# Asset Ownership and the Hold-Up Problem with Asymmetric Information*

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**Abstract**

We study a contract environment with an *ex ante* investment stage and where *ex post* bargaining takes place under one-sided asymmetric information. We offer a model where only the presence of an outside option allows for approximately *ex ante* efficiency. Without an outside option, any static or sequential mechanism performs worse, which we view as a rationale for the role of ownership allocation in contracting environments with asymmetric information. We take these theoretical predictions to a laboratory setting and find that outside options as implemented through asset ownership are valuable, not only because of somewhat more efficient *ex ante* investment but because they reduce *ex post* frictions.

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# 1 Introduction

There are two principal ways to organize economic activity: markets and firms. Understanding the demarcation between the two has long occupied the attention of economists–at least since Coase (1937) famously asked why, if markets are an efficient means of allocating resources, do firms exist at all?

Given that about half of all economic activity takes place in markets, and half in firms, it is perhaps not surprising that the study of the boundary between firms and markets has been an important topic for economists–indeed, giving rise to three Nobel prizes (Coase, Williamson, and Hart).

Coase (1937) introduced the concept of transaction costs as a rationale for why using the price mechanism can be costly, and hence why transacting inside the firm may be preferable. In a series of contributions, Williamson (1971, 1975, 1979) unpacked the broad concept of transaction costs, emphasizing *ex post* frictions such as haggling.

The modern theory of the firm–Property-Rights Theory–pioneered by Grossman and Hart (1986) and Hart and Moore (1990), emphasizes the *ex ante* friction of underinvestment. Specifically, parties anticipate renegotiation of their (incomplete) contract, and because only one party can hold residual control rights through asset ownership, the other party underinvests in the relationship.

The emphasis on *ex ante* frictions in Property-Rights Theory (PRT) is a consequence of an elegant modeling choice–that there is symmetric information at the renegotiation stage, and hence the Nash Bargaining solution can be utilized. This modeling choice is partially responsible for the broad applicability and portability of PRT, to settings as diverse as corporate finance, international trade and macroeconomics.[1]

Recent theoretical work in PRT has moved toward emphasizing *ex post* frictions, however, through the introduction of behavioral ingredients, in particular "reference points" and "aggrievement." As Hart (2008) puts it:

> The transaction cost literature does not take a formal approach and has implicitly assumed the existence of haggling (or rent-seeking) costs: it has not confronted the issue of how to model them. The more formal property rights approach has sided with Coase (1960), thereby avoiding haggling costs. In a typical model the parties bargain costlessly ex post, and the focus is on ex ante investment inefficiencies. I have argued elsewhere (Hart and Moore 2007) that, while such an approach can yield useful insights about optimal asset ownership, it is unlikely to be helpful for studying the internal organization of large firms. Specifically, in a world of Coasian bargaining, it is hard to see why important aspects of organizational form such as authority, hierarchy and delegation matter. Why would the parties not simply bargain about everything all the time, using monetary side-payments?
>
> In my view, in order to make progress on the Coasian agenda, we must move away from Coase (1960) and back in the direction of Coase (1937). We need to bring back haggling costs!

This is quite clearly an attempt to formally model haggling costs and to allow asset

[1] See Aghion and Holden (2011) for further details and references.

ownership to play a role. Even though in its relatively early days, this approach has proved quite fruitful.

To an economist, however, perhaps the most natural haggling cost arises from bargaining under asymmetric information. And, of course, PRT lends itself to just such an analysis if one does not assume symmetric information at the renegotiation stage.[2]

It is this avenue that we pursue in this paper. We introduce a buyer-seller contracting model with *ex post* bargaining under one-sided asymmetric information based on Aghion, Fudenberg, Holden, Kunimoto, and Tercieux (2012), and where the seller can make an *ex ante* investment that increases the buyer's valuation, as in Che and Hausch (1999).[3] In particular, we consider a setting with full commitment where *ex post* the buyer decides whether or not to buy one unit of an indivisible good at a pre-specified price. This is also similar in spirit to Bester and Münster (2016), who emphasize the value of outside options in a closely related model of performance evaluation.[4]

We then take this to a laboratory setting and find that outside options as implemented through asset ownership are valuable, not only because of somewhat more efficient *ex ante* investment but because they reduce *ex post* frictions. The presence of an outside option for the seller (buyer) enhances *ex ante* investment and amounts to 74.4% (72.1%) of the optimal investment level compared to 64.5% with joint ownership. However, observed investment behavior in our experiment is far from optimal. Furthermore, we document trade effects: the *ex ante* efficient outcome is never to trade whenever the good is of low value. While fully allocating asset ownership to either the uninformed or the informed party almost completely eliminates such trade of low-value goods, with joint ownership almost 50% of low-value goods are traded as a result of contract-acceptance by the informed party. Lastly, we find evidence of wealth effects through allocating asset ownership to either party. Total surplus generated by buyer-seller relationships is significantly higher when outside options are available. While this may not be surprising whenever the good is of low value because the outside option can be consumed, participants in our experiment also achieve higher payoffs after trading and thus *not* consuming the outside option. Overall, outside options as induced by asset ownership mitigate inefficient trade of low-value goods and lead to higher social welfare both with and without trade.

As the Grossman-Hart-Moore Property-Rights-Theory (PRT) framework teaches us, because asset ownership *is* contractible in economies with sound rule-of-law, we should expect parties to gravitate to the ownership structure that maximizes social welfare. This

[2]The fact that ownership matters in models with asymmetric information has been recognized. E.g., Myerson and Satterthwaite (1983) consider a bargaining problem with one buyer and one seller. In their model, *ex post* efficiency cannot be achieved by voluntary bargaining, while Cramton, Gibbons, and Klemperer (1987) have shown that the first-best solution can be achieved when the ownership rights are more evenly distributed.

[3]Che and Hausch (1999)'s main result can be viewed as showing that contracting is futile in the case of cross-investments when renegotiation cannot be ruled out. To the best of our knowledge, this result was first shown by Maskin and Moore (1987), and subsequently published in Maskin and Moore (1999), as can be seen in their buyer-seller example.

[4]In a series of prolific papers, Schmitz (2002, 2006, 2008) considers similar settings with important variations. E.g., hidden action–the seller can exert unobservable effort producing the good; a party may invest and acquire private information about the default payoff that it can realize on its own; and two-sided private information. To the best of our knowledge, Schmitz (2006) was the first to introduce asymmetric information into the renegotiation stage of an otherwise standard PRT-model akin Grossman and Hart (1986) and Hart and Moore (1990).

is, of course, a basic implication of the Coase Theorem. A contribution of this paper is to demonstrate as both a matter of theory and in a laboratory setting that asset ownership can serve to mitigate both *ex ante* and *ex post* frictions.

And while contract theorists take this outcome as part of any equilibrium, scholars and practitioners of business strategy focus on the important question of how that outcome comes about. Of particular relevance in this setting are how: (i) competition between firms pushes toward the optimal allocation of asset ownership; and (ii) the internal organization of firms is a complement or substitute for market-based competition in this respect.

An old literature, dating to Machlup (1967)–including an antecedent due to Leibenstein (1966) and an important modern treatment by Hart (1983)–explores these issues in a pre-PRT setting. An implication of our work here–but well beyond the scope of this paper–is that a fully satisfactory treatment of the internal efficiency of firms must involve a unified framework involving the joint determination of asset ownership, market structure, and managerial incentives.

Our paper also relates to an experimental literature on outside options. Hackett (1993) considers a two-period model where both parties initially make transaction-specific investments that may either enhance a product's value or reduce its production costs. Bargaining under symmetric information takes place after the surplus realization. McKelvey and Page (2000) study the effect of private information on Coase's famous theorem, emphasizing efficiency and allocative neutrality. Private information leads to inefficiency and allocative bias as well as sizeable bargaining breakdown. The experimental results are arguably more in line with Myerson and Satterthwaite (1983) than Coase (1960). In a series of papers, Ellingsen and Johannesson (2004a,b) present a hold-up experiment with *ex ante* unilateral investment and *ex post* bargaining over the surplus. The focus is on the effect of unilateral communication between the two parties. Hoppe and Schmitz (2011) report on a hold-up experiment in which different contracts (no contract, fixed-price contract, option contract, and option contract with renegotiation) are implemented. One party makes an *ex ante* observable but not verifiable "cooperative" investment à la Che and Hausch (1999), which directly benefits the non-investing party. The experimental findings are consistent with Hart's (2008) idea that contracts may mitigate the hold-up problem by serving as reference points. Kusterer and Schmitz (2017) present a PRT application in the laboratory where Aghion and Tirole's (1994) management of innovation theory is experimentally implemented. Both parties can invest and bargain afterwards over the division of the revenue whenever an innovation is made. While ownership affects the division of both investments and revenue, communication between the parties can alleviate underinvestment.

The paper proceeds as follows. In Section 2 we present our model with the contracting environment and theoretical results. Section 3 shows how we implement the economic environment in a laboratory setting and highlights the main predictions of the model. Section 4 is the heart of the paper, containing our experimental results. Section 5 includes some brief concluding remarks.

## 2 Statement of the Problem

Suppose there is a seller and a buyer of a single unit of an indivisible object with utility $v \in \{v_L, v_H\}$ and $v_H > v_L > 0$. The utility of the seller for the good is assumed to be always zero. He can make a product-specific investment $i \in [0, 1]$ to increase the probability that it is of high value. Suppose that at cost $c(i)$ the seller achieves $v = v_H$ with probability $i$ where $c(\cdot)$ is continuous, twice differentiable and satisfies $c'(i) > 0$, $c''(i) > 0$, $c(0) = 0$, $c'(0) < v_H - v_L$, and $c(1) = +\infty$. Time is discrete with four different stages:

- **Stage 1** The seller offers the object to the buyer at a pre-specified price. This is the *contract* stage.
- **Stage 2** The seller can increase the buyer's valuation of the object. This is the *investment* stage in which the seller has the opportunity to make an investment that increases the probability that the object is of high value, i.e., $v = v_H$.
- **Stage 3** The buyer realizes the value of the object, which is stochastically determined, and can accept the trade as previously specified in the contract. This is the *trading* stage where only the buyer learns the value of the object and the seller's investment is not observed. Thus, there exists one-sided asymmetric information.
- **Stage 4** With fully-allocated asset ownership to either the uninformed party or the informed party, the (uninformed) seller or the (informed) buyer exerts the *outside option* if trade does not occur in the trading stage. In this case, whoever owns the asset receives $v_L$. By contrast, no outside options are available with joint ownership.

We interpret asset ownership as the *right* to exercise the outside option in the spirit of Grossman and Hart (1986), where asset ownership of a firm permits the owner to make alternative use of its resources if the other party disagrees with the asset owner in the *ex post* bargaining process. In contrast, we view joint ownership of an asset–in line with Hart and Moore (1990)–as each party having veto power over the use of the asset. Thus, the default value for both parties is zero. In a closely related framework, Hart (2013) studies non-contractible investments in a model with shading. He also introduces outside options in a similar fashion, however, he allows the parties' outside options to be different from $v_L$. Formally, Schmitz (2002) is isomorphic to Hart (2013): the second-best solution is similar in both models. This can be interpreted–to some degree–as asymmetric information on one hand and the behavioral approach on the other hand being, in fact, interchangeable. We view our approach as complementary and study a model where the purpose of the contract is to encourage the seller to make an *ex ante* quality-enhancing investment, and to achieve *ex post* efficiency. We closely follow Aghion, Fudenberg, Holden, Kunimoto, and Tercieux (2012) and show that asset ownership is indeed valuable and can increase efficiency. In the analysis that follows, we rule out third parties.[5]

In our set-up, the expected total surplus in the first-best solution is determined by

$$\Pi = i^* v_H + (1 - i^*) v_L - c(i^*) \tag{1}$$

The *ex ante* efficient outcome is to trade whenever the object is of high value and to consume the outside option when $v = v_L$.[6] The solution to the following first-order condition highlights the optimal investment level

[5]Whether or not it is possible to include third parties and whether or not it is possible to rule out renegotiation or collusion is at the heart of a heated debate in the Hart-Moore vs. Maskin-Tirole literature on foundations of incomplete contracts/property rights methodology.

[6]Note that it is *ex post* efficient to trade when $v = v_H$, but trade is also *ex post* efficient when $v = v_L$ and outside options exist, as it is negligible whether trade occurs or the outside option is consumed.

$$c'(i^*) = v_H - v_L \tag{2}$$

***Outside options and ex ante efficiency*** We consider implementation in dominant strategies. Let $q$ = trade probability, transfers $t_S$ and $t_B$ to the seller and the buyer, a probability $p_S$ that the seller (and $p_B$ for the buyer, respectively) keeps the object if there is no trade. Thus, the probability that the object gets destroyed if no trade is realized is $1 - p_S - p_B \geqslant 0$. The mechanism maps the buyer's announcement $\tilde{v} \in \{v_L, v_H\}$ into $\Lambda$ where

$$\Lambda = \{(q, p_S, p_B, t_S, t_B) \in [0,1] \times \mathbb{R}^4_+ | p_S + p_B \leqslant 1, t_S + t_B \leqslant 0\}. \tag{3}$$

If we let $p_S \equiv 1$, then the mechanism, $\Lambda$, maps $f(v_L) = (q^L, t^L_S, t^L_B)$ if $v_L$ was announced, and $f(v_H) = (q^H, t^H_S, t^H_B)$ if $v_H$ was announced, respectively. For $\epsilon > 0$ small enough, the mechanism implements $(1, -(v_H - \epsilon), v_H - \epsilon)$ when the buyer announces $\tilde{v} = v_H$ and $(0,0,0)$ when the buyer announces $\tilde{v} = v_L$. Truthful revelation is (i) a strictly dominant strategy, (ii) individually rational, and (iii) *ex post* efficient, i.e., trade occurs if and only if there are social gains from trade. Therefore, truthful revelation by the informed party–the buyer–satisfies incentive compatibility. The seller maximizes

$$i(v_H - \epsilon) + (1 - i)v_L - c(i), \tag{4}$$

where $i^*$ is determined by the first-order condition

$$c'(i^*) = v_H - v_L - \epsilon \tag{5}$$

It follows from the concavity of the problem that approximately efficient *ex ante* investment is achieved. However, $i$ is not specified because of its non-verifiability.

***Absence of any outside option and ex ante efficiency*** Let $p_S = p_B = 0$, then no mechanism exists that achieves *ex ante* efficiency. To ensure (at least weak) incentive compatibility, the following needs to hold:

$$v_L(q^H - q^L) \leqslant t^L_B - t^H_B \leqslant v_H(q^H - q^L) \tag{6}$$

The social choice function $f$ maps the buyer's true valuation $\tilde{v}$ onto a triple $f(\tilde{v}) = (\tilde{q}, \tilde{t_B}, \tilde{t_S})$ which is implemented by a mechanism as a Perfect Bayesian Equilibrium.

Note that there does not exist any social choice function with the property $p_S = p_B = 0$ that is both approximately *ex ante* efficient and incentive compatible. Consider this proof by contradiction: Suppose a mechanism $f^\epsilon$ exists with an *ex ante* surplus of at least $\Pi^* - \epsilon$. Then, $i^\epsilon \rightarrow i^*$, $q^{L,\epsilon} \rightarrow 1$, $q^{H,\epsilon} \rightarrow 1$, and the difference in transfers, i.e., $|t^{L,\epsilon}_S - t^{L,\epsilon}_B| \rightarrow 0$ and $|t^{H,\epsilon}_S - t^{H,\epsilon}_B| \rightarrow 0$. Then the incentive compatibility constraint implies that $|t^{L,\epsilon}_B - t^{H,\epsilon}_B| \rightarrow 0$ and thus $|t^{H,\epsilon}_S - t^{L,\epsilon}_S| \rightarrow 0$. In Stage 2 (the "investment stage"), the seller choses $i$ to maximize $it^{H,\epsilon}_S + (1 - i)t^{L,\epsilon}_S - c(i)$. By rearranging the proof by contradiction is completed:

$$t^{L,\epsilon}_S + i(t^{H,\epsilon}_S - t^{L,\epsilon}_S) - c(i) \tag{7}$$

As $|t^{H,\epsilon}_S - t^{L,\epsilon}_S| \rightarrow 0$ and $c'(i) > 0$, the solution $i^\epsilon$ to this maximization problem converges to zero and thus contradicting the assumption that *ex ante* total surplus converges to $\Pi^*$. This highlights that no approximately *ex ante* efficient social choice function can be implemented by any static or sequential mechanism without any outside option. In the presence of outside options, however, approximately *ex ante* efficient outcomes can be implemented. We view this as a rationale for the role of ownership allocation in contracting environments with asymmetric information.

Using a buyer-seller contracting model where the seller can make an *ex ante* investment that increases the buyer's valuation and where *ex post* bargaining is realized under one-sided asymmetric information, we highlight that outside options as implemented through asset ownership are valuable because they improve *ex ante* efficiency and social welfare compared to mechanisms or contracts that do not allow for asset ownership. We are particularly interested in the full commitment case where *ex post* the buyer decides whether or not to buy one unit of an indivisible good at a pre-specified price. In this setting, carefully allocating ownership rights is a powerful tool to mitigate *ex ante* inefficiencies.

To set the stage for our experiment, we now consider the role outside options play when asset ownership is allocated to either seller, buyer, or when it is joint. Under Seller Ownership, the seller offers the good at $p = v_H - \epsilon$ and chooses $i$ to maximize (4). Thus, $i$ is approximately first-best as in (5). In turn, the buyer accepts the contract and trade is realized if and only if $v = v_H$. If no trade is realized, then the seller consumes his outside option equal to $v_L$. Under Buyer Ownership, the seller offers the good at $p = v_H - v_L - \epsilon$. The seller chooses $i$ to maximize $i(v_H - v_L - \epsilon) - c(i)$. Thus, $i$ is approximately first-best and determined by $c'(i) = v_H - v_L - \epsilon$. The buyer, in turn, agrees to the terms specified in the contract and trade is realized if and only if $v = v_H$. If the contract is rejected, then the buyer exercises the outside option and receives $v_L$. When asset ownership is joint, the seller offers the good at either a high or a low price. We begin with the former: the seller offers the object at $p = v_H - \epsilon$ and chooses $i$ to maximize $i(v_H - \epsilon) - c(i)$. Thus, the seller overinvests relative to the first-best according to $c'(i) = v_H - \epsilon$. The buyer, successively, accepts the contract and trade is realized if and only if $v = v_H$. If, however, the buyer rejects to trade, both parties receive a payoff of zero, as no outside options are available with joint ownership. Alternatively, the seller can offer the good at $p = v_L - \epsilon$ and sets $i = 0$, thus underinvests relative to the first-best solution whenever outside options are available. The buyer accepts to trade and payoffs are realized.

# 3 Parametrization and Experimental Design

## 3.1 Experimental Implementation

To implement this simple mechanism in the laboratory, we chose $v_L = 60$, $v_H = 100$, and a quadratic cost function $c(i) = 25i^2$. Solving the first-order condition with these parameters yields the optimal investment level $i^* = \frac{4}{5}$ whenever outside options are available. In contrast, with joint ownership $i^* < i_j = 1$ as $v_H > c'(i_j)$ for all $i_j \in [0, 1]$, where $i_j$ indicates optimal investment in the absence of any outside option. In the experiment, we allow sellers to invest fully in an attempt to ease subjects' understanding of the conceptual set-up. This is unproblematic as its effect on the incurred cost is miniscule. Our goal was to minimize the difference in expected total surplus across ownership allocations while ensuring that the expected total surplus of the first-best solution strictly dominates the setting with joint ownership. In order to keep things as simple as possible for our subjects, we let the seller offer an option contract *ex ante*, and *ex post* the buyer decided whether or not to exercise the option. Outside options are valuable, as the first-best solution requires trade in the good state, i.e., $v = v_H$, only.[7] To gain insights into how outside options as executed through asset ownership affect *ex ante* investment and social welfare in an environment with asymmetric information, we implemented three treatments in a between-subject design:

- **Joint Ownership** The seller and the buyer have joint asset ownership. Thus, neither party has an outside option.
- **Seller Ownership** The seller is the asset owner. Whenever there is no trade the seller can exercise the outside option.
- **Buyer Ownership** The buyer owns the asset. The buyer can exercise the outside option whenever trade is not realized.

In the experiment, subjects were randomly assigned the role of buyers and sellers at the outset and stayed in the same role throughout. Each participant was only exposed to one treatment and could not participate in more than one session. A turnpike ("zipper") protocol was implemented: For $N$ participants in a session, each buyer and seller randomly received an ID $i, j$ ($i, j \in \{1, \cdots, \frac{N}{2}\}$), where $B_i$ and $S_j$ indicate buyers and sellers, respectively, $\forall i, j$ in a session. In each round $t \geq 1$, the matching procedure followed $mod(S_j + t, max(S_j)) = B_i$. To ensure efficient data collection we set $T \equiv max(B_i) + max(S_j) = N$, i.e., buyers and sellers were re-matched with each other exactly once.

All experimental sessions took place in May and June 2016 at the BizLab Experimental Research Laboratory at UNSW Sydney. All participants were recruited from the university's subject pool and administered by the online recruitment system ORSEE (Greiner 2015). In total, 370 subjects, 225 of whom were female, participated in 12 sessions. The participants' age ranged from 18 to 41 years, with an average of 21.44 (st. dev. = 3.08). Between 28 and 32 subjects participated at a time in each session. Upon arrival, participants were seated in front of a computer at desks, which were separated by dividers to minimize potential communication. Participants received written instructions and had the opportunity to ask questions.[8] The experiment was programmed in zTree (Fischbacher 2007) and subjects only interacted via their computer screens using the software application. In each round, subjects went through Stages 1-4, as described in Section 2. In an attempt to disburden subjects' understanding of the conceptual set-up, subjects in the role of sellers chose an investment level in percentage points when prompted in Stage 2–the investment stage. At the end of the experiment, we collected some information on participants' demographic attributes. They were then privately paid their experimental earnings from one randomly selected round in cash with a conversion rate of E\$ 3 = AU\$ 1 plus a show-up fee of AU\$ 10 (subjects could use their show-up fee to prevent bankruptcy). The average earnings were AU\$ 22.82 (st. dev = AU\$ 10.07).

[7] See also Hori (2006) who analyzes a bilateral trading model with investment that is similar in spirit. He shows that no contract made prior to the investment can simultaneously induce efficient investment and efficient *ex post* trade when the buyer's type is continuously distributed.

[8] These written instructions are reproduced in the Online Appendix.

## 3.2 Asset Ownership Implications

One can relate outside options to the idea of asset ownership by taking the owner of the good to be the party with the right to exercise such option. Thus, under full seller (buyer) ownership, if the seller makes an offer to the informed buyer but it is refused, then the seller (buyer) can always choose to exert his outside option equal to $v_L = 60$. This can be viewed through the lens of Grossman and Hart (1986)–ownership allows the holder to make alternative use of its assets if the parties disagree. To enrich intuition, $v_H = 100$ can be thought of as the value that can be generated in a buyer-seller relationship. In contrast, $v_L = 60$ is the default value that can be otherwise achieved outside the buyer-seller pair.[9] We are interested in the comparative statics when varying the allocation of asset ownership in a natural environment with asymmetric information to study its role and implications in a laboratory setting. Before we discuss the experimental results, we highlight the key insights that arise in our buyer-seller contracting model.

***The Seller*** Subjects in the role of the seller have control over two strategic variables: **price** and **investment**. From our analysis in Section 2 follows that both *Seller Ownership* and *Buyer Ownership* induce strictly lower investment relative to *Joint Ownership*. In particular, in our experimental set-up $i^* = \frac{4}{5} < i_j = 1$ and thus asset ownership by either the seller or the buyer leads to efficient *ex ante* investment while it is not the case under joint ownership. The seller is, in expectation, better off by enhancing the quality of the good and to trade it for a price (arbitrarily) close to $v_H = 100$ when he owns the asset or ownership is joint. The same holds true whenever the buyer has the outside option with the important difference that the price cannot exceed $v_H - v_L = 40$. Thus, prices are highest (lowest) when the seller (buyer) owns the asset, as the asset owner can always ensure himself a payoff of $v_L$. Pre-specified prices are expected to be comparable with *Joint Ownership* and *Seller Ownership*, while *Buyer Ownership* induces the lowest price.

***The Buyer*** Subjects in the role of the buyer learn in the trading stage the realized value of the object–but not the seller's investment–and decide whether to **accept or reject** the contract. Thus, with both *Joint Ownership* and *Seller Ownership* the buyer's decision is a simple one: if the value of the good weakly exceeds the pre-specified price, accept; otherwise reject. Under *Buyer Ownership*, however, only high-value objects will be traded and only so if the pre-specified price is weakly less than 40.[10]

[9] Of particular interest are the natural cases of *Joint Ownership* and *Seller Ownership*. For symmetry, however, we implemented *Buyer Ownership* too, which can be interpreted as the seller having to provide some "service" on top of the physical good for the buyer to derive its high valuation.

[10] This bargaining process has similarities with the famous "Ultimatum Game," which has been introduced in the economics literature by Güth, Schmittberger, and Schwarze (1982). Consider a starkly simplified version of our set-up with joint ownership and an important difference–symmetric information– where $i \in \{0, 1\}$ rather than $i \in [0, 1]$. The pre-specified price would correspond to the proposed split. If sellers ("proposers" in the Ultimatum-Game literature) were choosing between invest 0 at cost 0 or invest 1 at cost 25, then the game for the seller amounts to a choice between playing an ultimatum game with a pie size equal to $v_L = 60$ or an ultimatum game with pie size $100 - 25 = 75$. Finally, the buyer ("responder") decides whether the contract ("proposal") will be implemented or not.

***Total Surplus*** As hinted at above, optimal investment with *Joint Ownership* yields an expected total surplus of 75, while it is 76 in the first-best solution, which can be attained when the outside option $v_L$ is available. Although in line with the theory, since this difference is only marginal, we do not expect to see differences in social welfare across ownership allocations.

# 4 Experimental Findings

This section studies how asset ownership allocation with asymmetric information affects subjects' behavior with respect to the hold-up problem and social welfare. To give some guidance, throughout this section we analyze and discuss the relevant variables in chronological order as subjects go through each stage. We begin with summary statistics and then explore in more depth the sellers' and buyers' strategic choices as well as total surplus generated in buyer-seller relationships. Here, the analysis is static: we report mean strategic variables for each treatment.[11] To test for treatment differences non-parametrically, we apply two-sided Wilcoxon rank-sum (Mann-Whitney) tests, using observations from each buyer-seller pair.[12] As we have argued in Subsection 3.2, pricing decisions in the contract stage are highly correlated with (unobserved) investment in the investment stage. Trade acceptance by subjects in the buyer-role depends whether the terms as specified in the contract are (at least weakly) profitable for the informed party. We expect social welfare, i.e., total surplus, to be roughly the same across all three treatments. Table 1 lists observed mean price, mean investment, frequency of contract acceptance, and mean total surplus.

Table 1: Mean Price, Investment, Contract Acceptance, and Total Surplus, by Ownership Allocation

| | | Ownership | | |
|---|---|---|---|---|
| Stage | Variable | Joint | Seller | Buyer |
| 1 | Price | 75.38 [17.81] | 86.15 [15.96] | 45.85 [21.28] |
| 2 | Investment | 64.46 [33.62] | 60.30 [34.24] | 57.66 [30.32] |
| 3 | Contract Acceptance | 0.73 [0.44] | 0.53 [0.50] | 0.45 [0.50] |
| | $CA \mid v = v_H$ | 0.87 [0.33] | 0.83 [0.38] | 0.73 [0.45] |
| | $CA \mid v = v_L$ | 0.46 [0.50] | 0.11 [0.32] | 0.09 [0.28] |
| 4 | Total Surplus | 53.90 [40.37] | 67.38 [17.17] | 65.71 [17.77] |
| | $TS \mid CA = 1$ | 77.24 [12.01] | 80.88 [10.24] | 82.68 [10.75] |
| | $TS \mid CA = 1$ & $v = v_H$ | 82.45 [7.38] | 83.19 [7.28] | 85.29 [6.74] |

Mean [st. dev.]. Contract Acceptance: trade realized = 1; rejected = 0. CA | $v = \tilde{v} \in \{v_L, v_H\}$: Contract Acceptance conditional on value realization. TS | CA = $a \in \{0, 1\}$: Total surplus conditional on trade realization.

[11] In contrast, Section 4.4 and Appendix B will study dynamics: that is, we report mean strategic variables in the last ten rounds.

[12] As a robustness test and to complement the non-parametric analysis in this section, we ran ordinary least-square regressions with random effects controlling for learning effects. These results can be found in Section 4.4.

***Stages 1 & 2*** As predicted, asset ownership strongly affects *ex ante* investment and the posted price by the seller in the early stages. When the seller (buyer) holds the outside option the pre-specified price is significantly higher (lower) compared to *Joint Ownership* (all $p$-values of 0.001 for *Joint Ownership* vs. *Seller [Buyer] Ownership*, and *Seller Ownership* vs. *Buyer Ownership*, respectively).[13] *Ex ante* investment is lower in the presence of any outside option. This is statistically significant for either *Seller Ownership* or *Buyer Ownership* with all $p = 0.001$. Testing for differences between asset ownership allocation among the seller and the buyer produces a $p$-value of 0.001.

***Stage 3*** Since the quality of the good is stochastically determined, *ex ante* investment directly impacts the realized quality. Taken together with the pre-specified price in the contract stage and the fact that we have asymmetric information in the trading stage, the conjunction of these forces affect the actual realization of trade in Stage 3. In line with our predictions, the frequency of trade is lower when outside options are available because the first-best solution requires trade in the good state only when $v = v_H$ (all $p = 0.001$). At the same time, the difference in contract acceptance when outside options are available to either seller or buyer cannot be explained by theory ($p = 0.001$).

Let us delve further into contract acceptance conditional on product quality. Our first test excludes goods with $v = v_L$ from the analysis of realized trades. Transactions are optimal when $v = v_H$, independently of asset ownership. Excluding $v_L$ from the analysis thus serves, in a sense, to "level the playing field" between *Joint Ownership* and *Seller (Buyer) Ownership*. Overall, the vast majority of high-value goods are traded, with *Buyer Ownership* featuring the lowest frequency. As we will discuss in Subsection 4.2, this is mostly driven by sellers specifying a price that exceeds $v_H - v_L = 40$, thus resulting in the buyer exercising his outside option. Our tests produce a $p$-value of 0.002 for *Joint Ownership* vs. *Seller Ownership*, and $p$-values of 0.001 for *Joint Ownership* vs. *Seller Ownership*, and *Seller Ownership* vs. *Buyer Ownership*, respectively.

Our second test is to consider, instead of high-value goods, the production of goods with $v = v_L$. Trade of such goods is virtually eliminated whenever outside options are available. Still, roughly one in ten contracts is accepted by the informed party and hence implemented.[14] When asset ownership is joint, we observe that–strikingly–about one in two contracts is indeed accepted by the buyer after learning the realized value of the object. The difference in frequency of such $v_L$-trades is highly statistically significant with $p$-values of 0.001 for *Joint Ownership* vs. *Seller (Buyer) Ownership*, while the difference among treatments with outside options is only mildly significant ($p = 0.091$).

***Stage 4*** Finally, we turn to total surplus. The mere availability of outside options in case of disagreement leads to higher total surplus. Unconditional total surplus is lowest under *Joint Ownership*, as neither party can make use of any outside option. When asset ownership is joint, disagreement in the trading stage can lead to a large negative payoff of −25 for the seller, which in turn increases the observed variance substantially. As a result, the

[13] We conjecture that the difference in mean prices between *Joint Ownership* and *Seller Ownership* is due to the more equal nature of the arrangement compared to the setting when the seller holds the outside option, and therefore a lower price may be considered as "fair."

[14] These are very like mistakes by subjects; the frequency of implemented contracts conditional on low-value realizations sharply decreases over time.

difference in total surplus for each buyer-seller pair across treatments is less significant. Under *Seller (Buyer) Ownership* total surplus is higher compared to *Joint Ownership*; it is, however, only statistically significant for *Seller Ownership* ($p = 0.081$) and insignificant for *Buyer Ownership* ($p = 0.835$). Total surplus under *Seller Ownership* dominates the social welfare that is generated under *Buyer Ownership*. This is highly statistically significant with a $p$-value of 0.001.

Next, we further disentangle the effects of asset ownership on total surplus by focusing first on successful trades only. Subsequently, we restrict attention to successful trades conditional on the production of high-value goods. In both cases, differences across treatments are more strongly pronounced. Realized total surplus after trade (of high-value goods) increases monotonically from *Joint Ownership* to *Seller Ownership* to *Buyer Ownership* with $p$-values of 0.001 (0.008), 0.001 (0.001), and 0.001 (0.001) for *Joint Ownership* vs. *Seller Ownership*, *Joint Ownership* vs. *Buyer Ownership*, and *Seller Ownership* vs. *Buyer Ownership*, respectively.

We now explore behavior in the different stages in more depth and relate the data to our theoretical framework and asset ownership implications.

## 4.1 The Seller's Strategic Choices: Price and Investment

In our set-up, renegotiation may not proceed without costs through the introduction of one-sided asymmetric information in the trading stage. However, even if negotiation is costless, the division of the total surplus generated by each buyer-seller pair may be "wrong" in the sense that it will not encourage the right *ex ante* investments. In our experiment, the highest *ex ante* investment is observed when outside option are unavailable. This is consistent with the theoretical predictions, nonetheless, the empirical observations are bounded away from optimal investment. With *Joint Ownership*, the seller's dominant strategy is to set $i_j = \bar{i} = 1$, as opposed to $i^* = \frac{4}{5}$ whenever outside options are available.[15] The presence of an outside option for the seller (buyer) enhances *ex ante* investment and amounts to 74.4% (72.1%) of the optimal investment level compared to just 64.5% when asset ownership is joint.[16]

Figure 1 shows the observed frequencies of choices made in the early stages when specifying the contract and choosing the investment $i$, by ownership allocation. The larger the circles, the higher the observed frequency of that particular price–investment combination.

The red horizontal lines indicate the optimal investment level and, in the *Joint Ownership* case, the lower horizontal line indicates the required investment level of $i_j = \frac{73}{100}$ to obtain, in expectation, a higher surplus as opposed to setting $i_j = \underline{i} = 0$, thus incurring $c(0) = 0$ and simply trading the low-value good.

The red vertical lines indicate the upper bound of prices, assuming standard tie-breaking rules. While these lines are at prices of 60 and 100 for *Joint Ownership* and *Seller Ownership*, respectively, it is no longer the case in the setting where the outside option is allocated

[15] Recall that in the experiment we allow sellers to invest fully in order to fascilitate subjects' understanding of the conceptual set-up.

[16] While, theoretically, approximately efficient outcomes can be implemented whenever outside options are available, we do not find supporting experimental evidence. Observed *ex ante* investment is significantly different from the theoretical benchmark in all three ownership allocations (all $p$-values of 0.0001 for one-sample t-tests).

to the informed party–the buyer. In this scenario, the buyer has all bargaining power and thus the lower (upper) bound for pricing is at 25 (40).

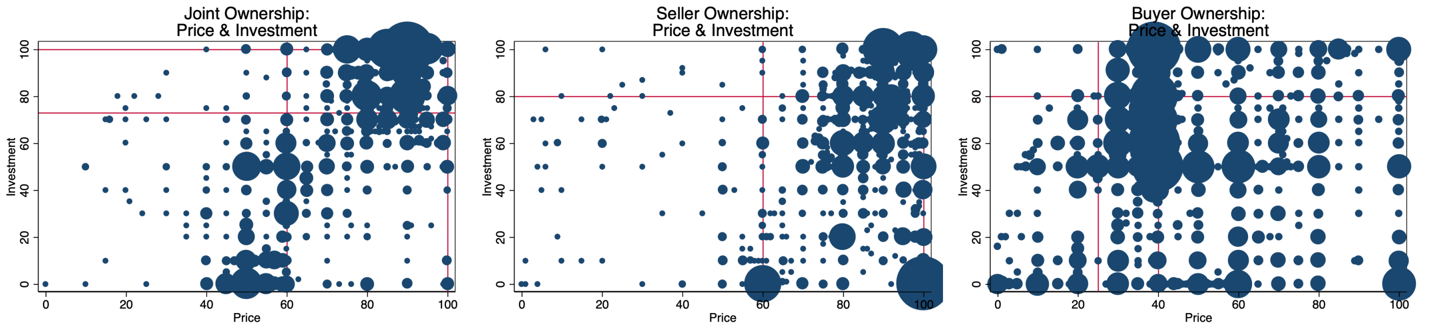


Figure 1: Price-Investment Combinations, by Ownership Allocation

Figure 1 suggests different clustering of price-investment combinations across our three treatments. Under *Joint Ownership*, two major clusters emerge: one cluster in the top-right corner with both high *ex ante* investment and price, as the theory predicts. By contrast, the second concentration of price-investment combinations occurs with low investment in the range $i_j \in [0, \frac{3}{5}]$ and price choices strictly below $60 = v_L$. When the seller owns the asset, clustering occurs mostly in the top-right corner as well with both high *ex ante* investment and price. On the other hand, when asset ownership is allocated to the buyer, the observations are concentrated with high *ex ante* investment in the range $i \in [\frac{2}{5}, 1]$ and price choices around $40 = v_H - v_L$. This case is, however, very noisy and indicates difficulties faced by our experimental subjects in the role of the seller when the buyer holds the outside option.

***Seller Behavior*** Overall, the comparative statics of *ex ante* investment across treatments are in line with our theoretical framework. Observed behavior under both *Seller Ownership* and *Buyer Ownership* is closest to the point predictions derived in Section 3. Nonetheless, investment falls short in all settings and we observe underinvestment rather than overinvestment under *Joint Ownership* relative to the first-best solution.

## 4.2 The Buyer's Strategic Choice: Trade

Asset ownership can be interpreted as taking the owner of the good to be the party to whom the residual control rights belong. The key right of asset ownership is to exercise the outside option. As a result, if the seller makes an offer to the buyer but he rejects the offer and the seller (buyer) is the asset owner, then the seller (buyer) can always choose to exert his outside option and gets $v_L = 60$. A natural interpretation is that the low-valuation is the default value that can be generated outside the buyer-seller relationship.

It our model, outside options are valuable because with fully-allocated asset ownership to either seller or buyer, the first-best solution requires trade in the good state only. At the same time, when the outside option is available, then trading and consuming the outside option are both efficient in the case of $v = v_L$. When asset ownership is joint, the seller can, in principle, always secure higher profits for himself by always producing a high-value good. Figure 1 highlights that price-investment combinations are clustered in different ways across the three treatments. We are particularly interested in one of the two clusters under *Joint Ownership* that features very low *ex ante* investment and price choices weakly below 60.

How do sellers respond to posted prices as specified in the contract stage after learning the realized value of the object? Figure 2 illustrates the share of accepted trades conditional on the stochastically determined value in all treatments.

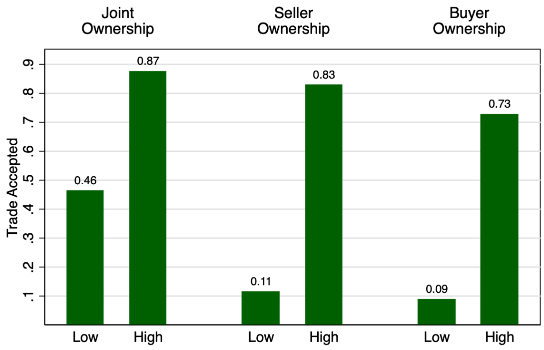


Figure 2: Share of Accepted Trades Conditional on Value, by Ownership Allocation

To shed some light on the consequences of asset ownership, we explore the observed trade realizations conditional on the production of either a low-value or high-value good.

*Low-Value Goods* In the presence of outside options and conditional on the production of a good $v = v_L$, 88.6% (91.1%) of the proposed contracts are rejected by the informed party under *Seller (Buyer) Ownership*. The underlying reason is simply that pre-specified prices exceed either $v_L$ when the seller owns the asset (mean price of 87.48, st.dev.=12.88) or zero when the asset belongs to the buyer (mean price of 47.34, st.dev.=23.29). Differences across treatments, i.e., which party holds the outside option at that point in time, appear to be tangential, though mildly significant ($p = 0.091$ for *Seller Ownership* vs. *Buyer Ownership*).

While trade of low-value objects can be virtually eliminated through the implementation of asset ownership as an outside option, it is no longer the case whenever outside options are absent. Under *Joint Ownership*, 46.2% of proposed contracts with goods $v = v_L$ are accepted by the informed party. The difference in trade completion is highly statistically significant for both types of outside options (both $p = 0.001$ for *Joint Ownership* vs. *Seller (Buyer) Ownership*). Acceptance by the informed party is only sensible if the pricing is such that the terms specified in the contract are weakly welfare-improving for the buyer; i.e., if the price is weakly less than $v_L$. Without outside options, we observe mean prices of 50.12 (st.dev.=8.82), which suggests that some sellers deliberately set a low price in the contract stage and invest $i$ accordingly in the investment stage. This observation is also consistent with the "low-price and low-investment"-cluster depicted in Figure 1. We view this as a source of inefficiency as both sellers and buyers would be better off had a high-value good been produced and successfully traded in the first place. In addition, we also examine the breakdown of trade. Under *Joint Ownership*, 53.8% of proposed contracts with goods $v = v_L$ are rejected by the buyer. Across ownership allocations, trade is most likely to break down inefficiently under *Joint Ownership* (both $p = 0.001$ for *Joint Ownership* vs. *Seller (Buyer) Ownership*). As argued in Section 2, the breakdown of such trade has the most serious consequence when ownership is joint, as all potential surplus drops to zero and the seller incurs weakly positive costs from investing in Stage 2.

*High-Value Goods* Conditional on the realization of an object $v = v_H$, the acceptance rate ranges from 72.8% when the buyer owns the asset to 82.8% when the asset belongs to the seller. Buyers accept to trade with mean prices of 86.19 (st. dev.= 14.69) with *Seller Ownership* and mean prices of 37.78 (st. dev.= 11.31) with *Buyer Ownership*, respectively. The driving force behind buyers' rejection of contracts is almost exclusively due to pre-specified prices being "too high." While this is easy to see in the *Buyer Ownership* case with mean prices of 67.74 (st. dev.= 19.21), with *Seller Ownership* it can only be explained with the buyers' perceiving the offered contract as "unfair"–an extensively documented phenomenon in the Ultimatum-Game literature (Güth, Schmittberger, and Schwarze 1982). We find mean prices of 96.99 (st. dev.= 4.99) and a median ask-price of 99.00. Without any outside option, 87.5% of posted contracts are accepted with a mean price of 80.17 (st. dev.= 14.34), while the rejected contracts feature an average price of 92.21 (st. dev.= 7.46).

***Buyer Behavior*** Significantly more trade of low-value goods is realized when asset ownership is joint. Outside options induced as asset ownership mitigate significantly the trade of low-value objects by letting the owner exercise them in case of disagreement in the trading stage. Conditional on the production of $v = v_L$, 53.8% of proposed contracts are rejected by the buyer under *Joint Ownership*. Across ownership allocations, trade is most likely to break down inefficiently under *Joint Ownership*. At the same time, this also highlights some "mechanical mistakes" of subjects in playing the game by specifying prices in the contract stage that are (perceived as) too high.

## 4.3 Total Surplus

To analyze *ex post* efficiency, we now focus on the total surplus that is generated by each buyer-seller pair. We begin by examining unconditional total surplus and then step-by-step add conditions to enrich our understanding of subjects' behavior in all three treatments.

As we have seen in Table 1, the presence of outside options improves total surplus both unconditionally and conditional on realized trade as well as conditional on realized trade *and* the eventual production of a good $v = v_H$.

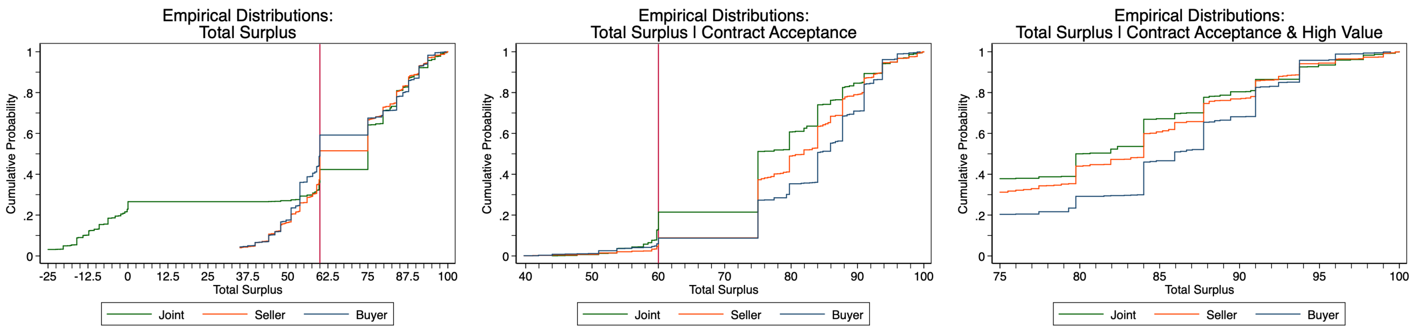


Figure 3: Empirical Distribution of Total Surplus, Total Surplus Conditional on Contract Acceptance, and Total Surplus Conditional on Contract Acceptance & High-Value Good, by Ownership Allocation

Moving beyond point estimates, Figure 3 shows the empirical distribution of total surplus, total surplus conditional on accepted trades, and total surplus conditional on successful trades and the production of a high-value good, by ownership allocation. Both unconditional and conditional total surplus distributions are significantly higher in stochastic dominance under *Buyer Ownership* and *Seller Ownership* than with *Joint Ownership*: two-sample Kolmogorov-Smirnov (KS) tests and two-sample Epps-Singleton (ES) tests both produce $p = 0.001$ for unconditional total surplus and total surplus conditional on [(contract acceptance) and high-value good realization]. The only exception is total surplus conditional on contract acceptance and high-value good realization between *Joint Ownership* and *Seller Ownership* ($p = 0.012$ and $p = 0.042$ for KS and ES, respectively).

Asset ownership as implemented through outside options has–of course–distributive consequences. Whoever holds the outside option receives the lion's share, even if the option is not exercised in the first place. The seller's share of the unconditional total surplus is, on average, the lowest when the buyer has asset ownership with 9.0% and increases from 75.9% with joint asset ownership to 89.5% when the seller owns the asset.

Conditional on trade acceptance (and $v = v_H$), the seller's share of total surplus increases monotonically from 28.0% (27.0%) with *Buyer Ownership* to 77.1% (75.9%) when asset ownership is joint to 83.6% (83.4%) with *Seller Ownership.* All payoff distributions for both buyers and sellers are illustrated in Figure A.1 in Appendix A.

***Total Surplus*** Taken altogether, the key insight is that asset ownership reduces *ex post* frictions and total surplus is significantly higher whenever outside options are available. This is true regardless whether they are consumed or not.

## 4.4 Optimal Behavior, Learning, and Robustness of Results

Before we conclude we want to explore subjects' behavior in more detail. We are especially interested in optimal behavior with respect to our theoretical considerations sketched in Section 2. Additionally, we will briefly discuss observed behavior in the last ten rounds to see if learning played a role in our setting. Lastly, we present an econometric robustness test to complement our non-parametric analysis and key elements discussed so far in this section.

***Optimal Behavior*** Our model provides sharp predictions in terms of *ex ante* investment and *ex post* transactions. We are curious to see how subjects fared "in the model." With outside options, the first-best solution requires trade in the good state only, therefore, we want to look closer into subjects who successfully traded high-value goods by analyzing their strategic choices in the contract stage and investment stage.[17]

Whenever outside options are available the *ex ante* efficient outcome is to trade whenever the good is high-value and to consume the outside option when $v = v_L$. The solution to (2) together with our parametrization yields an optimal investment level (and trade probability) $i^* = \frac{4}{5}$. In contrast, when outside options are not available, optimal seller behavior consists in always manufacturing a high-value good by setting $i_j = \bar{i} = 1$.

[17]This is of course a necessary, but by no means sufficient, condition for us to have "the right model" to approach these questions with.

Given the good state and accepted contracts, we work backwards in time and take our *ex ante* investment predictions at "face value." Sellers' choices in the investment stage are remarkably close to the theoretical prediction under *Seller Ownership*, amounting, on average, to 79.38 (st.dev.=20.59) and $p = 0.358$ for one-sample t-test. When the buyer–the informed party–is the asset owner, observed investment levels are approximately 5 percentage points lower than $i^* = \frac{4}{5}$, averaging 74.49 (st.dev.=18.32). This difference, however, is highly statistically significant with a $p$-value of 0.001 for one-sample t-test.[18]

Meanwhile, in the setting where ownership is joint, even conditional on the realization of high-value goods and successful trades, the observed average investment level in our data is bounded away from optimal behavior with 81.14 (st.dev.=20.88), and $p = 0.001$ for one-sample t-test.

Whenever outside options are available and conditional on successfully traded high-value goods, *ex ante* investment in our laboratory setting is remarkably close to what our theory predicts. By contrast, under *Joint Ownership*, while mean investment is higher compared to the other two forms of asset ownership–consistent with our theory–it is nevertheless significantly lower in absolute terms than what the theory would predict.

***Learning*** So far, our analysis throughout Section 4 was static: it focused on all-round pricing, investment, and trading choices. To collect a rich dataset we set in each session the number of rounds $T \equiv N$, where $N \in \{28, 30, 32\}$. We will briefly step away from the static setting that uses all data collected and focus on behavior in later rounds only. Given the complexity of the conceptual set-up imposed on our subjects, we look into sellers' and buyers' strategic choices in the *last ten* rounds only to account for learning.[19]

While this implies the loss of a large amount of data, and hence statistical power, our qualitative conclusions remain unaltered. Below we report the main noteworthy differences in behavior compared to the results presented thus far. These include contract acceptance by the informed party, both unconditionally and conditionally. The unconditional trade rate reduces from 73.4% to 63.9% without outside options. While it remains unchanged under *Seller Ownership*, the unconditional acceptance rate of contracts under *Buyer Ownership* also decreases from 44.7% to 37.1%. Conditional on the production of high-value goods, the share of accepted trades increases with *Buyer Ownership* from 72.8% to 91.7%, otherwise, when either the seller or both parties own the asset, no significant changes are observed. Additionally, total surplus decreases considerably under *Joint Ownership* from 53.90 to 44.41. All tables and figures presented in this section are replicated using data collected in the last ten rounds only. These can be found in Appendix B.

***Robustness Test*** Lastly, we conduct a robustness test on this section's results. To complement the non-parametric analysis and key elements discussed so far, we ran ordinary least-square regressions with random effects controlling for learning effects. In particular, we regressed price, investment, contract acceptance, and total surplus on the treatment dummies *Seller Ownership* and *Buyer Ownership* (with *Joint Ownership* as baseline), and

[18] Thus, *ex ante* investment amounts to 99.2% (93.1%) of the optimal investment level when the seller (buyer) has asset ownership conditional on contract acceptance and a high-value object.

[19] We also split our our sample in half and ran all tests for data collected in rounds $1 \leq t \leq \frac{N}{2}$ and $\frac{N}{2} < t \leq T$ separately. Our results remain qualitatively unchanged.

the dichotomous variables high-value ($0 = v_L$ and $1 = v_H$) and contract acceptance ($0 =$ rejected and $1 =$ accepted).

In order to verify that subjects treated the buyer-seller encounter when re-matched as an independent problem rather than as the second part of a larger super-game, we include a dummy *Re-match*, which is 0 for $t \leq \frac{T}{2}$ and 1 for $t > \frac{T}{2}$ where $t$ ($t \in \{1, \cdots, T\}$) corresponds to the round. Furthermore, we use two additional learning functions: to validate that subjects treated the buyer-seller encounters they successively had as independent problems rather than as parts of a larger super-game, we define a weighted learning function $\{g_t\} = \{\frac{1}{t}\}$. The results do not qualitatively change when we replace *Re-match* with a control for trends over time using this weighted learning function. The same holds true when we replace it with a linear version such that $\{g_t\} = \{t\}$. To account for the fact that behavior within sessions is not independent, we treat each session as our units of statistically independent observations and cluster standard errors by session.

Table 2 lists the results from this analysis.

Table 2: OLS Estimations with Random Effects of Price, Investment, Contract Acceptance, and Total Surplus

| | *Price* | *Investment* | *Contract Acceptance* | *Total Surplus* |
|---|---|---|---|---|
| *Intercept* | 72.47$^{***}$ | 11.12 | 1.02$^{***}$ | 17.66$^{***}$ |
| | (2.45) | (8.57) | (0.00) | (5.82) |
| *Price* | | 0.56$^{***}$ | −0.01$^{***}$ | |
| | | (0.12) | (0.00) | |
| *High-Value Good* | 5.07$^{***}$ | | 0.69$^{***}$ | 3.30$^{**}$ |
| | (1.01) | | (0.03) | (1.40) |
| *Contract Acceptance* | | 14.38$^{***}$ | | 46.77$^{***}$ |
| | | (1.46) | | (7.30) |
| *Seller Ownership* | 10.90$^{***}$ | −7.03 | −0.05$^{*}$ | 23.13$^{***}$ |
| | (2.04) | (4.80) | (0.03) | (2.38) |
| *Buyer Ownership* | −29.18$^{***}$ | 13.91$^{***}$ | −0.51$^{***}$ | 25.54$^{***}$ |
| | (2.00) | (4.86) | (0.03) | (2.65) |
| *Re-match* | −0.53 | 1.39 | 0.03$^{***}$ | −0.46 |
| | (2.11) | (1.87) | (0.01) | (0.76) |
| $\sigma_\epsilon$ | 14.07 | 19.71 | 0.33 | 14.59 |
| $\sigma_u$ | 11.48 | 12.64 | 0.08 | 5.06 |
| N | 5718 | 5718 | 5718 | 5718 |
| (Between) R-squared | 0.68 | 0.35 | 0.83 | 0.66 |

For all estimations, robust standard errors are clustered at the session level and shown in parenthesis.
$^{***}$Significant at the 1 percent level; $^{**}$Significant at the 5 percent level; $^{*}$Significant at the 10 percent level.

We find a strong positive effect of seller and buyer asset ownership, as well as contract acceptance on total surplus. The production of a high-value good also positively affects total surplus as well. *Seller (Buyer) Ownership* has a strong positive (negative) effect on pre-specified prices in the contract stage. In contrast, *Seller (Buyer) Ownership* has a strong negative (positive) effect on the seller's investment choice. While this effect is highly significant when the buyer owns the asset, it is no longer the case whenever the seller is the asset owner.

The production of a high-value good strongly positively affects posted prices, and contract acceptance has a strong positive effect on investment. Further, the generation of high value in the buyer-seller relationship has a strong positive effect on contract acceptance by the informed party. Both *Seller Ownership* and *Buyer Ownership* have a negative effect on trade realization. This effect is highly significant and strongly pronounced when the buyer is the asset owner. Whenever the seller owns the asset, however, this effects is alleviated and only mildly statistically significant. Lastly, the pre-specified price has a negative effect on trade realization.

Thus, our OLS estimations with random effects confirm all of our previous, non-parametric, results. In particular, there is no evidence of super-game effects, as subjects' behavior does not significantly change in response to being re-matched for a second time (as well as the number of buyer-seller encounters they previously had when using alternative learning functions). The only exception constitutes contract acceptance, where we find that experience has a positive affect. This effect is driven by our *Buyer Ownership* treatment, where the share of realized contracts increases sharply from 36.8% in $t \leq \frac{N}{2}$ to 52.6% in $t > \frac{N}{2}$. This observation is consistent with the noisy picture of price-investment combinations depicted in Figure 1, while a clearer picture emerges in the last ten rounds of play, as illustrated in Figure B.1. We conjecture that subjects perceived the *Buyer Ownership* treatment as less intuitive compared to the other two forms of asset ownership studied in this paper.

# 5 Concluding Remarks

Beginning with Hart and Moore (2008) the formal literature on the theory of the firm has started to focus on the trade-off between flexible and rigid contracts and on *ex post* frictions, rather than *ex ante* underinvestment. The approach pioneered by Hart and Moore (2008) and Hart (2009) involves behavioral considerations with contractual arrangements being viewed as "reference points" by the contracting parties, which was subsequently also analyzed experimentally by Fehr, Hart, and Zehnder (2011).

This approach has been fruitful, and it has a ring of truth to it in terms of how contracting parties actually behave. Perhaps one of the central messages of this body of work is that asset ownership plays a role in mitigating agrievement, not just in enhancing *ex ante* investment as in classic Property-Rights Theory.

Our contribution is to show that in an environment with no behavioral considerations, but with asymmetric information, asset ownership also plays a vital role in ameliorating *ex post* frictions.

In our experiment we find that outside options such as those induced by asset ownership are valuable, not only because of somewhat more efficient *ex ante* investment but because they reduce *ex post* frictions. Total surplus is significantly higher whenever outside option are available regardless of whether or not they are consumed.

We see the behavioral approach of Hart (2008), Hart and Moore (2008) and Hart (2009) and our asymmetric-information approach as complementary. We hope that further exploration of both will provide a richer theory of "haggling" and the role that asset ownership can play in reducing it.

As we mentioned in the introduction, is has not escaped our attention that an implication of our paper is that *how* firms arise at the optimal mix of asset ownership–both vertically and laterally–involves thinking about how both *ex ante* investment incentives and *ex post* haggling are affected by strategies that firms adopt. To date the PRT literature has left this issue of how the optimal asset ownership structure comes about as something of a black box. But we hope that our paper both points to the importance of, and offers a basic framework for analyzing this important issue bearing on both "what managers do" (Gibbons and Henderson 2012) and the efficiency implications of so doing.

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# Asset Ownership and the Hold-Up Problem with Asymmetric Information
## Online Appendix

September 17, 2021

## A Appendix: Distribution of Payoffs

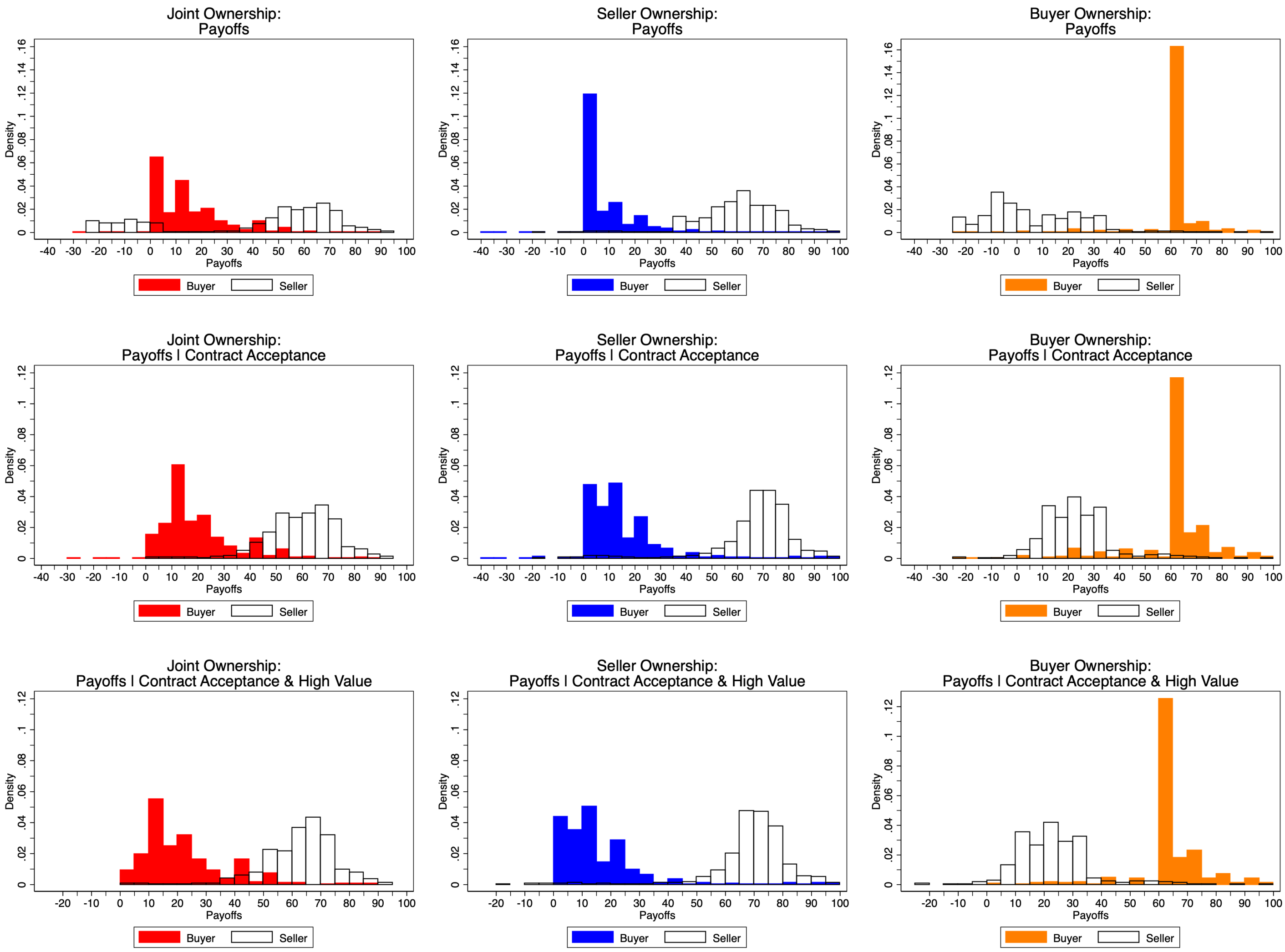


Figure A.1: Payoff Distributions of Buyers and Sellers, by Total Surplus, Total Surplus Conditional on
Contract Acceptance, and Total Surplus Conditional on Contract Acceptance & High Value, by Ownership Allocation

# B Appendix: Learning

Table B.1: Mean Price, Investment, Contract Acceptance, and Total Surplus in Last Ten Rounds, by Ownership Allocation

| | | Ownership | | |
|---|---|---|---|---|
| Stage | Variable | Joint | Seller | Buyer |
| 1 | Price | 79.31 [16.19] | 87.40 [14.01] | 38.92 [16.08] |
| 2 | Investment | 66.61 [36.01] | 58.71 [34.93] | 54.31 [27.62] |
| 3 | Contract Acceptance | 0.64 [0.48] | 0.52 [0.50] | 0.37 [0.49] |
| | $CA \mid v = v_H$ | 0.86 [0.35] | 0.82 [0.39] | 0.92 [0.28] |
| | $CA \mid v = v_L$ | 0.32 [0.48] | 0.17 [0.38] | 0.03 [0.16] |
| 4 | Total Surplus | 44.41 [42.13] | 65.80 [16.70] | 64.94 [16.86] |
| | $TS \mid CA = 1$ | 75.04 [9.78] | 78.33 [12.47] | 85.07 [8.09] |
| | $TS \mid CA = 1 \,\&\, v = v_H$ | 79.21 [6.10] | 82.61 [7.33] | 86.21 [6.16] |

Mean [st. dev.]. Contract Acceptance: trade realized = 1; rejected = 0. CA | $v = \tilde{v} \in \{v_L, v_H\}$: Contract Acceptance conditional on value realization. TS | CA = $a \in \{0, 1\}$: Total surplus conditional on trade realization.

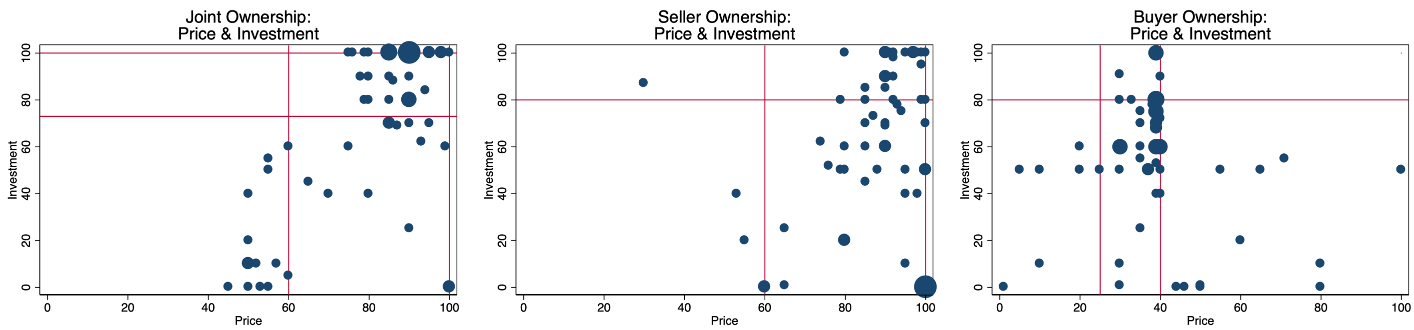


Figure B.1: Price-Investment Combinations in Last Ten Rounds, by Ownership Allocation

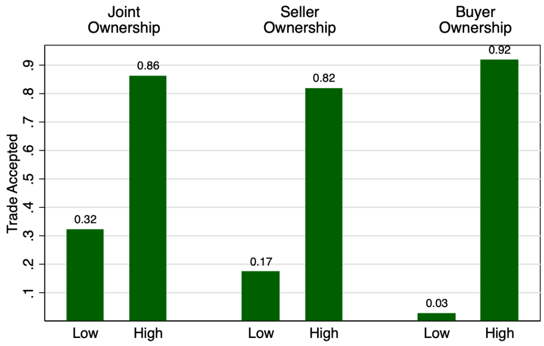


Figure B.2: Share of Accepted Trades Conditional on Value in Last Ten Rounds, by Ownership Allocation

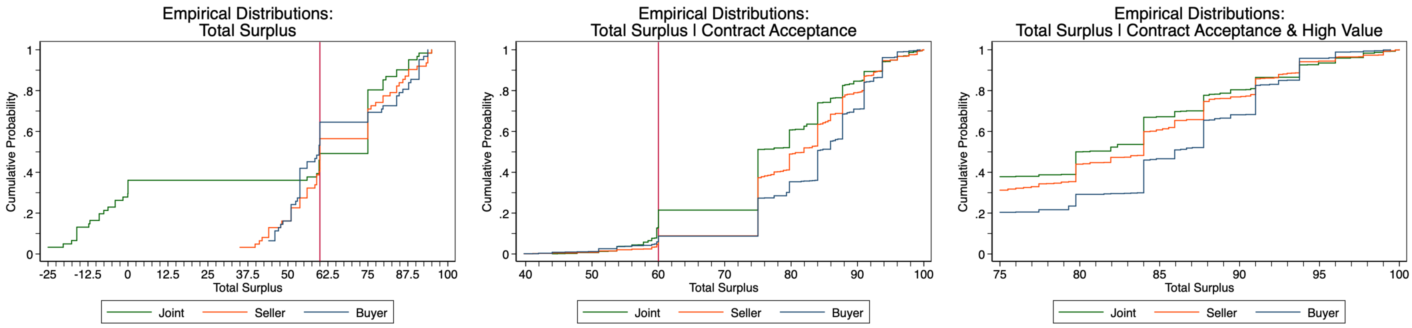


Figure B.3: Empirical Distribution of Total Surplus, Total Surplus Conditional on Contract Acceptance, and Total Surplus Conditional on Contract Acceptance & High-Value Good in Last Ten Rounds, by Ownership Allocation

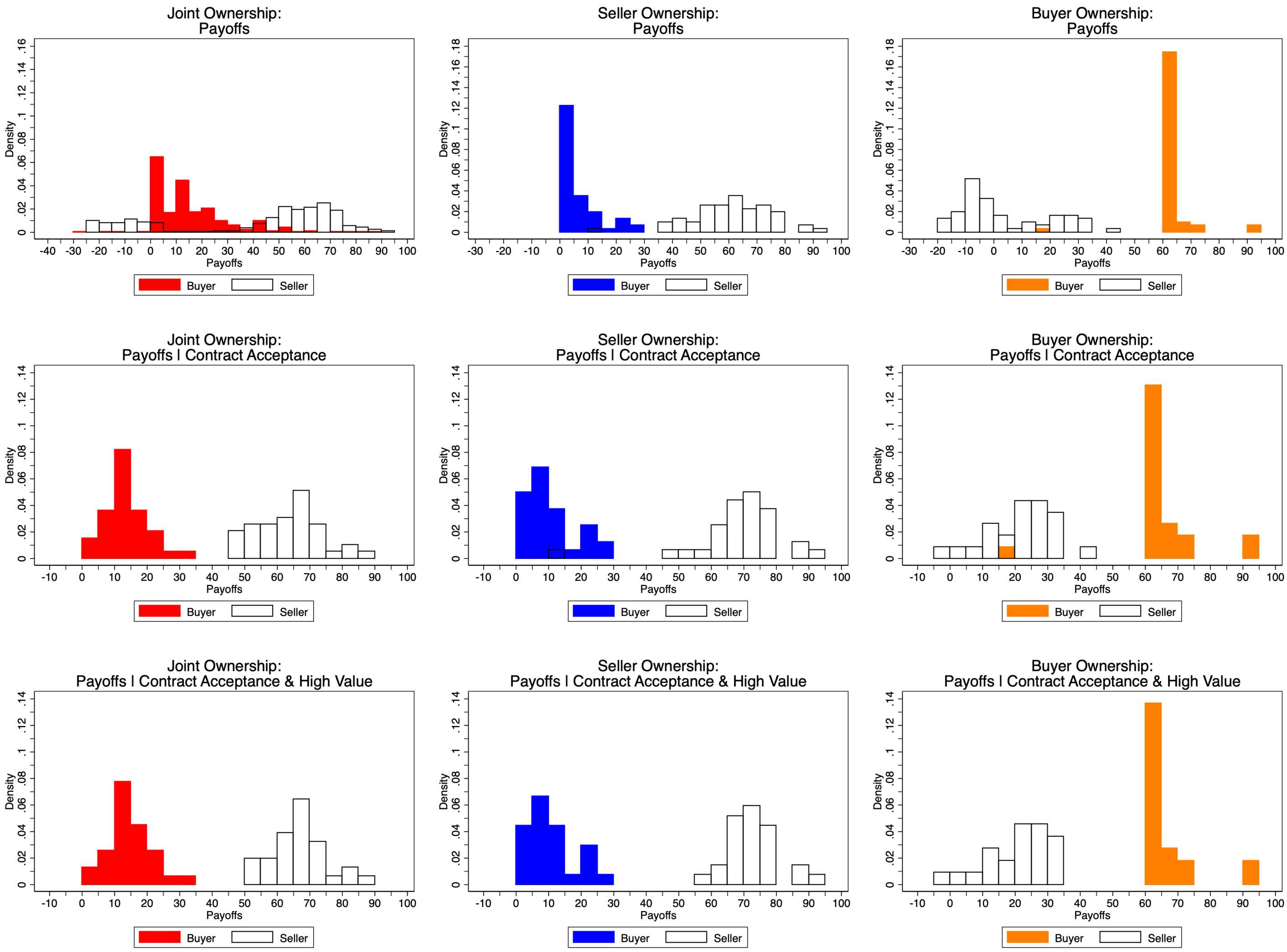


Figure B.4: Payoff Distributions of Buyers and Sellers in Last Ten Rounds, by Total Surplus, Total Surplus
Conditional on Contract Acceptance, and Total Surplus Conditional on Contract Acceptance & High Value, by Ownership Allocation