Strategic Inventory and Supply Chain Behavior

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Abstract:

Based on a serial supply chain model with 2-periods and price-sensitive demand, we present the first experimental test of the effect of strategic inventories on supply chain performance. In theory, if holding costs are sufficiently low, the buyer builds up a strategic inventory (even if no operational reasons for stock-holding exist) to limit the supplier's market power, and to increase the own profit share. As it turns out, this enhances the overall supply chain performance. The supplier anticipates the effect of the strategic inventory and differentiates prices to capture a part of the increased supply chain profits. Our results show that the positive effects of strategic inventories are even more pronounced than theoretically predicted, because strategic inventories empower buyers to reduce payoff inequalities and suppliers reduce inequalities as long as their payoff remains above a certain threshold. Overall, strategic inventories have a double positive effect, a strategic and a behavioral, both reducing the average wholesale prices and damping the double marginalization effect and the latter leading to more equitable payoffs.

Keywords:

supply chain coordination, vertical contracts, fair behavior, inter-temporal supplier pricing

1. Introduction

Non-cooperative play in supply chains is known to be a major source of inefficiencies, because the incentives of the supply chain parties are typically not aligned, leading to individually optimal decisions that harm the overall supply chain performance. A recently emerging strand of research on the effects of non-cooperative optimization in supply chains is concerned with the effects of multi-period interaction. One of the surprising findings in this literature is that the strategic interaction across periods can be advantageous to the overall supply chain performance. More specifically, Anand, Anupindi, and Bassok (2008) show that inefficiency is reduced in a multi-period supply chain, because buyers build up a *strategic inventory* solely to offset the strategic advantage that a monopoly supplier otherwise has. Although the strategic inventory is created by the buyer to increase his own payoff share, it also benefits the supplier, because the overall performance of the supply chain is enhanced, by partly reducing the supplier's monopoly power and, thus, the degree of double marginalization.[1]

Since most supply chain interactions in reality take place in multi-period settings, the efficiency enhancement due to strategic inventories may be good news for the economy. For the phenomenon to be effective, however, the players are required to demonstrate a high degree of strategic sophistication in their behavior. Given the extensive literature on behavioral biases in single period supply chain interactions, it is not self-evident that theoretically predicted efficiency gains are behaviorally sustained in this type of multi-period interplay. Especially the frequently observed failure to identify profit maximizing order quantities or wholesale prices (Schweitzer and Cachon, 2000; Katok and Wu, 2009) and the tendency to consider fairness consequences of supply chain decisions (Cui et al., 2007; Loch and Wu, 2008; Pavlov and Katok, 2011) may behaviorally interfere with the theoretical predictions.

[1] Intuitively, strategic inventory in a multi-period supply chain game reduces the monopoly power of a supplier, because the inventory acts as a "virtual competitor" and leads to a reduced equilibrium wholesale price, which in turn allows the buyer to reduce the market price and serve a larger number of consumers.

In this study, we present a laboratory experiment that allows us to test for the empirical relevance of the concept of strategic inventories. We find overwhelmingly clear evidence for the behavioral relevance of strategic inventories and the efficiency enhancing effect that they have on the overall supply chain performance. Using a control treatment, in which strategic inventories are out of equilibrium, we demonstrate that our subjects (management and economics undergraduates) use the inventories in a strategically sophisticated manner and not just because they are given the opportunity to do so.

The strong evidence that we find for the behavioral relevance of strategic inventories is surprising, given the interplay between strategic behavior and strategic uncertainty, which is inherent in this multi-period interaction. In equilibrium, both the supplier's wholesale price and the buyer's order quantity in the first period are greater than in the case without strategic inventories (Anand et al., 2008). Increasing both the price and the quantity, not only requires a clear understanding of the strategic situation on the side of both parties, but also a mutual trust in each others' strategic sophistication. Hence, for the equilibrium to be behaviorally relevant, both suppliers and buyers must trust that the other party deliberates with a high degree of strategic sophistication and plays the equilibrium strategy. A substantial part of the literature on behavior in supply chains, however, shows that players may fail to optimize or fail to believe that their counterparts optimize (e.g. Schweitzer and Cachon, 2000; Katok and Wu, 2009; Özer et al., 2011; Croson et al., 2012). In contrast to the persistent out of equilibrium behavior found in that literature, we observe a high degree of behavioral stability very close to the equilibrium. Hence, our results indicate that strategic inventories are a robust phenomenon of supply chain interaction, as long as holding costs are not prohibitively high.

While we observe that the strategic inventories are adopted whenever predicted by theory, they are significantly smaller than in equilibrium. By choosing smaller inventories the buyer can establish a more equitable distribution of the profits. We define *buyer empowerment* to be the possibility of reducing the inequity of the payoff distribution via inventory choices. We show that the suppliers facing empowered buyers are willing to reduce average wholesale prices as long as they can keep their profits above a certain threshold. This behavioral effect leads to a supply chain performance that is even more enhanced than in the game theoretic prediction of Anand et al. (2008).

2. Literature Review

Our paper contributes to the literature on the effects of strategic decision making in inter-temporal supply chains, by examining the behavioral validity and reliability of the game theoretic predictions. Recently, a rather large body of literature on the behavioral aspects of the newsvendor's problem and the bull-whip effect has emerged, demonstrating the contribution of experimental research to a better understanding of strategic interaction in supply chains. The main findings of this literature can be summarized in several behavioral phenomena, each interfering in a different manner with the game theoretic predictions. In the following, we briefly summarize the observed behavioral phenomena and relate them to our study.

A frequently observed behavioral phenomenon is a concern for fairness and reciprocity. The notion that fairness generally plays an important role in human interaction has been common knowledge in social sciences for centuries. But, an elaborate research of the concept and its consequences for economic performance only started after a series of early economic experiments had documented that concerns for fairness persistently affect economic behavior (e.g. Güth et al., 1982; Forsythe et al. 1994; Berg and Dickhaut, 1995; Bolton, 1991; Fehr et al. 1998). The research has culminated in a number of theoretical papers modeling different facets of fairness, including a preference for equity in income distribution (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000), a preference for reciprocal responses to acts of intentional kindness and spite (Rabin, 1993; Dufwenberg and Kirchsteiger, 2004), a preference for increasing mutual benefits, or any combination of the preferences listed above (Charness and Rabin, 2002; Falk and Fischbacher, 2006). Fairness concerns in ultimatum type games (as we depict in our model setup) have the following effects: First, the proposer's fairness concerns might lead to offers that are more equitable than offers in the absence of fairness concerns. Second, the receiver may reject offers that are perceived as unfair. The proposer may try to reduce this rejection risk by offering a larger share of profits.

While it is rather difficult to clearly separate the different facets of fairness preferences in supply chain settings,[2] it is important to note that in most cases all facets of the concern for fairness will have the same type of impact on behavior. Such concerns generally drive the wholesale prices down leading to a decrease in the payoff differences in the supply chain (Cui et al., 2007; Pavlov and Katok, 2011). As Loch and Wu (2008) show in their experimental study of supply chains with wholesale price contracts under deterministic, price sensitive demand, the profits in all treatments are more evenly distributed than predicted by standard theory, because the suppliers set lower wholesale prices than predicted. Additionally, if an inter-personal tie has been created between the supplier and the buyer, the buyer tends to increase sales boosting the overall efficiency gains. In another experimental study, Keser and Paleologo (2004) examine the behavior of supply chain members in a newsvendor setting under a wholesale price contract. They observe a tendency towards an equitable distribution

[2] A supply chain game in terms of an ultimatum game can be interpreted as follows. The supplier is the proposer who offers a contract (e.g., a wholesale price contract). The supplier affects the buyer's share of profits by the contract terms, e.g, setting a lower wholesale price results in a higher share of profits for the buyer. The buyer is the receiver who determines the sales quantity in a double marginalization context. The buyer may lower the supplier's profits by choosing suboptimal low sales quantities.

of profits. As the buyers tend to terminate games with high wholesale prices, suppliers seem to voluntarily choose lower wholesale prices that split the profits approximately equal.

While the above mentioned studies cannot distinguish between the two underlying behavioral effects that drive suppliers' behavior (i.e. suppliers' fairness concerns and/or perception of contract failure risk), Katok and Pavlov (2013) as well as Katok et al. (2012) perform experiments highlighting that suppliers' behavior is mainly driven by incomplete information about the risk of contract rejection (i.e. suppliers fear contract rejection, if the wholesale prices are set too high). In addition, they show that the buyers' behavior is mostly driven by their fairness concerns (i.e. if the suppliers do not suffer from a rejection because they have an outside option, then the buyers' tendency to reject offers is significantly lower).

Our paper contributes to this literature by studying the influence of other regarding preferences such as fairness concerns in the context of a 2-period supply chain interaction with strategic inventories.

3. The Model

Our experimental study is based on the theoretical model by Anand et al. (2008). They consider the interaction in a serial supply chain with a deterministic, price-sensitive demand in a 2-period game. The buyer (female pronouns) in the supply chain, has a downstream retail monopoly, but must rely on the supply chain supplier (male pronouns) as the only source for the retailed good (i.e. the supplier has an upstream monopoly). Anand et al. (2008) extend this classical setting introduced by Spengler (1950) by adding an additional period and allowing the buyer to build up inventory that she can use to serve part of her future demand.

At the beginning of each period ($t=1,2$), the supplier determines a wholesale price (w_t) and posts it to the buyer. The buyer then chooses her purchase quantity (Q_t) and the quantity of units that she supplies to an external market (q_t). The sales price (p_t) in the external market is determined by the linear inverse demand function $p_t(q_t)=a-b\cdot q_t$. If the quantity that the buyer has purchased in the first period is larger than the quantity sold in the first period (i.e. if $Q_1>q_1$), then she builds up inventory ($I=Q_1-q_1$) to be sold in the second period. The inventory reduces the second period purchase quantity that is required to optimize her profit ($q_2=Q_2-I$). To focus only on the strategic effects of building up inventory, we follow Anand et al. (2008) and deliberately leave out all other mechanisms (e.g. operational or supply and demand risks) that may motivate inventories.

The buyer faces holding cost h for each stored unit. At the end of period two, unsold units have a salvage value of zero. Both supplier and buyer have perfect information. The profit function of the supplier under zero production cost is

$$\begin{aligned}\pi_S(w_1,w_2)&=w_1\cdot Q_1+w_2\cdot Q_2\\&=w_1\cdot(q_1+I)+w_2\cdot(q_2-I),\end{aligned}\tag{1}$$

and the profit function of the buyer is given by

$$\begin{aligned}\pi_B(q_1,I,q_2)&=p_1(q_1)\cdot q_1-w_1\cdot Q_1-h\cdot I+p_2(q_2)\cdot q_2-w_2\cdot Q_2\\&=(a-b\cdot q_1)\cdot q_1-w_1\cdot(q_1+I)-h\cdot I+(a-b\cdot q_2)\cdot q_2-w_2\cdot(q_2-I).\end{aligned}\tag{2}$$

In an integrated supply chain, the wholesale prices only define the transfer payments between the supplier and the buyer and are, therefore, not relevant for optimizing the overall supply chain profit. Furthermore, since inventories are purely strategic and incur a positive cost, building up inventory is not rational when there is no conflict of interest between the two parties. Thus, in an integrated supply chain, we only need to choose the optimal sales quantities that maximize the joint profits

$$\begin{aligned}\pi_{SC}(q_1,q_2) &= p_1(q_1)\cdot q_1 + p_2(q_2)\cdot q_2 \\ &= (a-b\cdot q_1)\cdot q_1 + (a-b\cdot q_2)\cdot q_2.\end{aligned} \tag{3}$$

As Anand et al. (2008) demonstrate, the optimal quantities for the periods are independent of the number of periods and equal to $q_t = a/2b$ in every period. For a 2-period game, this results in a first-best total supply chain profit of $\pi_{SC} = a^2/2b$.

If the supply chain is not integrated, the supplier and the buyer independently choose their decision variables (w_t and q_t, I) to optimize their individual profits. As Anand et al. (2008) show, in equilibrium, strategic inventory is only built up, if the holding costs are not prohibitively high, i.e. $I > 0$ if $h < \frac{1}{4}\cdot a$. We call this case the *dynamic solution*, because the supplier has an incentive to choose dynamic prices, i.e. $w_1 > w_2$. However, if the holding costs are too high (i.e. if $h \geq \frac{1}{4}\cdot a$), the buyer no longer has an incentive to build up a strategic inventory. This leads to constant wholesale prices over both periods (i.e. $w_1 = w_2$) and to equilibria that resemble the standard solution of the one period setting. We call this case the *static solution*. The closed-form static and dynamic solutions can be derived using backward induction as shown by Anand et al. (2008) and are described below.

At the end of the second period the buyer chooses her selling quantity. The optimal response function to the supplier's wholesale price of the second period is

$$q_2(w_2) = \max\left\{I, \frac{a-w_2}{2b}\right\}. \tag{4}$$

The supplier anticipates this reaction by integrating the buyer's response function into his profit function and chooses a wholesale price

$$w_2(I) = \max\left\{0, \tfrac{a}{2} - b \cdot I\right\}. \tag{5}$$

The supplier's response function shows that by building up an inventory, the buyer can influence the equilibrium wholesale price. Anticipating the strategic effect of an inventory, the buyer chooses her optimal first period sales

$$q_1(w_1) = \max\left\{0, \tfrac{a-w_1}{2b}\right\} \tag{6}$$

and inventory

$$I(w_1) = \max\left\{0, \tfrac{a}{2b} - \tfrac{2}{3b} \cdot h - \tfrac{2}{3b} \cdot w_1\right\}. \tag{7}$$

Hence, the buyer only builds up inventory, if

$$w_1 + h < \tfrac{3}{4} \cdot a. \tag{8}$$

Since a and h are constant, the supplier's choice of the wholesale price determines whether or not the buyer build up strategic inventory. Anticipating this, the supplier chooses a wholesale price

$$w_1 = \max\left\{\tfrac{a}{2}, \tfrac{9a-2h}{17}\right\}. \tag{9}$$

Inserting the minimal wholesale price $w_1 = a/2$ into (8) directly shows that strategic inventory is only observed, if $h < \tfrac{1}{4} \cdot a$ holds.

Table 1 provides a summary of the first-best, the static, and the dynamic solutions of the game. Note that the total supply chain profit in the static solution corresponds to only 75% of the total supply chain profit in first-best solution. In the dynamic solution, the total supply chain profit depends on the holding cost, but it will not exceed about 79.8% of the first-best outcome, even if the holding cost are zero. The lower supply chain profits in the two non-cooperative settings is obviously due to the double marginalization effect that arises, because both supply chain members individually maximize their profits, by placing monopoly surcharges on their marginal costs.

Table 1: Comparison of Solutions

	first-best	static $h \geq 1/4 \cdot a$	dynamic $h < 1/4 \cdot a$		first-best	static $h \geq 1/4 \cdot a$	dynamic $h < 1/4 \cdot a$
wholesale prices $\{w_1, w_2\}$	-	$\left\{\frac{a}{2}, \frac{a}{2}\right\}$	$\left\{\frac{9a-2h}{17}, \frac{6a+10h}{17}\right\}$	market prices $\{p_1, p_2\}$	$\left\{\frac{a}{2}, \frac{a}{2}\right\}$	$\left\{\frac{3a}{4}, \frac{3a}{4}\right\}$	$\left\{\frac{13a-h}{17}, \frac{23a+10h}{34}\right\}$
order quantities $\{Q_1, Q_2\}$	$\left\{\frac{a}{2b}, \frac{a}{2b}\right\}$	$\left\{\frac{a}{4b}, \frac{a}{4b}\right\}$	$\left\{\frac{13a-18h}{34b}, \frac{3a+5h}{17b}\right\}$	profit supplier π_S	-	$\frac{a^2}{4b}$	$\frac{9a^2-4ah+8h^2}{34b}$
inventory I	0	0	$\frac{5\cdot(a-4h)}{34b}$	profit buyer π_B	-	$\frac{a^2}{8b}$	$\frac{155a^2-118ah+304h^2}{1156b}$
market quantities $\{q_1, q_2\}$	$\left\{\frac{a}{2b}, \frac{a}{2b}\right\}$	$\left\{\frac{a}{4b}, \frac{a}{4b}\right\}$	$\left\{\frac{4a+h}{17b}, \frac{11a-10h}{34b}\right\}$	profit supply chain π_{SC}	$\frac{a^2}{2b}$	$\frac{3a^2}{8b}$	$\frac{461a^2-254ah+576h^2}{1156b}$

If the holding costs are sufficiently low and strategic inventories are used (i.e. in the dynamic solution), then the first period's wholesale price is greater and the second period's wholesale price is smaller than in the static solution. The intuition is that the supplier sets a higher price in the first period to reduce the buyer's incentives to build up an inventory. In the second period, the wholesale price is lower than in the static solution, because the buyer only needs to satisfy her residual demand, given the inventory. Thus, the strategic inventory reduces the monopoly power of the supplier. Nevertheless, the comparison also shows that the supplier is always better off in the dynamic solution, because the reduced monopoly power leads to price differentiation across periods. These differentiated prices yield lower average wholesale prices which reduces the degree of double marginalization. The buyer is also better off with a strategic inventory, as long as the holding costs are not too high, i.e. as long as $h < \frac{21}{152} \cdot a$. Her profits in the dynamic solution are only less than those in the static solution, if $\frac{21}{152} \cdot a < h < \frac{1}{4} \cdot a$.

The overall performance of a non-integrated supply chain in the dynamic solution is superior to the performance in a static solution for sufficiently low holding costs ($h < \frac{55}{288} \cdot a$). For holding costs above this threshold, the benefits of the lower wholesale prices (i.e. the benefits from the reduction of the double marginalization) are offset by the increase in the total costs of the inventory. The greatest improvement in supply chain performance (about 6.34% more than in the static solution) can be achieved with strategic inventory, when the holding costs are zero. Nevertheless, even at zero holding costs, the first-best solution cannot be achieved, because the double marginalization effect is only diminished, but not fully eliminated. Furthermore, as Anand et al. (2008) show, no dynamic contract exists that can perfectly coordinate the supply chain and allow the supplier to extract all residual profits.

4. Behavioral Hypotheses and Experimental Design

4.1 Experimental Parameterization and Behavioral Hypotheses

Table 2 shows the theoretical predictions for our two experimental treatments. In both treatments, the inverse demand function is $p_t(q_t) = 152 - 2 \cdot q_t$. In the low cost treatment (LC), due to the relatively low inventory holding cost ($h = 4$), the game theoretic model predicts a dynamic solution, with falling wholesale prices, a strategic inventory, and higher payoffs both for the supplier and the buyer, when compared to the static solution without strategic inventory. The distribution of supply chain payoffs is asymmetric in equilibrium, with about two-thirds going to the supplier and one-third to the buyer. In the high cost treatment (HC), the relatively high holding cost ($h = 42$) prohibits the profitable adoption of a strategic inventory, so that the game theoretic model predicts a static solution with constant wholesale prices and order quantities. As in the other treatment, the distribution of supply chain payoffs is asymmetric in equilibrium, with about two-thirds going to the supplier and one-third to the buyer. Hence, while the treatments are very different concerning the strategic situation, they are very similar in the distribution of equilibrium payoffs. This similarity is important, because it guarantees that differences in the frequency of equilibrium play are not due to the ex-ante differences in the equilibrium payoff distributions.

Table 2: Theoretical Predictions

	low cost treatment (LC) $h=4$		high cost treatment (HC) $h=42$	
	period 1	period 2	period 1	period 2
w_t*	80	56	76	76
p_t	116	104	114	114
q_t	18	24	19	19
I*	10		0	
π_S	3,024 (66.55%)		2,888 (66.67%)	
π_B	1,520 (33.45%)		1,444 (33.33%)	
π_{SC}	4,544		4,332	

* decision variables in the experimental analysis

The game implements a variant of ultimatum bargaining (Güth et al. 1982), because the buyers can terminate the relation after receiving the supplier's offer in period 1. This results in a risk of contract failure for the supplier as in many other behavioral supply chain studies (Keser and Paleologo 2004, Katok et al. 2012, Katok and Pavlov 2013). The experimental literature of supply chains generally finds that the risk of contract failure can be alleviated by shifting payoffs from the proposer to the receiver. Hence, we conjecture that our suppliers in HC and LC may reduce their period 1 wholesale prices to reduce the risk of contract failure. In fact, the parameterization seems to make contract rejects more likely in HC than in LC, because in HC rejecting the contract is the only option buyers have to punish suppliers. Note that in period 2 suppliers have no risk of contract failure, because in our experimental design we only allow for buyers' payoff maximizing period 2 responses (i.e. we give them no rejection option in period 2, see section 4.2). Hence, we conjecture in line with Katok and Pavlov (2013) that suppliers – due to the absence of contract failure risk – will choose payoff maximizing period 2 prices. Finally, we conjecture that the buyers in both HC and LC choose payoff maximizing inventory levels, because as second movers in the game they face no risk of contract failure. We summarize these conjectures in the following behavioral hypothesis 1:

Behavioral Hypothesis 1 ("Contract failure risk"):

(1a) In HC and LC, the period 1 wholesale price is smaller than the equilibrium wholesale price.

(1b) In HC, the difference between observed and equilibrium period 1 wholesale prices is greater than in LC.

(1c) In HC and LC, the period 2 wholesale price is equal to the best response.

(1d) In HC and LC, the strategic inventories are equal to the best response levels.

The behavioral literature provides quite a bit of evidence on the effects of fairness in bilateral interactions. In both the LC and HC treatment, a supplier's concern for fairness leads to the choice of lower average wholesale prices. Such a decrease would dampen the effect of double marginalization and shift profits from the supplier to the buyer. Note, that shifting payoffs to the buyer generally leads to a more equal distribution of profits, since the buyer earns considerably less in both treatments.

Since we conjecture that lower first period wholesale prices may either be due to the risk of contract failure (as in hypothesis 1) or due to fairness concerns (as described in hypothesis 2 below), the question is whether we can identify differences in observations that support the one or the other hypothesis. We can differentiate between the two hypotheses by examining the difference between the wholesale prices in HC and LC. As stated in hypothesis 1b, if behavior is influenced by the risk of contract failure, we should observe lower period 1 prices in HC than in LC. We do not expect such a difference if behavior is guided by fairness concerns. In that case, we expect to observe period 1 and period 2 prices that decrease the payoff differences between suppliers and buyers to the same extent in both treatments.

The buyer's possibility of showing a concern for fairness is different in HC than in LC. In LC, a concern for fairness translates to lower levels of strategic inventory as long as the buyer's marginal loss is smaller than the supplier's marginal loss (see online appendix B). Going beyond this point would harm the buyer more than the supplier and, thus, increase payoff inequality. In contrast to the buyer in LC, we do not expect the buyer in HC to be able to reduce payoff inequality by reducing the strategic inventory, since she holds no inventory in equilibrium. The expected effects of fairness concerns on the interplay in the supply chains are summarized in hypotheses 2.

Hypothesis 2 ("Fairness Concerns"):

(2a) In HC and LC, the average wholesale price of both periods is smaller than the equilibrium wholesale price.

(2b) In HC and LC, the observed strategic inventory levels minimize the payoff difference between buyers and suppliers.

4.2 Experimental Procedure

The experiment was conducted at a German University using the software z-tree (Fischbacher, 2007). A total of 96 subjects, 24 suppliers and 24 buyers in each of the two treatments, participated in the experiment. At the outset of the experiment, each subject was randomly assigned either the role of a supplier or of a buyer. Subjects maintained their roles throughout the 15 decision rounds. Hence, a total of 360 games were played per treatment. The subjects were divided into matching groups of three suppliers and three buyers and randomly re-matched within their matching groups in every decision round to avoid reputation (i.e. repeated game) effects. As each matching group forms an independent observation, a total of 8 observations per treatment were used for the statistical analysis.

The instructions were handed out to the subjects upon arrival and were read aloud. Then, after a short individual re-reading time, the subjects had the possibility to ask questions that were answered privately. Communication between the subjects was prohibited. The subjects were then given a computerized comprehension quiz to ensure that they had fully understood the rules of the game. Subjects were paid the sum of their profits in all rounds in cash, immediately after the experiment.

The course of events in each decision round is displayed in Figure 1. First, the supplier determines the period 1 wholesale price (w_1). Next, the buyer decides whether to terminate the game or to continue. If the buyer terminates the game, the payoffs of both the buyer and the supplier are set to zero and the round ends immediately. If the buyer continues, she chooses the size of her strategic inventory (I) and the system automatically supplements the optimal sales quantity of period 1 (q_1). Providing the optimal quantity choices allows buyers to focus on their choice of the strategic inventories (I) that constitute the essential strategic element of the game. In period 2, the supplier sets his wholesale price (w_2) and the round ends with the automatic choice of the buyer's optimal period 2 sales quantity (q_2).

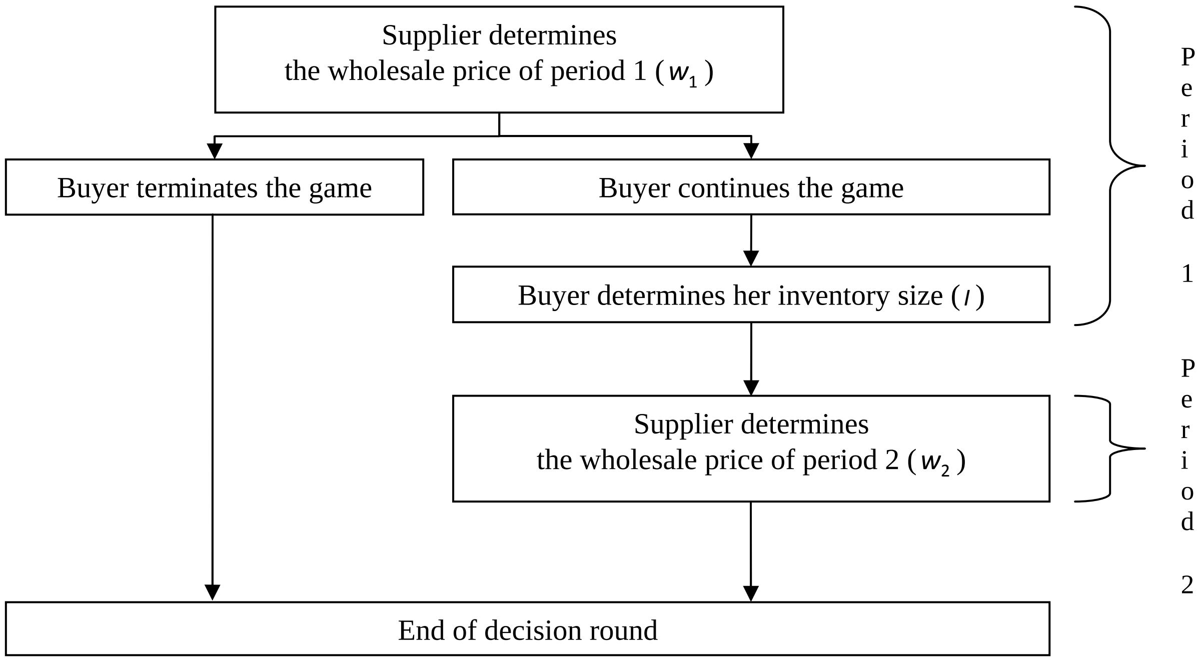

Figure 1: Sequence of Decisions

The suppliers choose any wholesale price in the interval between 0 and 152. At the lower price bound the supplier earns nothing from selling his units and at the upper price bound buyers have no incentive to purchase any goods from the supplier.

The buyers decide to build up an inventory in the range between 0 and 38 units. The optimal response function of the buyer in (7) shows that even if both the wholesale price of the first period and the inventory holding cost would be zero, quantities greater than 38 cannot be optimal. Hence, choosing values outside of the permitted intervals cannot be reasonable.

To further facilitate decision making, the subjects were provided with a profit calculator and a payoff table as decision support. The profit calculator displays the profits of both players for any combination of decision variables. The subjects could also use the payoff tables that displayed the profits for some integer value combinations of the decision variables. The subjects were informed that the tables do not contain payoff information for all possible values of the decision parameters and only serve as a guide, giving an overview of the payoff space. The instructions also point out that the onscreen profit calculator can be used to look up profits for any feasible combination of decision parameters. An English translation of the instructions for the treatment with low inventory holding cost, including the corresponding payoff table, is contained in online appendix A.

5. Results

Table 3 displays the theoretical predictions of the strategic inventory model next to the observed mean and median values of our experiment for both treatments. The values for the individual and supply chain profits are shown excluding and including the cases, in which the game was terminated and both players earned zero (these values are displayed in the brackets). Since decisions on the inventory size and the second period wholesale price are only made when the game is not terminated, only data from non-terminated games are contained in these aggregate values. In the low cost treatment (LC), 34 games of 360 were aborted, i.e. about 9%. The rate of termination in the high cost treatment (HC) was only about 4% (14 of 360 games were terminated), i.e. less than half the termination rate in LC.

Table 3: Theoretical Analysis vs. Experimental Results

	low cost treatment (LC)			high cost treatment (HC)		
	equilibrium	median	mean	equilibrium	median	Mean
period 1 wholesale price	80	70	70.11	76	76	73.91
inventory	10	10	8.98	0	0	1.37
period 2 wholesale price	56	56	58.58	76	76	71.34
profit supplier	3,024	2,888 (2,884)	2,870.40 (2,599.30)	2,888	2,887.75 (2,885.375)	2,848.13 (2,729.46)
profit buyer	1,520	1,759.25 (1,744.63)	1,803.60 (1,633.33)	1,444	1,444 (1,444)	1,533 (1,470.08)
profit supply chain	4,544	4,731.50 (4,686)	4,674 (4,232)	4,332	4,332 (4,332)	4,381 (4,199.54)

The observed mean and median values of the game parameter are extremely close to the equilibrium predictions for both treatments. In fact, the empirical medians and the theoretical predictions are identical except for the first period wholesale price and the corresponding profits in the LC treatment, in which the adoption of strategic inventories was observed to be almost perfectly in the range of values theoretically predicted. In the HC treatment, in which the holding cost is too high to allow for the adoption of a strategic inventory, we observe almost no inventories (the median of observed values is zero and the mean is just slightly greater than one). Furthermore, we observe a substantial deviation between the median first and second period wholesale prices – as predicted by the game theoretic model – in LC, but no difference between the two wholesale prices in HC. Overall, it seems that the strategic interaction that is incorporated in the game theoretic analysis of the strategic inventory game is an almost perfect predictor of observed behavior.

The only noteworthy deviation of the observed behavior from the game theoretic predictions is connected to a period 1 wholesale price in LC that is significantly lower than the equilibrium price. Below, we provide a detailed analysis of the data. The results are presented in four parts: the supplier's decision on the first period wholesale price, the buyer's decision on the strategic inventory size, the supplier's decision on the second period wholesale price, and finally the resulting individual and supply chain profits. The statistical analyses are based on the independent observations (i.e. every observation is the median of 45 games).

5.1 Supplier's Period 1 Wholesale Price

Figure 2 displays the development of the median period 1 wholesale prices over the 15 decision rounds for both treatments. In both treatments, the median period 1 price starts about 8 or 9 points below the theoretical benchmark. While the median in HC quickly moves up to reach the equilibrium prediction and stays there by round 4, the observed period 1 prices in LC tend to drop over time, moving significantly further away from equilibrium towards the end of the experiment.[3] Hence, we observe a clear difference between the behavior of the suppliers in HC and LC concerning the period 1 wholesale prices.

Since lower than predicted period 1 wholesale price in LC (lower than the dynamic equilibrium price and lower than the static outcome price, sign test, $p<0.001$ and $p=0.008$, two-tailed, correspondingly) only holds for LC, but not for HC, we cannot confirm hypothesis 1a that states that the risk of contract failure leads to below equilibrium prices in both treatments. We also do not find support for hypothesis 1b that predicts lower period 1 wholesale prices in HC than in LC. Hence, we have no clear evidence that suppliers' behavior is strongly affected by the risk of contract failure.

[3] Comparing the observed values in the first five to those of the last five rounds using a sign test, the error probability is $p = 0.063$, two-tailed. We also find a significant negative correlation between the period 1 wholesale prices and the decision round using Spearman's rank correlation measure ($r = -0.188$, $p < 0.001$).

The other hypothesis that we derived from previous behavioral literature on supply chain interaction relates to fairness concerns. On first sight, it seems that the observed period 1 wholesale prices in LC that are well below the equilibrium support hypothesis 2a. In fact, we do observe that payoff is shifted from the suppliers to the buyers via these low period 1 prices in LC. This observation, however, is not sufficient to establish that the suppliers' behavior is driven by fairness concerns. If this were the case, we should also observe lower than equilibrium period 1 prices in HC (see hypothesis 2a). But, we do not. Hence, we also have no clear evidence that suppliers' behavior is mainly affected by fairness concerns. The behavioral effects in supply chains with strategic inventories seem to go beyond fairness concerns and contract failure risk, i.e. beyond the concepts that are so far reported in the literature.

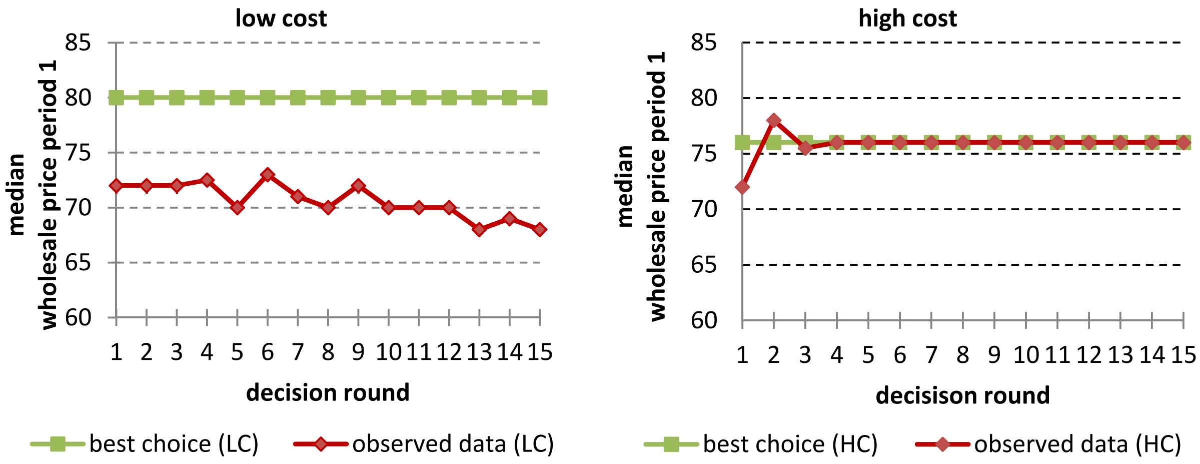

Figure 2: Development of Period 1 Wholesale Prices

5.2 Buyers' Strategic Inventory Decision

We find no significant differences between the observed strategic inventory sizes and the corresponding equilibrium predictions in either of the treatments. Note, however, that while the equilibrium inventory size happens to be an empirical best response to the observed median period 1 wholesale prices in HC, it is not an empirical best response to the much lower observed period 1 wholesale prices in LC.

Table 4 displays the equilibrium, the empirical best response, and observed strategic inventory sizes for both treatments. The buyers' empirical best response to the suppliers' period 1 prices in HC are very close to the equilibrium prediction. The best response to the median period 1 wholesale price in HC is to adopt no strategic inventory (as in equilibrium), and the best response to the average period 1 wholesale price in HC is to adopt a strategic inventory of size 1. We observe a median inventory size of zero and a mean inventory size of 1.37. We find no statistical differences between observed inventory sizes and the equilibrium predictions or the empirical best responses (sign test, p = 1, two-tailed). It seems that buyers in HC make strategic inventory decisions that are almost perfectly in line with the non-cooperative, payoff maximizing equilibrium of the game. Note, however, that buyers in HC have no leeway to reduce payoff inequality by reducing the level of strategic inventories, because inventory choices below zero are not feasible and inventory choices above zero increase inequality. Thus, observed behavior in HC neither contradicts hypothesis 1d nor 2b.

Table 4: Inventory Choices and Best Responses

treatment	equilibrium	empirical best response		observed data	
		to median	to mean	median	mean
LC	10	13.67	13.33	10	8.98
HC	0	0	1	0	1.37

In the LC treatment, the observed inventory size is significantly larger than zero (sign test, p = 0.016, two-tailed). Hence, as predicted by theory, inventory is only utilized if the holding cost is sufficiently low. However, in contrast to the observation of best response inventory choices in HC, the observed inventory choices in LC cannot be considered as best responses to the observed wholesale prices of period 1. Figure 3 displays the median best responses and the median observed inventory sizes in LC (left panel) and HC (right panel). It is evident that inventory choices are almost perfectly in line with best response in HC, but well below the best responses in LC.[4] On average, the chosen inventory size in LC is about 27 percent smaller than the best response. This difference is significant (sign test, p = 0.008, two-tailed). This lower than best response inventory choices contradicts hypothesis 1d, but strongly supports hypothesis 2b.

Figure 3 displays the median of the inventory size choices in LC that would minimize the payoff difference between buyers and suppliers ("fair response"). The derivation of the buyer's fair response inventory quantity is given in online appendix B. It seems that instead of choosing profit maximizing inventory sizes, buyers are choosing inventory sizes that equalize the profits of both supply chain partners as much as possible. As mentioned above, inventory choices in LC are significantly smaller than the best responses, but not significantly different from the "fair response " (sign test, p = 1, two-tailed).

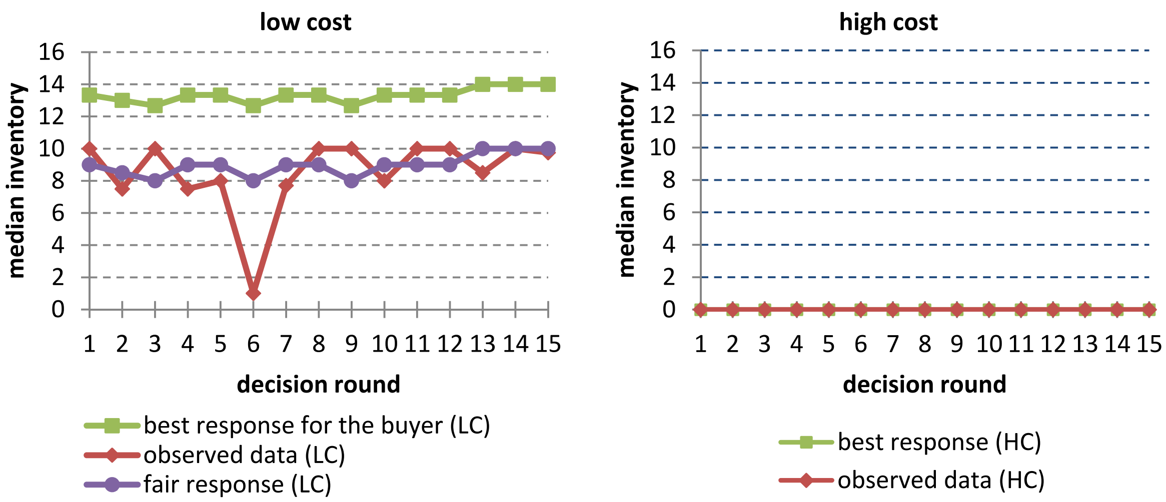

Figure 3: Development of Inventory Quantities

[4] Note that the observed median inventory size is always either an integer or exactly halfway between two integers. This makes the median slightly more volatile than the mean and explains the sudden, substantial drop we observe in the inventory size in round 6 of LC.

5.3 Supplier's Period 2 Wholesale Price

In the last decision stage of the game, the supplier sets the period 2 wholesale price. Table 5 shows the equilibrium values for the period 2 wholesale prices, the empirical best responses and the observed data.

Table 5: Period 2 Wholesale Prices and Best Responses

treatment	equilibrium	empirical best response		observed data	
		to median	to mean	median	mean value
LC	56	56	58.04	56	58.58
HC	76	76	73.26	76	71.34

We neither observe a significant difference between the empirical best responses and the observed prices in the LC treatment (sign test, p = 1.000, two-tailed) nor in the HC treatment (sign test, p = 0.500, two-tailed). Hence, giving a best response to the inventory choice of the buyer seems to be the stable behavior of suppliers in period 2. The fact that the buyers' inventory choices are strategically affecting the wholesale prices of suppliers, as predicted in the analysis by Anand et al. (2008), is further supported by a correlation analysis. Calculating Spearman's rank correlation coefficients separately for both treatments, we find that period 2 wholesale prices are significantly and negatively correlated to the inventory sizes both in LC (r = -0.748, p < 0.001) and in HC (r = - 0.496, p < 0.001). Hence, in both treatments the suppliers take the inventory size of their buyer into account, choosing lower period 2 wholesale prices, the more inventory buyer has acquired.

Period 2 wholesale prices that are best responses to the buyers' inventory choice strongly support hypothesis 1c, i.e., in the absence of contract failure risk suppliers make profit maximizing contract offers. Yet, for testing the fairness hypothesis 2a, we need to evaluate the period 2 wholesale prices in conjecture with the period 1 wholesale prices. Since we observe period 2 prices that are fully in line with the theoretical predictions in both treatments and since the period 1 prices deviate from the theoretical predictions only in LC, it is not surprising that we observe average prices in HC that are indistinguishable from the theoretical benchmarks (sign test, p = 0.25, two-tailed), while in LC the observed average wholesale prices are significantly smaller than the theoretical benchmarks (sign test, p = 0.008, two-tailed). However, as mention in section 5.1, if supplier's fairness concerns drive behavior, we would expect lower average wholesale prices in both treatments. We, thus, reject hypothesis 2a.

5.4 Supply Chain Performance and the Distribution of Payoffs

Table 6 shows an overview of the equilibrium and observed payoffs in both treatments. We find no difference between equilibrium and observed profits in HC. In LC, however, we find that suppliers have lower payoffs and that buyers have significantly higher payoffs than in equilibrium (sign test, p = 0.008, two-tailed). On the one hand, this implies less inequality in payoffs than in equilibrium. On the other hand, since the observed positive payoff difference for buyers is greater than the observed negative payoff difference for suppliers, the overall supply chain performance is significantly higher than in equilibrium (sign test, p = 0.008, two-tailed). Hence, we can summarize that the behavioral effect of strategic inventories on supply chain performance is both efficiency and fairness enhancing.

Table 6: Comparison of the profits of both treatments

profits	equilibrium		LC		HC	
	LC	HC	median	mean value	median	mean value
profit supplier	3,024 (66.55%)	2,888 (66.67%)	2,888	2,870.4 (61.41%)	2,887.75	2,848.13 (64.01%)
profit buyer	1,520 (33.45%)	1,444 (33.33%)	1,759.25	1,803.6 (38.59%)	1,444	1,533 (34.99%)
profit supply chain	4,544	4,332	4,731.5	4,674	4,332	4,381.13

6. Discussion and Implications

Based on the serial supply chain model by Anand et al. (2008) with 2-periods and price-sensitive demand, we present the first experimental test of the effect of strategic inventories on supply chain performance. In theory, if wholesale price contracts are used and the holding costs are sufficiently low, building up a strategic inventory allows the buyer not only to increase her profit share, but also to enhance the overall supply chain performance by inducing a differentiated pricing behavior by the supplier. Verifying the predicted effects of strategic inventories in the field is extremely difficult, because supply chain interaction is generally embedded in a complex relationship that is simultaneously affected by numerous stochastic and strategic variables. The multiple confounds (i.e. parallel causal relationships) make the separation and identification of the effects of strategic inventories on prices and performance almost impossible in field data.

Using carefully devised controls and variations in our experiment, we can filter out all other causes and effects and, thus, observe the pure effect of strategic inventories. We observe a positive effect of strategic inventories on supply chain performance that qualitatively is perfectly in line with the theoretical results and that quantitatively goes even beyond the equilibrium prediction. As predicted theoretically we observe no strategic inventories in the case of prohibitively high holding cost (HC treatment). Supply chain performance in this setting is neither enhanced nor impaired by the possibility of building up inventories. In the case, in which the holding cost is sufficiently low (LC treatment), we observe an extensive adoption of strategic inventories, leading to a strong enhancement of supply chain performance. In fact, the observed supply chain performance is even superior to the game theoretically expected enhancement when the cost of holding inventory is low. We show that this enhancement of supply chain performance cannot be uniquely attributed to fairness preferences or perception of contract failure risk, because we only see lower than predicted average wholesale prices in LC, but not in HC. We identify two characteristics that explain why average wholesale prices are even lower than predicted in LC.

The first striking difference in behavior across treatments is due to buyer empowerment, i.e. due to the fact that low cost buyers have a range of feasible inequality-reducing inventory choice alternatives that high cost buyers do not have. It turns out that low cost buyers frequently choose inventory sizes that are not payoff maximizing, but reduce the payoff inequality within the supply chain. It is possible that this buyer empowerment also influences the suppliers' perception of contract failure risk leading to lower than predicted average wholesale prices.

The second key difference between treatments is the additional distributional flexibility that results from the adoption of strategic inventories. We show that the seller's willingness to reduce the wholesale price in period 1 has clear limits. While many suppliers are willing to contribute the part of their payoffs exceeding the payoff that they would have achieved in the static solution (i.e. without a strategic inventory), we hardly observe any suppliers, who are willing to share their payoffs beyond this point. Hence, it seems that payoff in the static solution is a decisive benchmark, a focal point, for the suppliers' fairness concerns. A simple explanation why the static solution may be a natural focal point of the game is that it is the best outcome that can be enforced by suppliers (i.e. it is the maximin outcome). In fact, the existence of this focal point also explains why we see almost no sharing by the sellers in the high cost treatment. The highest achievable payoff for suppliers in that treatment is equal to the payoff in the static solution, i.e. at the level of the focal point. Securing payoffs at the focal point level, obviously, leaves no financial leeway for other-regarding behavior in the high cost treatment.

In sum, we find that the theoretically predicted strategic interaction dominates behavior in our multi-period game. However, when the supply chain partners manage to cooperate and to generate a surplus, they tend to divide the surplus in a way that equalizes payoffs as also previously observed in the literature. The interesting new behavioral aspect that we observe here is that fairness only matters when both parties can actively contribute to generating a surplus. In our setting, the buyers can only contribute to the surplus, when their holding cost are low, allowing them to create and vary the size of their strategic inventories. Without the distributional flexibility that provides buyers with the strategic option to contribute to the joint surplus, i.e. without *buyer empowerment*, we find that suppliers see no reason to equalize payoffs in our setting.

Our findings have several implications for supply chain management. First, our findings suggest that when holding costs are reasonably low, inventories may (at least partially) be adopted for strategic reasons, both enhancing the supply chain performance and empowering the buyer. In other words, our results give strong empirical support to the theoretical findings of Anand et al (2008). Second, our results suggest that there may be behavioral effects that top off the purely strategic effect. Seeking a more equitable payoff distribution in the supply chain, the empowered buyers may harm the supply chain performance by choosing suboptimal small inventories. But, this negative effect of buyer empowerment on supply chain performance is generally offset by the positive effect of the low first period prices. Third, our results highlight that the positive effects on supply chain performance can only be achieved with some flexibility concerning the distribution of profits. We find that the extent of profit sharing may strongly depend on focal points that emerge from the interaction situation and induce upper bounds for the willingness to share. Obviously, such focal points may be based on historical, legal, or cultural details of the interaction environment. Our study shows that they may also be based on strategic features of the interaction (e.g. a maximin outside option).

Finally, our results also have some implications for future research, emphasizing that the role of strategic inventories should be considered both in non-cooperative supply chain modeling and in behavioral research. One important open issue is the design of dynamic contracts that can be used to implement the optimal supply chain performance in the presence of strategic inventories. It would be interesting to examine, whether the optimal contract is strategically feasible and behaviorally robust. Another direction for further research is to study the role of information asymmetries, especially regarding the inventory size, in a setting with strategic inventories. It is not yet clear how the supplier can set optimal wholesale prices without the exact knowledge of the inventory size. More complex contracts, such as screening contracts, may be necessary to successfully deal with these information asymmetries. But, if the complexity of the contracts goes up too much, it may be more effective to rely on less sophisticated contractual agreements that take truth-telling and trust into account (see e.g. Charness and Dufwenberg, 2011; Inderfurth et al., 2012).

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Strategic Inventory and Supply Chain Behavior

Online Appendix

<u>Appendix A:</u>

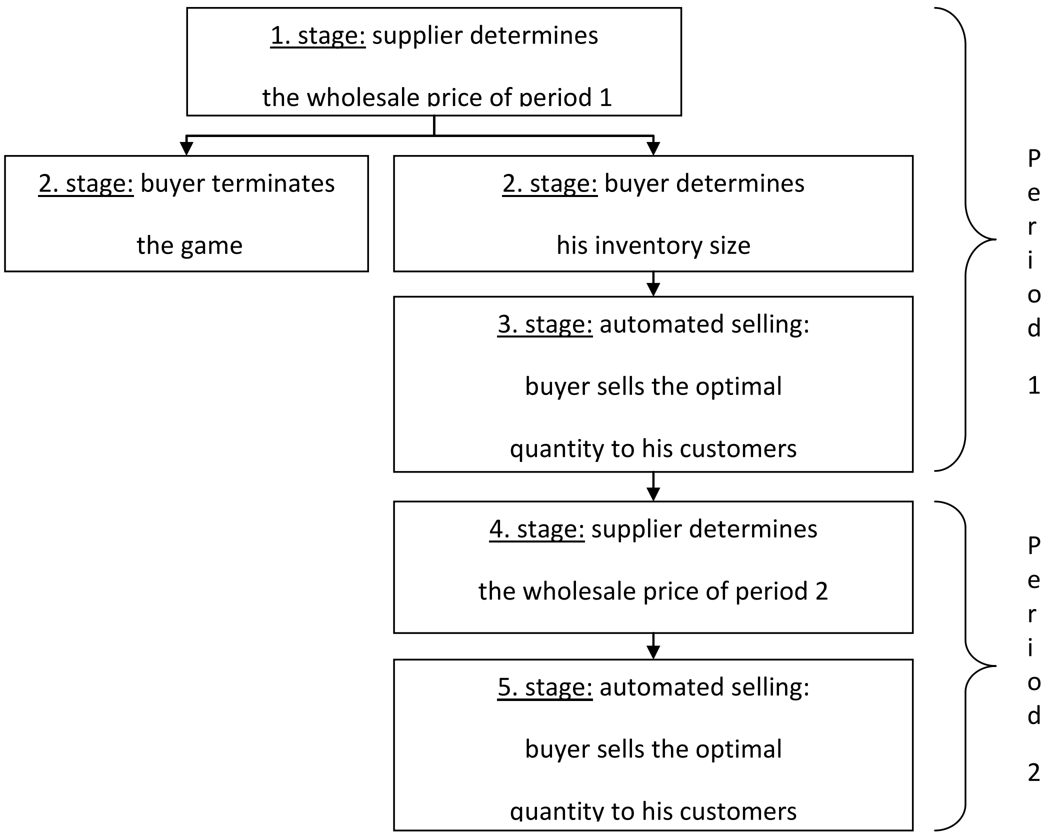
Instructions

Please read the instructions carefully and raise your hand, if you have a question.

In the experiment, in which you participate now, you can earn lab dollars (LD) that will be converted into money and paid to you at the end of the experiment. The amount of LD you will earn in each of the decision rounds depends both on your decisions and the decisions of your co-player. Every decision you make in the experiment is anonymous.

Background:

You are in a vertical supply chain consisting of one supplier and one buyer. At the beginning of the game you will be assigned either the role of the supplier or the buyer. This allocation will be maintained in all 15 rounds of the experiment. At the beginning of each round you will be randomly assigned to one player with the other role. Each round is divided into five stages (see figure):



Stage 1: Decision of the Supplier in Period 1

In the first decision stage of the experiment, the supplier sets the wholesale price at which the buyer may purchase goods in the first period. For the wholesale price each value in the interval from 0 to 152 with a maximum precision of three digits after the decimal point is allowed. In the attached payout table the wholesale price of the first period is displayed on the left side of each table. However, the table does not include all feasible prices but only the 0 and the numbers in the interval between 52 and 84 in steps of four. Thus, the payout table serves only as guidance. For the prices not listed, use the profit calculator provided.

	0	
wholesale price period 1	52	
	56	
	…	
	84	

Stage 2: Decision of the Buyer in Period 1

At the beginning of the second stage in period one the buyer is informed about the current wholesale price. Then, the buyer can decide whether to continue or terminate the game. If the buyer terminates the game, the round ends immediately. If the buyer instead continues the game, he decides about his inventory size. Here, each value in the interval between 0 and 38 with a maximum precision of three digits after the decimal point is allowed.

For each unit purchased to build up inventory the wholesale price of the first period needs to be paid to the supplier. Additional, holding costs of 4 LD per item are caused. In the attached payout table the inventory size is displayed in the upper left corner. Again, not all possible inventory sizes but only those in the interval between 0 and 20 in steps of five are given. For other values the provided calculator can be used, to obtain the corresponding profits.

	0	
wholesale price period 1	52	
	56	
	…	
	84	

Stage 3: Automated Vending of the Buyer in Period 1

If the game was not terminated, an automated vending for the first period is operated after the buyer has decided about his inventory size. In this stage, the program calculates the optimal selling quantity of the buyer and sells them on the market. The optimal selling quantity only depends on the wholesale price of the first period, but not on the inventory size of the buyer.

Stage 4: Decision supplier in period 2

If the game was not terminated, the buyer’s inventory size will be communicated to the supplier and the supplier is prompted to set the wholesale price of the second period. For the wholesale price each value in the interval from 0 to 152 with a maximum precision of three digits after the decimal point is allowed. In the payout table the price of the second period is displayed in the columns (top edge). Again, only the 0 and the values in the interval between 52 and 84 are given in steps of four. For further calculations the provided calculator can be used.

inventory		wholesale price period 2				
		0	52	56	…	84
	0					
wholesale price period 1	52					
	56					
	…					
	84					

Stage 5: Automated Vending of the Buyer in Period 2

If the game was not terminated, again an automated vending for the second period will be conducted, after the supplier has set the wholesale price of the second period. Again, the exact amount that maximizes the profit of the buyer will be sold. If the buyer built up inventory in the first period, he can use these goods for the vending process and needs to buy fewer units from the buyer in the second period. Thus, the optimal selling quantity of the second period depends on both the wholesale price of the second period and the inventory size of the buyer. It should be noted that the buyer will not purchase further goods from the supplier in the second period, if the wholesale price of the second period is too high. In this case, the buyer would only sell his inventory to the external market.

Calculation of the Profits of each Round:

After all decisions have been made, the profits of the current round for both the supplier and the buyer will be displayed. If the trade was rejected, the profit would be zero LD for both players. In all other cases, the respective profits for the specified values of the wholesale prices and the inventory size correspond to the profits given by the payout table or the calculator.

Control Question:

The wholesale price of the first period is 72 LD, the inventory size is 15 and the wholesale price of the second period is 60 LD. What are the profits for the supplier and the buyer for this round? Please use the payout table and write down your answers on the prepared paper. Please wait until we have checked your responses. A correct answering of this control question is required to participate in the experiment.

How will the payment be carried out?

Your payment (in Euros) matches the sum of your LD divided by 3000. This means that 30 LD correspond to exactly 1 euro cent. You will be paid at the end of the experiment. Please wait until we call your name.

Good luck.

Profit Table Supplier:

		Wholesale Price Period 2									
Inventory	0	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	0	1.300	1.344	1.380	1.408	1.428	1.440	1.444	1.440	1.428
	52	1.300	2.600	2.644	2.680	2.708	2.728	2.740	2.744	2.740	2.728
	56	1.344	2.644	2.688	2.724	2.752	2.772	2.784	2.788	2.784	2.772
	60	1.380	2.680	2.724	2.760	2.788	2.808	2.820	2.824	2.820	2.808
	64	1.408	2.708	2.752	2.788	2.816	2.836	2.848	2.852	2.848	2.836
	68	1.428	2.728	2.772	2.808	2.836	2.856	2.868	2.872	2.868	2.856
	72	1.440	2.740	2.784	2.820	2.848	2.868	2.880	2.884	2.880	2.868
	76	1.444	2.744	2.788	2.824	2.852	2.872	2.884	2.888	2.884	2.872
	80	1.440	2.740	2.784	2.820	2.848	2.868	2.880	2.884	2.880	2.868
	84	1.428	2.728	2.772	2.808	2.836	2.856	2.868	2.872	2.868	2.856

		Wholesale Price Period 2									
Inventory	5	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	0	1.040	1.064	1.080	1.088	1.088	1.080	1.064	1.040	1.008
	52	1.560	2.600	2.624	2.640	2.648	2.648	2.640	2.624	2.600	2.568
	56	1.624	2.664	2.688	2.704	2.712	2.712	2.704	2.688	2.664	2.632
	60	1.680	2.720	2.744	2.760	2.768	2.768	2.760	2.744	2.720	2.688
	64	1.728	2.768	2.792	2.808	2.816	2.816	2.808	2.792	2.768	2.736
	68	1.768	2.808	2.832	2.848	2.856	2.856	2.848	2.832	2.808	2.776
	72	1.800	2.840	2.864	2.880	2.888	2.888	2.880	2.864	2.840	2.808
	76	1.824	2.864	2.888	2.904	2.912	2.912	2.904	2.888	2.864	2.832
	80	1.840	2.880	2.904	2.920	2.928	2.928	2.920	2.904	2.880	2.848
	84	1.848	2.888	2.912	2.928	2.936	2.936	2.928	2.912	2.888	2.856

		Wholesale Price Period 2									
Inventory	10	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	0	780	784	780	768	748	720	684	640	588
	52	1.820	2.600	2.604	2.600	2.588	2.568	2.540	2.504	2.460	2.408
	56	1.904	2.684	2.688	2.684	2.672	2.652	2.624	2.588	2.544	2.492
	60	1.980	2.760	2.764	2.760	2.748	2.728	2.700	2.664	2.620	2.568
	64	2.048	2.828	2.832	2.828	2.816	2.796	2.768	2.732	2.688	2.636
	68	2.108	2.888	2.892	2.888	2.876	2.856	2.828	2.792	2.748	2.696
	72	2.160	2.940	2.944	2.940	2.928	2.908	2.880	2.844	2.800	2.748
	76	2.204	2.984	2.988	2.984	2.972	2.952	2.924	2.888	2.844	2.792
	80	2.240	3.020	3.024	3.020	3.008	2.988	2.960	2.924	2.880	2.828
	84	2.268	3.048	3.052	3.048	3.036	3.016	2.988	2.952	2.908	2.856

		Wholesale Price Period 2									
Inventory	15	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	0	520	504	480	448	408	360	304	240	168
	52	2.080	2.600	2.584	2.560	2.528	2.488	2.440	2.384	2.320	2.248
	56	2.184	2.704	2.688	2.664	2.632	2.592	2.544	2.488	2.424	2.352
	60	2.280	2.800	2.784	2.760	2.728	2.688	2.640	2.584	2.520	2.448
	64	2.368	2.888	2.872	2.848	2.816	2.776	2.728	2.672	2.608	2.536
	68	2.448	2.968	2.952	2.928	2.896	2.856	2.808	2.752	2.688	2.616
	72	2.520	3.040	3.024	3.000	2.968	2.928	2.880	2.824	2.760	2.688
	76	2.584	3.104	3.088	3.064	3.032	2.992	2.944	2.888	2.824	2.752
	80	2.640	3.160	3.144	3.120	3.088	3.048	3.000	2.944	2.880	2.808
	84	2.688	3.208	3.192	3.168	3.136	3.096	3.048	2.992	2.928	2.856

		Wholesale Price Period 2									
Inventory	20	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	0	260	224	180	128	68	0	0	0	0
	52	2.340	2.600	2.564	2.520	2.468	2.408	2.340	2.340	2.340	2.340
	56	2.464	2.724	2.688	2.644	2.592	2.532	2.464	2.464	2.464	2.464
	60	2.580	2.840	2.804	2.760	2.708	2.648	2.580	2.580	2.580	2.580
	64	2.688	2.948	2.912	2.868	2.816	2.756	2.688	2.688	2.688	2.688
	68	2.788	3.048	3.012	2.968	2.916	2.856	2.788	2.788	2.788	2.788
	72	2.880	3.140	3.104	3.060	3.008	2.948	2.880	2.880	2.880	2.880
	76	2.964	3.224	3.188	3.144	3.092	3.032	2.964	2.964	2.964	2.964
	80	3.040	3.300	3.264	3.220	3.168	3.108	3.040	3.040	3.040	3.040
	84	3.108	3.368	3.332	3.288	3.236	3.176	3.108	3.108	3.108	3.108

Profit Table Buyer:

		Wholesale Price Period 2									
Inventory	0	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	5.776	4.138	4.040	3.946	3.856	3.770	3.688	3.610	3.536	3.466
	52	4.138	2.500	2.402	2.308	2.218	2.132	2.050	1.972	1.898	1.828
	56	4.040	2.402	2.304	2.210	2.120	2.034	1.952	1.874	1.800	1.730
	60	3.946	2.308	2.210	2.116	2.026	1.940	1.858	1.780	1.706	1.636
	64	3.856	2.218	2.120	2.026	1.936	1.850	1.768	1.690	1.616	1.546
	68	3.770	2.132	2.034	1.940	1.850	1.764	1.682	1.604	1.530	1.460
	72	3.688	2.050	1.952	1.858	1.768	1.682	1.600	1.522	1.448	1.378
	76	3.610	1.972	1.874	1.780	1.690	1.604	1.522	1.444	1.370	1.300
	80	3.536	1.898	1.800	1.706	1.616	1.530	1.448	1.370	1.296	1.226
	84	3.466	1.828	1.730	1.636	1.546	1.460	1.378	1.300	1.226	1.156

		Wholesale Price Period 2									
Inventory	5	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	5.756	4.378	4.300	4.226	4.156	4.090	4.028	3.970	3.916	3.866
	52	3.858	2.480	2.402	2.328	2.258	2.192	2.130	2.072	2.018	1.968
	56	3.740	2.362	2.284	2.210	2.140	2.074	2.012	1.954	1.900	1.850
	60	3.626	2.248	2.170	2.096	2.026	1.960	1.898	1.840	1.786	1.736
	64	3.516	2.138	2.060	1.986	1.916	1.850	1.788	1.730	1.676	1.626
	68	3.410	2.032	1.954	1.880	1.810	1.744	1.682	1.624	1.570	1.520
	72	3.308	1.930	1.852	1.778	1.708	1.642	1.580	1.522	1.468	1.418
	76	3.210	1.832	1.754	1.680	1.610	1.544	1.482	1.424	1.370	1.320
	80	3.116	1.738	1.660	1.586	1.516	1.450	1.388	1.330	1.276	1.226
	84	3.026	1.648	1.570	1.496	1.426	1.360	1.298	1.240	1.186	1.136

		Wholesale Price Period 2									
Inventory	10	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	5.736	4.618	4.560	4.506	4.456	4.410	4.368	4.330	4.296	4.266
	52	3.578	2.460	2.402	2.348	2.298	2.252	2.210	2.172	2.138	2.108
	56	3.440	2.322	2.264	2.210	2.160	2.114	2.072	2.034	2.000	1.970
	60	3.306	2.188	2.130	2.076	2.026	1.980	1.938	1.900	1.866	1.836
	64	3.176	2.058	2.000	1.946	1.896	1.850	1.808	1.770	1.736	1.706
	68	3.050	1.932	1.874	1.820	1.770	1.724	1.682	1.644	1.610	1.580
	72	2.928	1.810	1.752	1.698	1.648	1.602	1.560	1.522	1.488	1.458
	76	2.810	1.692	1.634	1.580	1.530	1.484	1.442	1.404	1.370	1.340
	80	2.696	1.578	1.520	1.466	1.416	1.370	1.328	1.290	1.256	1.226
	84	2.586	1.468	1.410	1.356	1.306	1.260	1.218	1.180	1.146	1.116

		Wholesale Price Period 2									
Inventory	15	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	5.716	4.858	4.820	4.786	4.756	4.730	4.708	4.690	4.676	4.666
	52	3.298	2.440	2.402	2.368	2.338	2.312	2.290	2.272	2.258	2.248
	56	3.140	2.282	2.244	2.210	2.180	2.154	2.132	2.114	2.100	2.090
	60	2.986	2.128	2.090	2.056	2.026	2.000	1.978	1.960	1.946	1.936
	64	2.836	1.978	1.940	1.906	1.876	1.850	1.828	1.810	1.796	1.786
	68	2.690	1.832	1.794	1.760	1.730	1.704	1.682	1.664	1.650	1.640
	72	2.548	1.690	1.652	1.618	1.588	1.562	1.540	1.522	1.508	1.498
	76	2.410	1.552	1.514	1.480	1.450	1.424	1.402	1.384	1.370	1.360
	80	2.276	1.418	1.380	1.346	1.316	1.290	1.268	1.250	1.236	1.226
	84	2.146	1.288	1.250	1.216	1.186	1.160	1.138	1.120	1.106	1.096

		Wholesale Price Period 2									
Inventory	20	0	52	56	60	64	68	72	76	80	84
Wholesale Price Period 1	0	5.696	5.098	5.080	5.066	5.056	5.050	5.048	5.048	5.048	5.048
	52	3.018	2.420	2.402	2.388	2.378	2.372	2.370	2.370	2.370	2.370
	56	2.840	2.242	2.224	2.210	2.200	2.194	2.192	2.192	2.192	2.192
	60	2.666	2.068	2.050	2.036	2.026	2.020	2.018	2.018	2.018	2.018
	64	2.496	1.898	1.880	1.866	1.856	1.850	1.848	1.848	1.848	1.848
	68	2.330	1.732	1.714	1.700	1.690	1.684	1.682	1.682	1.682	1.682
	72	2.168	1.570	1.552	1.538	1.528	1.522	1.520	1.520	1.520	1.520
	76	2.010	1.412	1.394	1.380	1.370	1.364	1.362	1.362	1.362	1.362
	80	1.856	1.258	1.240	1.226	1.216	1.210	1.208	1.208	1.208	1.208
	84	1.706	1.108	1.090	1.076	1.066	1.060	1.058	1.058	1.058	1.058

Appendix B:

Fairness inventory size:

The buyer can use strategic inventory to reduce the absolute difference in profit between herself and the supplier. The fairness inventory size that minimizes the profit difference is obtained by a comparison of the marginal profit of the supplier and the buyer with respect to the inventory size.

The marginal profit of the buyer can be obtained by calculating the first derivative of the buyer's profit function with respect to the inventory size. Under consideration of the automated determination of the selling quantities in both periods (see (6) and (4)) and under the assumption that the supplier will choose the optimal response wholesale price from (5) in the second period[1], according to (2) the relevant profit function of the buyer is:

$$\pi_B = \frac{5 \cdot a^2 - 8 \cdot a \cdot w_1 + 4 \cdot w_1^2 + 12 \cdot b \cdot a \cdot I - 16 \cdot b \cdot I \cdot (w_1 + h) - 12 \cdot b^2 \cdot I^2}{16 \cdot b}. \quad (10)$$

Therefore, the derivation of the buyer's profit function (10) is:

$$\begin{aligned} \frac{\partial \pi_B}{\partial I} &= \frac{3}{4} \cdot a - (w_1 + h) - \frac{3}{2} \cdot b \cdot I \\ &= 114 - (w_1 + h) - 3 \cdot I. \end{aligned} \quad (11)$$

Hence, in the LC treatment (i.e., for $h = 4$), the buyer should only build up inventory if $w_1 < 110$. Further, we see that the advantage of building up inventory is larger, the lower w_1. Therefore, by setting a low wholesale price in the first period, the supplier can influence the incentive of the buyer for building up inventory. This becomes visible from the optimality condition (setting the marginal profit in (11) equal to zero) so that the buyer's profit maximizing inventory decision is derived as $I_B(w_1) = (114 - w_1 - h)/3$. Further, the marginal profit of the inventory is diminishing.

The influence of inventory on the supplier's profit can be obtained similarly. Because of the automation of the buyer's selling quantities, the optimal response quantities again need to be inserted into the profit function (1) of the supplier. Under the assumption that the supplier will choose the optimal response wholesale price in the second period, the relevant profit function of the supplier is:

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[1] The analysis of the observed wholesale price decision of the supplier shows that this assumption is fulfilled.

$$\pi_S = \frac{a^2 + 4 \cdot a \cdot w_1 - 4 \cdot w_1^2 + 8 \cdot b \cdot w_1 \cdot I - 4 \cdot b \cdot a \cdot I + 4 \cdot b^2 \cdot I^2}{8 \cdot b}. \quad (12)$$

Therefore, the derivation of the supplier's profit function (12) is:

$$\begin{aligned} \frac{\partial \pi_S}{\partial I} &= w_1 - \frac{a}{2} + b \cdot I \\ &= w_1 - 76 + 2 \cdot I. \end{aligned} \quad (13)$$

If the buyer aims to minimize the profit difference by using strategic inventory, she should only lower her inventory size, if her marginal disadvantage of this action is lower than the corresponding marginal disadvantage of the supplier. The inventory size, for which the marginal profits from (11) and (13) are equal, therefore, is:

$$\begin{aligned} I &= \frac{5 \cdot a - 8 \cdot w_1 - 4 \cdot h}{10 \cdot b} \\ &= 38 - \tfrac{2}{5} \cdot w_1 - \tfrac{1}{5} \cdot h. \end{aligned} \quad (14)$$

As inventory size smaller than zero are not possible, the fairness inventory size is given by:

$$\begin{aligned} I &= \max\left\{0,\ \frac{5 \cdot a - 8 \cdot w_1 - 4 \cdot h}{10 \cdot b}\right\} \\ &= \max\left\{0,\ 38 - \tfrac{2}{5} \cdot w_1 - \tfrac{1}{5} \cdot h\right\}. \end{aligned} \quad (15)$$