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Fairness ideals in inventory allocation

Eirini Spiliotopoulou[1] | **Anna Conte**[2]

[1] Department of Management, Tilburg School of Economics and Management, Tilburg University, Tilburg, Noord-Brabant, The Netherlands

[2] Department of Statistical Sciences, Sapienza University of Rome, Roma, Lazio, Italy

Correspondence
Eirini Spiliotopoulou, School of Economics and Management, Tilburg University, Tilburg, Noord-Brabant, The Netherlands.
Email: e.spiliotopoulou@tilburguniversity.edu

ABSTRACT

We study fairness ideals in distribution systems where inventory is allocated to multiple retailers and there is supply–demand mismatch. In particular, we focus on (a) what is considered fair inventory allocation by retailers (e.g., equal profit, same fill rate, equal share of supply–demand mismatch?) and (b) how the supply chain context affects fairness perceptions. We consider an integrated supply chain setting where total inventory is allocated at the retail level and retailers may face either shortage or surplus, and a disintegrated supply chain where retailers may face supply scarcity when total demand exceeds available inventory. Our experimental data suggest that subjects, taking on the role of retailers in the same supply chain, are often motivated by fairness considerations: they claim for themselves inventory that is not exactly equal to their needs in more than one-third of the instances. Across settings, "fair" allocations depend on retail demands rather than on profit comparisons, even when these are facilitated by a decision support tool. However, in cases of surplus, the most prevalent fairness ideal is that of equal split of inventory–demand mismatch, while in cases of shortage, the most prevalent fairness ideal is that of equal fill rates. Follow-up experiments suggest that retailers under both cases of shortage and surplus are more likely to evaluate an allocation as fair when it is based on realized demands, and this is independent of whether it was determined by a rule or a human decision maker.

KEYWORDS

behavioral operations, experimental economics, fairness ideals, inventory allocation

1 | INTRODUCTION

Concerns for fairness affect decisions in a variety of business contexts, ranging from simple decisions in economic games such as the ultimatum and dictator games (for a recent review, see, e.g., Cooper & Kagel, 2016) to pricing decisions in distribution channels (Cui & Mallucci, 2016; Ho et al., 2014) and contract design and performance (Katok & Pavlov, 2013; Katok et al., 2014). In resource allocation problems, the importance of fairness has been recognized in a variety of settings, ranging from engineering applications in communication networks to financial applications. For example, Bertsimas et al. (2011) study the price of fairness, that is, the relative efficiency loss compared to the allocation that maximizes system utility, adopting two axiomatic notions of fairness. But what is perceived as a fair outcome depends on the specific context (Cooper & Kagel, 2016) and is ultimately an empirical question (Fehr & Schmidt, 1999). The aim of this article is to explore what is considered fair inventory allocation among retailers when supply is different than demand. Understanding what drives fairness perceptions, we can ultimately derive implications about how to incorporate fairness in the design of allocation policies.

While strictly prioritizing customers based on importance (e.g., own channel) or profitability criteria (e.g., profit margin) could maximize short-term profits, the perceived fairness of the allocation policy may affect a company's reputation and long-term supply chain relationships. For example, Apple was blamed by independent retailers for prioritizing its own sales channels at the expense of autonomous channels (Wingfield, 2004). Procedural and distributive justice of a supplier's policies has been shown to affect customers' long-term orientation and relational behaviors such as flexibility and information sharing (Griffith et al., 2006) and ultimately relationship performance (Liu et al., 2012).

Hence companies, for commercial or other reasons (e.g., cultural, legal), often choose to treat their supply chain partners equally, by employing a variety of "fair" allocations policies such as uniform allocation of available capacity/inventory, or giving customers the same fraction of the ordered volume. For example, many Japanese companies in the aftermath of the Fukushima nuclear disaster in 2011 gave their customers the same fraction of their orders, while Intel, being a large supplier in the PC industry who regularly deals with supply–demand mismatches, uses a similarly fair approach by employing a uniform policy (Sheffi, 2020). But what is considered as a fair deal when a common resource, for example, inventory, is allocated among multiple customers, for example, retailers? Does the supply chain context (integrated vs. disintegrated system) or the type of supply–demand mismatch (shortage vs. surplus) affect what is perceived as a fair allocation by the retailers?

In the behavioral economics literature, "inequity aversion" models have been proposed to capture the idea of fairness, based on the notion that people dislike receiving a payoff that is lower (Bolton, 1991) or different (Fehr & Schmidt, 1999) from that of the others, or that in general their utility depends on their absolute payoff as well as their relative share of the total payoff (Bolton & Ockenfels, 2000). In more complex situations that involve "production", for example, a distribution channel where price is endogenous, additional fairness ideals have been explored, such as strict egalitarianism, liberal egalitarianism, libertarianism (Cappelen et al., 2007), and the sequence-aligned ideal (Cui & Mallucci, 2016). However, the reference outcome, or in other words the fairness ideal, in supply chain settings where a common resource (e.g., inventory or capacity) is shared across multiple retailers is poorly understood.[1] Allocation mechanisms commonly used in practice and studied in the literature prioritize retailers differently when there is either inventory shortage or surplus (Cachon & Lariviere, 1999b; Spiliotopoulou et al., 2019). Understanding the drivers of perceived fairness in inventory allocation has direct implications for the design of more "fair" allocation mechanisms.

We experimentally study fairness ideals when there is supply–demand mismatch. To understand how the context may affect fairness considerations, we consider two settings that differ in the level of supply chain integration and hence the type of supply–demand mismatch that retailers may face (shortage/surplus or shortage only). First, we look at an integrated distribution system where multiple retailers are serviced from a common pool of inventory and total inventory is allocated at the retail level (as in Spiliotopoulou et al. (2016)). This captures the dynamics of integrated systems[2] where total cost (both underage and overage) is distributed among retailer locations (Fiestras-Janeiro et al., 2011; Özen et al., 2012) and may represent the case of a vertically integrated firm or a pooling coalition (e.g., retailers coordinate their orders and are replenished from common warehouses) (Özen et al., 2008). This setting allows us to study fairness considerations both when demand exceeds supply (shortage) and when supply exceeds demand (surplus). Next, we consider a disintegrated setting where multiple retailers buy from the same supplier. In this setting, we only focus on the shortage case, where inventory is rationed among retailers when the total demand from the retailers exceeds available supply (Cachon & Lariviere, 1999b). When available supply exceeds total demand, that is, there is surplus at the supplier, the allocation of inventory is not relevant as the retailers can each receive the exact amount they order. Thus, unlike the integrated setting, the surplus for the supplier does not have any implications for the retailers.

We employ an allocation game where, similar to Cappelen et al. (2007), participants have a stake in the outcome. Participants take on the role of a retailer and propose how inventory shall be split between themselves and another retailer, who is serviced from the same inventory. While in practice a supplier or a central decision maker would make the allocation decision, this experimental setup allows us to directly estimate the fairness ideals of retailers being part of a distribution system (i.e., what drives the perception of a "fair" outcome for those experiencing the allocation policy), and at the same time to determine the importance they attach to fairness (in relation to the motivation of self-interest). Participants must make a trade-off between own profit and fairness considerations, and their choices allow us to explore the drivers of "fair" allocations and estimate the prevalence of fairness ideals under different scenarios. In a follow-up experiment, to validate the drivers of perceived fairness, retailers are asked to evaluate the fairness of allocations that are externally determined (either by a predetermined allocation rule or a human decision maker).

Our results show that fairness considerations play a role in the allocations proposed, with participants proposing an own inventory allocation that is not exactly equal to their demand in more than one-third of the instances. Across both settings, we find that what is perceived as a fair inventory split between retailers is primarily based on realized market demands, rather than on total profit comparisons. While there is heterogeneity in fairness ideals, in the context of surplus the most prevalent fairness ideal is that of equal split of excess inventory, while in the context of supply scarcity the most prevalent ideal is that of equal fill rates. Across all settings, only one-fourth of the participants propose allocations in line with the ideal of equal inventories. Our results suggest that independent of the specific supply chain context, companies/decision makers who want to treat their supply chain partners fairly shall base their allocation decisions on the size of their customer needs, applying a proportional allocation policy in times of scarcity and an equal split of excess inventory in cases of surplus (if this is shared at the retail level). An allocation appealing most to the fairness ideal of a retailer does not necessarily mean that other allocations are considered unfair. Our experimental results show that when retailers evaluate allocations, those based on the proportional and the linear rules are more often considered fair (compared to

[1] In our setting, the common resource is fixed (similar to the ultimatum or dictator games across peers) but total profit may depend on the allocation decision, if retailers have different profit margins, leading to efficiency losses. On the other hand, there is no "production" preceding the distribution phase, as in the class of economic games where fairness ideals have been previously explored (see, e.g., Cappelen et al., 2007).

[2] We note that an integrated setting does not necessarily imply centralized control.

uniform or max–min profit allocations) under both cases of shortage and surplus. This implies that, independent of the type of supply–demand mismatch, retailers are more likely to perceive an allocation policy fair when it is responsive to retail demands.

We contribute to the behavioral operations literature by exploring ideals of fairness in common distribution settings, and establishing the drivers of fairness perceptions. In an era of the increasing importance of multiple sales channels and more integrated fulfillment methods (e.g., omnichannel strategies), sound theoretical understanding of the drivers of fairness perceptions must inform managerial practice regarding inventory allocation policies (e.g., evaluation of a supplier's own rationing practices, choice of (cost) allocation policies in an integrated distribution setting). We also contribute to the experimental economics literature by identifying that (random) "pre-selection" of a participant to make a proposal that will be implemented influences fair choice in the context of inventory allocation.

The rest of the article is organized as follows. Section 2 reviews the literature on fairness and its implications, focusing on the context of operations/supply chain. Section 3 presents our theoretical model of fairness and the definition of plausible fairness ideals in the context of inventory allocation. Section 4 describes the experimental design, and Section 5 summarizes and discusses the empirical findings. Section 6 presents the follow-up experiment and its implications for supply chain management. Section 7 concludes.

2 | LITERATURE REVIEW

During the last decades, there has been a large body of evidence, mainly within the experimental economics and psychology literature, that people are strongly motivated by other-regarding preferences, such as concerns for fairness and reciprocity, and this has an important impact in many economic and business contexts (Camerer, 2011; Fehr & Schmidt, 2006). For recent reviews, the reader is referred to Cooper and Kagel (2016) and Bolton and Chen (2018). We focus our discussion here on the literature regarding (a) fairness ideals, and (b) fairness considerations in a supply chain context. Last, we review the literature on behavioral issues in allocation settings, the context of our study.

In the most popular models of social preferences, that of Fehr and Schmidt (1999) and Bolton and Ockenfels (2000), people care about their own income but also about the distribution of payoffs. An equal split of payoffs is usually assumed as the fair outcome and aversion to differences is the driving force of preferences. While in simple economic situations, such as the ultimatum or the dictator game, an equal distribution of the total fixed payoff is undisputedly considered as fair, in more complex situations what is fair may not be that straightforward. Cappelen et al. (2007) study fairness ideals in a situation that involves production, and estimate the prevalence in the population of three principles of distributive fairness: egalitarianism (norm of strict equality), libertarianism (each person shall get what s/he produces), and liberal egalitarianism (people should be held responsible only for the factors under their control, i.e., their choices). They use a dictator game where the distribution phase is preceded by a production phase and find that while the majority of the population are strict egalitarians, there is considerable pluralism in the fairness ideals. More recently, Cui and Mallucci (2016) study what is considered a fair deal in a manufacturer–retailer setting, where players first invest to increase demand and then set prices sequentially. They propose another fairness ideal, the "sequence-aligned" ideal, which suggests that the fair channel profit split is in line with the exogenously determined game structure. Charness and Rabin (2002) argue that concerns for efficiency (total payoff of the group) and the payoffs for the least well off players in the group (maximin preferences) are the key factors underlying outcome-based preferences. Next to outcome-based preferences, concerns of procedural fairness (Bolton et al., 2005) and of intentions (Blount, 1995) may also affect preferences. We focus on outcome-based preferences and explore additional fairness ideals when a common resource (i.e., inventory) is allocated among retailers that have different needs (i.e., local demands).

Within the supply chain domain, the majority of the current literature studies analytically and experimentally the role of fairness in pricing games in distribution channels. Cui et al. (2007) consider a manufacturer–retailer monopoly setting, and show analytically that when supply chain partners care about fairness, defined as inequality in payoffs, a simple wholesale price can mitigate double marginalization and coordinate the channel. Katok et al. (2014) extend the analysis to the case where supply chain partners' fairness concerns are private information. They provide theoretical and experimental evidence that when fairness concerns are mild, channel efficiency is lower under incomplete information. In a similar dyadic channel, Katok and Pavlov (2013) experimentally show that inequality aversion, next to incomplete information, are the main reasons for channel inefficiency. Ho et al. (2014) extend the model to a setting with multiple retailers, and study the impact of distributional versus peer-induced fairness. They find that, similar to Ho and Su (2009), peer-induced fairness is more salient than distributional fairness. More recently, Cui and Mallucci (2016) show that in a more complex pricing game that involves prior investments in developing demand, concerns for fairness are strong and significantly affect channel pricing decisions. We look instead at the case of multiple retailers who are serviced from the same pool of inventory, and explore what is considered a fair allocation after local demands are known. We estimate the prevalence of various ideals, and show that the supply chain context may affect fairness perceptions.

While the topic of capacity allocation is well-studied in the analytical supply chain literature (see, e.g., Cachon & Lariviere, 1999a, 1999b; Hall & Liu, 2010), behavioral issues in such contexts only recently started being explored. When several retailers compete for limited capacity, a broad class of allocation mechanisms incentivize retailers to order more than needed to secure a higher allocation. However, recent experimental evidence suggests that strategic ordering (i.e., order inflation) may not be as severe as the standard theory (Nash equilibrium) predicts (Chen et al., 2012; Chen & Zhao, 2015). To explain the observed ordering behavior, Chen et al. (2012) propose a model of bounded rationality, based on the quantal response equilibrium, while Cui and Zhang (2018) propose a cognitive hierarchy model where decision makers engage in different levels of strategic thinking. These papers consider proportional allocation of scarce capacity based on received orders. Pekgün et al. (2019) consider instead an allocation rule that is based on past forecast accuracy, and find that this policy significantly reduces forecast inflation. While prior work focuses on the impact of a given allocation policy on retailers' strategic ordering, we ask subjects to freely propose an inventory allocation, always based on realized demands (and not orders). Hence, we abstract from the issue of strategic ordering, and explore instead fairness perceptions in such an allocation context.

3 | THEORY

Consider two retailers that trade a common product and are replenished from a single warehouse. Total inventory in the warehouse is set before the selling season, under demand uncertainty. During the selling season and after retail demands are known, inventory is allocated to the two retailers.[3]

3.1 | Standard economic incentives

We first consider retailers' economic incentives. We denote by Q total inventory and by q_i the quantity retailer i receives. Let d_i be the local demand of retailer i, p_i be the market price, and c_i the cost for each unit allocated to retailer i ($i = 1, 2$). Retailer i's profit is

$$\pi_i(d_i, q_i) = p_i \min[d_i, q_i] - c_i q_i = \pi_i^0 - c_i^u (d_i - q_i)^+ - c_i^o (q_i - d_i)^+, \tag{1}$$

where $\pi_i^0 = (p_i - c_i)d_i$ is the maximum potential profit, $c_i^u = (p_i - c_i)$ denotes the per unit cost of understocking, and $c_i^o = c_i$ is the per unit cost of overstocking. The allocated quantity that maximizes $\pi_i(d_i, q_i)$ is simply $q_i = d_i$. In other words, retailer i enjoys maximum profit when s/he receives inventory quantity that exactly matches her/his demand. For every unit above this quantity, her/his profit decreases by c_i^o, and for every unit below this quantity her/his profit decreases by c_i^u.

[3] While in practice there may be some remaining demand uncertainty when inventory allocation takes place, in line with prior behavioral research, we assume for simplicity that local demands are known (see, e.g., Cui & Zhang, 2018).

3.2 | Behavioral model with fairness

Next to people's desire for income, we assume that individuals are also motivated by a desire for fairness. Following Cappelen et al. (2007), the utility of retailer i is modeled as

$$V_i(\mathbf{q}; \mathbf{d}) = \gamma\, \pi_i(q_i, d_i) - \beta_i \frac{[\pi_i(q_i, d_i) - m_i(\mathbf{d})]^2}{2\, \pi_i^0(d_i)}, \tag{2}$$

where $m_i(\mathbf{d})$ represents the equitable payoff for a fair-minded firm i, given $\mathbf{d}$, which denotes the vector of demand. The utility function of retailer i has two components. The first component is associated to (and increasing in) i's income; the second accounts for the retailer's fairness considerations. It represents the marginal disutility of deviating from her/his fairness ideal, which is quadratically increasing in the difference between retailer i's profit and the profit s/he considers fair, $m_i(\mathbf{d})$ (as in Bolton and Ockenfels (2000)), divided by twice retailer i's maximum potential profit, $\pi_i^0(d_i)$.[4] The parameters $\gamma > 0$ and $\beta_i \geq 0$ represent the relative importance retailer i places on these two components.[5] Given an interior solution, the profit that maximizes retailer i's utility satisfies

$$\pi_i^* = m_i(\mathbf{d}) + \theta_i \pi_i^0(d_i), \tag{3}$$

where $\theta_i = \frac{\gamma}{\beta_i}$. The optimal profit for retailer i depends on the fairness ideal and on the maximum potential profit via the parameter θ_i, known as "selfishness coefficient." The latter term in Equation (3) is referred to as retailer i's "selfishness premium," which is the amount of profit exceeding the ideally-fair profit that the retailer is willing to earn (see Conte & Moffatt, 2014). If $\beta_i \to \infty$, retailer i suffers enormously from even a small deviation from the ideally-fair profit, so that $\theta_i \to 0$ and π_i^* tends to coincide with i's ideally-fair profit $m_i(\mathbf{d})$. Differently, if i has no concern for fairness so that $\beta_i \to 0$, then $\theta_i \to \infty$ and i tends to collect as much as s/he can. For every fairness ideal and pair of demand realizations (d_i, d_j), there is an inventory allocation (q_i, q_j) that corresponds to the equitable payoff for firm i, that is, $m_i(\mathbf{d})$. In the next section, we explore fairness ideals in this setting.

3.3 | Fairness ideals in inventory allocation

Motivated by (a) prior literature about fairness ideals, and (b) common allocation rules studied in the context of inventory allocation, we define possible fairness ideals in our setting. According to the fairness ideal of strict egalitarianism, that is, the social norm of strict equality (Cappelen et al., 2007), retailers should enjoy the same profit. However, in our setting,

[4] Cappelen et al. (2007) use in the denominator the total profit to be split between participants that effectively represents the maximum amount a participant may get, which is $\pi_i^0(d_i)$ in our setting.

[5] Consider that profit and fairness are measured in two different units, and that γ can be interpreted as an exchange rate which converts profit into units of fairness.

a retailer's maximum profit depends on her/his demand and profit margin. Hence, in the setting of inventory allocation to retailers that have different demand realizations and possibly different profit margins, an inventory split that equates retailers' profits may not exist. We therefore turn our attention to the ideal of "max–min" fairness, a commonly used notion of fairness in resource allocation settings (Bertsimas et al., 2011). Intuitively, "max–min" fairness maximizes the minimum profit that both players achieve. For example, in case of shortage it would prioritize the retailer with the lowest demand and profit margin, reducing the difference between retailers' profits without wasting inventory. The fair payoff suggested by this ideal is

$$m_i^{MMF}(\mathbf{d}) = \pi_i\left(q_i^{MMF}\right)$$
$$\text{where} \quad q_i^{MMF} := \arg\max_{(q_i,q_j)} \min[(\pi_i(q_i,d_i),\pi_j(q_j,d_j)], \quad (4)$$

where $q_i + q_j = Q$ in an integrated supply chain, while $q_i + q_j \leq Q$ and $q_i \leq d_i$, $q_j \leq d_j$ in a disintegrated supply chain. In other words, in the former case total inventory is split between retailers, even when total retail demand is smaller than total inventory, while in the latter case there may be leftover inventory at the warehouse (retailers do not receive more than their demand).

Next, we look at how inventory is allocated based on rules commonly employed in practice and studied in the literature (Cachon & Lariviere, 1999b; Spiliotopoulou et al., 2019), and what notion of allocation fairness they may imply. In an integrated system, these allocation rules are applied when there is either inventory shortage or surplus. In a disintegrated supply chain, these are relevant only for the case of supply shortage. In case of sufficient supply, each retailer can simply receive an inventory quantity that equals her/his demand (profit maximizing quantity). Under both settings, all allocation rules that we consider ensure that there is no wastage, that is, there are no unsold units when total demand is equal to or higher than inventory, and there is no unsatisfied demand when total demand is lower than inventory (Spiliotopoulou et al., 2019). However, they prioritize retailers in different ways in case of shortage or surplus, and therefore may appeal to different fairness ideals that retailers have.

We start with the rule that is perhaps the most intuitive and widely applied in practice, the proportional allocation (Cachon & Lariviere, 1999b; Cui & Zhang, 2018). It ensures that all retailers enjoy the *same fill rate*, as inventory is allocated to retailers in proportion to their demands. The equitable payoff when a decision maker considers as fair that retailers enjoy the same service level, defined as demand fill rate, is

$$m_i^{PA}(\mathbf{d}) = \pi_i\left(q_i^{PA}\right) \quad \text{where} \quad q_i^{PA} = \frac{d_i}{d_i + d_j}Q. \quad (5)$$

Another allocation rule, common in the literature, is the linear (Cachon & Lariviere, 1999b, 1999c). Under the linear rule, any shortage (or extra inventory in an integrated system) is divided equally among the retailers if this is feasible (i.e., it does not result in a negative allocated quantity). It ensures an *equal split of demand–inventory mismatch*. The equitable payoff when an equal split of mismatch is desired is

$$m_i^{LA}(\mathbf{d}) = \pi_i^0 - c_i^u\frac{(D-Q)^+}{2} - c_i^o\frac{(Q-D)^+}{2}, \quad (6)$$

where D denotes total demand, that is, $D = d_i + d_j$.

Last, we consider the fairness ideal that the uniform allocation suggests. Under the uniform allocation rule (Cachon & Lariviere, 1999b; Liu, 2012), both retailers simply get equal quantities, as long as this allocation does not exceed (falls below) their demand when there is shortage (surplus), to avoid wastage of units. In the special cases where both retail demands are above (below) half of the inventory in case of shortage (surplus) the uniform rule simply prescribes an *equal split of inventory*.[6] In these cases, the implied equitable payoff is

$$m_i^{UA}(\mathbf{d}) = p_i \min\left[d_i, \frac{Q}{2}\right] - c_i\frac{Q}{2}. \quad (7)$$

Each fairness ideal defined in this section suggests a different equitable payoff, corresponding to a different inventory allocation for a pair of retail demand realizations. We will proceed to explore the prevalence of these fairness ideals in the context of inventory allocation under two supply chain settings: an integrated distribution system where total inventory is split at the retail level (retailers assume both the underage and overage costs), and a disintegrated system where available inventory may be rationed among the retailers due to supply shortage (retailers only experience underage costs).

4 | EXPERIMENTAL DESIGN AND PROCEDURES

Two retailers are serviced from a single warehouse with given inventory (exogenous) that is allocated between them once local demands are known (retail demands are randomly drawn from a distribution). Participants take on the role of a retailer and upon observing both retail demands propose an allocation of the available inventory. One of the two proposals is selected at random and implemented (i.e., determines the final outcome). Subjects only observe the implemented proposal. While in practice allocation decisions would be made by the supplier or the warehouse manager, in our experiment participants take on the role of a retailer and also make allocation decisions, to ensure that decision makers have a stake in the outcome. This is in line with the goal of the article to elicit fairness ideals of retailers that are part of a distribution system, which in turn can inform the design of alloca-

[6] For a complete characterization of the uniform allocation under all possible cases of demand realization, the reader is referred to Spiliotopoulou et al. (2019).

TABLE 1 Experimental design: main treatments

	Profit margin	
	Same	**Different**
	($p = 2, c = 1$)	**($p_H = 4, p_L = 2, c = 1$)**
Integrated SC	20 subjects	28 subjects
Disintegrated SC	20 subjects	16 subjects

tion policies. Our experimental setup is similar in design to the dictator game, which is popular in the experimental economics literature to study fairness (Cooper & Kagel, 2016) and elicit fairness ideals (Cappelen et al., 2007).

We conducted two sets of controlled laboratory experiments. In the first set of experiments, we capture the dynamics of an integrated supply chain (SC) where total inventory costs are assigned at the retail level. Demand realizations may result in inventory shortage (total demand is larger than total inventory) or surplus (total demand is lower than total inventory) and total inventory has to be split between the two retailers. Hence, retailers may face either underage or overage costs. In the second set of experiments, we look at a disintegrated SC where inventory is rationed among retailers when supply is insufficient to satisfy total demand. Total demand is at least as large as total inventory, since allocation is not relevant when supply exceeds demand in a disintegrated system (then each retailer can simply receive inventory quantity to satisfy its local demand). Retailers may only face shortage (underage costs) and no retailer receives (involuntarily) more than their demand.[7]

To distinguish whether allocation decisions are driven by how profits between individuals compare (e.g., consistent with the max–min fairness ideal) or only by inventory considerations (e.g., ideals implied by common inventory allocation rules), under both settings we vary whether the two retailers have the same profit margin (i.e., $p = 2$ and $c = 1$) or different profit margins (i.e., $p_H = 4$ for the high margin retailer, $p_L = 2$ for the low margin retailer). In all cases, players have complete information on everyone's profit margin. Table 1 summarizes the main treatments of the study. In addition to the main treatments presented here, we ran two additional treatments to test the robustness of our main results. We present the rationale and results of these in Section 5.3.

We used a between-subjects design to assign subjects to treatments. In the first set of experiments, we conducted either two or three experimental sessions per treatment. Total inventory was 200 units and demand for each retailer was randomly drawn from a discrete uniform distribution with support [50, 150]. Each session consisted of 32 rounds (except for session 1 with 22 rounds) with the first two rounds being trial rounds.[8] At the beginning of each round, participants were randomly and anonymously matched to form pairs of retailers. Players were informed that rounds are independent and that they would not be matched with the same participant in consecutive rounds. To avoid end-of-treatment effects, participants were not informed how many rounds they would play in total. In the second set of experiments, we conducted one experimental session per treatment, following the same experimental protocol as in the first set. Total inventory was 100 units and demand at each retail location was drawn from a discrete uniform distribution with support [50, 100].

At the beginning of each session, each subject received a detailed instruction sheet and asked any clarification questions they may have had to the experimenter (same person in all sessions). At the end of each session, participants completed a postgame survey that elicited information on their objective when proposing a split of the total inventory, the factors that were considered for their proposal, and what they believe a fair outcome was. It also included control questions, checking for the subjects' understanding of the experimental setting.

All experiments were conducted in the laboratories of two European universities and participants were enrolled in undergraduate economics and business programs. The use of students in laboratory experiments is common, and existing evidence suggests that student decision strategies are similar to those of professionals in operations tasks (Lonati et al., 2018). Furthermore, the decision task in our context is quite simple (i.e., does not require sophisticated calculations), giving us confidence that students' behavior is not expected to be qualitatively different than that of practitioners with more context experience.

In the first set of experiments, participants were granted research credits for their participation (students are required to gather a certain amount of research credits during their studies). On top, to have an incentive-compatible compensation scheme, five participants were selected at random and received a gift voucher of value proportional to the profit they generated during all (except for trial) rounds of the experiment (i.e., lottery payment approach as, for example, in De Vericourt et al. (2013) and Eckerd et al. (2013)). Participants were informed about this before the session started, and were specifically instructed that by making good decisions they could earn up to 50 Euros. In the rest of the experiments, participants received a show-up fee of 5 Euros and additional compensation based on their performance (i.e., experimental profit generated). The average subject compensation was 13 Euros in total. The experiment was programmed in z-Tree (Fischbacher, 2007). The detailed instructions and screenshots of the experiment are provided in online Appendix A and B, respectively.

5 | EXPERIMENTAL RESULTS

5.1 | Are allocations "fair"?

We first provide descriptive statistics of subjects' proposed allocations, focusing on whether players' choices are in line with fairness considerations in general, what we call "fair"

[7] If a player's proposal is selected s/he receives q_i, but if not, s/he receives $\min[d_i, Q - q_j]$. Hence, no player is *forced* to purchase more inventory than s/he needs.

[8] In session 1, one of the two sessions of integrated SC–same profit margin treatment, the 10 subjects played only 22 rounds because of lab time limitations.

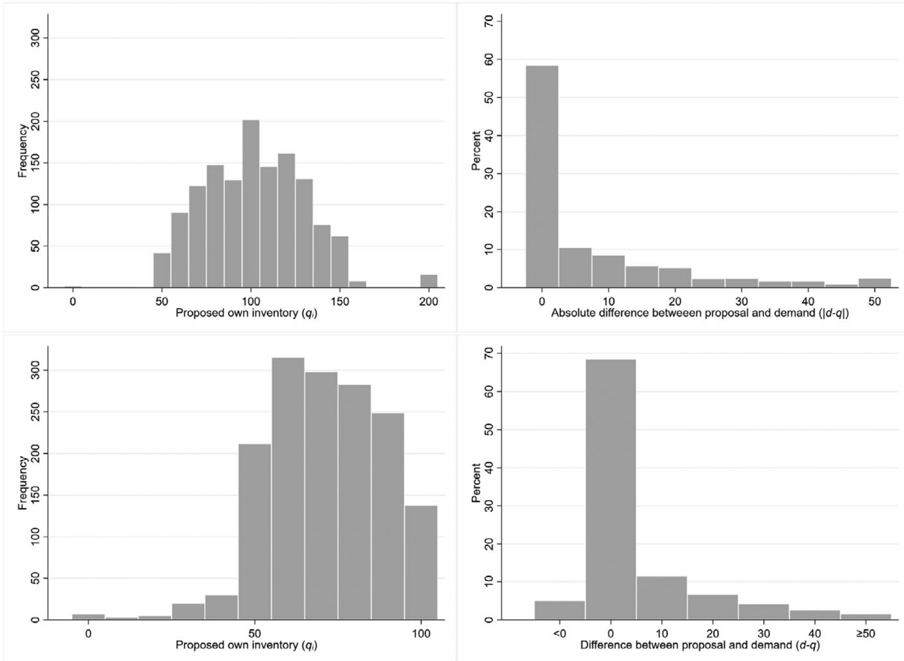

FIGURE 1 Distribution of proposed *own* inventory (left) and the proposed (absolute) difference between own inventory and own demand (right), for the first (top panels) and second set of experiments separately (bottom panels)

allocations. Figure 1 plots for each set of experiments the distribution of players' decisions, that is, the histogram (frequency) of proposed *own* inventory allocation, and the (absolute) difference between proposed own inventory and demand (percentages). In the first set of experiments (top panel), we observe (left part) that participants more often propose for themselves an inventory quantity that is closer to 100 units, which is the average inventory, even if the underlying demand distribution is uniform between 50 and 150 units. We also observe (right part) that the proposed own inventory is not equal to own demand in around 40% of the cases, suggesting that participants often incorporate fairness in their proposed allocations. Looking at each participant separately, less than one-third always allocates to themselves inventory equal to their demand (the full distribution is presented in Appendix C, Figure C.1, left panel). The postgame survey provides some evidence of the hypothesized underlying mechanism of fairness. Twenty-two of 48 participants reported that they considered (at least sometimes) the fairness of their proposed allocation. Subjects mentioned "I reduced my inventory level to help the other participant," "I considered the points of both stores," "I wanted to make it as fair as possible," and "I considered fairness but only if a middle ground would be profitable."

In the second set of experiments (Figure 1, bottom panels), we observe (left panel) that the distribution of participants' inventory proposals is skewed to the left, toward the average inventory that is now 50 units, even if the underlying demand distribution is uniform between 50 and 100 units. Under inventory scarcity, fairness considerations would motivate retailers to always allocate themselves inventory that is lower than their demand (i.e., $q_i < d_i$). In around 30% of total instances, a retailer's proposed own inventory allocation is lower than their demand (Figure 1, bottom-right panel). Around half of the participants make "fair" choices in at least some rounds (see distribution in Appendix C, Figure C.1, right panel). In the postgame survey, 14 of 36 participants reported that they also considered the (profit of the) other store when making an allocation proposal, mentioning as their objective to "propose a fair amount that would still give my store a little benefit in sales," "[…]to do it in a fair way - based on proportions," "let everyone get something," and "optimizing revenue for my own firm, but also ensuring that the other shop would not fall behind."

Next we focus on how often retailers' proposed allocations are in line with fairness considerations under each treatment. We differentiate between cases of shortage and cases of surplus. Under supply shortage, fairness would motivate a player to allocate own inventory that is *less* than their demand (i.e., $q_i < d_i$). Under supply surplus, fairness would imply that a player allocates own inventory that is *more* than their demand (i.e., $q_i > d_i$). Hence, we calculate how often a retailer's proposed *own* inventory allocation is lower (higher) than their demand under shortage (surplus), and when this is the case by how much, on average, across treatments.[9] Table 2 presents the results. In the integrated setting, while the frequency of "fair" allocations does not seem to differ under instances of shortage versus instances of surplus, the magnitude of the difference between own inventory and demand is larger in cases

[9] To exclude the alternative explanation of allocation errors, we also calculate how often subjects do the reverse, that is, propose own inventory allocation that is higher (lower) than their demand in case of shortage (surplus). That happens in only 5.3% (3.9%) of the cases.

TABLE 2 Summary statistics

		Shortage				**Surplus**			
		$q_i < d_i$	$d_i - q_i \mid q_i < d_i$			$q_i > d_i$	$q_i - d_i \mid q_i > d_i$		
Treatment	Obs	%	Med.	[Mean]	(St.D.)	%	Med.	[Mean]	(St.D.)
Integrated—Same	500	50.0%	16	[17.9]	(11.9)	50.0%	9	[13.8]	(14.6)
Integrated—Different	840	32.3%	14	[17.7]	(14.3)	32.0%	9	[15.9]	(19.5)
Disintegrated—Same	600	42.3%	15	[18.3]	(12.8)	(–)			
Disintegrated—Different	480	29.0%	17	[20.6]	(15.7)	(–)			

TABLE 3 Summary statistics: Low versus high profit margin retailers

	Shortage				**Surplus**			
	Low		**High**		**Low**		**High**	
	% $q_i < d_i$	Med.	% $q_i < d_i$	Med.	% $q_i > d_i$	Med.	% $q_i > d_i$	Med.
Integrated	27.9%	15.5	36.8%	14	32.7%	6	31.3%	14
Disintegrated	42.1%	19	15.8%	6.5	(–)		(–)	

of shortage within a treatment (Wilcoxon rank-sum (Mann–Whitney) tests, $p < 0.05$). Considering instances of shortage only, there are no significant differences between the two settings. Overall, we observe that when both retailers have the same profit margin, the frequency of "fair" allocations is higher compared to the treatments where the two retailers have different profit margins.

In treatments where retailers have different profit margins, we also distinguish between high profit margin (High) versus low profit margin (Low) retailers (Table 3). We do so to explore whether retailers with higher profit margins more often sacrifice own profits, as one would expect if players are trying to "equate" total profits. Under supply shortage and integrated setting, high margin retailers more often sacrifice own profit (i.e., set $q_i < q_i$), but in the disintegrated setting the reverse is true. While in practice retailers in a disintegrated setting would face cases of limited supply as well as cases of sufficient supply that do not affect their profits, in our experiment retailers continuously experience shortage, while the foregone profit for each unit of shortage is higher for high margin compared to low margin retailers. This may partially explain why high margin retailers appear to be less willing to sacrifice own profits in the disintegrated setting. In case of surplus (integrated setting), the frequency of allocations being higher than own demand is similar for high versus low margin retailers, but the magnitude of the difference is larger for the former group. High margin retailers seem to be willing to absorb more inventory surplus that is equally costly for both retailer types.

5.2 | What drives "fair" allocations?

We continue investigating the drivers of proposals that are different than demand and in line with fairness, under the different settings. We regress the difference between proposed own inventory and demand on the determinants of a retailer's profit and fairness ideals: retail demands and retailers' relative profit margin. We use panel data censored (tobit) regression analysis to control for possible correlation in decisions made by the same individual and account for the high number of observations being zero (Greene, 2003; Moffatt, 2015).[10] We estimate the following models:

$$q_{it} - d_{it} = \beta_0 + \beta_H \cdot H + \beta_i \cdot d_{it} + \beta_j \cdot d_{jt} + \beta_p \cdot (d_{it} \cdot p_i) + \beta_t \cdot t + \omega_i + \epsilon_{it} \text{ (if surplus)}, \tag{8}$$

$$d_{it} - q_{it} = \beta_0 + \beta_H \cdot H + \beta_i \cdot d_{it} + \beta_j \cdot d_{jt} + \beta_p \cdot (d_{it} \cdot p_i) + \beta_t \cdot t + \omega_i + \epsilon_{it} \text{ (if shortage)}, \tag{9}$$

where subscript i is the index for a participant and t denotes the round. The variable H indicates whether a retailer has high profit margin or not (binary variable), while d_{it} and d_{jt} are a retailer's own demand in a round and the demand of the player s/he is matched with, respectively. As total inventory is constant within a treatment, d_{it} and d_{jt} effectively also capture the magnitude of supply–demand mismatch in a round. We also include the interaction between a retailer's profit margin and demand, which practically represents the retailer's maximum possible revenue.[11] We use the round t to account for possible time effects within a treatment. The term ω_i is a retailer's individual specific error while ϵ_{it} is the independent error across decisions. Table 4 presents the results.

[10] A random effects tobit model is known to be consistent and provides unbiased estimates of the coefficients of interest.

[11] Results are similar if we include the term $H \cdot d_i$ instead.

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TABLE 4 Results of tobit regression analysis: drivers of "fair" allocations

	Estimate (Standard error)					
	Integrated				Disintegrated	
	Surplus		Shortage		shortage	
Variable	$q_i - d_i$		$d_i - q_i$		$d_i - q_i$	
Intercept	33.280***	(8.944)	−91.298***	(9.828)	−58.190***	(8.190)
H	−7.699	(10.244)	−10.510	(12.809)	−19.160	(16.558)
d_i	−0.298**	(0.010)	0.445***	(0.076)	0.432***	(0.099)
d_j	−0.207***	(0.054)	0.292***	(0.040)	0.313***	(0.042)
$p_i \cdot d_i$	0.026	(0.052)	−0.003	(0.041)	−0.097	(0.077)
t	−0.124	(0.126)	−0.211*	(0.099)	−0.221**	(0.070)
No. of obs	650		672		1080	
No. of uncensored obs	261		265		393	
No. of groups	48		48		36	
ρ	0.3707		0.6707		0.8404	
Log likelihood	−1363.32		−1289.14		−1807.98	

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

Across all regression models, being the retailer with the higher profit margin does not have a significant impact on the difference between own allocation and demand, that is, $q_i - d_i$ ($d_i - q_i$) under surplus (shortage). The ideal of max–min fairness would imply this difference to be positively correlated with a retailer's relative profit margin, as retailers should be willing to absorb more inventory–demand mismatch when their profit margin is higher than that of the other retailer in the supply chain, other things being equal. On the contrary, the coefficient of H in the models is negative, though statistically insignificant.

On the other hand, own demand and the demand of the other retailer have a significant impact on retailers' decisions across all treatments, with the impact of own demand being the larger.[12] In case of shortage (surplus), as retail demands increase (decrease), total inventory–demand mismatch increases, and hence retailers assume more underage (overage) units. Under an integrated system, "fair" proposals appear to be more responsive to retail demands under shortage compared to surplus (i.e., larger estimated coefficients, though not different), with the estimates in case of shortage being similar to the estimates under shortage in a disintegrated system. Last, retailer's maximum potential revenue from the round does not have a significant impact on decisions. That suggests that the relationship between retail demands and "fair" proposals is not moderated by a retailer's profit margin. We also observe that the effect of the round is negative in all scenarios and (marginally) significant under the cases of shortage.[13]

In summary, retailers' "fair" allocations depend on realized demands at both locations, but not on their relative profit margin or maximum potential profit. In other words, allocation policies that appeal to retailers' fairness ideals should be responsive to retail demands (i.e., individually responsive as defined in Cachon and Lariviere (1999b)) and based on retail demands rather than on profit or profit margin comparisons.

5.3 | Robustness of results

We further explore whether our results are robust to two experimental design modifications: (a) when players are preselected to decide on the allocation and (b) when they have a decision support tool (DST) available that facilitates profit comparisons.

5.3.1 | Player pre-selection

Similar to simple distribution experiments, in our setting there are two roles: a "decider" who determines the inventory allocation and a "receiver" who gets paid according to the allocation determined by the decider. There are two ways in which such experiments are usually implemented: using role uncertainty, that is, soliciting responses from both subjects and randomly determining which role's actions will be implemented, or assigning subjects to specific roles before decisions are made (Iriberri & Rey-Biel, 2011).[14] While in our main experiments we opted for the first option for

[12] We also tested for a quadratic relationship but it was not significant in any of the three models.

[13] This may suggest that decision makers become less fair over time, especially under cases of shortage. In our postgame survey, we find limited evidence that subjects change their strategy in the course of the game and intentionally become less "fair." In particular, 6 of 84 subjects mentioned that they only considered fairness in the beginning of the game.

[14] A third option would be role reversal, where subjects play in both roles and both decisions are rewarded, but this option suffers from endowment effects.

TABLE 5 Summary statistics: Version B

		Shortage				Surplus			
		$q_i < d_i$	$d_i - q_i \mid q_i < d_i$			$q_i > d_i$	$q_i - d_i \mid q_i > d_i$		
Treatment	**Obs**	**%**	**Med.**	**[Mean]**	**(St.D.)**	**%**	**Med.**	**[Mean]**	**(St.D.)**
Version B - Same	240	17.1%	16	[20.1]	(17.23)	18.3%	14	[15.3]	(14.3)
Version B - Different	240	10.1%	14	[17.7]	(14.3)	17.3%	9	[15.9]	(19.5)

reasons of efficiency,[15] we also implemented the latter option for comparison. Under an integrated setting, we ran two treatments (same and different profit margins) where at the beginning of each round one of the two players was first selected at random to propose a split, and then this split was implemented. We refer to this design as Version B. We recruited 32 participants in total, split equally between the treatments.[16] Table 5 presents the results.

We observe that under both treatments, the frequency that a proposed allocation is in line with fairness considerations is significantly lower compared to the main treatments (Integrated – Same and Integrated – Different, Table 3), both when participants face shortage and when they face surplus. One possible explanation why participants more often show selfishness when they are pre-selected to propose a split, in line with the theory of self-concept maintenance (Mazar et al., 2008), is that subjects can justify better (to themselves) behaving unfairly when they were first randomly selected to decide on the allocation (i.e., they feel "entitled" to do so).

The magnitude of the difference between own inventory and demand is, however, not lower when proposers are preselected, under all cases. As before, to explore the drivers of "fair" allocations, we regress the difference between proposed own inventory and demand on profit margin and retail demands. We find that the effect of high profit margin is again negative and not significant in the case of surplus ($\beta_H = -4.522$, $p = 0.766$) and marginally significant in the case of shortage ($\beta_H = -29.062$, $p = 0.082$). The effect of own retail demand is negative in case of surplus ($\beta_i = -0.442$, $p = 0.022$) and positive in case of shortage ($\beta_i = 0.407$, $p = 0.031$), in line with fairness considerations, but that of the other player's demand is not significant ($p > 0.05$). We present the full results in Appendix D. In short, subjects appear to be more selfish when pre-selected, while the "fairness" of their allocation decisions seem to be dependent on their own rather than the other player's demand.

5.3.2 | Decision support tool

To exclude that subjects base their decisions on realized demands rather than on profit comparisons because the latter is more difficult to calculate, we design a treatment where players have a DST at their disposal that calculates both retailers' profits for a given allocation.[17] We recruited 16 participants and ran one session in the context of limited supply (disintegrated setting) where participants had different profit margins. Participants could try multiple allocations before making their final decision.

Around 18% of proposed own allocations are lower than own demand (median 9, mean 14.5, st. dev. 19.4), while the retailers with the lower profit margin propose more often $q_i < d_i$ (26%) than the retailers with the higher margin (10%). To test the effect of a DST on proposed allocations, we estimate Equation (9) using all data from a disintegrated setting and including an indicator variable of whether a DST was available or not (model 1). We also include the interaction between a retailer's relative profit margin (high PM) and the presence of a DST (model 2). Table 6 presents the results.

The introduction of a DST does not have a significant impact on $(d_i - q_i)$ (model 1). Furthermore, the coefficient of the interaction term between a retailer's relative profit margin (H) and the DST is not significant, while the indicator variable for profit margin remains negative and insignificant (model 2). Being the high margin retailer does not have a significant impact on the difference between proposed own inventory and own demand, even when we facilitate profit comparisons by making a DST available. If fair allocations were driven by the desire to decrease retailer profit differences, $(d_i - q_i)$ would be higher for high margin retailers who would be more willing to "sacrifice" part of their own profit to increase the minimum profit that both retailers earn.[18] Overall, we find no evidence that proposed allocations are driven by total profit comparisons as suggested by the ideal of max–min fairness. Last, we observe that the effect of round t on $(d_i - q_i)$ appears to be larger compared to Table 4 (though 95% CIs overlap). Including in model (2) the interaction of DST and round (i.e., $t \cdot DST$), the estimate suggests that subjects became more "selfish" over time when a DST was available ($\beta = -0.743$, $p = 0.000$).

5.4 | The prevalence of fairness ideals

We continue to explore individual heterogeneity in fairness considerations by estimating the prevalence of different ideals

[15] This choice allows us to observe the (incentivized) choices of both players in a round and obtain more information from a given sample size.

[16] We ran two sessions of eight participants per treatment.

[17] We thank an anonymous reviewer for this suggestion.

[18] Please note that with our experimental parameters, the high margin retailer's maximum potential profit is at least as large as that of the low margin retailer, for any pair of demand realizations.

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TABLE 6 Impact of decision support tool (tobit regression analysis)

	Estimate (Standard error)			
	(1)		(2)	
Variable	$d_i - q_i$		$d_i - q_i$	
Intercept	−60.641***	(7.856)	−58.190***	(8.190)
H	−20.360	(13.512)	−31.330	(12.250)
d_i	0.431***	(0.089)	0.431***	(0.089)
d_j	0.272***	(0.043)	0.271***	(0.043)
$p_i \cdot d_i$	−0.019	(0.059)	−0.019	(0.059)
t	−0.403***	(0.071)	−0.403***	(0.071)
DST	−0.723	(9.655)	−9.783	(12.250)
$H \cdot DST$	(–)		−15.537	(15.460)
No. of obs	1560		1560	
No. of uncensored obs	480		480	
No. of groups	52		52	
ρ	0.7751		0.7705	
Log likelihood	−2329.18		−2328.48	

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

under each setting. Since we did not find evidence that profit margins affect allocation decisions in line with the max–min fairness ideal, we focus on the fairness ideals implied by the three common allocation rules.

5.4.1 | Empirical model

Following Cappelen et al. (2007), we assume that each individual is of one of three types. Each type, $k \in \{PA, LA, UA\}$, is characterized by one of the fairness ideals defined above. The individual-specific, idiosyncratic parameter θ_i determines the degree of "selfishness" of each retailer. We build on the econometric modeling approach proposed by Conte and Moffatt (2014) and Moffatt (2015, Chap. 15), referred to as the "Modified Random Behavioral Model."

The random behavioral model is the econometric approach that entails estimating the behavioral equation (3), under the assumption that the observed profit resulting from retailer i's choice is equal to the optimal profit plus a continuous error term. Its modified version, introduced by Conte and Moffatt (2014), allows i's behavior to correspond exactly to her/his fairness ideal in some of the choices in order to accommodate some peculiarities of the data, namely, a mass at the exact value of the fairness ideal. The model estimated from our data enables retailers of different types to be exactly at their fairness ideal each with a different probability, and adds an additional error term, known as "tremble," to control for the possibility that subjects lose concentration and choose at random (see Moffatt et al., 2002).

We opt for this econometric approach with respect to the "Random Utility" one used by Cappelen et al. (2007) because in our data set 59.18% of choices correspond to the maximum potential profit, which is a clear indication of upper censoring. As extensively discussed in Conte and Moffatt (2014), in similar cases, the random behavioral model is preferable and more parsimonious than the random utility model.

The model is defined as follows. The latent proposed profit of subject i, with fairness ideal k, in round t is[19]

$$\tilde{\pi}_{it} = m_i^k(\mathbf{d_t}) + \theta_{it}\pi_{it}^0 + \upsilon_{it},$$

$$\upsilon_{it} \sim N(0, \sigma^2) t = 1, \ldots, T \quad i = 1, \ldots, n \quad k \in \{\text{PA, LA, UA}\},$$

$$\theta_i \sim \text{Lognormal}(\mu, \eta^2),$$

$$\theta_{it} = \begin{cases} \theta_i & \text{with probability } (1 - p^k), \\ 0 \text{ and } \upsilon_{it} = 0 & \text{with probability } p^k. \end{cases} \tag{10}$$

The idea underlying this model is that retailer i's profit implied by the proposed allocation—the argument that maximizes the deterministic utility function in Equation (2)—corresponds to her/his optimal profit, $m_i^k(\mathbf{d_t}) + \theta_{it}\pi_{it}^0$ (see Equation 3), plus a two-sided random error, υ_{it}. Retailer i is characterized by a selfishness coefficient θ_i, drawn from a lognormal distribution, with μ and η being the mean and the standard deviation of the underlying normal distribution, respectively. However, with probability p^k, i behaves exactly according to the fairness ideal with no two-sided error (both θ_i and υ_{it} equal 0); instead, with probability $(1 - p^k)$, s/he requests the selfishness premium $\theta_i\pi_{it}^0$. Unlike Conte and Moffatt (2014), such a probability is allowed to be type-specific, because the data show that the proportion of observations which are exactly at the fairness ideal depends on the

[19] We note that T differs across subjects. For the sake of simplicity, we did not make this explicit in the formulas that follow, but their generalization is straightforward.

type.[20] The error υ_{it}, which is assumed to follow a normal distribution, accounts for between-round variation in behavior, and also accommodates the observations where a subject proposes an allocation that implies a profit lower than that of all possible fairness ideals.

As aforementioned, there is a great proportion of observations which correspond to the maximum potential profit. We deal with this feature of the data via the following censoring rule which links the latent profit $\tilde{\pi}_{it}$ in Equation (10) to the profit which is actually observed, π_{it}:

$$\pi_{it} = \begin{cases} \tilde{\pi}_{it} & \text{if } \tilde{\pi}_{it} < \pi^0_{it}, \\ \pi^0_{it} & \text{if } \tilde{\pi}_{it} \geq \pi^0_{it}. \end{cases} \tag{11}$$

We also define the related censoring indicator $d_{it} = \{1, \text{if } \pi_{it} = \pi^0_{it}; 0, \text{if } d_{it} = 0\}$ and, finally, another indicator pointing at the observations which correspond to the various fairness ideals, $h^k_{it} = \{1, \text{if } \tilde{\pi}_{it} = m^k_{it}(\mathbf{d_t}); 0, \text{otherwise}\}$.

The individual likelihood function l^k_i, which is the sum of the individual likelihood contributions conditional on being of type k, with $k \in \{PA, LA, UA\}$, weighted with the mixing proportions of types λ^k, that is, the proportions of the population who are of each type,[21] $0 \leq \lambda^{PA}, \lambda^{LA}, \lambda^{UA} \leq 1$ and $\lambda^{UA} = 1 - \lambda^{PA} - \lambda^{LA}$, is

$$\begin{aligned} L_i(\Omega) &= \sum_k \lambda^k l^k_i \\ &= \sum_k \lambda^k \int_0^\infty \prod_t \Big\{ (1-\omega) \Big[(1-d_{it}) \Big[p^k h^k_{it} + (1-p^k) \\ &\quad \times \frac{1}{\sigma} \phi \left(\frac{\pi_{it} - m^k_{it} - \theta \pi^0_{it}}{\sigma} \right) \Big] \\ &\quad + d_{it} \left[p^k h^k_{it} + (1-p^k) \Phi \left(\frac{m^k_{it} + \theta \pi_{it} - \pi^0_{it}}{\sigma} \right) \right] \Big] + \frac{\omega}{200} \Big\} \\ &\quad \times f(\theta; \mu, \eta) d\theta. \end{aligned} \tag{12}$$

Here, $\Omega = \{\lambda^{PA}, \lambda^{LA}, \lambda^{UA}, \mu, \eta, p^{PA}, p^{LA}, p^{UA}, \sigma, \omega\}$ is the vector of parameters to be estimated, where $\phi(\cdot)$ and $\Phi(\cdot)$ are the standard normal pdf and cdf, respectively, and $f(\theta; \mu, \eta)$ is the lognormal pdf evaluated at θ; the parameter ω represents the tremble probability.[22]

5.4.2 | Estimation results

The sum of the logarithm of the individual likelihood functions defined in the previous section, $L_i(\Omega)$, is maximized with respect to the parameters in Ω, for each of the three samples: integrated surplus, integrated shortage, and disintegrated shortage, using all experimental data.[23] To estimate the model, we use the method of Maximum Simulated Likelihood.[24] Integration in Equation (12) is performed by a set of Halton sequences (100 draws per subject).[25] Estimation results are displayed in Table 7.

Our model is a mixture of fairness considerations in the allocations proposed. Estimating it for each sample enables us to discover the prevalence of the fairness ideals in the population under each setting. We observe that under instances of surplus in an integrated setting, the vast majority of the subjects, 72%, proposes inventory allocations in line with the fairness ideal of equal split of inventory–demand mismatch (linear allocation). Around 27% of the subjects are motivated by the fairness ideal of equal inventories (uniform allocation), while the remainder 2% seems to make inventory allocation decisions influenced by fill rate considerations (proportional allocation), though the mixing proportion of this category is not statistically significant. Under instances of shortage, in the same integrated setting, only 16% of the population seems to be driven by the ideal of equal split of inventory–demand mismatch, while the majority, 62%, makes inventory allocation decisions in line with the ideal of equal fill rates. Around 22% of the subjects are motivated by the fairness ideal of equal split of inventories.

The mean of the "selfishness coefficient" θ_i is estimated to be 1.8725 (st. err. 1.2094) under surplus and 0.7822 (st. err. 0.3699) under shortage.[26] This implies that, on average, subjects require a rather large selfishness premium for themselves, and this is even higher when they experience surplus and share excess inventory. Consistent with our model assumption, we can reject the joint null hypothesis that p^{PA}, p^{LA}, and p^{UA} are all equal (Wald test$\chi^2(3) = 44.05$, p-value $= 0.0000$ under integrated surplus and $=27.23$, p-value $=$ 0.0000 under integrated shortage).[27] Finally, the standard deviation of the error term is estimated to be 18.30 under surplus and 15.35 under shortage, and the tremble probability about 4% and 6%, respectively.

Under the disintegrated setting where subjects face only supply shortage, the vast majority, 71%, proposes inventory

[20] Actually, different proportions of observations at the different fairness ideals may well depend on the relative popularity of the corresponding types in the population. Since we cannot know this beforehand, we let p^k vary with type, and, after estimation, we test the hypothesis that such proportions are all equal.

[21] The mixing proportion of a type represents the probability of drawing a subject of that type when sampling at random from the population.

[22] It is worth noting that, unlike in Conte and Moffatt (2014), in this version of the random behavioral model a retailer of a certain type can be at his ideally-fair profit not only with probability p^k, but also as a result of the combination of a positive selfishness premium and the error term, which may annul each other. This is rather unlikely, but this modification of the model is needed to accommodate another peculiarity of the data. In fact, in some cases, which are prominent for type UA, the ideally-fair profit coincides with the maximum profit i can achieve. As a consequence, it is unclear whether the subject wants to be perfectly fair or whether her/his desire to express a positive selfishness premium is hidden behind censoring. In those cases, the parameter p^k lets the likelihood discriminate between these two behaviors.

[23] Using only data from the main treatments, the estimates are very similar both qualitatively and quantitatively.

[24] Estimates are obtained in STATA version 14.2. Some of the parameters and their standard errors are calculated via the delta method. The program is available from the authors on request.

[25] Details can be found in Train (2009).

[26] We note that θ_i is assumed to follow a lognormal distribution, and its mean is obtained by the parameters of the underlying normal distribution as $\exp(\mu + \eta^2/2)$.

[27] Unlike the assumption in Conte and Moffatt (2014).

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TABLE 7 Maximum simulated likelihood estimates of fairness ideals under each setting

	Integrated						Disintegrated		
	Surplus			Shortage			Shortage		
Ω	**Estimate**	**Standard error**	***p*-value**	**Estimate**	**Standard error**	***p*-value**	**Estimate**	**Standard error**	***p*-value**
λ^{PA} (equal fill rates)	0.0193	0.0174	0.269	0.6151	0.1035	0.000	0.7123	0.0818	0.000
λ^{LA} (equal split of mismatch)	0.7152	0.0739	0.000	0.1636	0.0954	0.086	0.0390	0.0271	0.150
λ^{UA} (equal split of inventory)	0.2655	0.0722	0.000	0.2212	0.0641	0.000	0.2487	0.0796	0.002
μ - mean of log(θ)	−0.9203	0.2360	0.000	−1.4370	0.1886	0.000	−0.5678	0.0681	0.000
η - standard deviation of log(θ)	1.7593	0.2950	0.000	1.5436	0.2548	0.000	1.4323	0.2164	0.000
p^{PA}	0.4262	0.1225	0.000	0.0000	0.0000	0.876	0.2331	0.0733	0.001
p^{LA}	0.0184	0.0072	0.011	0.0813	0.0395	0.040	0.0002	0.0015	0.897
p^{UA}	0.1826	0.0386	0.000	0.2335	0.0432	0.000	0.3498	0.0670	0.000
σ - st.dev.	18.2990	2.0243	0.006	15.3498	1.0807	0.000	17.3934	0.8371	0.000
ω	0.0359	0.0130	0.006	0.0595	0.0105	0.000	0.0092	0.0028	0.001
Number of subjects	80			80			52		
Number of observations	892			904			1560		
Log-likelihood	−1365.9410			−1658.0819			−2039.5121		

allocations in line with the fairness ideal of equal fill rates, similar to what we observed under supply shortage within an integrated system. Similarly to an integrated setting, around 25% of the subjects are motivated by the fairness ideal of equal split of inventories. Regarding the selfishness parameter, this is estimated to be 1.5808 (std. err. 0.5695), indicating that the relative weight that subjects place on own profit is larger, on average, than the case of supply scarcity in an integrated system. However, we note that the distributions of the selfishness parameter across samples are nondegenerate, and show high heterogeneity. In this case also, we reject the joint null hypothesis that p^{PA}, p^{LA}, and p^{UA} are all equal (Wald test$\chi^2(3) = 56.14$, p-value=0.0000). The standard deviation of the error term is estimated to be 17.39 (similar to the other models), while the tremble probability is only 1%.

Last, to evaluate the performance of our models in assigning subjects to types, we calculate the posterior probabilities of each subject in the sample of being of each fairness ideal type (as in Conte & Moffatt, 2014). A good mixture model is expected to assign subjects to types with high posterior probabilities. In our mixture, only one, two, and zero subjects cannot be assigned to a type with a high degree of certainty by the estimated models in the integrated-surplus, integrated-shortage, and disintegrated-shortage cases, respectively. The method and results are presented in Appendix E.

To summarize, our results suggest that the type of supply–demand mismatch within the same distribution context may raise different fairness considerations in allocating inventory. Furthermore, proportional allocation (or the ideal of equal fill rates) seems to be in line with fairness perceptions of the majority of the subjects in situations of supply shortage, independent of whether they are part of a system where they may also face surplus. On the other hand, equal split of excess inventory (linear allocation) seems to be the fair choice for the majority of the subjects in situations of surplus.

6 | FOLLOW-UP EXPERIMENT: IMPLICATIONS FOR SUPPLY CHAIN MANAGEMENT

We explored the pluralism of fairness perceptions when supply is different than demand and estimated the prevalence of retailers' fairness ideals in different settings. However, an allocation rule being the preferred fair choice of a retailer does not necessarily mean that another allocation rule is rejected as unfair. This may be especially true if the resulting allocation is often not far from a retailer's perception of a fair deal. When retailers experience an allocation policy, which allocations are perceived as fair (and which ones as unfair) and under what conditions? To answer these questions, we design a new set of experiments where retailers experience and rate the fairness of inventory allocations determined either by an external party (i.e., a warehouse manager) or an allocation rule.

6.1 | Experimental design

As previously, two retailers receive inventory from a warehouse once local demands are known. We construct two settings: one where allocation is based on a predetermined rule, and another where allocation is determined by a warehouse manager. Under the first setting, one of the four allocation rules (proportional, linear, uniform, and max–min) is selected at random at the beginning of each round and implemented. Retailers do not have additional information about the rule the allocation is based on. Under the second setting, a player who takes on the role of the warehouse manager chooses an inventory allocation that is then implemented. The warehouse manager is presented with four allocation options, in randomized order, based on the same rules. Under both settings, in

TABLE 8 Allocations considered fair by the retailers: predetermined allocation rule

	Shortage			Surplus		
Allocation rule	**Obs**	**Fair**	**Fair $\vert q_i \neq d_i$**	**Obs**	**Fair**	**Fair $\vert q_i \neq d_i$**
Proportional	88	65.9%	65.5%	78	65.4%	65.4%
Linear	82	64.6%	64.2%	62	71.0%	69.0%
Uniform	82	45.1%	35.7%	70	45.7%	35.6%
Max–min	72	25.0%	8.5%	66	34.8%	14.0%

every round retailers observe the inventory allocation and rate whether it is fair or not.

Since our previous analysis suggests that fairness ideals vary between types of supply–demand mismatch, we consider an integrated setting where retailers face in some rounds shortage and in other rounds surplus. To clearly elicit fairness perceptions with regard to the max–min rule, we consider retailers with different profit margins. We implemented the same parameterization as in our main study (i.e., inventory is 200 units, retail demand follows the discrete uniform distribution with support [50; 150], $p_H = 4$ and $p_L = 2$).

We implemented a between-subjects design. For the allocation rule treatment, we conducted two sessions and recruited 20 subjects in total (20 retailers), and for the warehouse manager treatment we conducted three sessions and recruited 30 subjects (10 warehouse managers and 20 retailers). Subjects played the game for 30 rounds. The roles of the players (i.e., high/low margin retailer or a warehouse manager) remained constant throughout the game. At the beginning of each round, participants were randomly and anonymously matched to form supply chains. The experiment was programmed in otree (Chen et al., 2016) and conducted online using the same subject pool. Participants that took on the role of a retailer received a show-up fee of 5 Euros and additional compensation based on their experimental store profit. The average total retailer compensation was 9.20 Euros. Participants who took on the role of a warehouse manager received a fixed payment of 10 Euros. How store profits were calculated and player compensation (being dependent on store performance or not) was common knowledge. The detailed instructions and screenshots of the experiment are provided in online Appendices F and G.

6.2 | Experimental results

We first look at how often retailers perceived an allocation as fair under each of the four allocation rules. Table 8 presents the results when allocation was based on a predetermined rule. Because issues of fairness arise when a retailer does not receive exactly the inventory quantity that s/he needs, we also calculate the frequency an allocation is regarded as fair given that the inventory received does *not* equal retailer's demand. Under both cases of shortage and surplus, allocations based on proportional and linear rules are more often considered fair compared to uniform or max–min allocations. While linear allocations are considered fair slightly more often under surplus than shortage, overall we observe no significant differences between proportional and linear allocations. One possible explanation is that, since the resulting allocations are often very similar, subjects do not consider unfair the allocations which are in the vicinity of their fairness ideal. This is to say that a certain fairness ideal does not necessarily make other allocations unfair. Last, the large difference between "Fair" and "Fair$|q_i \neq d_i|$" for max–min allocation indicates that mainly the low margin retailers, who received inventory equal to their demand under this rule and their profit was maximized, considered max–min allocations as fair.

Table 9 reports similar results for the case where the allocation is chosen by a human warehouse manager. Proportional and linear allocations are considered by retailers more often fair compared to uniform and max–min allocations. It is interesting to notice that when there is shortage, proportional allocation is the allocation most often considered fair (in 72.2% of the cases) but it was chosen by the warehouse managers only in 11.4% of the cases. This may be because warehouse managers received no feedback in the experiment about retailers' fairness ratings. The uniform allocation followed by the linear one were most often chosen by the warehouse managers in case of shortage, while the linear allocation was the most common choice under surplus.

To formally test whether the allocation rules have a significant effect on the probability of an inventory allocation to be considered fair by retailers, we estimate random effects logit models for panel data, where the outcome variable is whether the inventory allocation in a round was judged as fair (binary) (Table 10). In the base model (model 1), we include as control the round t and whether the allocation was based on a rule or it was the choice of a human decision maker, the warehouse manager (binary variable "*wm*"). We also control for the difference between a retailer's allocation and her/his demand, that is, $|q_{it} - d_{it}|$ (model 2) as it could intuitively affect the attractiveness of an allocation.[28]

Compared to the max–min profit rule (the base case), the other three allocation rules significantly increase the probability that the resulting inventory split is considered fair under shortage, with the impact of the proportional rule being the largest (though not statistically different from the linear and the uniform). Under surplus, the linear and the proportional

[28] Controlling instead for the difference between a retailer's realized profit and maximum potential profit from the round, that is, $(\pi_{it}^0 - \pi_{it})$, yields similar results.

TABLE 9 Allocations chosen by the warehouse manager and considered fair by the retailers

	Shortage			Surplus		
Allocation rule	**Chosen**	**Fair**	**Fair $\vert q_i \neq d_i$**	**Chosen**	**Fair**	**Fair $\vert q_i \neq d_i$**
Proportional	11.4%	72.2%	72.2%	19.6%	66.1%	65.6%
Linear	34.8%	66.4%	66.4%	34.2%	63.9%	63.6%
Uniform	44.3%	56.4%	51.6%	13.9%	34.1%	19.4%
Max–min	9.5%	40.0%	10.0%	20.9%	45.5%	18.2%

TABLE 10 Impact of allocation rules on perceived allocation fairness

	Estimate (Standard error)							
	Shortage				Surplus			
Variable	**(1)**		**(2)**		**(1)**		**(2)**	
Intercept	−1.037**	(0.352)	−0.664*	(0.369)	−0.506	(0.336)	0.154	(0.372)
PA	2.086***	(0.328)	2.158***	(0.337)	1.035***	(0.286)	1.153***	(0.310)
LA	1.826***	(0.305)	1.903***	(0.311)	1.514***	(0.284)	1.705***	(0.311)
UA	1.061***	(0.288)	1.092***	(0.294)	0.053	(0.287)	0.095	(0.308)
wm	0.411	(0.342)	0.480	(0.354)	−0.133	(0.317)	−0.092	(0.350)
t	−0.015	(0.010)	−0.017	(0.011)	−0.001	(0.011)	−0.002	(0.012)
$\vert q_i - d_i\vert$	(–)		−0.024***	(0.006)	(–)		−0.044***	(0.008)
No. of obs	640		640		556		640	
No. of groups	40		40		40		40	
ρ	0.1971		0.2103		0.1594		0.1960	
Log likelihood	−393.48		−385.71		−352.34		−330.66	

*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$.

rules increase the probability that the allocation is considered fair with respect to the max–min profit rule, with the estimated effect of the linear rule being the largest (but again not statistically different from the proportional). Whether the allocation was the result of a predetermined rule or the choice of a warehouse manager does not have a significant impact on retailers' fairness evaluation. The decision round does not have a significant impact either. However, as expected, larger differences between a retailer's demand and allocated quantity decrease the probability that the allocation is considered fair by the retailer.

Our results show that retailers, who experience inventory allocations determined by either a rule or a warehouse manager, overall rate more often as fair allocations that are dependent/responsive to individual demands (corresponding to proportional and linear rules), while their fairness ratings are also driven by the difference between the quantity received and the quantity that equals their demand (i.e., maximizes their profit).

7 | CONCLUSION AND DISCUSSION

We study fairness in distribution systems where multiple retailers, with possibly different profit margins and demand, are serviced from a common pool of inventory. We consider two settings. One is the case of retailers being part of an integrated system and responsible for total inventory (i.e., all inventory is allocated at the retail level and retailers may assume either inventory shortage or surplus costs), as often encountered in practice in cooperative inventory pooling settings (Fiestras-Janeiro et al., 2011; Özen et al., 2008). We also consider the case of a disintegrated system where, when there is scarce supply, inventory is rationed across retailers who are serviced from a common supplier (as in, for example, Cachon and Lariviere (1999b)) and retailers assume inventory shortage costs.

First, in line with the behavior that has been extensively documented in ultimatum and dictator games in the experimental economics literature (e.g., Charness & Rabin, 2002; Fehr & Schmidt, 2006), we show that many people are motivated by fairness considerations. Subjects, taking on the role of retailers in the same supply chain, allocate for themselves inventory quantity that is not exactly equal to their demand in more than one-third of the instances, across both settings. They are willing to sacrifice own profits in order to avoid large deviations from what they consider a fair inventory allocation.

We continue by exploring what fairness ideals may prevail in such contexts to derive implications for "fair" allocation policies. Besides the commonly used notion of max–min fairness in resource allocation settings (Bertsimas et al., 2011), we study the prevalence of fairness ideals implied by inventory allocation rules that are common in practice and studied in prior literature (see, e.g., Cachon & Lariviere, 1999b, 1999c). First, we find that in both settings differences in profit margins of retailers do not significantly affect the proposed inventory allocations, contrary to what the max–min fairness ideal would suggest. Instead, participants seem to base their proposals for inventory split on realized demands rather than on total profit comparisons, even when these are facilitated by a DST. Second, in our experiment situations of shortage and situations of surplus give rise to different fairness ideals. In case of surplus, the most prevalent ideal is that of equal split of inventory–demand mismatch, corresponding to the linear inventory allocation rule. We estimate that around three-fourths of the subjects make allocation decisions that are consistent with this fairness ideal, while roughly one-fourth makes allocation decisions that are consistent with the ideal of equal inventory split. In cases of inventory scarcity, instead, the most prevalent fairness ideal is that of equal fill rates, implied by the most widely applied rule for inventory allocation, the proportional rule. We estimate that 62% of the subjects make allocation decisions that are consistent with the ideal of equal fill rates in the context of an integrated system and 72% in the context of a disintegrated system where subjects face only instances of supply shortage. Again, roughly one-fourth makes allocation decisions that are consistent with the ideal of equal inventory split. While there is significant individual heterogeneity, subjects do not seem to disregard their own income in their decisions.

Our results suggest that inventory allocation rules, to appeal to the majority of customers' fairness perceptions, shall be responsive to retail demands (i.e., retailers with higher demand shall get a higher allocation). Results from a follow-up experiment where subjects are asked to evaluate inventory splits based on established allocation rules or decided by a warehouse manager (i.e., a human decision maker) support this finding. Retailers are more likely to perceive as fair allocations that are based on the proportional and the linear rules compared to uniform and max–min allocation policies. Hence, allocation rules that have been shown to contain order inflation either in a disintegrated (Cachon & Lariviere, 1999b) or an integrated setting (Spiliotopoulou et al., 2019) because they are not individually responsive, such as the uniform or lexicographic rules, may be not considered as fair policies by retailers in a distribution system.

Furthermore, our behavioral model estimates suggest that in times of supply shortages, reducing customer orders by the same percentage, a policy commonly adopted in practice, may appeal to the most prevalent fairness ideal of equal fill rates if orders are a good proxy for actual demand. In an integrated distribution system, allocating common inventory in proportion to retailers' needs in times of scarcity, while equally sharing the excess inventory in situations of surplus, seems to be the most desirable deal for retailers. However, retailers are likely to accept as fair allocations based on either the proportional or the linear rules, under both types of supply–demand mismatch (they similarly often rate such allocations to be fair).

Our research sheds light on what is considered a fair inventory allocation in a distribution system and gives directions on how to incorporate fairness in allocation policies. Hence, we contribute to the growing supply chain management literature regarding fairness in contracting (Ho et al., 2014; Katok & Pavlov, 2013; Wu & Niederhoff, 2014), by considering a setting where what is a fair outcome is not straightforward. Our results suggest that the type of supply–demand mismatch drives differences in fairness ideals and not the supply chain setting (integrated vs. disintegrated). However, our results also imply that retailers may consider fair multiple outcomes or allocations that are not far from their perception of a fair deal. Last, our results suggest that perceptions of fairness in supply chain interactions may be based on decision rules rather than profitability outcomes per se, complementing the notion of procedural fairness (Bolton et al., 2005), through the choice of the allocation rule, and the principles of distributive justice (Cappelen et al., 2007), showing that retailers' demand size but not their profit margins (both factors outside players' control) may affect what is considered a fair allocation.

Better understanding of fairness in inventory allocation can, in turn, inform decisions of suppliers that ration inventory across multiple customers in periods of shortage, or decision makers in cooperative distribution systems that allocate inventory among multiple retailers who are serviced from the same pool of inventory. Knowing what fairness ideals are prevalent in distribution settings, one can choose or design resource allocation mechanisms that, for example, find a better trade-off on the efficiency versus fairness spectrum, or are more attractive to firms when participation in a pooling coalition is voluntary. Our findings may also provide alternative explanations and new insights regarding the success (or stability) of horizontal collaborations with inventory sharing. Perceived fairness in distribution systems has been shown to affect partners' satisfaction and ultimately supply chain performance (Cui & Mallucci, 2016; Griffith et al., 2006).

In terms of experimental implementation, we find that random "pre-selection" of participants to propose and implement an allocation results in subjects incorporating less often fairness in their proposals. Previous studies have shown that average ultimatum splits are higher for the proposer when participants paid to take on the role of a proposer (Güth & Tietz, 1990) or performed better in a quiz (Hoffman et al., 1994). Our results suggest that random pre-selection may be enough for people to feel entitled to be selfish. This is consistent with the finding of Cui and Mallucci (2016) that the structure of the game may create entitlement (first-mover advantage in a sequential game). However, in our game players do not make sequential decisions and have a 50–50 chance to decide the split in each round under both experimental procedures.

We recognize the following limitations of our study. Although the use of students in laboratory experiments is common, the generalizability of our findings limits to the extent that student behavior is representative of managers' behavior in this particular context. At the same time, while controlled laboratory experiments provide high internal validity, they abstract from many real-life features that could influence behavior in practice. In this study, in particular, in order to estimate retailers' fairness perceptions and get a precise measurement of a hard-to-measure construct, the design of the experiment reduced mundane realism by asking retailers themselves to propose an inventory split. To strengthen the validity of our findings, we conduct a follow-up experiment where retailers are asked to evaluate the fairness of allocations determined exogenously. At the same time, our study provides several interesting opportunities for further research. One fruitful direction is to estimate the impact of perceived fairness regarding inventory allocation on retailers' decisions to continue or terminate a business relationship. Another step would be to explore additional factors that may affect what a fair inventory split is, by allowing retailers to influence total available inventory, either by investing (at a cost) in the common pool of inventory or by sharing their demand forecasts.

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ORCID

Eirini Spiliotopoulou https://orcid.org/0000-0002-0478-8195

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AUTHOR BIOGRAPHIES

Eirini Spiliotopoulou is an Assistant Professor of Supply Chain Management at Tilburg School of Economics and Management. Her research lies within supply chain coordination and information sharing, studying both economic incentives and behavioral factors. Her work has been published in leading international academic journals. Before joining Tilburg University, she worked at VU University in Amsterdam, the Netherlands, and EBS Business School in Wiesbaden, Germany. She received her MEng and PhD in logistics and supply chain management from MIT-Zaragoza International Logistics Program in Spain.

Anna Conte is an Associate Professor of Economics in the Department of Statistical Sciences, Sapienza University of Rome. She holds a PhD in econometrics and empirical economics from Tor Vergata University of Rome. Her research specialism is the econometric modelling of data from economic experiments. She also has research interests in Monte Carlo simulations, discrete choice models, and structural modeling. She has published her work in top journals in econometrics (like the *Journal of Econometrics*) and economics (like *Economica* and the *Journal of Risk and Uncertainty*). She previously worked in the Strategic Interaction Group at the Max Planck Institute of Economics and at the University of Westminster, UK.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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