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# 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 low enough, the buyer builds up a strategic inventory (even if no operational reasons for stock-holding exist) to limit the supplier's market power, to increase the own profit share, and to enhance 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 exhibit a willingness to 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

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# 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 the own payoff share, it also benefits the supplier, because the overall performance of the supply chain is enhanced, by partly reducing the suppliers 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.

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.

[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.

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 to 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. The supplier faces the coordination risk that the buyer may fail to build up a sufficiently large strategic inventory to support the equilibrium, while the buyer faces the coordination risk that the supplier may fail to decrease the second period's wholesale price sufficiently to compensate the buyer for the higher first period price and the occurring holding cost. 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; Wu and Katok, 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 to reduce 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.

The situation in the field is obviously much richer than in our lab and it may be complicated by numerous effects that we have controlled for in the experiment. Yet, our experiment does provide evidence that strategic inventories provide an endogenous mean(s) for the contract partners to flexibly allocate profits within the supply chain. We observe that the supplier uses this additional flexibility to show kindness by reducing average wholesale prices to some extent and the buyer reduces the inequality of payoffs by choosing an inventory smaller than in the game theoretic equilibrium. This behavioral effect leads to a supply chain performance that is even more enhanced than in the game theoretic prediction by Anand et al. (2008).

## 2. Literature Review

Our experimental study is based on the theoretical model by Anand et al. (2008), in which they consider the interaction in a serial supply chain with a deterministic, price-sensitive demand. 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 allowing the buyer to build up an inventory that she can use to serve part of her future demand. Thus, the buyer's strategic inventory reduces the supplier's monopoly power and leads to a reduction of the wholesale price. However, anticipating the buyer's inventory buildup, the supplier differentiates prices across periods, setting a higher wholesale price in the first and a lower wholesale price in the second period. The sales expanding effect of the strategic inventory works in favor of both buyer and supplier, but the buyer only achieves additional payoffs for sufficiently low holding cost. Due to the additional holding cost and due to some degree of double marginalization that persists, the supply chain optimum in the 2-period game cannot be achieved in equilibrium.[2]

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. 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.

One frequently observed behavioral phenomenon is the failure of supply chain players to choose profit maximizing order quantities (Schweitzer and Cachon, 2000; Katok and Wu, 2009). In their seminal paper, Schweitzer and Cachon (2000), for example, study the ordering behavior of buyers in a newsvendor setting under stochastic demand without price-sensitivity. They observe that buyers fail to optimize, but tend to place orders that lie between the average demand and the optimal quantity. They show that the observed "pull-to-center effect" cannot be explained by risk preferences, loss aversion,

[2] It is worth noting that Anand et al. (2008) show that a two-part tariff in this setting does not necessarily coordinate the supply chain efficiently, because the buyer may have an incentive to build up inventory today to save the fixed fee tomorrow. As a reaction the supplier will no longer use his marginal production costs for the per unit payment to maintain his profit. This highlights the fact that strategic considerations in inter-temporal decision making can affect the outcome of contracting mechanism in both towards and away from the efficient solution.

or prospect theory. They conclude that the observed behavior may be due to an effort to minimize the ex-post inventory error (orders are positively correlated with past demand) or due to anchoring and an insufficient adjustment heuristic (orders move towards optimal value over time). In a careful and extended experimental reassessment of the newsvendor problem, Katok and Wu (2009) can confirm the pull-to-center effect and the buyer's inventory error minimization behavior. They additionally show that while both buy-back and revenue sharing contracts can improve the supply chain efficiency, neither leads to a stable optimal behavior. Although our setting is obviously different from the newsvendor game with demand uncertainty, generalizing the observed behavioral phenomenon, we can conjecture that both our suppliers and our buyers will make decisions that are insufficiently adjusted to the optimal strategic play.

Another 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 (e.g. Güth et al., 1982; Forsythe et al. 1994; Berg and Dickhaut, 1995; Bolton, 1991; Fehr et al. 1998) had documented that concerns for fairness persistently affect economic behavior. 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).

While it is rather difficult to clearly separate the different facets of fairness preferences in supply chain settings, 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 (and sometimes the ordered quantities up) 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 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. Our paper contributes to this literature by studying the influence of other regarding preferences in the context of 2-period supply chain interaction with strategic inventories.

Another behavioral phenomenon observed by Croson et al. (2012) in a laboratory study of the beer game is that coordination risk is a driving force in supply chain interaction. According to their definition, a coordination risk exists if individuals make independent decisions and if the "decision makers have limited knowledge of, or trust in, their partner's motives or cognitive abilities." As a result, individuals may consider the effects of a deviation from the equilibrium solution and decide to hedge themselves against an out of equilibrium decision of their supply chain partner. For example, Croson et al. (2012) observe that subjects deviate from the theoretically optimal behavior by building up a coordination stock to hedge against the possibility that their partners might not behave optimally (e.g. order too much). In our setting, the supplier faces a coordination risk because his profits drop, if he decides to raise the first period's wholesale price, but the buyer fails to build up strategic inventory. The buyer also faces a coordination risk, because the supplier might fail to lower the second period's wholesale price sufficiently to compensate the buyer for the cost of her strategic inventory.

## 3. The Model

The model of strategic inventories, introduced by Anand et al. (2008), is a 2-period game with two players, a supplier and a buyer. 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 these cases the *dynamic solutions*, 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 these cases the *static solutions*. The closed-form static and dynamic solutions can be derived using backward induction as shown by Anand et al. (2008) and 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

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

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

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

and inventory

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

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

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

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 $\pi_S$ | - | $\frac{a^2}{4b}$ | $\frac{9a^2-4ah+8h^2}{34b}$ |
| inventory $I$ | 0 | 0 | $\frac{5\cdot(a-4h)}{34b}$ | profit buyer $\pi_B$ | - | $\frac{a^2}{8b}$ | $\frac{155a^2-118ah+304h^2}{1156b}$ |
| 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 $\pi_{SC}$ | $\frac{a^2}{2b}$ | $\frac{3a^2}{8b}$ | $\frac{461a^2-254ah+576h^2}{1156b}$ |

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 cost ($h < \frac{55}{288} \cdot a$). For holding cost 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 a strategic inventory, when the holding cost is zero. Nevertheless, even at zero holding cost, 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 | |
| $\pi_S$ | 3,024 (66.55%) | | 2,888 (66.67%) | |
| $\pi_B$ | 1,520 (33.45%) | | 1,444 (33.33%) | |
| $\pi_{SC}$ | 4,544 | | 4,332 | |

* decision variables in the experimental analysis

The cognitive coordination risk of each player depends on the payoff consequences of boundedly rational out-of-equilibrium play by the other player. In HC, the coordination risk is negligible for both players. Trivially, the supplier has no coordination risk in period 2, because no further decisions follow. Hence, we expect to observe profit maximizing choices. While it seems unlikely that the supplier chooses a period 2 wholesale price higher than the optimal one, it is possible that the buyer will hedge against a high period 2 wholesale price by increasing inventories. In HC, however, the expected price increase must be dramatically high (i.e., the expected second period's wholesale price must be greater than the first period's wholesale price plus the holding cost) to support such inventory decisions. We do not expect to observe this scenario frequently, because it entails high losses both for the supplier and the buyer. If the supplier nevertheless assigns a positive probability that the buyer hedges against increasing wholesale prices, the first period's wholesale price will be set higher, but never lower than the static solution price, i.e., not below 76.

Behavioral Hypothesis 1 ("Cognitive coordination risk in HC"):

(1a) In HC, the period 1 price is greater than the static solution price.

(1b) In HC, strategic inventories are greater than the optimal level, if period 2 wholesale prices are sub-optimally high.

(1c) In HC, the period 2 price is equal to the price of the static solution.

In LC, the players face substantial cognitive coordination risks in period 1, but – as in HC – not in period 2. Hence, we expect the period 2 prices to be optimal. In LC, it might be slightly more likely than in HC that we observe hedging against increasing wholesale prices, simply because the cost of hedging (holding costs) are lower. However, as the cost effect is still substantial for both the supplier and the buyer, we do not expect to observe this behavior frequently. In contrast, if the buyer expects sub-optimally low wholesale prices in the second period, then she chooses lower inventories in order to stock less in period 1, thereby reducing holding cost, and buying more in period 2. In period 1, if the supplier believes that the buyer may choose an inventory that is greater than the equilibrium level, he can hedge against the coordination risk by choosing a wholesale price greater than the equilibrium price. In contrast, if the supplier believes that the buyer may choose inventory levels smaller than the equilibrium level, hedging would entail choosing a price below the price of the dynamic solution, but not smaller than the price of the static solution.

Behavioral Hypothesis 2 ("Cognitive coordination risk in LC"):

(2a) In LC, the period 1 price is greater than or equal to the static solution price.

(2b) In LC, strategic inventories are greater (smaller) than the optimal level, if period 2 wholesale prices to be sub-optimally high (low).

(2c) In LC, the period 2 price is equal to the optimal price.

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.

The buyer's possibility to show 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 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 the hypotheses 3 and 4 below.

Hypothesis 3 ("Fairness Concerns in HC"):
(3a) In HC, the average wholesale price of both periods is smaller than the equilibrium price.
(3b) In HC, strategic inventories are equal to the equilibrium level.

Hypothesis 4 ("Fairness Concerns in LC"):
(4a) In LC, the average wholesale price of both periods is smaller than the equilibrium price.
(4b) In LC, strategic inventories are smaller than the equilibrium level.

## 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. Before the game started, the subjects were 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.

To reduce the decision load on the subjects and to focus on the role of strategic inventories in supply chain interactions, we set the market sales quantities ($q_1, q_2$) automatically to the optimal value in every period. Hence, the buyer's decision is limited to her strategic inventory size ($I$) in the first period, while the supplier sets his wholesale prices ($w_1, w_2$) in periods one and two. Since automating the choice of the sales quantities deprives the buyer of the option to punish the supplier by reducing the quantity sold to the market, we provide the buyer with the opportunity to terminate the game after being informed about the wholesale price of the first period. If this outside option is chosen by the buyer, the payoffs of both the buyer and the supplier are set zero and the round ends immediately. The course of events of each decision round is displayed in Figure 1.

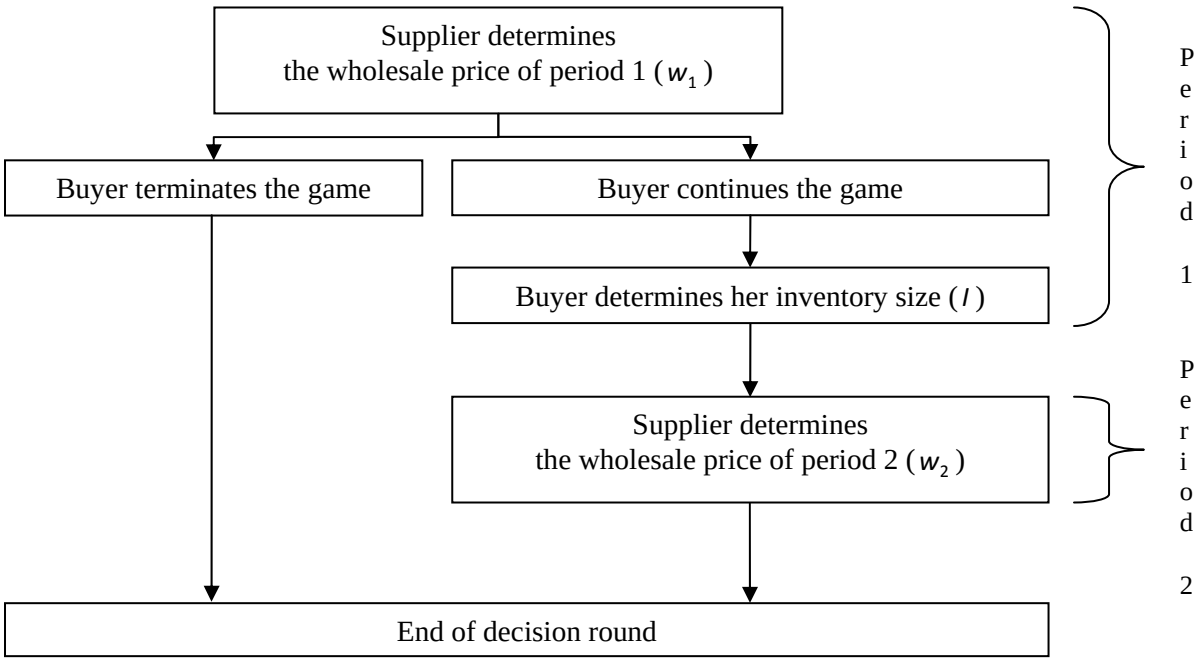


**Figure 1: Sequence of Decisions**

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 supports. 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 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 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 – in LC, but no difference between the two wholesale prices 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 the more equitable division of supply chain profits in LC, in which a strategic inventory is feasible. These observations provide substantial support for our behavioral hypothesis 4 ("Fairness Concerns in LC"), but not for any of the other behavioral hypotheses.

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.

The observed deviation of wholesale prices from the dynamic solution in LC in line with the concern for fairness as in hypothesis 4a that predicts lower than equilibrium wholesale prices may be used to reduce the payoff gap between suppliers and buyers. We can reject the hypothesis H2a that the lower wholesale prices are due to the suppliers' perceived cognitive coordination risk, because the lower

[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 ($r = -0.188$, $p < 0.001$).

bound for prices according to that hypothesis is the static outcome price of 76. Observed wholesale prices in LC, however, are significantly below 76 (sign test, p=0.008, two-tailed).

Surprisingly, suppliers in HC neither exhibit behavior that indicates cognitive coordination risk nor do they show a concern for fairness in the first period. The former (H1a) would lead to wholesale prices above equilibrium, while the latter (H3a) would yield wholesale prices below the equilibrium in period 1. We find no significant difference between the observed period 1 wholesale prices and the static solution price (i.e., 76) and, thus, find no strong support for either of the hypotheses.

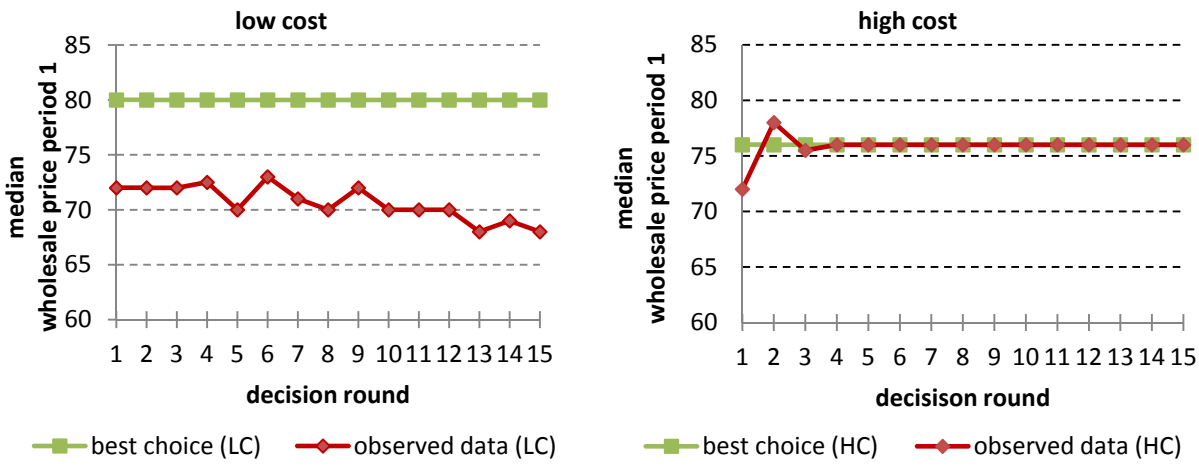


**Figure 2: Development of Period 1 Wholesale Prices**

## 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). Hence, we have no strong support for H1b and can conclude that the buyers in HC show no tendency to hedge against the suppliers' out of equilibrium price choices in period 2. Instead, it seems

that they make strategic inventory decisions that are almost perfectly in line with the non-cooperative, payoff maximizing equilibrium of the game.

**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).

The difference between observed and best response inventory sizes in LC may either be due to the buyers' perception of cognitive coordination risk (as in hypothesis H2b) or due to the buyers' concern for fairness (as in hypothesis H4b). Since the observed inventory sizes are smaller than the best response, hypothesis H2b can only hold, if we assume that buyers expect the period 2 wholesale prices to be sub-optimally low. While we cannot reject this notion formally, our analysis of the period 2 prices shows (see the next sub-section) that sub-optimally low wholesale prices are hardly observed in period 2, i.e. the period 2 prices are not significantly different from the optimal response. Hence, it seems unlikely that buyers' behavior is driven by the perception of cognitive coordination risk.

In contrast, the hypothesis on the buyers' concern for fairness in LC (H4b) is supported strongly. 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 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

[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.

significantly smaller than the best responses, but not significantly different from the "fair response " (sign test, p = 1, two-tailed).

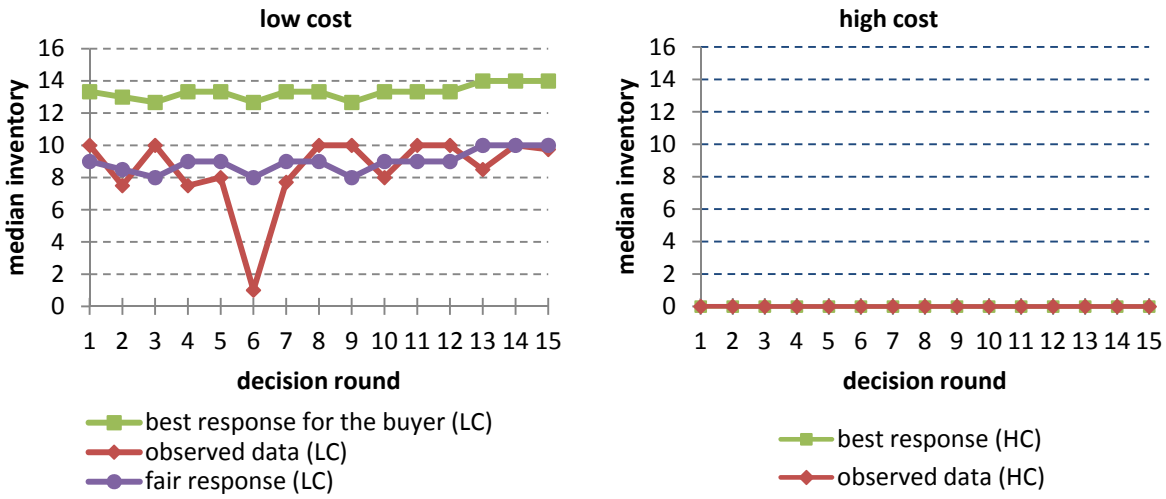


**Figure 3: Development of Inventory Quantities**

## 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.

Obviously, we find no empirical evidence for boundedly rational behavior based on cognitive limitations. It seems that the risk of coordination failure due to cognitive limitations is low in our setting, underlining the fact that the hypotheses H1 and H2 receive little support.

To test for the relevance of the hypotheses H3a and H4a, 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). Hence, we can conclude that there is no evidence for H3a ("Fairness Concern in HC"), but clear evidence for H4a ("Fairness Concern in LC").

There are two important observations to notice here. First, we only find an effect of fairness concerns in LC, but not in HC. In LC, the buyer has the possibility to reduce the supplier's payoff at a low cost in the empirically relevant range. It seems that only when the buyer is empowered to reduce the supplier's payoff, the supplier displays behavior driven by fairness considerations. Second, note that while average wholesale prices in LC are well below the static and the dynamic equilibrium levels, the entire price reduction is realized in period 1. This seems to indicate that the supplier prefers to display his "fair" behavior before the buyer takes an action, which can be related to the supplier's perception of the buyer's empowerment.

## 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 low enough, 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. In the case, in which the holding cost are prohibitively high (HC treatment), we observe no strategic inventories as predicted theoretically. Supply chain performance in this setting is neither enhanced nor impaired by the possibility to build 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.

Analyzing the behavioral mechanisms that lead to the enhancement of supply chain performance, we find little support for the impact of cognitive coordination risk on supply chain behavior. Even though the subjects are dealing with a complex interaction situation, we find no clear evidence that buyers or

suppliers are strategically hedging against the possibility of stochastic or boundedly rational behavior of the other party. Instead, we find strong support for fairness considerations influencing the supply chain behavior, but only in the low cost treatment. The 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. Buyer empowerment in the low cost setting has two consequences. First, low cost buyers frequently choose inventory sizes that are not payoff maximizing, but reduce the payoff inequality within the supply chain, because they harm the supplier more than they harm the buyer. Second, instead of simply choosing a best response to the fairness seeking behavior of the buyers, sellers tend to contribute even more to the reduction of the payoff inequality by choosing low first period prices.

The seller's willingness to reduce inequality, however, 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.

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 that sellers choose in response. Third, our results highlight that the positive effects of fair behavior in supply chains 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 important to examine, whether the optimal contract is strategically feasible and behaviorally robust. In addition, the role of information asymmetries, especially regarding the inventory size, should be further investigated 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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# Appendix

## Appendix A:

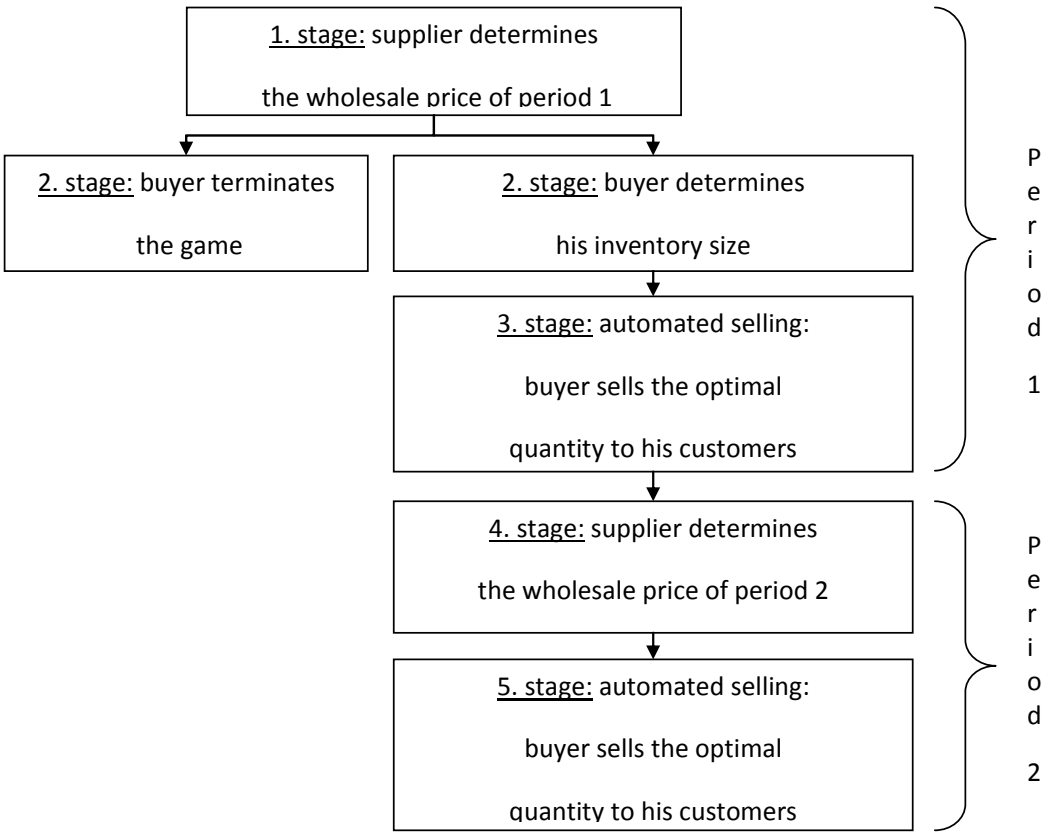
## Instructions

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 at 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 non-displayed prices a provided profit calculator can be used.

| | | |
|---|---|---|
| | 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 the period one the buyer is informed about the current wholesale price. Then, the buyer can decide whether he continues or terminates 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 |
| wholesale price period 1 | 0 | | | | | |
| | 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 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:

| Inventory 0 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 5 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 10 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 15 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 20 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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:

| Inventory 0 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 5 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 10 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 15 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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 |

| Inventory 20 | | Wholesale Price Period 2 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 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[5], according to (2) the relevant profit function of the buyer is:

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

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

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

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:

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

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

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

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

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:

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

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

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

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