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# Price-setting power versus private information: An experimental evaluation of their impact on holdup.\*

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## Abstract

This paper investigates the extent of the holdup underinvestment problem in a buyer-seller relationship in which the seller has private information about his alternative trading opportunities. Theory predicts that, compared with a situation in which outside options are publicly observed, the seller obtains an informational rent while the buyer bears an informational loss. As a result the seller is predicted to invest more while the buyer is expected to invest less. In contrast to these predictions, private information appears to have no impact on the investment levels observed in the experiment. A second main finding is that investments do increase with the price-setting power of the investor. Overall the results question some recent theoretical suggestions that private information rents might substitute for price-setting power in mitigating holdup.

## 1 Introduction

When a party makes a relationship-specific investment, this investment is at risk because the other party may terminate the relationship. Anticipating that she may be unable to reap the full return, the investor will invest less than the efficient level. This is the well-known holdup underinvestment problem. It is considered to be of central importance in a wide variety of economic contexts (cf. Klein et al. 1978, Williamson 1985). For example, it provides the main ingredient for the property rights theory of the firm; see Hart (1995) for an overview.

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Most existing theoretical work analyses the holdup problem under the assumption of symmetric (and typically complete) information. This carries over to the experimental studies in the field. In reality, however, the contracting parties usually possess some private information, and this may have important implications for holdup. Malcomson (1999, p. 2333) for instance notes that:

“...in some cases at least, a firm will not know the value of the employee’s outside option  $w(s)$ , if only because it does not know how much the employee enjoys this job relative to others. Similarly, an employee may not know the value of the firm’s outside option  $\pi(I, s)$ . Little is known about hold-up and renegotiation under these circumstances.”

Intuitively the impact of private information on holdup seems quite clear. Private information yields the informed party an informational rent, while the uninformed party bears an informational loss. This boosts the investment incentives of the informed party and weakens those of the uninformed party. Some theoretical contributions indeed indicate that holdup is less severe when the investor is better informed. Gul (2001), for example, shows that the holdup problem disappears when the investor is privately informed about the actual investment made and (only) the non-investor makes frequently repeated offers.<sup>1</sup> In his model the creation of private information rents induces efficient investment incentives. The analysis in Malcomson (1997) suggests that similar results can be expected when the investor has private information about its alternative trading opportunities (rather than about the investment made). The private information rent that he so obtains may alleviate holdup. The downside of course is that the other party, who now has an informational disadvantage, then has less incentives to invest.

The theoretical literature thus suggests that investment incentives under private information are quite different from those under public information and, moreover, that private information itself can serve as an effective instrument in alleviating holdup. Indeed, one objective of Gul (2001, p. 344) is:

“...to emphasize the role of allocation of information as a tool in dealing with the hold-up problem. Audits, disclosure rules or privacy rights could be used to optimize the allocation of rents and guarantee the desired level of investment. Controlling the flow of information may prove to be a worthy alternative to controlling bargaining power in designing optimal organizations.”

Rogerson (1992) and Lau (2002) similarly suggest that private information rents might substitute for bargaining power in mitigating holdup. This paper addresses

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<sup>1</sup>See also Konrad (2001), Lau (2002) and Tirole (1986, Proposition 3) for settings in which the specific investment itself is private information.

the empirical validity of this suggestion by means of a controlled laboratory experiment. In particular, the experiment studies the impact of both (i) price-setting power and (ii) private information about outside options on investment behavior.

Only a few other experiments on holdup under asymmetric information have been conducted. Inspired by the theoretical predictions of Gul (2001), Sloof et al. (2002) compare two treatments. In the control treatment the non-investor dictates the division of a surplus which is created by an *observable* investment. Here no investment is predicted. In another – *unobservable* investment – treatment only the investor knows the actual investment made, and thus the size of the surplus that can be divided. Here investment is predicted to occur with positive probability. The main conclusion the authors obtain is that subjects do invest more when the investment is private information (as standard theory predicts), but that they only do so when fairness and reciprocity considerations provide only weak incentives to invest (i.e. when investment costs are high).

Ellingsen and Johannesson (2002b) consider a setting in which the investor makes an ultimatum offer about how to divide the (observable) surplus created by her investment. In one treatment the investor is privately informed about the costs of investment, in two other treatments these costs are publicly observed. Standard predictions are exactly the same in the three treatments; the investor invests efficiently and obtains the complete surplus. The authors indeed find that investment rates do not differ significantly across treatments.<sup>2</sup>

The essential difference between the current experiment and these previous ones is that we consider a situation in which parties may have private information about their outside opportunities, rather than about the investment made. As illustrated by the quote from Malcomson in the second paragraph, this is a particularly interesting and relevant situation to consider. Another important difference is that we also consider the impact of variations in the investor’s bargaining (price-setting) power on investment incentives.

The remainder of this paper is organized as follows. In the next section we present a simple model on which our experiment is based. This section also derives the equilibrium predictions regarding the impact of price-setting power and private information on investment behavior. Section 3 provides the details of the experimental design and formulates the hypotheses that are put to the test. Results are discussed in Section 4. The final section summarizes our main findings and concludes.

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<sup>2</sup>Hackett (1994) and Oosterbeek et al. (1999) also include a treatment in which investors have private information about the actual investment made. Theoretically private information should not matter in their respective setups, and that is basically what they observe in the experiments.

## 2 Theory

### 2.1 The economic environment

Two risk neutral parties, viz. a female buyer and a male seller, may trade one unit of a particular good. The seller has an alternative trading opportunity denoted  $s$ , with  $s$  unknown at the start of the relationship. We assume that this outside option is distributed according to a continuous and (twice) differentiable c.d.f.  $F(s)$ , with strict positive density  $f(s) > 0$  on the complete support  $[s_l, s_h]$  (with  $s_h > s_l \geq 0$ ). The expected value of  $s$  is denoted  $E[s]$ .

Production costs are normalized to zero.<sup>3</sup> When the seller trades with the original buyer the surplus gross of investment and opportunity costs equals  $R(I)$ . Here  $I$  denotes the specific investment made by either the buyer or the seller. We assume that  $R(I)$  is monotonically increasing and strictly concave:  $R'(I) > 0$  and  $R''(I) < 0$ , where primes denote derivatives. Moreover, we assume that  $R'(0) > 1$  and  $R'(I) \rightarrow 0$  for  $I \rightarrow \infty$ .

Our main interest lies in investment incentives. The efficient level of investment follows from maximizing net social surplus  $S(I)$ :

$$\begin{aligned} S(I) &= F[R(I)] \cdot R(I) + (1 - F[R(I)]) \cdot E[s \mid s > R(I)] - I \\ &\equiv G(I) - I \end{aligned} \quad (1)$$

Here  $G(I)$  is defined as social surplus gross of investment costs. Differentiating the above expression we obtain:

$$\begin{aligned} \frac{\partial S(I)}{\partial I} &= f[R(I)] \cdot R'(I) \cdot R(I) + F[R(I)] \cdot R'(I) - R(I) \cdot f[R(I)] \cdot R'(I) - 1 \\ &= F[R(I)] \cdot R'(I) - 1 \end{aligned}$$

In order to allow for holdup and to facilitate comparison of equilibrium investment levels with a clear cut benchmark, we assume that the efficient investment level is positive and unique.

**Assumption 1.**  $F[R(0)] \cdot R'(0) > 1$ .

**Assumption 2.**  $\frac{\partial}{\partial I} (F[R(I)] \cdot R'(I)) < 0$ .

Assumption 1 implies that necessarily  $R(0) \geq s_l$ , i.e. separation is never efficient when  $s = s_l$ . This is sufficient for the efficient level of investment to be strictly positive. (From  $R'(I) \rightarrow 0$  as  $I \rightarrow \infty$  it follows that the efficient investment

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<sup>3</sup>Formally our model is equivalent to one in which the seller has no alternative trading opportunity, but his costs of production are equal to  $s \in [s_l, s_h]$ , see Gibbons (1992, p. 159). The outside trading opportunity in our setup just reflects opportunity costs.

level is finite.) Assumption 2 guarantees a unique solution  $I_{eff}$  to the first order condition:

$$F[R(I)] \cdot R'(I) = 1 \quad (2)$$

When  $s \leq R(I)$  efficiency requires that the seller and the buyer trade with each other. In case  $s > R(I)$ , separation is efficient. The term  $F[R(I)]$  in equation (2) reflects the probability that the specific investment indeed pays off. The efficient level of investment is an increasing function of this probability.

To facilitate the equilibrium analysis we also make the following regularity assumption concerning the distribution of types:

**Assumption 3.** The distribution  $F(s)$  is log-concave, i.e.  $\left[\frac{F(s)}{f(s)}\right]' \geq 0$ .

Log-concavity is a standard and fairly mild assumption. For example, the uniform, normal and exponential distribution are all log-concave; see Bagnoli and Bergstrom (1989) for a full discussion and overview.

## 2.2 The strategic situation

Buyer and seller are assumed to play the following sequential-moves game:

1. *Investment stage.* Either the buyer or the seller chooses the investment level  $I$ . Investment costs, equal to  $C(I) = I$ , are borne by the investor;
2. *Information stage.* Nature draws the type of seller, i.e. the value of his outside option  $s \in [s_l, s_h]$ , according to c.d.f.  $F(s)$ . The seller observes nature's draw of  $s$ , the buyer does so with probability  $1 - q \in [0, 1]$ ;
3. *Offer stage.* One of the parties makes a take-it-or-leave-it price proposal to the other party. The identity of the proposer is drawn by nature. With probability  $\alpha_B \in [0, 1]$  the buyer makes a price offer to the seller, with probability  $\alpha_S = 1 - \alpha_B$  the seller formulates a price demand;
4. *Trading stage.* The responder accepts or rejects the proposer's price proposal. In the first case trade takes place with the original buyer at the agreed price, in the second case the seller trades with an outside buyer at price  $s$ .

In fact various different situations are considered that differentiate along three dimensions. The first one concerns the identity of the investor. We consider both the case in which the buyer invests and the one in which the seller does so. The second dimension relates to the amount of information the buyer has about the seller's type. Like in Lau (2002), parameter  $q$  measures the degree of information asymmetry between the buyer and the seller. The larger  $q$ , the less likely it becomes that also the buyer is informed on the seller's outside option.

The theoretical analysis is performed for any possible value of  $q$  within the unit interval. In the experiment we will look at the two border cases, i.e. the common information case in which both agents become informed in stage 2 ( $q = 0$ ) and the private information situation in which only the seller becomes informed of his type ( $q = 1$ ).<sup>4</sup> The third dimension is given by the price-setting power  $\alpha_B$  of the buyer. Again the theoretical analysis applies for any  $\alpha_B \in [0, 1]$ . Yet in the experiment we focus on the two extreme cases of seller-sets-price ( $\alpha_B = 0$ ) and buyer-sets-price ( $\alpha_B = 1$ ) respectively.

In the next subsection we solve for the perfect Bayesian Nash equilibria. The main predictions that follow from the analysis, in particular those with respect to the equilibrium investment levels, are summarized in Subsection 2.4. Readers who are not interested in the precise derivations can directly turn to this.

### 2.3 Equilibrium analysis

**Trading behavior** Consider trading stage 4. When the seller acts as responder he trades with the original buyer whenever  $P_B \geq s$ , i.e. whenever the buyer's price offer  $P_B$  at least matches the seller's actual outside option.<sup>5</sup> Otherwise he goes to an outside buyer. In case the buyer responds to price demand  $P_S$  of the seller, she will accept whenever  $P_S \leq R(I)$ .

**Offer behavior** First consider the case in which the seller makes a price demand. The maximum price he can obtain from the original buyer equals  $R(I)$ , the most he can get from an outside buyer equals  $s$ . Hence his equilibrium demand equals:

$$P_S^* = \max\{s, R(I)\} \quad (3)$$

In case the buyer formulates a price proposal, her offer depends on whether she is informed on  $s$  or not. When she observes  $s$ , which happens with probability  $1 - q$ , she chooses  $P_B^* = s$  whenever  $s \leq R(I)$ . In case  $s > R(I)$  the buyer simply makes some offer that the seller refuses for sure. Without loss of generality we assume that she offers  $P_B^* = R(I)$  in that case. An informed buyer thus offers:

$$P_B^* = \min\{s, R(I)\} \quad (4)$$

When the buyer does not observe the exact value of  $s$ , which occurs with probability  $q$ , she cannot simply match the seller's outside option. Her equilibrium

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<sup>4</sup>Our setup in which the outside option of only one of the parties is private information corresponds to the one considered in Section 7.1 in Malcomson (1997). Fudenberg et al. (1987) consider a setting in which a seller bargains with a buyer that has a valuation unknown to the seller. The seller has the outside opportunity to go to a different buyer whose valuation is unknown to both the seller and the current buyer. Hence the seller and the current buyer are incompletely but equally well informed about each others outside opportunities.

<sup>5</sup>Our tie-breaking assumption that the seller trades with the original buyer when  $P_B = s$  is inessential for our results.

price offer then follows from:

$$\max_P F(P) \cdot (R(I) - P)$$

Clearly this price offer depends on the actual investment  $I$  made. Let  $p(I)$  denote the equilibrium price offer the uninformed buyer makes. Assuming an interior solution ( $s_l < P < s_h$ ), the first order condition yields that:

$$p(I) = R(I) - \frac{F(p(I))}{f(p(I))} \quad (5)$$

From Assumption 1 we have that  $F(R(I)) > 0$ . Therefore necessarily  $p(I) < R(I)$ . In choosing her price offer the uninformed buyer faces a tradeoff between a loss of profitable trades and a loss on actual trades realized. Her equilibrium pricing strategy is such that in some instances her offer is too low for trade to occur, although profitable trades do exist ( $p(I) < s \leq R(I)$ ). In this case private information thus creates inefficient separations, like in Hall and Lazear (1984). In other instances her price offer is too high ( $p(I) > s$ ), in the sense that a lower offer would already keep the seller in the relationship. The tradeoff between a loss of profitable trades and a loss on actual trades realized has important implications for investment incentives under asymmetric information (i.e.  $q > 0$ ). In particular, Assumption 3 implies that  $p'(I) > 0$ . Ex ante investments thus can be used to increase the price offer of an uninformed buyer.

**Investment behavior** First consider the case in which the buyer invests. Given the equilibrium trading and pricing strategies, the buyer's expected payoff from investment level  $I$  equals:

$$\pi_B(I) = \alpha_B \cdot (1 - q) \cdot [G(I) - E[s]] + \alpha_B \cdot q \cdot [F(p(I)) \cdot (R(I) - p(I))] - I \quad (6)$$

Only when the buyer formulates the price offer herself, she can capture some share of the gross social surplus  $G(I)$ . This happens with probability  $\alpha_B$ . The exact share she then obtains depends on whether she becomes informed on the seller's outside option  $s$  or not. The former occurs with probability  $1 - q$ , the latter with probability  $q$ . An informed buyer can get a share equal to  $G(I) - E[s]$ , an uninformed buyer uses equilibrium price strategy  $p(I)$  and obtains  $F(p(I)) \cdot (R(I) - p(I))$  in expectation. This explains the first two terms on the r.h.s. in (6). Irrespective of the division of the gross surplus, the buyer bears the costs of investment, explaining the third term.

The difference between the share an informed buyer gets and the share an uninformed buyer obtains can be decomposed as follows:

$$\begin{aligned} \Delta(I) &\equiv [G(I) - E[s]] - [F(p(I)) \cdot (R(I) - p(I))] \\ &= [F(R(I)) - F(p(I))] \cdot [R(I) - E[s \mid p(I) < s \leq R(I)]] \\ &\quad + F(p(I)) \cdot [p(I) - E[s \mid s \leq p(I)]] \end{aligned} \quad (7)$$

The difference in shares gives the reduction in the buyer's expected payoffs owing to the outside option being private information to the seller. It consists of two components. The first one reflects the loss of profitable trades. In case  $p(I) < s \leq R(I)$ , profitable trades do exist, but the price offer of the uninformed buyer is too low for trade to occur. The second component represents the loss on actual trades realized. For  $p(I) \geq s$  trade occurs, but the buyer pays too high a price because  $p(I) = s$  would already be sufficient to keep the seller in the relationship. Using  $\Delta(I)$ , the buyer's expected payoffs can be rewritten as follows:

$$\pi_B(I) = \alpha_B \cdot [G(I) - E[s]] - \alpha_B \cdot q \cdot \Delta(I) - I \quad (8)$$

The term  $\alpha_B \cdot q \cdot \Delta(I)$  can be defined as the buyer's *informational loss*. Note that this informational loss is increasing in both  $\alpha_B$  and  $q$ . Moreover, from the envelope theorem it follows that:

$$\frac{\partial \Delta(I)}{\partial I} = [F(R(I)) - F(p(I))] \cdot R'(I) > 0 \quad (9)$$

The informational loss thus also increases with the investment made. Hence its presence in general weakens investment incentives.

Differentiating expression (8) it follows that the first order condition for the buyer's equilibrium investment level  $I_B^*(\alpha_B, q)$  becomes:

$$\alpha_B \cdot R'(I) \cdot \{F[R(I)] - q \cdot [F(R(I)) - F(p(I))]\} = 1 \quad (10)$$

Without additional assumptions the solution to (10) need not be unique.<sup>6</sup> Still, some observations of interest can be made. First, when  $\alpha_B = 1$  and  $q = 0$  the above equality reduces to (2), such that  $I_B^*(1, 0) = I_{eff}$ . For all other values of  $\alpha_B$  and  $q$  the equilibrium investment level is necessarily below the efficient one (cf. Assumption 2). Second, for  $\alpha_B = 0$  we obtain  $I_B^*(0, q) = 0$ . This suggests that  $I_B^*(\alpha_B, q)$  is increasing in the buyer's price-setting power  $\alpha_B$ . Third, the term within curly brackets is highest for  $q = 0$ . Together with Assumption 2 this implies that  $I_B^*(\alpha_B, q) \leq I_B^*(\alpha_B, 0)$  for any value of  $q$ . This suggests that  $I_B^*(\alpha_B, q)$  is decreasing in the degree of information asymmetry  $q$ .

When the seller makes the investment his expected payoffs are given by:

$$\pi_S(I) = E[s] + \alpha_S \cdot [G(I) - E[s]] + (1 - \alpha_S) \cdot q \cdot (F(p(I)) \cdot [p(I) - E[s | s \leq p(I))]) - I \quad (11)$$

The seller can always secure his outside option value, thus  $E[s]$  in expectation. In case the seller sets the price himself, he is residual claimant of the remaining surplus, explaining the second term. The third term represents the *informational*

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<sup>6</sup>Given Assumption 2, assuming that  $\frac{\partial}{\partial I} (F[p(I)] \cdot R'(I)) < 0$  would be sufficient for uniqueness.

rent the seller obtains. This rent is increasing in  $\alpha_B (= 1 - \alpha_S)$ ,  $q$  and  $I$ . The first order condition for the seller's equilibrium investment level  $I_S^*(\alpha_B, q)$  equals:

$$\alpha_S \cdot F[R(I)] \cdot R'(I) + (1 - \alpha_S) \cdot q \cdot F[p(I)] \cdot p'(I) = 1 \quad (12)$$

In case  $\alpha_S \equiv 1$ , i.e.  $\alpha_B = 0$ , the above condition reduces to (2). In that case  $I_S^*(0, q) = I_{eff}$ . For all other values  $\alpha_B > 0$  it follows from Assumptions 2 and 3 that  $I_S^*(\alpha_B, q) < I_{eff}$ . In particular, for  $\alpha_B = 1$  and  $q = 0$  it holds that  $I_S^*(1, 0) = 0$ . This suggests that  $I_S^*$  decreases with  $\alpha_B$ . Finally,  $I_S^*(\alpha_B, q) \geq I_S^*(\alpha_B, 0)$  for any  $q$ , suggesting that informational rents in general boost investment incentives.

In all situations the equilibrium investment level is (weakly) below the efficient one. The extent of the underinvestment problem depends on the investor's price-setting power and his/her informational (dis)advantage. In general it holds that (i) price-setting power boosts investment incentives, (ii) that the presence of an informational loss weakens the buyer's investment incentives, and (iii) that the seller's informational rent strengthens his investment incentives. However, equilibrium investment levels are not necessarily monotonic in  $\alpha_B$  and  $q$ . To illustrate, consider the case in which the buyer invests and focus on variations in  $\alpha_B$ . The payoffs to the buyer depicted in (8) are equal to her payoffs under common information (i.e.  $q = 0$ ) minus the informational loss. Solely focusing on the first component, investment levels should increase with  $\alpha_B$ . Yet the informational loss increases with  $\alpha_B$ , and this may weaken investment incentives. When the latter effect dominates the former, the buyer's investment may actually decrease with  $\alpha_B$  (over some interval). In a similar vein, when the seller gets more price-setting power his informational rent decreases. The latter adversely affects his investment incentives and may even dominate the direct impact of more price-setting power.

For specific type-distributions  $F(s)$  unambiguous comparative statics in  $\alpha_B \in [0, 1]$  and  $q \in [0, 1]$  can be obtained.

**Assumption 4.**  $F(s)$  is uniform on  $[s_l, s_h]$ .

Under Assumption 4 it holds that  $I_B^*(\alpha_B, q)$  is (monotonically) increasing in  $\alpha_B$  and decreasing in  $q$ , while  $I_S^*(\alpha_B, q)$  is decreasing in  $\alpha_B$  and increasing in  $q$ .<sup>7</sup> More price-setting power then always strengthens investment incentives, just like informational rents do. Informational losses adversely affect investment incentives.

## 2.4 Equilibrium predictions

The equilibrium investment level is (weakly) below the efficient one. The extent of underinvestment depends on the investor's price-setting power and on the degree

<sup>7</sup>In this case  $p(I) = \min\{\frac{R(I)+s_l}{2}, s_h\}$ . Together with Assumption 2, this implies that  $F[p(I)] \cdot R'(I)$  and  $F[p(I)] \cdot p'(I)$  are decreasing in  $I$ . The result now follows from the first order conditions (10) and (12).

of information asymmetry. The analysis of the previous subsection results in the following comparative statics predictions:

- P1** (a)  $I_B^*(0, q) = 0$  and  $I_B^*(\alpha_B, q)$  is decreasing in  $q \in \{0, 1\}$  for  $\alpha_B > 0$ ;  
(b)  $I_S^*(0, q) = I_{eff}$  and  $I_S^*(\alpha_B, q)$  is increasing in  $q \in \{0, 1\}$  for  $\alpha_B > 0$ ;
- P2** (a)  $I_B^*(\alpha_B, q)$  is increasing in  $\alpha_B \in \{0, 1\}$ ;  
(b)  $I_S^*(\alpha_B, q)$  is decreasing in  $\alpha_B \in \{0, 1\}$ .

Under Assumptions 1 through 3 unambiguous comparative statics predictions in  $\alpha_B$  and  $q$  are obtained when we only consider the extreme cases  $\alpha_B = 0$  versus  $\alpha_B = 1$  and  $q = 0$  versus  $q = 1$ . In general this does hold for the full range of  $\alpha_B$  and  $q$ . Therefore we use the set  $\{0, 1\}$  rather than the unit interval  $[0, 1]$  in the above predictions. However, when the type distribution  $F(\cdot)$  is uniform, investment levels are monotonic in both  $\alpha_B$  and  $q$  over the full range  $[0, 1]$ .

The first prediction concerns the impact of private information. When the buyer is uninformed, which happens with probability  $q$ , she bears an informational loss whenever she can make a price offer (which occurs with probability  $\alpha_B$ ). This informational disadvantage leads to smaller possibilities for rent extraction. As a result the buyer has less incentives to invest when it becomes more likely that she is uninformed. For the seller the effect is in the opposite direction. He obtains better possibilities for rent extraction and thus stronger incentives to invest.<sup>8</sup> The second prediction concerns the effect of variations in price-setting power. The investor is predicted to invest more when s/he obtains more price-setting power.

According to Prediction P2 price-setting power can be used as an effective instrument in mitigating holdup. Prediction P1(b) suggests that informational rents provide an alternative instrument. The impact of both price-setting power and private information on investment incentives is the focus of our experiment.

### 3 Experimental design and hypotheses

This section consists of three parts. The first subsection discusses the choice of parameter values. The next subsection summarizes the hypotheses obtained from the equilibrium predictions. The final subsection gives an overview of the experimental treatments and sessions.

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<sup>8</sup>Only when  $\alpha_B = 0$  the buyer never gets to make a price offer, and investment incentives are predicted to be independent of the information structure represented by  $q$ .

### 3.1 Setup of the experimental game

We use the following parameterization. The gross surplus is equal to  $R(I) = 4000 + 100 \cdot I$  and investment costs are  $C(I) = I^2$ . In contrast to the theoretical setup of Section 2, we thus have quadratic investment costs and do not measure investments in money terms. We do so only for ease of presentation to the subjects. Note that this is nothing but a normalization; subjects choose  $\sqrt{I}$  rather than  $I$  in the context of the model of Section 2. Investment choices are restricted to integer values between 0 and 80.

For the outside option value  $s$  we employ a two-type distribution. We either have  $s = s_l = 0$  or  $s = s_h = 4000$ , both with equal probabilities:  $\Pr(s = 4000) = \frac{1}{2}$ . In this case the price offer of the uninformed buyer equals either  $p(I) = 0$  or  $p(I) = 4000$ . Her choice is governed by the tradeoff between a loss owing to lost trades (when  $p(I) = 0$  and actually  $s = 4000$ ) and a loss on actual trades realized (when  $p(I) = 4000$  and actually  $s = 0$ ). The equilibrium offer is such that one of these two losses necessarily vanishes. This does not necessarily apply with more than two types. Then balancing the two losses may imply that the uninformed buyer chooses some in-between price  $s_l < p(I) < s_h$ , in the continuous case governed by first order condition (5). In this sense the buyer's price offer decision, and in turn the investment decision, is much simpler in the two-type case.

Our main interest lies in how investment levels vary with the degree of information asymmetry  $q$  and the buyer's price-setting power  $\alpha_B$  (cf. Predictions P1 and P2). In order to keep the experimental setup as simple as possible we focus on the polar cases of these two variables. In particular, with respect to the information asymmetry we consider the Common information case in which both agents become informed in stage 2 ( $q = 0$ ) and the Private information situation in which only the seller becomes informed of his type ( $q = 1$ ). Apart from that, we look at both the seller-sets-price ( $\alpha_B = 0$ ) case and the buyer-sets-price ( $\alpha_B = 1$ ) case. By restricting  $\alpha_B$  and  $q$  to  $\{0, 1\}$ , the only stochastic element for the subjects involves the value of the outside option  $s$ . Table 1 summarizes the various situations considered (together with the predicted investment levels, see below). For ease of future reference they are labeled after the identity of the investor (B or S) and the type of information (C or P). The third dimension is accounted for through parameter  $\alpha_B \in \{0, 1\}$ .

From  $s \leq R(0)$  it follows that separation is never efficient. The efficient level of investment is thus easily calculated from  $R(I)$  and the costs of investment  $I^2$ . We have  $I_{eff} = 50$ . This level is used as benchmark to determine the extent of the underinvestment problem.

## 3.2 Hypotheses

In the experiment we use a two-type distribution of seller types, while Section 2 assumes a continuum of types. Equilibrium predictions thus do not immediately follow from the formal analysis presented there, yet these are easily derived. Trading and offer behavior is as described in Subsection 2.3, except for the price offer  $p(I)$  of an uninformed buyer. Here the relevant choice for the buyer is between a low price of 0 and a high price of 4000. Choosing  $p(I) = 0$  yields the buyer  $\frac{1}{2} \cdot (4000 + 100 \cdot I)$ , while  $p(I) = 4000$  gives her  $100 \cdot I$ .<sup>9</sup> It follows that the buyer's equilibrium offer under private information ( $q = 1$ ) equals:

$$\begin{aligned} p(I) &= 0 && \text{when } I < 40 \\ p(I) &= 4000 && \text{when } I \geq 40 \end{aligned} \tag{13}$$

In all other cases the price-setter is residual claimant and puts the other party on his/her outside option. Given these pricing strategies, it is straightforward to calculate the equilibrium investment levels in the different situations. These are summarized in Table 1. The predicted investment levels lead to the following two comparative statics hypotheses:

- H1** (a) When the seller sets the price ( $\alpha_B = 0$ ), investments are independent of the information condition. (b) In the buyer-sets-price case ( $\alpha_B = 1$ ), the buyer invests less and the seller invests more under private information ( $q = 1$ ).
- H2** For a given information structure, the buyer's investment is increasing in  $a_B$  and the seller's investment is decreasing in  $a_B$ .

The first hypothesis concerns the impact of private information on investment incentives. Theoretically the information asymmetry should matter only when the buyer gets to make the price offer. Then, making the seller privately informed on his outside option  $s$  strengthens his investment incentives and weakens those of the buyer. The second hypothesis considers variations in price-setting power of the buyer. When the investor gets more price-setting power, s/he is predicted to invest more. By testing these two hypotheses we investigate the effectiveness of both price-setting power and informational rents as instruments in alleviating holdup.

## 3.3 Treatments and sessions

The experiment is based on a  $2 \times 2 \times 2$  design. In each session we kept the identity of the investor and the information structure fixed. A session thus either

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<sup>9</sup>At the time of the pricing decision, investment costs are already sunk and do not affect the equilibrium pricing strategy. The low price leads to a loss of profitable trades equal to  $\frac{1}{2} \cdot (100 \cdot I)$ , the high price brings about a loss on actual trades realized of  $\frac{1}{2} \cdot (4000) = 2000$ .

Table 1: Equilibrium investment levels

	Common information ( $q = 0$ )	Private information ( $q = 1$ )
Buyer invests	$BC :$	$BP :$
$\alpha_B = 0$	0	0
$\alpha_B = 1$	50	25
Seller invests	$SC :$	$SP :$
$\alpha_B = 0$	50	50
$\alpha_B = 1$	0	40

*Remark:* The efficient level of investment equals 50.

considered the  $BC$ -case, the  $SC$ -case, the  $BP$ -case or the  $SP$ -case (cf. Table 1). We ran two sessions for each of these four cases, such that we had eight sessions in total. All subjects within a session were confronted with both values of  $\alpha_B$ . Overall 160 subjects participated in the experiment, with 20 participants per session. The subject pool consisted of the undergraduate student population of the University of Amsterdam. Most of them were students in economics. They earned on average 26.50 euros in less than two hours.

Each session contained 32 rounds. We employed a block structure of rounds to control for both learning and order effects. In particular, the 32 rounds were divided into four blocks of eight rounds. Within each block the identity of the price-setter was kept fixed. In one out of the two sessions per situation considered we used the 'upward'-order ( $\alpha_B = 0, \alpha_B = 1, \alpha_B = 0, \alpha_B = 1$ ). In the other session we employed the opposite 'downward' order of ( $\alpha_B = 1, \alpha_B = 0, \alpha_B = 1, \alpha_B = 0$ ). By making within-session comparisons between the two blocks that considered the same value of  $\alpha_B$  we could test for learning effects.<sup>10</sup> Using across-session comparisons between the two different orders we could also control for order effects. The start of every new block and the change of  $\alpha_B$  were both verbally announced and shown on the computer screen.

Subject roles' varied over the rounds. Within each block of eight rounds each subject had the role of buyer exactly four times, and the role of seller also four times. The experiment used a stranger design. Subjects were anonymously paired and their matching varied over the rounds. Within each block subjects could meet each other only once. Subjects were explicitly informed about this. Moreover, within a session we divided the subjects into two separate groups of

<sup>10</sup>In the  $BP$ -case buyers were informed on the seller's outside option  $s$  at the end of each round (i.e. after stage 4). Learning possibilities are thus equal in all treatments.

ten subjects. Matching of pairs only took place within these groups. We did this to generate two independent aggregate observations per session.

To enhance comparability, the empirical distribution of the outside option  $s$  was exactly the same over the different groups and sessions. We used an empirical distribution that in the aggregate exactly matched the theoretical distribution, yet contained sufficient variation over the individual subjects. We also used a common endowment of 20,000 points as show up fee. The conversion rate was 1 euro for 4000 points. All subjects thus started with a sufficient cash balance that enabled them to make investments in the first couple of rounds without immediately running into a debt.

The experiment was computerized. Subjects started with on-screen instructions. Before the experiment started all subjects first had to answer a number of control questions correctly. Subjects also received a summary of the instructions on paper (see Appendix A). At the end of the experiment subjects filled out a short questionnaire and the earned experimental points were exchanged for money. Subjects were paid individually and discreetly.

## 4 Results

In presenting the results of our experiment we pool the data from the sessions that differ only in the order of the  $\alpha_B$ 's. Although some order effects can be detected, these appear to be only minor (see Appendix B for details). Further aggregations are not possible, as it appears that behavior evolves over time (cf. Appendix B). Most findings are therefore reported separately for the first and second half of the experiment.

### 4.1 Investment levels

In the experiment the 32 rounds are divided into four blocks of 8 rounds. Within each block subjects have the role of investor four times. For each subject we calculate for each block his/her mean investment level based on 4 investment decisions. Statistical tests can then be based on a comparison of these *individual mean* investment levels. In addition we perform our tests on the group level data. As discussed in Section 3 we divided the 20 subjects within a session into two groups that were independently matched. We thus have in each session two independent observations at the aggregate group level and we can compare the *group mean* investment levels (based on 40 investment decisions) across treatments. In the sequel we base our inferences on the results of both types of tests. If not stated otherwise, a significance level of 5% is employed.

The first result compares mean investment levels across information conditions (cf. Hypothesis H1).

Table 2: Mean investments by treatment and tests for equality

	first: rounds 1-16			second: rounds 17-32		
	Common	Private	C vs. P	Common	Private	C vs. P
Buyer invests						
$\alpha_B = 0$	30.48	29.0	0.6335	25.34	25.39	0.6157
	[0]	[0]	1.0000	[0]	[0]	1.0000
$\alpha_B = 1$	45.21	42.78	0.4800	47.29	43.91	0.1502
	[50]	[25]	0.2000	[50]	[25]	0.2000
0 vs. 1	0.0000	0.0000		0.0000	0.0000	
Seller invests						
$\alpha_B = 0$	38.38	40.04	0.3418	37.85	38.17	0.5268
	[50]	[50]	0.3429	[50]	[50]	0.8857
$\alpha_B = 1$	30.31	29.09	0.5892	27.11	21.3	0.0526
	[0]	[40]	1.0000	[0]	[40]	0.3429
0 vs. 1	0.0002	0.0000		0.0000	0.0000	

*Remark:* Theoretical predictions within square brackets. The columns denoted ‘C vs. P’ report the p-values of Mann-Whitney ranksum tests. Per comparison made the upper (lower) p-value is based on individual (group) level data. The rows labeled ‘0 vs. 1’ give the p-values of Wilcoxon signed-rank tests for matched pairs, based on individual level data.

**Result 1.** Irrespective of which party sets the price, mean investment levels are independent of the information condition.

Result 1 immediately follows from Table 2. This table reports the mean (of individual mean) investment levels by treatment and gives the test statistics for equality of these levels across treatments. It does so for the first and second half of the experiment separately. The columns ‘C vs. P’ report the  $p$ -values of comparing the common information case with the private information case by means of a two-sided ranksum test. Per comparison made the upper  $p$ -value refers to individual level data, the lower  $p$ -value to group level data. None of the comparisons yields significant differences at the 5% level. Only when  $\alpha_B = 1$  the individual level data provide some weak indication that the seller invests less under private information (here the  $p$ -value equals  $p = 0.0526$  in the second half

of the experiment). Yet this only applies when subjects have gained experience and does not hold at the aggregate group level. Moreover, from a theoretical perspective the difference is in the wrong direction.

For the seller-sets-price ( $\alpha_B = 0$ ) cases Result 1 is in line with theoretical predictions. Theory then predicts informational rents and losses to be absent, because his price-setting power already gives the seller the possibility to extract the complete surplus. For the buyer-sets-price ( $\alpha_B = 1$ ) cases Result 1 deviates from theoretical predictions. Here informational rents/losses are predicted to affect investment incentives, but this is not what we observe. Investment levels remain constant when the seller's outside option becomes private information.

Our second result considers the impact of variations in price-setting power (cf. Hypothesis H2).

**Result 2.** Mean investment levels increase with the price-setting power of the investor.

In Table 2 the rows labeled '0 vs. 1' report the  $p$ -values of comparisons between the cases  $\alpha_B = 0$  and  $\alpha_B = 1$ , based on individual level data. Because comparisons are on a within-subjects basis, we make use of a signed-rank test for matched pairs. For all situations considered differences are highly significant. In line with theoretical predictions, the investor invests more when s/he has price-setting power.<sup>11</sup> A similar conclusion is obtained from the group level data. With only four matched pairs per comparison, the smallest possible level of significance that a two-tailed signed-rank test can attain equals  $p = 0.1250$ . For each situation we then obtain a significant difference at this level between the  $\alpha_B = 0$  and  $\alpha_B = 1$  case.<sup>12</sup>

Together, Results 1 and 2 suggest that price-setting power is an effective instrument for boosting investment incentives, while informational rents are not. To illustrate, take the *SC*-case with  $\alpha_B = 1$  as a benchmark. Over all 32 rounds, sellers in that case choose an investment level of  $28\frac{1}{2}$  on average. Giving the seller price-setting power ( $\alpha_B = 0$ ) increases his investment to around 38 on average, but providing him with an informational advantage instead (*SP*-case with  $\alpha_B = 1$ ) does not affect investment levels. In the latter case the average investment level equals 25. Theory predicts that both instruments would boost

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<sup>11</sup>This conclusion is obtained by comparing the  $\alpha_B = 0$  case with the  $\alpha_B = 1$  case, while keeping the identity of the investor (and the information condition) fixed. The same conclusion is obtained when comparing the Buyer invests case with the Seller invests case, while keeping  $\alpha_B$  (and the information condition) fixed. All these comparisons yield significant differences, at both the individual and the group level (ranksum tests). In particular, for  $\alpha_B = 0$  the seller invests significantly more than the buyer does. When  $\alpha_B = 1$  this is the other way around.

<sup>12</sup>Given the restrictions on the attainable significance level, these test results are not reported in Table 3. Because theory predicts significant differences between the  $\alpha_B = 0$  and the  $\alpha_B = 1$  case, one-sided tests may be considered appropriate here. The level of significance then equals  $p = 0.625$ .

investment incentives. Our experimental findings thus question the suggestion made in the theoretical literature that private information rents might substitute for bargaining power in mitigating underinvestment.

Another observation that can be made from Table 2 is that in situations where no investment is predicted, holdup appears less of a problem than theory predicts it to be. This finding is line with earlier experimental studies that consider complete information settings. These studies indicate that a partial solution to holdup is provided by reciprocity (and fairness) considerations. Investment is typically seen as a kind act, which is therefore rewarded by the non-investor with a larger than predicted return.<sup>13</sup> Our results suggest that this informal reciprocity mechanism carries over to situations with private information about outside options. In Subsection 4.3 we return to this issue.

Given Results 1 and 2, the question of interest becomes why price-setting power does appear to work as an effective instrument against holdup, while informational rents do not. In order to answer this question, the next subsection focuses on whether actual pricing behavior can provide an explanation for this. The idea is that when actual pricing behavior deviates from predicted behavior, actual investment incentives may deviate from predicted ones as well.

## 4.2 Pricing behavior

Theory predicts that the seller proposes a higher price than the buyer does. Our first result in this subsection relates to this prediction.

**Result 3.** Proposed and accepted relative prices  $P/R(I)$  are significantly higher in the seller-sets-price case than in the buyer-sets-price case.

Within each block of 8 rounds every subject makes 4 price proposals, either in the role of seller (blocks in which  $\alpha_B = 0$ ) or as a buyer (blocks with  $\alpha_B = 1$ ). We first convert absolute prices into relative prices and calculate the fraction of price  $P$  to the actual gross surplus  $R(I)$ . Because the different treatments induced different investment levels, and thus different values of  $R(I)$ , this normalization is needed to make prices comparable across treatments. Subsequently, we calculate for every treatment the *individual mean* relative price based on 4 relative prices, and the *group mean* relative price based on 40 relative prices. We do so for proposed and accepted prices separately. Tables 3 and 4 report the overall means for proposed and accepted relative prices respectively.<sup>14</sup> Statistical tests are based

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<sup>13</sup>See e.g. Berg et al. (1995), Ellingsen and Johannesson (2000, 2002a), Gantner et al. (2001), Hackett (1993, 1994), Königstein (2000, 2001), Oosterbeek et al. (2003) and Sonnemans et al. (2001).

<sup>14</sup>In these tables the predictions for the relative prices (appearing in square brackets) are based on the actual investment levels chosen.

Table 3: Mean proposed relative prices by treatment and tests for equality

	first: rounds 1-16			second: rounds 17-32		
	Common	Private	C vs. P	Common	Private	C vs. P
Buyer invests						
$\alpha_B = 0$	.728	.742	0.5867	.756	.801	0.0189
	[1]	[1]	0.6857	[1]	[1]	0.2000
$\alpha_B = 1$	.378	.455	0.0001	.387	.465	0.0000
	[.242]	[.367]	0.0286	[.235]	[.367]	0.0286
0 vs. 1	0.0000	0.0000		0.0000	0.0000	
Seller invests						
$\alpha_B = 0$	.733	.753	0.2366	.759	.776	0.3812
	[1]	[1]	0.1143	[1]	[1]	0.4857
$\alpha_B = 1$	.483	.512	0.3240	.509	.510	0.7182
	[.302]	[.188]	0.4857	[.309]	[.069]	1.0000
0 vs. 1	0.0000	0.0000		0.0000	0.0000	

*Remark:* Predicted relative prices within square brackets. The columns denoted ‘C vs. P’ report the p-values of Mann-Whitney ranksum tests. Per comparison made the upper (lower) p-value is based on individual (group) level data. The rows labeled ‘0 vs. 1’ give the p-values of Wilcoxon signed-rank tests for matched pairs, based on individual level data.

on comparing the individual and group mean relative prices across treatments. Result 3 follows from the reported  $p$ -values in the rows ‘0 vs. 1’.<sup>15</sup>

Quite intuitive, the seller obtains a better deal when he can make the take-it-or-leave-it price offer himself. Because a party can secure a larger (relative) gain when it has more price-setting power, it obtains a higher return on investment. This explains our earlier finding that investment levels increase with the price-setting power of the investor, i.e. why price-setting power is an effective instrument against holdup

We next consider the impact of private information on pricing behavior.

<sup>15</sup>These  $p$ -values are based on individual level data. The same conclusion is obtained by looking at the group level data. As before, the smallest possible significance level that can be attained by using the aggregate data equals  $p = 0.1250$  (two-sided). For each comparison we obtain a significant difference at this level between the  $\alpha_B = 0$  and  $\alpha_B = 1$  case.

Table 4: Mean accepted relative prices by treatment and tests for equality

	first: rounds 1-16			second: rounds 17-32		
	Common	Private	C vs. P	Common	Private	C vs. P
Buyer invests						
$\alpha_B = 0$	.707	.713	0.7508	.749	.781	0.0799
	[1]	[1]	1.0000	[1]	[1]	0.4857
$\alpha_B = 1$	.384	.469	0.0001	.390	.483	0.0000
	[.233]	[.387]	0.0286	[.231]	[.386]	0.0286
0 vs. 1	0.0000	0.0000		0.0000	0.0000	
Seller invests						
$\alpha_B = 0$	.718	.735	0.6168	.752	.761	0.5866
	[1]	[1]	0.6857	[1]	[1]	0.6857
$\alpha_B = 1$	.497	.539	0.2315	.511	.555	0.0833
	[.251]	[.226]	0.3429	[.278]	[.083]	0.6857
0 vs. 1	0.0000	0.0000		0.0000	0.0000	

*Remark:* Predicted relative prices within square brackets. The columns denoted ‘C vs. P’ report the p-values of Mann-Whitney ranksum tests. Per comparison made the upper (lower) p-value is based on individual (group) level data. The rows labeled ‘0 vs. 1’ give the p-values of Wilcoxon signed-rank tests for matched pairs, based on individual level data.

**Result 4.** (a) When the seller sets the price, proposed and accepted relative prices are independent of the information condition. (b) In case the buyer sets the price, proposed and accepted relative prices (i) vary with the information condition when the buyer invests, but (ii) are independent of the information condition when the seller invests.

This finding follows from the  $p$ -values reported in the columns ‘C vs. P’ in Tables 3 and 4. Again, the upper  $p$ -value refers to individual level data, the lower  $p$ -value to group level data. For the seller-sets-price case ( $\alpha_B = 0$ ) we find no significant differences at the 5% level.<sup>16</sup> In case the buyer sets the price ( $\alpha_B = 1$ ), results depend on the identity of the investor. When the buyer made the investment all differences are significant. The buyer then proposes (and pays) a higher relative price under private information. In case the seller made the investment, relative prices are independent of the information condition.

Result 4(a) is in line with theoretical predictions.<sup>17</sup> It provides an explanation for our finding that investment levels do not vary with the information condition when the seller sets the price (as is predicted). In that case private information about the outside option  $s$  does not yield the seller additional bargaining power. Investment incentives are therefore unaffected.

In case the seller sets the price, his equilibrium offer  $P = R(I)$  induces a very unequal distribution of the gross surplus. In line with numerous ultimatum game experiments, our subjects typically arrive at a more equal distribution. In all cases mean proposed and accepted prices are around 75% of the gross surplus  $R(I)$ . This implies that the buyer obtains some return on investment and that the seller is not full residual claimant. This in turn may explain why, when  $\alpha_B = 0$ , buyers invest more and sellers invest less than predicted (cf. Table 2). In Subsection 4.3 we will investigate this.

When the buyer sets the price (Result 4(b)) private information is predicted to have an impact on pricing behavior. Specifically, the buyer’s predicted offer equals  $P = s$  in the common information case. Under private information her equilibrium price offer is governed by (13); i.e.  $P = 0$  when  $I < 40$  and  $P = 4000$  for  $I \geq 40$ . Depending on the actual investments made, one thus either expects a lower relative price offer under private information (when typically  $I < 40$ ), or a higher relative price offer (in case typically  $I \geq 40$ ). Now, when the buyer invests she chooses  $I \geq 40$  in most cases, explaining why relative prices are higher under

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<sup>16</sup>Only when the buyer invests we find a significant difference between proposed relative prices in the second half of the experiment. The  $p$ -value at the individual level equals  $p = 0.0189$  (cf. Table 4). At the aggregate group level we then do not find significant differences though.

<sup>17</sup>Theory also predicts that seller’s pricing behavior is independent of who made the investment. We can test for this by comparing the Buyer invests case with the Seller invests case, while keeping  $\alpha_B = 0$  and the information condition fixed. None of these comparisons yield significant differences (at both the individual and the group level, and performed separately for the first half and the second half of the experiment). Proposed and accepted relative prices are thus also independent of the identity of the investor.

private information (Result 4(bi)). The seller typically invests  $I < 40$ , so here one would expect lower relative prices under private information (see the predictions in square brackets in Tables 3 and 4). Result 4(bii) indicates that this is not the case.

Result 4(b) is inconclusive about why private information does not affect investment incentives when the buyer sets the price. The remainder of this subsection therefore focuses on this particular case (i.e.  $\alpha_B = 1$ ). The next result compares the buyer's proposed absolute prices with the predicted ones.

**Result 5.** Consider the buyer-sets-price case ( $\alpha_B = 1$ ). (a) Under common information the buyer gives the seller a markup that decreases with his outside option  $s$ . (b) Under private information, in around 40 – 50% of the observations with  $I < 40$  the buyer offer a price of 4000 or more.

Result 5 follows from the frequency distributions of proposed prices in Figures 1 and 2.<sup>18</sup> Figure 1 considers the common information case, Figure 2 the one with private information. In both figures the left (right) hand panel corresponds to the situation in which the buyer (seller) makes the investment. Theoretical predictions imply that the dark bars should be at a price of  $P = 0$  and the light grey bars at a price of  $P = 4000$ .

< Figures 1 and 2 >

With common information the buyer gives the seller a markup on his outside option. This is most evident in the buyer invests case, see the left hand panel of Figure 1. The average markup when  $s = 0$  is around 2000 experimental points, while for  $s = 4000$  it is around 500 points.<sup>19</sup> The actual markup is thus substantially higher for lower values of  $s$ . This also applies when the seller makes the investment, although there somewhat more variation in the actual markups is observed.<sup>20</sup> The latter has an intuitive explanation. In case the seller invests the buyer can reciprocate higher investments with higher offered prices, such that the actual markup also varies with the investment made. Such a reciprocity mechanism is absent when the buyer invests herself.<sup>21</sup>

The finding of decreasing markups is consistent with a number of other experimental studies. Knez and Camerer (1995), Binmore et al. (2002) and Sloof

<sup>18</sup>The same conclusions follow when we look at the frequency distributions of accepted prices and when we consider the first and the second half of the experiment separately.

<sup>19</sup>Specifically, the mean proposed price when  $s = 0$  equals 2019, for  $s = 4000$  this is 4478. Considering accepted prices only these numbers become 2121 and 4537 respectively.

<sup>20</sup>Mean proposed (accepted) prices equal 2409 (2492) when  $s = 0$  and 4339 (4726) for  $s = 4000$ .

<sup>21</sup>Another explanation would be that the seller typically chooses somewhat higher investment levels, allowing for a larger range of markup values.

(2002), for instance, include ultimatum game treatments with varying outside option values. They all observe that the larger the outside option of the responder, the smaller the markup s/he receives in the actual bargaining.<sup>22</sup> A common sense explanation, alluded to in these papers, is that subjects are guided by notions of fairness and reciprocity. Indeed, the inequity-aversion model of Fehr and Schmidt (1999), for example, can explain the presence of markups that decrease with the responder's outside option (cf. Sloof 2002).

The most striking observation for the private information case is that in around 40 – 50% of the cases where  $I < 40$ , buyers offer a price of 4000 or more (cf. Result 5(b)).<sup>23</sup> Here standard theory predicts that they would offer  $P = 0$  instead. One potential explanation is that buyers are risk averse. Another explanation is provided by the observation made above that the seller requires a markup which is higher for low values of  $s$ . This affects the buyer's optimal pricing strategy. To illustrate, suppose that the buyer effectively chooses between two prices:  $P_l = s_l + M = M$  and  $P_h = s_h + m = 4000 + m$ . Here  $M$  denotes the required markup to induce the seller of type  $s = s_l$  to accept the low price  $P_l$ , while  $m$  gives the required markup for the high type  $s = s_h$ . Price  $P_l$  is accepted by the low type only,  $P_h$  is accepted by both types. (It is thus assumed that  $M < 4000 + m$ .) Under private information the buyer's optimal pricing strategy then becomes:

$$\begin{aligned} p_m(I) &= P_l = M \quad \text{when } I < 40 - \frac{(M - 2m)}{100} \equiv \tilde{I} \\ &= P_h = 4000 + m \quad \text{when } I \geq \tilde{I} \end{aligned} \quad (14)$$

For  $M = m = 0$  markup pricing strategy  $p_m(I)$  reduces to equilibrium prediction (13). With positive markups  $p_m(I)$  differs from the predicted one. For example, when  $M = 2000$  and  $m = 500$  we obtain  $p_m(I) = 2000$  when  $I < 30$  and  $p_m(I) = 4500$  for  $I \geq 30$ . The buyer is now more easily persuaded to attract more (i.e. also the high) outside option types through a higher price. In general this holds whenever  $\tilde{I} < 40$ , i.e. whenever  $M > 2m$ . The latter restriction has an intuitive explanation. Compared to the standard no-markup case, the price differential  $P_h - P_l$  is lower in the presence of decreasing markups. The high type can thus be persuaded more cheaply than standard theory predicts. In particular, the additional costs of attracting the high type are  $M - m$  lower. But the benefits of attracting the high type are also smaller than predicted; because the buyer now has to pay the high-type a markup of  $m$ , the benefits are  $m$  lower. Now, when  $M - m > m$  the reduction in costs exceeds the reduction in benefits,

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<sup>22</sup>A similar result is observed in experiments that consider more involved bargaining settings; see e.g. Binmore et al. (1989, 1991) and Kahn and Murnighan (1993) for alternating-offer bargaining games and Binmore et al. (1998) for Nash demand games.

<sup>23</sup>When the buyer invests this applies in 31 out of 63 observations (49%), in case the seller invests this holds for 91 out of 235 observations (39%).

and the buyer is more easily persuaded to attract more outside option types.<sup>24</sup>

The buyer's markup pricing strategy has implications for investment incentives. As long as the markup is independent of the investment made, incentives under common information are unaffected. The buyer remains residual claimant when she formulates the price, while the seller obtains no return on investment. Yet investment incentives under private information do change. First consider the case in which the buyer invests. When she attracts only the low type seller by charging price  $P_l$ , her optimum investment level equals 25. In case the buyer attracts both types through price  $P_h$  it equals the efficient level of 50. It is easy to derive that her optimal investment choice equals:

$$\begin{aligned} I &= 25 \quad \text{when } M < 2m + 250 \\ &= 50 \quad \text{when } M > 2m + 250 \end{aligned} \tag{15}$$

The buyer's investment incentives are thus strengthened compared to the standard prediction of  $I = 25$ . The intuition is that the buyer caters to more outside option types than predicted. Therefore, the buyer's own investment pays off in a larger number of contingencies, inducing her to invest more. For the actual markups observed in the experiment –  $M \approx 2000$  and  $m \approx 500$  – the second case in (15) applies. The buyer thus should choose the same investment as under common information, in line with Result 1. In general, when  $M > 2m + 250$  informational losses should have no impact on the buyer's investment incentives.

In the seller invests case, the purpose of his investment is to increase the buyer's price offer  $p_m(I)$ . With decreasing markups, such that the cutoff invest-

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<sup>24</sup>This reasoning can easily be adapted to the continuum of types case of Section 2. Suppose the required markup of type  $s$  is given by  $m(s) \geq 0$ , with  $-1 < \frac{\partial m}{\partial s} < 0$ . Let  $g(s) \equiv s + m(s)$ , such that  $0 < \frac{\partial g}{\partial s} < 1$ . The buyer's optimal pricing strategy then follows from:

$$\max_P F(g^{-1}(P)) \cdot (R(I) - P)$$

Here  $g^{-1}(\cdot)$  denotes the inverse of  $g(\cdot)$ . From the first order condition we obtain the optimal pricing strategy  $p_m(I)$  in the presence of markups:

$$p_m(I) = R(I) - \frac{1}{\frac{\partial g^{-1}}{\partial P}} \cdot \frac{F(g^{-1}(p_m(I)))}{f(g^{-1}(p_m(I)))}$$

From the log-concavity of  $F(\cdot)$  it follows that necessarily  $p_m(I) > p(I)$ . Yet also here it does not hold in general that the buyer necessarily want to attract more outside option types in the presence of decreasing markups. Although the extra costs of doing so are smaller compared with the standard no-markup case (because  $m(s)$  is decreasing), the additional benefits ( $R(I) - (s + m(s))$ ) are also smaller. It can be derived that when the markup satisfies

$$m(s) \leq -\frac{\partial m}{\partial s} \cdot \frac{F(s)}{f(s)}$$

the buyer attracts more seller types in the presence of decreasing markups than in the absence of these markups. (This condition corresponds to the condition  $M > 2m$  in the main text.)

ment level  $\tilde{I}$  is below 40, a lower investment already suffices to obtain the high price. Investment incentives are thus weakened compared to the no-markup case. Private information then still should have a positive impact on investment incentives ( $\tilde{I} > 0$ ), but less so than standard theory predicts ( $\tilde{I} < 40$ ). To illustrate, for the actual markups observed when the seller invests –  $M \approx 2400$  and  $m \approx 350$  – we obtain  $\tilde{I} = 23$ .

The markup pricing strategy of the buyer explains why, for our parameters, informational losses do not have an impact on buyers’ investment incentives. It also suggests that the impact of informational rents on sellers’ investment incentives should be lower than predicted. Yet informational rents should still boost investment levels (albeit to a lesser extent). In the next subsection we provide an explanation for why we do not observe this in the experiment.

### 4.3 “Optimum” investment levels

In this subsection we calculate the investment levels that can be considered optimal (from a selfish point of view) given actual pricing behavior. In order to do so, we have to determine what the investor actually can get out of the bargaining. When the non-investor proposes the price, the most the investor can get is given by the maximum of the proposed price and the investor’s outside option. We then take these *maximum* payoffs as the amount the investor can get out of the bargaining.<sup>25</sup> In case the investor proposes the price him/herself, this price proposal provides an imperfect measure. This holds because the non-investor still has to accept the proposal. We therefore take the *actual* payoffs as the amount the investor can get in these cases.<sup>26</sup>

We estimate regression equations with the investors’ maximum or actual payoffs (net of investment costs) as dependent variable, and the level of investment and investment squared as independent variables.<sup>27</sup> When the investor is also the price setter we take the actual payoffs as dependent variable. Otherwise the maximum payoffs are used. In all regressions we use the Huber-White covariance matrix estimator to correct for multiple observations per subject. The “optimum” levels of investment can be directly obtained from the estimated coefficients. Table 5 reports these “optimum” levels along with their standard errors.

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<sup>25</sup>Because we are interested in what the investor actually could secure with his/her acceptance decision, in these cases we do not look at *actual* payoffs. The latter may be lower owing to the investor’s reciprocal reaction to a low but profitable price proposal of the non-investor.

<sup>26</sup>It would be incorrect to focus on accepted prices only. To illustrate, consider the private information case with  $\alpha_B = 1$ . If the buyer uses equilibrium strategy (13) and the seller accepts only those prices that weakly exceed  $s$ , acceptance of the price proposal  $P = 0$  occurs only when  $s = 0$ . Focusing on accepted prices only ignores the fact that such a proposal would have been rejected when  $s = 4000$  and (in this example) severely overestimates what the investor could get out of the bargaining.

<sup>27</sup>We do so by pooling the data from the first half and the second half of the experiment. Considering these two halves separately leads to similar results.

Table 5: “optimum investment levels” by treatment

	Common info				Private info			
	Pred.	Actual	“Optimum”		Pred.	Actual	“Optimum”	
Buyer invests								
$\alpha_B = 0$	0	27.91	27.26	(1.55)	0	27.19	42.93	(12.18)
$\alpha_B = 1$	50	46.25	41.78	(4.37)	25	43.35	41.67	(4.06)
Seller invests								
$\alpha_B = 0$	50	38.11	30.91	(3.06)	50	39.10	27.80	(2.11)
$\alpha_B = 1$	0	28.71	1.56	(8.01)	40	25.19	17.28	(2.48)

*Remark:* Robust standard errors appear in parentheses.

**Result 6.** (a) When the buyer invests observed average investment levels are within one-and-a-half standard error from the “optimum” levels given actual bargaining outcomes. (b) The seller overinvests from a selfish point of view.

Result 6 follows from Table 5. When the buyer makes the investment the “optimum” investment levels are very close to the actual ones, except when  $\alpha_B = 0$  in the private information treatment. In that case there is much variation in actual bargaining outcomes, leading to an imprecise estimate of the optimum investment level. In case the seller invests actual investment levels are always more than two standard errors above the calculated optima.<sup>28</sup>

We next discuss, in row-wise order, the various cases in more detail. When the buyer invests while the seller sets the price ( $\alpha_B = 0$ ), standard theory predicts no investment at all. Yet in the experiment buyers on average invest around  $27\frac{1}{2}$ . These higher investments are also optimal, given the actual return on investment the buyer gets. As noted at the end of Subsection 4.1, the higher than predicted return can be explained by a informal reciprocity mechanism. Investment can be regarded as a kind act, because it increases the surplus the parties can share. The seller is therefore willing to reward investment with a larger than predicted return. This makes an investment of around  $27\frac{1}{2}$  indeed individually rational for the buyer.

When the buyer acts both as investor and as price-setter (second row in Table 5), theory predicts that informational losses should adversely affect investment incentives. However, the calculated “optimum” levels indicate that the informa-

<sup>28</sup>When the buyer formulates the price ( $\alpha_B = 1$ ), the seller invests less in the second half of the experiment. But only under private information the decrease in investment levels is large enough to end up within two standard deviations of the “optimum” investment levels. In the three other cases overinvestment is robust to experience effects. See Appendix B for details.

tion asymmetry should play no role. The discussion in the previous subsection provides an explanation. Because the seller requires a larger markup when the outside option is low, the buyer is more easily persuaded to attract higher types through a higher price. And when the buyer attracts more types, she has stronger incentives to invest because her investment pays off with a larger probability (cf. expression (15)).

Turning to the seller invests case, on average sellers choose too high an investment given the actual return they obtain. Sellers thus seem to anticipate the outcome of the price-setting stage incorrectly. A potential explanation for this is that parties have self-serving assessments of what is a fair return on investment (cf. Babcock and Loewenstein 1997, Camerer 2003). The seller may think that he deserves a high return because he has to bear the costs of investment. At the same time the buyer may think a low return is warranted because the seller is already advantaged by having the outside option.<sup>29</sup> Previous experiments by Sloof et al. (2000) have shown that such self-serving biases concerning the role of outside option can indeed explain (selfish) overinvestment.

Evidence for the presence of a self-serving bias follows from considering the case in which the seller proposes the price himself ( $\alpha_B = 0$ ). In this situation the “optimum” investment levels are based on actual payoffs. The latter indicate what the seller *can* get out of the bargaining. The seller’s own price proposals provide an indication of what he *expects* to get out of the bargaining. Assuming that the seller’s price offer is always accepted, the “best” investment level equals 45.53 under common information (with a standard error of 2.17).<sup>30</sup> This is substantially above the “optimum” investment level of 30.91. The seller thus incorrectly anticipates a higher price and a higher return on investment.

The seller’s incorrect anticipation of the bargaining outcome provides an explanation of why observed investment levels are not affected by the presence of informational rents (cf. Result 3). When the seller invests and the buyer proposes the price (last row in Table 5), theory predicts that private information rents strengthen investment incentives. The calculated “optimum” investment levels also indicate that this should be the case, albeit to a lesser extent.<sup>31</sup> However, the seller seems self-servingly biased in expecting a high return on investment as compensation for the sunk investment costs borne, making private information about his outside option irrelevant for actual investment behavior. Roughly put, overinvestment induced by a self-serving bias crowds out the effect of private in-

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<sup>29</sup>Another way of formulating this is that the self-serving bias makes the seller trusting on the reciprocity mechanism mentioned earlier. Because this trust is unfounded, he overinvests (from a selfish point of view).

<sup>30</sup>Under private information we obtain a very imprecise estimate; the “best” investment level equals 70.36 with a standard error of 34.98.

<sup>31</sup>The calculated optima nicely illustrate that in the presence of decreasing markups, the impact of private information rents on investment levels should be smaller than predicted; see the discussion at the end of Subsection 4.2.

formation rents on investment incentives. A similar result is found in Sloof et al. (2000), where it is observed that overinvestment caused by a self-serving bias supersedes the working of the so-called outside option principle as an instrument in solving holdup.

The self-serving bias is not observed when the buyer invests. She appears to anticipate the trade price and the actual return on investment correctly. For  $\alpha_B = 1$  (second row in Table 5), the “best” investment level equals 46.92 under common information, with a standard error of 2.89. This is close to the “optimum” investment level of 41.78 for this case. This finding seems perfectly understandable. When the buyer invests there is much less scope for self-serving assessments of fairness. The buyer bears both the costs of investment and the disadvantage of no outside option, so it should be clear for both parties that she deserves a substantial return on investment.

Overall we conclude that buyers on average choose the optimum investment levels given actual pricing behavior. Sellers overinvest from a selfish point of view, which can be explained by a self-serving bias. This in turn crowds out the potential stimulating impact of private information rents on investment incentives.

## 5 Conclusion

The holdup underinvestment problem emerges in a wide variety of economic contexts. For instance, it provides the cornerstone of the property rights theory of the firm. Most of the existing theoretical and experimental studies analyze this problem in situations where the ex post bargaining takes place under symmetric information. However, in reality contracting parties typically possess some private information, in particular about the alternative trading opportunities they might have. This has important implications for holdup. Theory predicts that informational rents will strengthen investment incentives, while informational losses will weaken those incentives. The extent of the underinvestment problem is thus likely to be different under private information.

This paper reports an experiment that investigates the extent of the holdup problem in a buyer-seller relationship in which the seller may also trade with an alternative buyer. A first treatment variable concerns whether the value of this outside option is private information to the seller, or whether it is commonly observed. The price-setting power of the two parties is used as a second treatment variable. Apart from that, we also vary the identity of the investor, i.e. either the buyer or the seller makes the specific investment. This design enables us to establish (among other things) whether private information rents and price-setting power can be used as instruments for mitigating holdup.

We obtain two main findings with respect to the actual investments observed. First, investment levels increase with the price-setting power of the investor, as predicted. Second, for our parameterization we find no significant effect of

informational losses and rents on investment incentives, in contrast with standard predictions.

Actual bargaining behavior provides a (partial) explanation for why price-setting power works as an instrument in mitigating holdup and informational rents do not. Prices are significantly lower when the buyer rather than the seller formulates the price offer. The investor thus can obtain a larger return on investment when s/he sets the price her/himself. This boosts investment incentives. The ineffectiveness of private information can be partly explained by the buyer's pricing strategy. When the buyer sets the price, she offers the seller a markup that decreases with his outside option (whereas standard theory predicts that she would simply match the outside option). It therefore becomes cheaper for the buyer to attract higher (i.e. more) outside option types than standard theory predicts. When the buyer invests herself the investment thus pays off with a larger probability, resulting in a lower impact of informational losses on investment incentives. For our parameterization private information should even have no effect at all, as is observed. Decreasing markups also explain why informational rents have a smaller impact on investment incentives than predicted. Because already a lower investment induces the buyer to offer a higher price, the seller has less incentives to invest. However, informational rents should still boost the seller's investment incentives, albeit to a smaller extent.

An explanation for the complete ineffectiveness of private information rents is the presence of a self-serving bias. When the seller invests and the buyer sets the price, self-serving biases seem to induce disagreement about what is a fair return on investment. The seller seems to count on a high return as compensation for the costs of investment borne, while the buyer thinks a low(er) return is appropriate because the seller is already advantaged by having the outside option. As a result, the seller overinvests from a selfish point of view. This in turn crowds out the impact of informational rents on investment incentives. A similar observation was made by Sloof et al. (2000) when evaluating experimentally remedies against holdup that are based on the outside option principle. They also observe that overinvestment owing to self-serving biases makes these types of remedies ineffective.

A final interesting observation is that when the non-investor sets price, holdup appears much less of a problem than standard theory predicts it to be. In this case an informal reciprocity mechanism appears at work, implying that the non-investor rewards the kind act of investment with a higher than predicted (i.e. zero) return. A large number of earlier experimental studies have already found that reciprocity can serve as an informal mechanism that alleviates holdup. The current findings reveal that this mechanism is robust to private information about outside options. It is reassuring to find that some of the main regularities observed under complete information – viz. the importance of reciprocity and self-serving biases – carry over to the more realistic private information case.

Taken together, our findings cast doubt on the suggestion made in Gul (2001,

p. 344) that “...private information rents might substitute for bargaining power and ameliorate the hold-up problem...” We find that private information about outside options does not affect the extent of the underinvestment problem. Price-setting power does appear to be an effective instrument though.

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## A Summary of the instructions

Besides the on-screen instructions subjects also received a summary of these instructions on paper. Below a direct translation of this summary sheet is given. This summary belongs to the *BP*-case with the upward order. The summary sheets for the other cases are similar.

In the experiment participant A (B) corresponds with the seller (buyer). Amount  $T$  corresponds to the investment level  $I$ . Blue reflects the low outside option (turn-down amount) of 0, yellow the high outside option of 4000.

**Summary of the instructions** This experiment consists of 32 rounds. At the start of each round the participants are paired in couples. This division into couples is chosen such that it is impossible that you are paired with the same other participant in two consecutive rounds. It also holds that within each of the four consecutive blocks of eight rounds –viz. rounds 1 up to 8, rounds 9 up to 16, rounds 17 up to 24 and rounds 25 up to 32– you will never be paired with the same other participant in more than one round. When you will meet the same participant again is unpredictable. With whom you are paired within a particular round is always kept secret from you.

One of the participants within a pair has role A, the other has role B. Within a round you will always keep the same role. What exactly your role is, you will hear at the beginning of each round. Over the rounds your role varies. This variation is such that you will be assigned the role of A in exactly half (16) of the total number of rounds (32), and the role of B in the other half. It also holds that within each block of eight rounds, you are assigned the role of A four times and the role of B also four times.

Each of the 32 rounds consists of four stages. In stage 1 only the participant with role B takes a decision. In the second stage 2 a disk is turned around by the computer. In stage 3 one of the participants within a pair makes a proposal, to which the other participant reacts in stage 4. The stages take the following form:

1. Participant B within a pair chooses the amount  $T$  s/he wants to add to the base amount of 4000 points. This amount  $T$  needs to be a multiple of 100 and has to be between 0 and 8000. After B has made his/her choice, A is informed about this choice. The choice of participant B in stage 1 leads to costs for B only. The costs of choosing addition  $T$  equal  $(T/100)^2$ . In the table that is handed out to you [cf. Figure 3], you will find the exact costs for B belonging to each choice of  $T$ .
2. In order to determine the turn-down amount of participant A that applies in this round, a disk is turned around by the computer. When the disk comes to a stop it points at a particular color: either blue or yellow. The color indicated by the disk is shown to participant A only; participant B

thus cannot watch the turning of the disk. In each round the probability of obtaining blue is 50%, and the probability of getting yellow thus also equals 50%. In case the disk points at blue the turn-down amount of A equals 0, in case of yellow the turn-down amount of A equals 4000 points.

3. The amount up for division in stage 3 equals the base amount of 4000 points, plus the addition  $T$  chosen by participant B in stage 1. One of the participants within a pair now formulates a proposal how to divide the amount up for division. Which participant is allowed to make this proposal depends on which round the participants are in. It holds that:

rounds 1 up to 8 and 17 up to 24:	A formulates the proposal
rounds 9 up to 16 and 25 up to 32:	B formulates the proposal

4. Participant A or B chooses whether or not to accept the proposal made. When A made the proposal in stage 3, B reacts to this proposal in stage 4. In case participant B formulated the proposal, A reacts to it. When the proposal is accepted, the amount up for division is divided according to the proposal made. In case of rejection, the amount up for division vanishes. Participant A then obtains the turn-down amount that applies in this round, as determined by the turning of the disk in stage 2. (Please note, also when A formulates the proposal and B rejects this proposal, A obtains the turn-down amount.) Participant B earns no points after a rejection, but does have to bear the costs of his/her choice made in stage 1.

At the start of experiment you will get 20,000 points for free. At end of the experiment you will be paid in euros, based on the total number of points you earned. The conversion rate is such that 4000 POINTS in the experiment correspond to 1 EURO in money.

< Figure 3 >

## B Tests on aggregation of data

In this appendix we report the test results on order effects and learning effects. These tests reveal that we can pool the data from the sessions that differ in the order of  $\alpha_B$ 's only. However, we do find some significant learning effects (although they are typically rather small).

**Order effects** For all four situations of Table 1 we have one session with the 'upward' order ( $\alpha_B = 0, \alpha_B = 1, \alpha_B = 0, \alpha_B = 1$ ), and another session with the opposite 'downward' order ( $\alpha_B = 1, \alpha_B = 0, \alpha_B = 1, \alpha_B = 0$ ). Using across-session comparisons between the two different orders we can test for order effects. With only two group observations per session/order, no meaningful comparisons can be made at the matching group level. This holds because the smallest significance level that a two-tailed ranksum test can attain equals  $\frac{1}{3}$ . We therefore only look at tests performed at the level of individual means. We consider individual mean investment levels, individual mean relative price proposals and individual mean accepted relative prices. Table 6 reports the results.

Focusing on investment behavior first, we find 3 significant differences out of the overall 16 comparisons made. Significant differences are found in the *BP*-situation when  $\alpha_B = 0$  for the first time, and for the *SP*-case with  $\alpha_B = 1$  (both first and second half). When we look at relative prices no significant differences are found. This holds for both proposed and accepted prices. Order effects thus appear to be only minor. We therefore pool the data from the sessions that differ in the order of  $\alpha_B$ 's only.

**Learning effects** In both the 'upward' and the 'downward' order each value of  $\alpha_B$  is represented in one block of eight rounds in the first 16 rounds and in a second block of eight rounds in the last 16 rounds. We test for learning effects by comparing the first block and the second block by means of signed-rank tests, for both values of  $\alpha_B$  separately. We do so after having pooled the data from the different orders. At the aggregate group level we have only four matched pairs of observations per comparison. The smallest level of significance that a two-tailed signed-rank test then can attain equals  $\frac{1}{8}$ . In Table 7 we therefore do not report the  $p$ -values of the tests on group level data, but only indicate when these test statistics reach the lowest possible significance level (by means of the superscripts #). The table does report the  $p$ -values for individual mean investment levels, individual mean relative price proposals, and individual mean accepted relative prices.

For investment levels, five (out of 8) comparisons are significant at the 5%-level. When the buyer invests and the seller sets the price ( $\alpha_B = 0$ ), the buyer learns to invest somewhat less over time, both under common and under private information. As a result, the average investment levels in the second half of the

Table 6: Test results for equality of different orders

		first: rounds 1-16		second: rounds 17-32	
		Common	Private	Common	Private
Buyer invests					
$\alpha_B = 0$	invest	0.8390	0.0237	0.0733	0.2022
	price	0.4488	0.2674	0.1677	0.8498
	acc. price	0.4171	0.6168	0.2036	0.7868
$\alpha_B = 1$	invest	0.2720	0.0575	0.9527	0.0608
	price	0.7251	0.5978	0.9031	0.3099
	acc. price	0.6456	0.2792	0.6071	0.4163
Seller invests					
$\alpha_B = 0$	invests	0.3285	0.4390	0.7965	0.6432
	price	0.5978	0.7251	0.8392	0.3507
	acc. price	0.9569	1.0000	0.3437	0.2084
$\alpha_B = 1$	invest	0.4238	0.0022	0.0974	0.0023
	price	0.6652	0.8181	0.9353	0.1762
	acc. price	0.6168	0.5639	0.6456	0.2503

*Remark:* In each cell the  $p$ -value is reported of a two-tailed ranksum test using individual means. In each cell we have 20 individual means per order. The row ‘invest’ refers to the individual mean investment, the row ‘price’ to the individual mean price ratio (price divided by actual surplus), the row ‘acc. price’ refers to individual mean price ratios for accepted prices only.

Table 7: Test results on comparing first half with second half

		Common information	Private information
Buyer invests			
$\alpha_B = 0$	invest	0.0070	0.0196
	price	0.0853 <sup>#</sup>	0.0000 <sup>#</sup>
	acc. price	0.0174 <sup>#</sup>	0.0000 <sup>#</sup>
$\alpha_B = 1$	invest	0.0138 <sup>#</sup>	0.4088
	price	0.6001	0.8772
	acc. price	0.9250	0.7748 <sup>#</sup>
Seller invests			
$\alpha_B = 0$	invest	0.3092	0.4746
	price	0.0051 <sup>#</sup>	0.0051 <sup>#</sup>
	acc. price	0.0039 <sup>#</sup>	0.0039
$\alpha_B = 1$	invest	0.0045 <sup>#</sup>	0.0001 <sup>#</sup>
	price	0.2792	0.8402
	acc. price	0.9893	0.0634

*Remark:* In each cell the  $p$ -value is reported of a two-tailed signed rank test using individual means. In each cell the test statistic is based on 40 individual means. The row ‘invest’ refers to the individual mean investment, the row ‘price’ to the individual mean price ratio (price divided by actual surplus), the row ‘acc. price’ refers to individual mean price ratios for accepted prices only. The superscript # indicates that the test statistic based on group means (with 4 groups per cell) reaches its lowest possible  $p$ -value of 0.1250 (two-tailed).

experiment are closer to the “optimum” investment levels, see Tables 2 and 5 respectively. The differences between the first and second half are fairly small in absolute magnitude though (around 15%). This also applies when  $\alpha_B = 1$  under common information. Here average investment levels significantly increase from 45.21 to 47.29. In case the seller invests significant differences are found only for  $\alpha_B = 1$ . There the seller decreases his investment when he has gained experience. But only under private information the decrease is sufficiently large such that investment levels end up in the vicinity (i.e. within two standard deviations) of the “optimum” level.

For proposed and accepted relative prices we find 3 and 4 significant differences respectively. These differences all belong to the seller-sets-price case ( $\alpha_B = 0$ ). Over time the seller tend to ask and obtain a somewhat higher relative price, from around 72.8% to around 76.7% of the gross surplus on average.

Overall we conclude that, although typically rather small in absolute magnitude, some learning effects can be detected in around half of the treatments. In the main text we therefore consider the first 16 rounds separately from the last 16 rounds.

Figure 1. Price proposal of the buyer ( $\alpha_B=1$ ) under common information

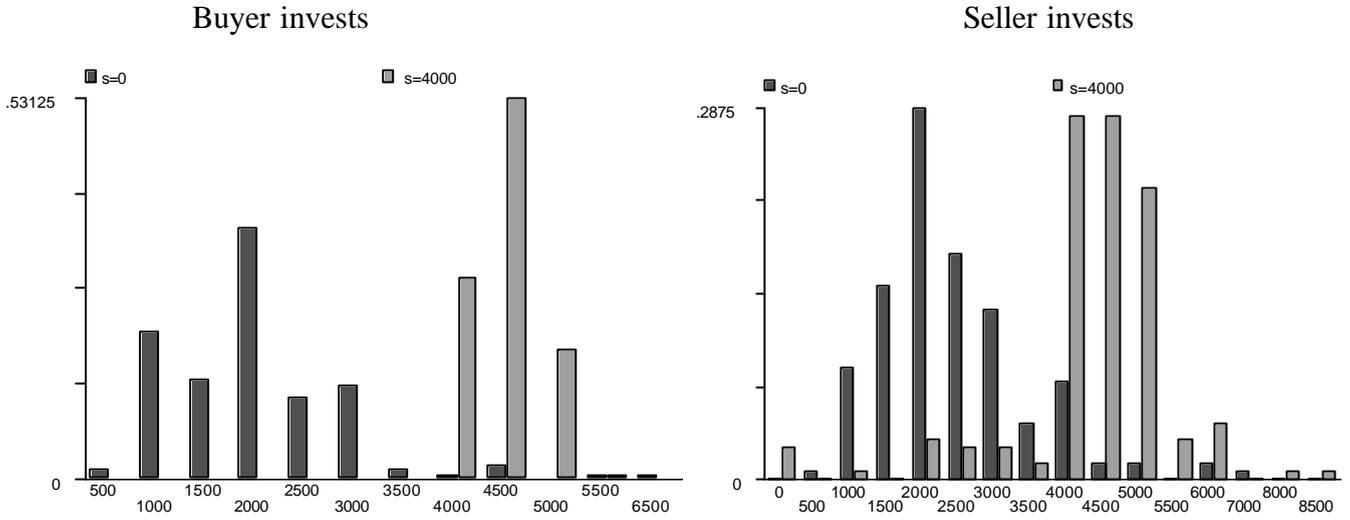


Figure 2. Price proposal of the buyer ( $\alpha_B=1$ ) under private information

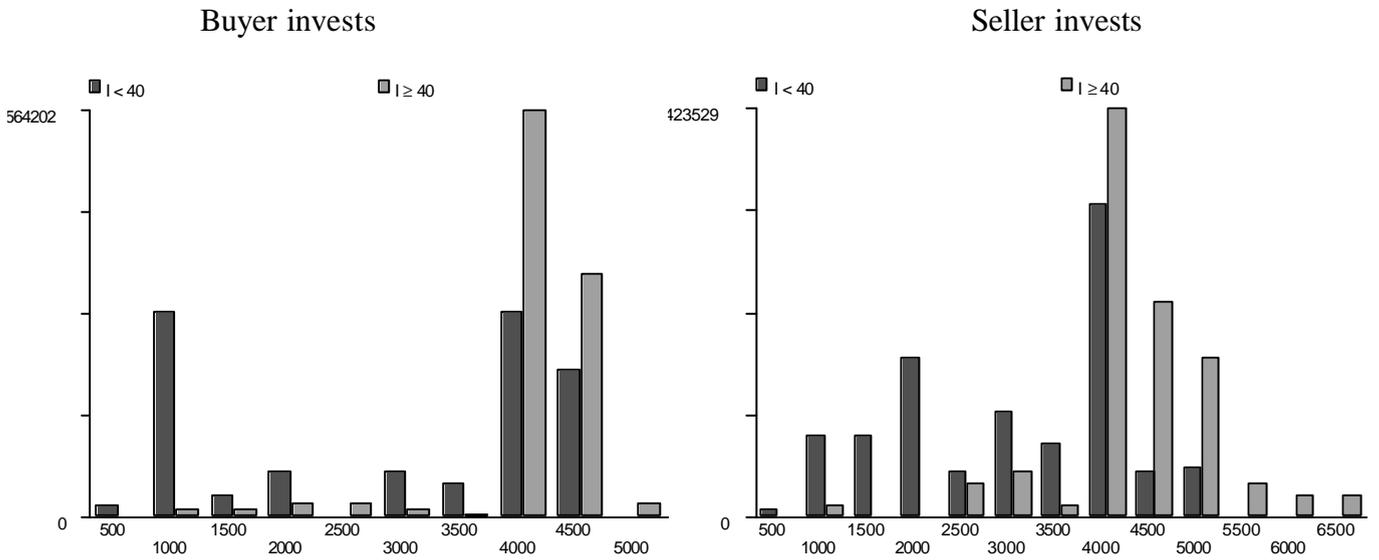


Figure 3. In the table below you find for every possible choice of addition T, the corresponding costs for participant B in stage 1.

<b>T</b>	<b>costs</b>	<b>T</b>	<b>costs</b>
0	0	4000	1600
100	1	4100	1681
200	4	4200	1764
300	9	4300	1849
400	16	4400	1936
500	25	4500	2025
600	36	4600	2116
700	49	4700	2209
800	64	4800	2304
900	81	4900	2401
1000	100	5000	2500
1100	121	5100	2601
1200	144	5200	2704
1300	169	5300	2809
1400	196	5400	2916
1500	225	5500	3025
1600	256	5600	3136
1700	289	5700	3249
1800	324	5800	3364
1900	361	5900	3481
2000	400	6000	3600
2100	441	6100	3721
2200	484	6200	3844
2300	529	6300	3969
2400	576	6400	4096
2500	625	6500	4225
2600	676	6600	4356
2700	729	6700	4489
2800	784	6800	4624
2900	841	6900	4761
3000	900	7000	4900
3100	961	7100	5041
3200	1024	7200	5184
3300	1089	7300	5329
3400	1156	7400	5476
3500	1225	7500	5625
3600	1296	7600	5776
3700	1369	7700	5929
3800	1444	7800	6084
3900	1521	7900	6241
4000	1600	8000	6400