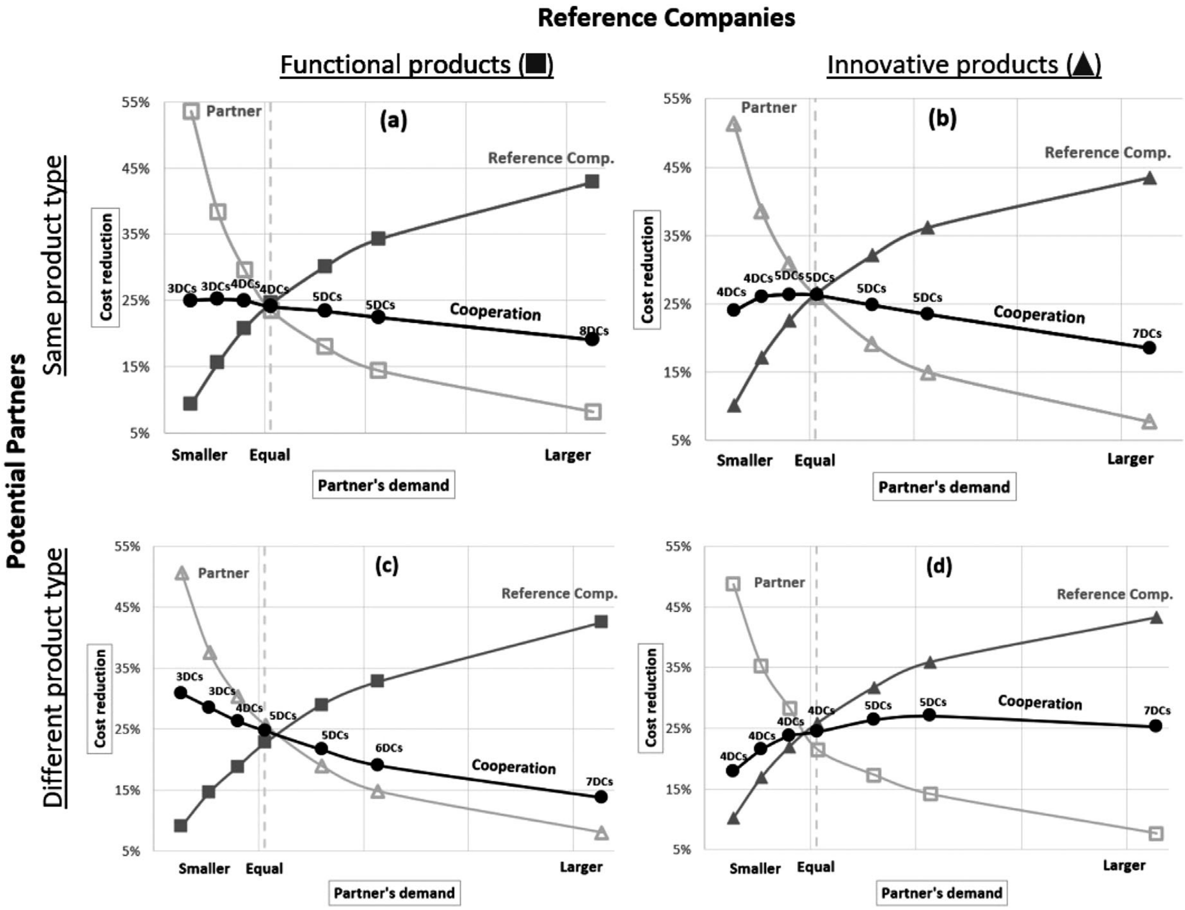

Fig. 3. Cost reductions that can be achieved by the collaboration of a reference company supplying functional (□) or innovative (△) products with potential partners with various demand levels and with an identical or a different product type.

The reference companies each look independently for the best suited partner, depending on their own products characteristics. Potential partners with each product type and with various demands (ranging from four times smaller to four times larger than the reference company) are considered. We assume here that all companies taking part in a collaboration have the same weight in the decision process (i.e., all γ_i are equal, leading to the maximum collaborative benefit).

To improve the understanding of the different analyses, we report the benefits of potential collaborations in Fig. 3 depending on the reference company product characteristics (two columns) as well as the partners' product type (lines) and demand (x-axes of the graphs). The demand level of the reference company is represented by a dashed line in the four graphs. Figure 3a and b illustrates reference companies collaborating with potential partners offering a the same product type (see Section 4.4.1). Figure 3c and d represents the collaborations between reference companies and potential partners selling a different product type (see Section 4.4.2). Finally, by comparing vertically Fig. 3a and c, or Fig. 3b and d in Section 4.4.3, we present some recommendations on the most promising partnerships for a reference company, depending if it supplies functional or innovative products.

4.4.1. Identical product types

In this section, we examine the cases where a reference company considers collaborating with potential partners offering the same product type. Whether the reference company supplies innovative or functional products, the benefits from cooperation are best when the demand level of the partner is not too different: the benefits increase and then decrease when the partner's demand increases (see the black circles in Fig. 3a and b). More specifically, the benefits of the cooperation are highest in our experiments when the partner's demand is slightly smaller (75% in our experiments) than the demand of the reference company. Comparing the individual cost reductions, we see that the company with the smallest demand always benefits more. This is in line with the experimental results of Verdonck et al. (2019) and Hacardiaux et al. (2021) and is due to the fact that the larger partner already has a more effective supply network before cooperating, due to better economies of scale. In Fig. 3a and b, the partner's benefits stand over when the partner's demand is smaller than the reference company's (fixed) demand, and under when it is larger. In the following, we analyze more in-depth the various situations depending on the partner's demand volume.

- \- *When the potential partner has a very small demand* (solution on the left of Fig. 3a and b), the cooperative benefits are around 25% for both product types. The partner's supply chain is particularly expensive in the stand-alone case as its low demand prevents economies of scale. Its vehicles are weakly loaded and few DCs are opened. When cooperating, the small partner benefits a lot (around 50% of cost reduction) from the access to more DCs, reducing the average distance with the retailers, and from the vastly improved vehicle loading rate. On the contrary, the reference company, with its larger demand, sees much smaller benefits (around 10%) as the partner's demand is not sufficient to justify opening more DCs or to improve its vehicle loading rate significantly. As the reference company makes a large share of it, the overall collaborative benefit is not the highest, despite the very high benefits for the partner.
- \- *When the potential partner's demand is larger than the demand of the reference company* , the partner's stand-alone supply chain is effective as economies of scale are already obtained. The collaboration still leads to cost reductions, especially due to higher delivery frequencies and the opening of additional DCs, but the marginal gain is reduced (as the vehicles were already efficiently filled).

When both companies have the same product type, the highest collaborative benefits are thus indeed reached when they have similar demand sizes. However, it is interesting to note that the highest relative cost reduction may be obtained when companies have slightly different demands. This tends to differ from most literature, which suggests that partners of similar size lead to the highest collaborative benefits (Verstrepen et al., 2009), except Verdonck et al. (2016) who observe that partners may benefit from having different, but complementary, characteristics. In our experiments, the maximum benefit is reached when the partner's demand equals 75% of the reference demand. In this configuration, the demand of both companies becomes sufficient to open an additional DC in the collaboration case (see Fig. 3a and b). The partner benefits from a more efficient vehicle loading rate (+3.7% and +18.8% with functional and innovative products, respectively) and from more DCs, while it represents a good share of the total benefit of the collaboration.

In conclusion, the complementary of the partners' demands is essential to maximize the benefits of the collaboration. However, contrary to most literature, our results show that the highest benefit is not necessarily achieved when companies have the exact same demands. Moreover, depending on the demand sizes of the partners, their individual benefit may differ significantly.

4.4.2. Different product types

In this section, we analyze the cases where a reference company examines potential partners offering products of a different type. In Fig. 3c and d, the product types are reversed for the reference company and the potential partner. The opposite trends observed in these two figures (i.e., decreasing vs. increasing benefit for the cooperation when the partner's demand gets bigger) reveal the same main insight: the cooperation tends to be more profitable when the demand for the functional product is higher than the demand for the innovative one. In the following, we analyze the reasons in details.

As observed in Section 4.4.1, looking at individual cost reductions, the company with the smallest demand benefits more from the cooperation, as it benefits more from improved economies of scale, with access to more DCs and a more efficient loading of the vehicles. Contrary to the cases with the same product type (Fig. 3a and b), when both companies supply products of different types, the logistics cost for the same demand size differs very significantly for both companies. Innovative products are vastly more expensive to supply (see Fig. 1 and Table 3). As a consequence, the benefits incurred by the company with innovative products generally outweighs the benefits of the company supplying functional products in the relative cost reduction. In Fig. 3c and d, the collaboration benefits tend to follow the trend given by the individual benefits of the company supplying innovative products (△). The collaboration benefits are higher when the company with innovative product has a lower demand and thus a high potential improvement in economies of scale.

For a reference company with functional products (Fig. 3c), the highest benefit is reached collaborating with a partner with a smaller demand for its innovative products. When its demand is four times smaller, the partner enjoys a cost reduction around 50%, which represents a good share of the total collaboration's benefits (up to 30.9% in our experiments). When its demand increases, the partner's potential efficiency improvement decreases and so does the benefit of the collaboration (in which the partner's cost makes a larger share of the total cooperation costs). In Fig. 3d, when the partner supplying functional products is small, it benefits a lot from having a joint supply network with a much larger company (reduction close to 50%) but it does not reflect in the overall benefits of the collaboration as its share in the logistics costs is minimal (around 20%). When the partner's size increases, the reference company supplying innovative products benefits more and more, impacting positively the benefits of the cooperation. At a point however, the supply chain has become very efficient, and the benefits in absolute values increase slower than the total logistics cost, leading to a diminution of the cost reduction (observed in the right-most solution in Fig. 3d).

In conclusion, unlike what is often observed in the existing literature, when partners supply products of different types, the highest collaborative benefits are not reached when the partner have similar demand sizes. Besides the demand size, the logistics cost also plays an important role. In this

Table 5
Logistics cost reduction for the collaboration scenarios under study, differing in terms of demand volume and product type. The number above the brackets provides the logistics cost reduction for the coalition as a whole. The numbers between brackets show the individual cost reductions for both coalition partners (with the number on the left coinciding with the results for the reference company)

	Product type and size of reference company					
	Functional products			Innovative products		
	Larger	Equal	Smaller	Larger	Equal	Smaller
Partner company offers same product type	**24.9%** (9.3|53.6)	24.0% (24.8|23.7)	19.0% (42.9|8.2)	24.0% (10.2|51.3)	**26.3%** (26.6|26.0)	18.6% (43.5|7.8)
Partner company offers different product type	**30.9%** (9.0|50.7)	24.7% (22.8|25.6)	13.8 (42.5|8.0)	17.9% (10.1|48.8)	24.5 (25.9|21.4)	**25.3%** (43.3|7.7)

regard, accounting for the level of innovativeness and cost structure of the products supplied by the partners is imperative. When comparing innovative and functional products, the benefits of the company supplying innovative products have more weight, leading to higher collaborative benefits when this company is smaller and benefits from more economies of scale when cooperating.

4.4.3. Guidelines for companies considering collaboration

Based on the insights discussed in the previous subsections, we summarize the guidelines for a company looking to enter a collaboration, wishing to maximize its benefits, depending on the type of products it offers. In this context, Table 5 provides an overview of the logistics cost reduction for the studied collaboration scenarios, differing in terms of demand volume and product type.

For each company, a discrepancy exists between the objective to maximize the individual benefit or the cooperation benefit. A company looking only to increase its own benefits should always cooperate with a partner having a higher demand, leading to larger economies of scale, whatever the product type the companies are supplying. In Table 5, we see that, in all cases, the individual benefits of the reference company increase as its size decreases.

When the goal is to increase the overall relative benefit of the collaboration (to then fairly share it), a reference company supplying functional products should first look for a partner supplying innovative products, and with a lower demand, as demonstrated by the collaborative cost reduction of 30.9% (see Table 5). Such a partner's efficiency would improve a lot from collaborating with a larger company and would lead to a high collaboration benefit. If such a partner is not available, a company with functional products should favor a partner with similar characteristics in terms of product type and demand size (ideally slightly smaller, as this increases the collaborative cost reduction to 24.9%), and avoid a partner having a large demand for innovative products (resulting in a cost reduction of only 13.8%).

For a company supplying innovative products, collaborating with a partner with a similar demand for innovative products or with a higher demand for functional products should be favored. In the first case, the complementarity between partners' demands lead to a cost reduction of 26.3% (see Table 5). In the second case, the collaborative cost reduction amounts to 25.3%. The reference company with a smaller demand for innovative products benefits the most from the collaboration and reduces its expensive stand-alone costs by collaborating with a large efficient company. A company supplying innovative products should avoid partnering with large companies with innovative products or small companies with functional products, resulting in cost reductions of only 18.6% and 17.9%, respectively.

5. Conclusions

Horizontal collaboration promises clear benefits for the partners but those benefits are difficult to assess as they notably depend on the partners' products characteristics. Despite that, the influence of the innovativeness of the partners' products on the level of achievable benefits and the collaborative supply chain organization is not studied in the literature. Moreover, the majority of current collaborative logistics research ignores the inherent multi-partner nature of a collaboration, assuming the collaboration to be a single entity, neglecting the identity of the partnering companies. In addition, existing research quantifies and explores the potential cost reductions associated with horizontal collaboration, without accounting for the impact of collaboration on customer service level and stock-outs. Based on these research gaps, the contribution of this paper is twofold. On the one hand, we are the first to quantitatively analyze how collaborative benefits are impacted by the individual partners' product characteristics in a multipartner collaborative location–inventory model. On the other hand, based on numerical experiments analyzing the impact of the innovativeness level of products and their respective demands, we provide insights to support practitioners in selecting the right collaborative partners and designing the ideal collaborative supply chain regarding their products characteristics. The main insights are summarized in the following.

Collaboration is beneficial for partners whatever the product type, but companies with innovative products have more incentives to cooperate. Indeed, when the demand volumes of partners are similar, the cooperation between two partners supplying innovative products is the most profitable with cost reductions of 26.6% (compared to 23.7% for companies with functional products, see Section 4.3.1). All companies, with functional or innovative products, are able to reduce their costs, sharing DCs and vehicles, increasing their delivery frequency and improving their customer service. For companies supplying innovative products, the difference comes from their ability to strongly improve their vehicle loading rate while companies with functional products already use nearly full vehicles in the stand-alone case. Moreover, stock-outs become twice less frequent for all companies cooperating, but these are much more costly for innovative products. The benefits are also larger for companies with innovative products when they cooperate with a partner supplying functional products (25.9% compared to 22.9%, see Section 4.3.2). In such an asymmetric partnership, the maximum collaborative benefit (24.9%) is reached when both company share the decisions ($\gamma^F = \gamma^I$).

When the demand volumes of partners are dissimilar, the potential cost reductions from collaboration vary significantly with the products' type (see Section 4.4). The individual benefits are always larger for the smaller company that benefits from more economies of scale when cooperating compared to its stand-alone supply chain. When trying to maximize the overall relative benefit of the collaboration, a company supplying functional products should look for a partner with smaller demand for innovative products, while a company supplying innovative products should look for a partner with similar demand for innovative products, or larger demand for functional products.

When interpreting our research results, the reader should account for the following limitations, which can inspire future research. First, all models presented in this paper consider only differences in logistics costs when comparing the stand-alone situation with its collaborative alternative. Costs related to the formation of the coalition (e.g., the alignment of IT systems, changes in business processes, and related training) as well as the running costs (e.g., coordination, maintenance of decision support systems, alignment meetings) are not accounted for. This means that, based on the logistics cost reduction, individual partners should decide if these cost reductions are sufficient to cover additional expenses related to their engagement in the collaboration. Second, the numerical values that serve as an illustration of our models relate to the simulation of a theoretical application. It would be valuable to extend our analysis with real company data and cases to allow for a better generalization of the numerical results. Finally, all numerical results presented at the individual company level are subject to the chosen cost allocation model. Alternative cost allocation models (e.g., more complicated models such as the Shapley value, founded on fairness principles defined in cooperative game theory) might lead to different outcomes at individual company level, especially due to the differences in size, cost structure and preferences among the companies.

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Appendix

In this Appendix, we detail the mathematical derivation for the equations of the shipment size Q_{dr} (9) and of the reorder level R^i_{dr} (10). First, to find Q_{dr}, for a given d and a given r (supposing that

$x_{dr} = 1$, which is the only relevant case), we derive the objective function (8) according to Q_{dr} and equal it to zero. It leads to the following equations, and then to Equation (9) for Q_{dr}, accounting for the vehicle capacity.

$$\sum_i \gamma^i \left[\frac{\lambda_r^i}{\Lambda_r} T\, D_{dr} \frac{-\Lambda_r}{(Q_{dr})^2} + H_r^i \frac{1}{2} \frac{\lambda_r^i}{\Lambda_r} + p_r^i\, n_{dr}^i(R_{dr}^i) \frac{-\Lambda_r}{(Q_{dr})^2} \right] = 0 \tag{A1}$$

$$\frac{1}{(Q_{dr})^2} \sum_i \gamma^i (T\, D_{dr}\, \lambda_r^i + p_r^i\, n_{dr}^i(R_{dr}^i)\, \Lambda_r) = \frac{1}{2} \sum_i \gamma^i\, H_r^i \frac{\lambda_r^i}{\Lambda_r}. \tag{A2}$$

Second, to find R_{dr}^i, for a given i, d, and r, we derive the objective function (8) according to R_{dr}^i and equal it to 0, using the fact that $\frac{d\, n_{dr}^i(R_{dr}^i)}{d R_{dr}^i} = F_{dr}^i(R_{dr}^i) - 1$, as $n_{dr}^i(R_{dr}^i) = \int_{R_{dr}^i}^{\infty} (x - R_{dr}^i)\, f_{dr}^i(x)\, dx$ (where $f_{dr}^i(x)$ is the probability density function of the demand) and by application of the Leibniz integral rule. It leads to the following equations, and then to Equation (10) for R_{dr}^i .

$$\gamma^i \left[H_r^i + p_r^i \left(F_{dr}^i(R_{dr}^i) - 1 \right) \frac{\Lambda_r}{Q_{dr}} \right] = 0. \tag{A3}$$