

Private Information and Endogenous Matching in Supply Chains: Theory and Experiments

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We investigate a supply chain setting where a supplier's cost information may be private information (and they have the ability to disclose it) and buyers and suppliers may endogenously match into pairs. After forming pairs, the two parties interact in a dynamic back-and-forth bargaining environment. We first derive theoretical predictions depending on whether the supplier's cost information is private or not, and the matching protocol type. We then test these predictions through a human-subject experiment, which yields a number of insights. A key one is that suppliers always make less than the normative theory predicts, whether their cost information is known or private information. This effect is especially pronounced under private information for high cost suppliers, because buyers make more aggressive bargaining offers in such a setting. Thus, contrary to theory, a second result is that higher cost suppliers actually benefit from disclosing their private costs, in an effort to achieve a more favorable outcome while bargaining. A third important result is that endogenous matching leads to a higher variance of profits, compared to an exogenous matching protocol. This is due to the ability of higher quality buyers to choose to contract with higher quality suppliers and vice-versa.

Key words: behavioral operations; supply chains; private information; endogenous matching; disclosure

1. Introduction

A majority of the existing experimental research on supply chain management assumes full information of cost, price, and demand parameters. This literature, when investigating two-stage supply chains, also tends to focus on settings where buyer-supplier pairs are exogenously (i.e. randomly) determined prior to any sort of contracting. Yet, in practice it is common for certain information to be private to one party and that buyers and suppliers may endogenously decide with whom they want to contract. For example, an executive for a large durable goods manufacturer recently told us, "I usually don't know my supplier's cost structure exactly, but I have a rough estimate of what it might be," suggesting that the supplier's cost details may be private information.

There is also evidence that buyers are interested in targeting specific suppliers. For example, a recent study by McKinsey & Company showed that buyers should look for suppliers interested in

collaborative relationships: buyers that collaborated with their suppliers achieved EBIT (earnings before interest and tax) growth rates that were double compared to those that did not (Noor et al. 2012). This same report also details how these collaborative efforts include “negotiations (which) are based on full transparency into costs.” In our study, we investigate supply chain contracting in a dynamic bargaining environment where supplier costs may be private or full information, under endogenous and exogenous matching.

Industry is replete with examples of buyers wanting transparency from their suppliers. A famous one is Toyota. Its purchasing department encourages suppliers to share their cost details with them so that they can attempt to identify joint gains (Mishina 1995). Yet, suppliers may be reluctant to share this private information if they feel it will put them at a disadvantage in subsequent negotiations. This creates a tension between disclosing costs and being able to contract (or ‘match’ hereafter) with a higher quality buyer, versus having private information that may be advantageous in negotiations.

The literature on supply chain management, combined with these observations in practice, brings us to our main research questions. What is the effect of private supplier cost information on supply chain outcomes (e.g., contract terms and distribution of profits) and bargaining dynamics? How are supply chain outcomes affected when buyers and suppliers can endogenously choose with whom to contract? When is it in a supplier’s best interest to disclose their private cost information?

We address these questions in an unstructured bargaining environment with random demand. In particular, we deviate from the classical one-shot ultimatum setting and allow for both parties to make multiple offers and send limited feedback. Thus, we study our main research questions in a setting where two parties engage in a more natural bargaining process, and both parties have relatively equal bargaining power. We also focus exclusively on wholesale price contracts such that the two parties negotiate a wholesale price and stocking quantity simultaneously, and the supplier incurs the cost of any unsold inventory.¹

We begin by deriving theoretical predictions under full and private information regarding the supplier’s cost, under both exogenous and endogenous matching. We refer to any buying firm in a B2B relationship (e.g., manufacturers, retailers, distributors, assemblers, etc) as ‘retailers’ for simplicity. In order to provide heterogeneity amongst suppliers and retailers, we assume that ‘higher quality’ suppliers have lower per unit production costs, and ‘higher quality’ retailers have

¹This setting closely matches a dropshipping, vendor-managed inventory (Cachon and Fisher 1997), or e-commerce environment. Randall et al. (2006) estimate that between 23% and 33% of e-retailers use drop-shipping, and the U.S. Census estimates that sales by e-retailers totaled \$340.4 billion in 2015 (United States Census Bureau 2015).

higher selling prices. Regardless of the production cost or selling price, the quality of the product and demand distribution remain the same (i.e., a low production cost is not associated with low quality and a high selling price is not associated with low demand). Regarding the supplier's cost details, under full information we rely on the Nash bargaining solution (Nash 1950) to generate theoretical predictions, whereas under private information we adapt the solution concept from Myerson (1984), which seeks to generalize the full information Nash bargaining solution. With regards to matching, under exogenous matching we assume supplier-retailer pairs are randomly formed and immediately begin bargaining, whereas our endogenous setting assumes that there is an initial stage where retailers and suppliers can signal with whom they want to match. If two parties agree to match, then they form a pair and proceed to the bargaining stage.

In these settings, we generate point predictions including distribution of profits, efficiency, wholesale prices, and quantities. While the solution concepts employed are general, in some cases we derive results for the experimental parameters in order to derive clear, testable predictions. Some examples of the theoretical insights are as follows. First, while bargaining, all supplier types benefit from their cost information being private. This means that when a supplier's cost information is unknown to retailers, they can use this private information to their advantage while bargaining and always earn weakly higher (sometimes strictly) expected profits compared to the full information case. Second, endogenous matching under full information should lead to lower cost suppliers matching with higher priced retailers and vice versa, contributing to an increase in the variance of profits across parties. And third, in an environment where a supplier's cost information remains private while bargaining if they did not disclose it while matching, then either all or none of the suppliers should disclose their costs, depending on the specific cost and price parameters.

We formulate a number of hypotheses based on our theoretical predictions and test them through a controlled human-subjects experiment. We accomplish this through a $2 \times 3 - 1$ design which manipulates two dimensions. For the first dimension we vary the matching protocol with two levels: exogenously matched pairs versus endogenously matched pairs (where retailers and suppliers can choose with whom to bargain with). For the second dimension we vary the availability of the supplier's cost information across three levels. In the first, all of the suppliers' costs are full information and known by retailers. In the second, suppliers' costs are private and they have the option of disclosing their costs to the other players. Regardless of whether they disclose their costs, once they are matched with a retailer their cost becomes known by the retailer they are matched with. In the third variant, suppliers' costs are private and they also have the option of disclosing

their costs to the other players. However, if they do not choose to disclose their costs, then this information remains private while bargaining with their matched retailer.

Our experiments yield a number of insights. First, we reject nearly all of the theoretical predictions for the contract parameters. For example, agreed wholesale prices are less than the equilibrium predictions for every pairing of retailer price and supplier cost, and regardless of whether the supplier costs are private or full information. We also observe that agreed quantities systematically differ from the theoretical predictions. Second, contrary to the normative theory, supply chain efficiency is significantly below 100% under full information and, because wholesale prices are below the equilibrium predictions, suppliers earn considerably less than their retailer counterparts. Third, consistent with theory, endogenous matching between retailers and suppliers leads to a higher variance of profits, compared to the more common exogenous matching protocol. Fourth, under private information while bargaining, retailers make offers as if they assume the supplier has the lowest cost. As a consequence, high cost suppliers earn only a small fraction of the overall supply chain surplus under private information, between 13.99% and 21.95%, when the normative theory predicts that they should earn between 57.41% and 65.87%. Fifth, because high cost suppliers are unable to take advantage of their private cost information while bargaining, they actually benefit from disclosing their private costs to retailers. Lastly, we find that both parties are susceptible to ‘superficial fairness’ and anchoring when bargaining, even in our private information setting, which accounts for many of our results, such as suppliers earning less than their predicted shares of the supply chain surplus.

2. Related Literature

The literature most related to our work includes supply chain research that considers wholesale price contracts, dynamic bargaining processes, private information, and/or endogenous matching. In regards to contracting, there have been a number of theoretical and experimental studies. From a theoretical standpoint, Lariviere and Porteus (2001) consider wholesale price contracts in a two-stage supply chain and investigate how aspects like demand variability affect prices and the distribution of profits. Bernstein et al. (2006) identify how wholesale price contracts can coordinate a supply chain with a single supplier and multiple retailers. Taylor and Plambeck (2007) study how price-only (and price-and-quantity) contracts can induce investment in a product development setting between a supplier and buyer. For a summary of the theoretical features of supply chain contracts please see Cachon (2003).

Experimentally, some papers which investigate supply chain contracting include Ho and Zhang (2008), who study how framing a fixed fee can affect overall supply chain efficiency and Kalkanç

et al. (2011), who demonstrate how simple price-only contracts can perform well in a setting where the retailer has accurate information regarding demand. Davis et al. (2014) investigate wholesale price contracts in three alternative inventory risk arrangements, while Zhang et al. (2015) compare buy-back and revenue-sharing contracts under alternative overage and underage costs with loss-averse suppliers. For a comprehensive summary of the experimental supply chain contracting literature we refer the interested reader to Chen and Wu (2018).

A vast majority of the works mentioned above assume that one party in the supply chain makes a one-shot ultimatum offer to the other party. Some studies have extended this setting by allowing for a more natural bargaining process. Theoretically, one key framework for solving these problems under full information is the Nash bargaining solution (Nash 1950). Experimentally, the only supply chain papers that we are aware of which deviate from one-shot offers are Haruvy et al. (2014), Leider and Lovejoy (2016), Davis and Leider (2017) and Davis and Hyndman (2017). Haruvy et al. (2014) extend the one-shot scenario by permitting only one party to make multiple offers. Leider and Lovejoy (2016) consider back-and-forth bargaining in a three-stage supply chain with chat box communication. Davis and Leider (2017) and Davis and Hyndman (2017) are similar to our work in that they allow for back-and-forth offers with the ability for players to send limited feedback over a limited time frame.

The supply chain literature frequently assumes full information of price, demand, and cost parameters (e.g., Cachon (2004)). There have been certainly some deviations from this, especially in a shot-shot offer setting. For example, some studies have examined a setting where the retailer may have private knowledge about consumer demand. Thus the issue of sharing forecast information is relevant (e.g., Cachon and Lariviere (2001) from a theoretical perspective and Ozer et al. (2011) from an experimental perspective). There are also studies which investigate how a supplier can obtain information about a buyer's cost structure (Corbett et al. 2004). More relevant to our work are those papers in supply chain management which consider private information combined with a more natural bargaining interaction between two parties. Theoretically, one paper which satisfies this is Feng et al. (2015), who investigate multiple alternating offers where both parties are impatient and the buyer has private information about their type. There is also work in economics pertaining to bargaining with private information (for a summary please see Muthoo (1999)). From an experimental perspective, Rapoport et al. (1995) investigate a setting where there is private information on one side with regards to a buyer's reservation price, and a seller can make multiple offers of price, where each offer is discounted in a way that makes delay costly.

Lastly, many experimental supply chain studies exogenously match suppliers and retailers into pairs. Exceptions to this include Beer et al. (2017), Fan et al. (2018), Hyndman and Honhon (2017) and Honhon and Hyndman (2017), though the latter two do not allow people to choose new partners, only to terminate existing partnerships. Fan et al. (2018) look at entry into a costly-to-join group and as such players cannot veto others from joining the group. Only Beer et al. (2017) involves mutual consent to enter into a contractual relationship.

Overall, we believe our work extends the existing literature in three important dimensions: (1) we consider a more natural back-and-forth bargaining process between retailers and suppliers which allows for multiple offers and limited feedback, (2) we evaluate private versus full information with respect to the supplier’s cost, and (3) we compare endogenous matching with exogenous matching between groups of retailers and suppliers. In addition, we investigate these issues from both a theoretical and experimental perspective.

3. Theoretical Background

In this section we provide a theoretical analysis for the bargaining and matching institutions that we will test in the lab. The basic framework consists of a set of retailers indexed by their retail price, $p_1 > p_2 > \dots > p_n$ and a set of suppliers indexed by their per-unit cost of production, $c_1 < c_2 < \dots < c_n < p_n$. We assume that the set of possible costs for suppliers and prices for retailers is common knowledge. We consider several settings depending on whether: supplier costs are private or full information, matching is exogenous (i.e., random) or endogenous, and, under endogenous matching with private costs, suppliers can truthfully disclose their private cost information during the matching phase. For the full information case we provide a more general analysis, while for private information we present a general approach to solving the problem but generate predictions based on the parameters in our experiments.² Since, under endogenous matching, it matters what subjects expect to happen in the bargaining stage, we first provide results for bargaining and subsequently discuss endogenous matching.

3.1. Bargaining with Full Information

We implemented an unstructured bargaining protocol in which a retailer – with selling price p – negotiates a wholesale price, w , and order quantity, q , with a supplier – with unit cost $c < p$. We assume that the supplier bears the risk of unsold inventory.³ We assume that both c and p are

² In particular, we considered markets of three retailers and three suppliers. The possible selling prices were 10, 11 or 12 and exactly one retailer had each selling price. Similarly, the possible per-unit costs for suppliers were 3, 4 or 5 and exactly one supplier had each unit cost.

³ We opted for the supplier to incur the inventory risk because, unlike when the retailer incurs the risk, both parties face random demand. For instance, when the retailer incurs the inventory risk, the supplier can produce exactly what the retailer orders, and avoid both inventory and demand risk.

common knowledge. In all cases, the underlying demand, D , is drawn uniformly from $[a, b]$ where $0 \leq a < b < \infty$, but the actual realization of demand is unknown at the time of bargaining.

Because of our unstructured bargaining protocol, the relevant theoretical lens for the full information case (i.e., the supplier's cost is known) is the Nash bargaining solution (see, Camerer (2003, Ch. 4.1) as well as Davis and Hyndman (2017)). Denote by $\pi_i(w, q)$ the expected profits for firm $i \in \{r(\text{retailer}), s(\text{supplier})\}$, from an agreement with wholesale price, w , and order quantity, q . The expected profits can be expressed as:

$$\pi_r(w, q) = \frac{p-w}{b-a} \int_a^b \min\{q, x\} dx; \quad \pi_s(w, q) = \frac{w}{b-a} \int_a^b \min\{q, x\} dx - cq. \quad (1)$$

The disagreement payoff is 0 for both players. The Nash bargaining solution is the solution to:

$$\begin{aligned} \max_{w, q} \quad & \pi_r(w, q) \cdot \pi_s(w, q) \\ \text{s.t.} \quad & c \leq w \leq p \text{ and } a \leq q \leq b. \end{aligned}$$

Since the full information bargaining environment is identical to Davis and Hyndman (2017), we state without proof the following result:

PROPOSITION 1. *The Nash bargaining solution has the following properties: (i) $q^* = a + (b - a)^{(p-c)/p}$, which means that the supply chain is coordinated; (ii) expected payoffs for the retailer and supplier are equalized; and (iii) $w^* = \frac{p(3ac^2 + ap^2 - 3bc^2 + 2bcp + bp^2)}{2(ac^2 + ap^2 - bc^2 + bp^2)} > \frac{p+c}{2}$.*

Because it will play a role in our empirical analysis, we emphasize that the agreed wholesale price, w^* , is strictly greater than the mid-point between c and p (i.e., $(p+c)/2$). This follows because the supplier bears the inventory risk. Therefore, to equalize the expected payoffs of the retailer and supplier, the wholesale price must increase beyond the midpoint between the retailer's price and the supplier's cost.

3.2. Bargaining with Private Information

When supplier costs are private information, we need a suitable generalization of the Nash bargaining solution. Using insights from mechanism design, Myerson (1984) provides such a generalization. The general approach is to find contract terms that maximize a weighted sum of the retailer's and supplier's expected profits subject to incentive compatibility constraints (i.e., that the supplier wants to reveal her cost type) and so-called *warrant conditions*, which are the minimum amounts that each player type "warrants" in a fair division. In addition to the warrant conditions, the other extra complication is that the weights must also be derived as part of the solution. Specifically, let $\pi_s(w, q, c_i)$ denote the expected profits of supplier type c_i when faced with the contract (w, q) .

Similarly, let $\pi_r(w, q, p)$ denote the expected profits of a retailer with selling price p facing the contract (w, q) . Then we must solve:

$$\begin{aligned} \max_{\lambda_i, q_i, w_i \geq 0} & \sum_{i=1}^3 \lambda_i \pi_s(w_i, q_i, c_i) + \frac{1}{3} \sum_{i=1}^3 \pi_r(w_i, q_i, p) \\ \text{s.t.} & \pi_s(w_i, q_i, c_i) \geq \pi_s(w_{i+1}, q_{i+1}, c_i), \quad i = 1, 2. \end{aligned}$$

The inequalities state that supplier type c_i prefers to report her cost type, rather than the cost type c_{i+1} , which would lead to contract (w_{i+1}, q_{i+1}) . Without loss of generality, we can take $\lambda_3 = 1 - \lambda_1 - \lambda_2$. Letting α_i denote the Lagrange multiplier on supplier type i 's incentive compatibility constraint and substituting in the expressions for expected profits, the Lagrangean can be written as:

$$\begin{aligned} \mathcal{L} = & \frac{1}{3} \left(3(\lambda_1 + \alpha_1) \left(\frac{w_1}{200} (200q_1 - q_1^2) - c_1 q_1 \right) + \frac{p - w_1}{200} (200q_1 - q_1^2) \right) \\ & + \frac{1}{3} \left(3(\lambda_2 + \alpha_2) \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_2 q_2 \right) - 3\alpha_1 \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_1 q_2 \right) + \frac{p - w_2}{200} (200q_2 - q_2^2) \right) \\ & + \frac{1}{3} \left(3(1 - \lambda_1 - \lambda_2) \left(\frac{w_3}{200} (200q_3 - q_3^2) - c_3 q_3 \right) - 3\alpha_2 \left(\frac{w_3}{200} (200q_3 - q_3^2) - c_2 q_3 \right) + \frac{p - w_3}{200} (200q_3 - q_3^2) \right) \end{aligned}$$

Observe that the wholesale price is effectively a linear transfer between the retailer and the supplier. Therefore, we can impose the constraints that $\lambda_1 + \alpha_1 = 1/3$ and $\lambda_2 + \alpha_2 - \alpha_1 = 1/3$. This temporarily obviates the need to solve for w_i in the optimization problem and allows us to focus on q_i . We will return to solve for the wholesale prices in the last step of the problem. Notice also that each line of the above equation represents the total *virtual* surplus if supplier type c_i interacts with the retailer.

We provide more details in Appendix A; here, we outline the steps to obtain the solution. In the first step, we find the optimal quantities for each supplier cost type as a function of the λ 's and α 's. In the second step, using the expressions for q_i and also the relationship between λ and α , we can write the Lagrangean as a function of c_i , p and the λ 's. Doing so yields:

$$\mathcal{L} = \frac{50}{3} \left(\frac{(p - c_1)^2}{p} + \frac{(p + c_1 - 3\lambda_1 c_1 + c_2(3\lambda_1 - 2))^2}{p} + \frac{(p + c_2(2 - 3\lambda_1 - 3\lambda_2) - 3c_3(1 - \lambda_1 - \lambda_2))^2}{p} \right)$$

where again, each of the three terms represents the total surplus assuming that given supplier cost type is drawn.

The next step is to solve the warrant conditions, which provides a virtual utility that each supplier type warrants – akin to the standard Nash bargaining solution, half the total virtual surplus generated by the interaction between the retailer and the particular supplier cost type. In particular, according to Myerson (1984), we must solve:

$$(\lambda_1 + \alpha_1)W_1 = \frac{1}{2} \frac{50}{3} \left(\frac{(p - c_1)^2}{p} \right)$$

$$\begin{aligned} (\lambda_2 + \alpha_2)W_2 - \alpha_1W_1 &= \frac{1}{2} \frac{50}{3} \left(\frac{(p + c_1 - 3\lambda_1c_1 + c_2(3\lambda_1 - 2))^2}{p} \right) \\ (1 - \lambda_1 - \lambda_2)W_3 - \alpha_2W_2 &= \frac{1}{2} \frac{50}{3} \left(\frac{(p + c_2(2 - 3\lambda_1 - 3\lambda_2) - 3c_3(1 - \lambda_1 - \lambda_2))^2}{p} \right) \end{aligned}$$

for W_i^* , $i = 1, 2, 3$.

The final step is to find values of λ_i and w_i such that:

$$\begin{aligned} \pi_s(w_i, q_i, c_i) &\geq W_i^*, \text{ with equality if } \lambda_i > 0, \\ \pi_s(w_i, q_i, c_i) &\geq \pi_s(w_{i+1}, q_{i+1}, c_i), \text{ for } i = 1, 2 \text{ and with equality if } \alpha_i > 0. \end{aligned}$$

With three supplier cost types and two incentive compatibility constraints this is, potentially, a system of five equations in five unknown variables: $(w_1, w_2, w_3, \lambda_1, \lambda_2)$. Moreover, one must check boundary conditions on the λ 's and α 's, making it necessary to consider seven different systems of equations to find the valid solution. Given the parameters of our experiment, it turns out that the bargaining solution involves $\lambda_1 = \lambda_2 = 0$, and the incentive constraints on the c_1 and c_2 supplier types are binding (the equilibrium contract parameters are provided in Table 2b and will be discussed when we review our experimental design). We can summarize the result as:

PROPOSITION 2. *Based on the parameters of the experiment, (i) all supplier cost types benefit from their cost being private information; (ii) The supply chain is coordinated only for the lowest cost supplier (c_1), with inefficiency for the other supplier types (c_2 and c_3); and (iii) the wholesale price increases in supplier cost but less steeply than under full information.*

3.3. Endogenous Matching with Full Information

We now generate predictions about how a group of n retailers and n suppliers would form matches if given the chance to do so, in contrast to the case in which retailers and suppliers are exogenously matched into pairs.

We first consider the case in which suppliers' costs are full information at the time of matching. Therefore, in the bargaining phase, each retailer-supplier pair will maximize the supply chain surplus, with each party receiving an equal share. Given our assumptions on demand, and further specializing to the case of $a = 0$ and $b = 100$, the first-best supply chain surplus is:

$$\pi(p, c) = 50 \frac{(p - c)^2}{p}.$$

Notice that this expression is increasing in p and decreasing in c . Therefore, $\pi(p_1, c_1)$ yields the highest supply chain surplus of all the possible matchings. Moreover, $\pi(p_i, c_i) > \pi(p_i, c_j)$ for any $j > i$. Similarly, $\pi(p_i, c_i) > \pi(p_k, c_i)$ for any $k > i$.

We define a matching, \mathcal{M} , as a relation from $\{p_1, \dots, p_n\}$ to $\{c_1, \dots, c_n\}$ and we say that a retailer p_i and supplier c_j are matched if $(p_i, c_j) \in \mathcal{M}$. Let $\pi_r(p_i, c_j)$ denote retailer p_i 's profit when matched with supplier c_j . Similarly, let $\pi_s(p_i, c_j)$ denote supplier c_j 's profit when matched with retailer p_i , assuming that they will bargain as in §3.1.

A matching, \mathcal{M} , is stable if there does not exist a retailer p_k and a supplier c_j such that $(p_k, c'_j) \in \mathcal{M}$ and $(p'_k, c_j) \in \mathcal{M}$ for which $u_r(p_k, c_j) > u_r(p_k, c'_j)$ and $u_s(p_k, c_j) > u_s(p'_k, c_j)$. That is, retailer p_k and supplier c_j both prefer to be matched with each other rather than remain matched with their respective partners under the matching \mathcal{M} .

PROPOSITION 3. *Under full information about supplier costs and retailer prices, the unique stable matching must be assortative. That is $\mathcal{M}^* = \{(p_i, c_i) | i = 1, 2, \dots, n\}$.*

Proof. Let \mathcal{M} denote a stable matching. We first show that $(p_1, c_1) \in \mathcal{M}$. Suppose that this is not the case. Then there exists $j, k > 1$ such that $(p_1, c_j) \in \mathcal{M}$ and $(p_k, c_1) \in \mathcal{M}$. Then retailer p_1 can expect profits of $0.5\pi(p_1, c_j)$ and supplier c_1 can expect profits of $0.5\pi(p_k, c_1)$. However, if they broke their matches to match together, then they would each earn $0.5\pi(p_1, c_1)$, which is strictly larger. This contradicts that \mathcal{M} was stable. Having shown that (p_1, c_1) must be part of any stable matching, we can proceed iteratively and show that $(p_2, c_2), (p_3, c_3), \dots$ must be part of any stable matching. Q.E.D.

3.4. Endogenous Matching with Private Information

The next case we consider is one in which, during matching, supplier costs are private information but suppliers have the ability to truthfully disclose their costs. Moreover, in this case we assume that regardless of whether or not a supplier discloses during matching, in the bargaining stage, the supplier's cost becomes full information for the retailer. Under these assumptions, we can show the following:

PROPOSITION 4. *When suppliers have the option to disclose their costs, all suppliers, except possibly the highest cost supplier, disclose and the unique stable matching is assortative. That is, $\mathcal{M}^* = \{(p_i, c_i) | i = 1, 2, \dots, n\}$.*

Proof. First, observe that supplier c_1 will certainly disclose as this ensures that he will match with retailer p_1 and earn $0.5\pi(p_1, c_1)$. If he did not disclose then there is a strictly positive probability that he will not be matched with retailer p_1 , which means his expected earnings would be strictly less than $0.5\pi(p_1, c_1)$. Thus, supplier c_1 discloses. Similar arguments show that supplier c_2 will disclose and be matched with retailer p_2 , and so on. The last supplier c_n need not disclose but since

all other suppliers strictly prefer to disclose, his cost will be correctly inferred to be the highest, which will lead to a matching of (p_n, c_n) . Thus, all suppliers except possibly c_n disclose and the matching is assortative, denoted by \mathcal{M}^* . Q.E.D.

Finally, we consider the case in which, during matching, suppliers' costs are private information. We still permit suppliers to truthfully disclose their cost to the other parties; however, if they do not disclose, then their cost will remain private information during the bargaining phase. In this case, there is a tension. As Proposition 4 shows, disclosure facilitates assortative matching, which is beneficial for the lowest cost supplier. However, Proposition 2 showed that, for the parameters of our experiment, all supplier types benefit from private information. Thus whether disclosure happens depends on whether the benefits from disclosing to improve one's match outweigh the resulting cost (in terms of bargaining surplus) from disclosing.

Restricting attention to the parameters used in our experiment ($c \in \{3, 4, 5\}$ and $p \in \{10, 11, 12\}$), all supplier types are strictly better off not disclosing their private cost (which effectively leads to random matching and bargaining with private information) rather than disclosing costs and being assortatively matched. For example, using the numbers in Table 2b (which illustrate the predictions for our experiment), if the supplier with lowest cost $c = 3$ discloses, she will be matched with the highest priced retailer $p = 12$ and can expect to earn 168.75. On the other hand, if she does not disclose her cost, then she has an equal chance to be matched with any retailer, leading to expected earnings of $(1/3)(149.17 + 178.79 + 207.64) = 178.53 > 168.75$. Therefore, the $c = 3$ supplier would not choose to disclose.

We can go further and show that there is no disclosure in equilibrium. First, observe that even if the supplier with highest cost $c = 5$ disclosed and the other two types did not, no retailer would choose to match with this supplier, preferring to take their chances with one of the other lower cost suppliers. Therefore, this supplier cannot disclose her information in the hope of being matched with a better retailer. Thus there can be no equilibrium in which only the $c = 5$ type discloses.

Last consider the case in which the $c = 4$ supplier disclosed. In the absence of any further disclosure, the $p = 12$ retailer would strictly prefer to match with the $c = 4$ supplier who disclosed. However, this cannot be stable because the $c = 3$ supplier would be strictly better off by immediately disclosing in order to initiate a match with the $p = 12$ supplier, which the $p = 12$ retailer would prefer. Therefore, the $c = 4$ type will not unilaterally disclose because it would set off a chain of disclosure which would end with assortative matching. For the $c = 4$ supplier, this assortative outcome is worse than not disclosing, being matched with a random retailer, and bargaining with private cost information.

Thus, given the parameters of our experiment, we have:

PROPOSITION 5. *If supplier cost information remains private during bargaining unless previously disclosed, no supplier types disclose their cost, leading to random matching between suppliers and retailers.*

REMARK 1. To be sure, this result depends on the parameters of the experiment. We can construct examples in which the lowest cost supplier prefers to disclose her private information. This occurs when, in the solution to the bargaining problem, λ_1 (the weight given to the lowest cost supplier in the optimization problem) is strictly greater than zero. In this case, the supplier does not earn any information rents from private information. Therefore, she would choose to disclose in order to improve the quality of her match. One such set of parameters is $p \in \{10, 11, 12\}$ and $c \in \{3, 6.5, 8.5\}$. However, this generates implausibly large variation in supplier costs, which is why we did not implement such a setting.

4. Experimental Design

In our experiment, participants were assigned a role of supplier or retailer and placed into a matching group of six, three retailers and three suppliers. Both roles and matching groups remained fixed for the duration of the experiment. In every round, each retailer was randomly assigned a selling price per unit, $p \in \{10, 11, 12\}$ where each retailer had a unique price (i.e., one retailer had $p = 10$, another $p = 11$, and the third $p = 12$). Similarly, in every round each supplier was randomly assigned a production cost per unit, $c \in \{3, 4, 5\}$, where each supplier had a unique cost. The possible prices and costs were common knowledge to both parties.

Each round consisted of up to two stages, a matching stage and a bargaining stage. In the matching stage participants would form retailer-supplier pairs and then, in the bargaining stage, they would bargain over contract terms for a product with uncertain demand (more details of each stage to follow). Regardless of the retailer's selling price and supplier's production cost, demand for the product was always a random draw from the discrete uniform distribution on $\{1, 2, \dots, 100\}$. If the two parties came to an agreement while bargaining, demand would be realized, and retailers would satisfy demand by sourcing product directly from the supplier, such that the supplier incurred the cost of any unsold inventory.

Our overall experimental design manipulated two dimensions: the matching protocol in which retailer-supplier pairs were formed and the availability of the suppliers' cost information. For the matching protocol, we implemented two levels. The first, 'Exo(genous),' randomly matched retailers and suppliers into pairs such that each round began with the bargaining stage. The second, 'End(ogenous),' began with a matching stage where retailers and suppliers could signal as to with

Table 1 Experimental Design and Number of Participating Subjects

	Match-Barg	Matching Protocol	
		Exo(ogenous)	End(ogenous)
Cost Information	F(ull)-F(ull)	48	54
	D(isc)-F(ull)	-	54
	D(isc)-P(riate)	48	54

Note: ‘Match’ represents cost information during the matching stage (for the endogenous treatments), ‘Barg’ represents cost information during the bargaining stage, and ‘Disc’ represents a scenario when the supplier had the ability to disclose their private cost while matching. Note that ‘Private’ cost information, during the bargaining stage under endogenous matching (End-D-P), represents that if a supplier did not disclose their cost while matching, then this cost information would remain private while bargaining.

whom they wanted to be matched. In these latter treatments, if a retailer and supplier both agreed to be matched together, then they would be paired for the subsequent bargaining stage. Any subjects who remained unmatched at the end of the matching stage would be randomly matched from within the group of unmatched subjects into pairs.

Regarding the suppliers’ cost information, we evaluated two levels for the exogenous treatments and three levels for the endogenous treatments. The two levels for the exogenous treatments varied as to whether the suppliers’ cost information was available, ‘Exo-F(ull),’ or not, ‘Exo-P(riate),’ to retailers while bargaining (since there was no formal matching stage in these treatments). Turning to the endogenous treatments, in the first of the three levels, ‘End-F(ull)-F(ull),’ each supplier’s cost was known to the other suppliers and retailers in the matching stage and the bargaining stage. In the next two levels, each supplier’s cost was private information in the matching stage. Specifically, in the second level, ‘End-D(isc)-F(ull),’ each supplier knew her own private cost information while matching, but had the option of disclosing this information to the other players. If a supplier chose to disclose her cost, the other suppliers and retailers would see this information. Then, while bargaining, *regardless* of the supplier’s disclosure decision, the supplier’s cost information would be known by the retailer. Lastly, in the third variant, ‘End-D(isc)-P(riate),’ once again, each supplier knew her own private cost information while matching and had the option of disclosing this cost information to the other players. However, if they did not choose to disclose this information while matching, then in the bargaining stage it remained as private information and was thus unknown to the retailer. Overall, the experiment consisted of a $(2 \times 3) - 1$ between-subjects design with 258 total participants, outlined in Table 1.

For details pertaining to the matching stage in the endogenous treatments, we gave participants two and a half minutes to form pairs. During this time, any retailer or supplier could ‘propose’ to be matched with a player of the opposite role, and they could propose to more than one player at a time. We also allowed players to ‘rescind’ a proposal that had not been accepted. If a player received a formal proposal and chose to accept it, then those two players formed a matched pair,

were removed from the screen, and unavailable for matching with the other participants. Also, in the two treatments where the supplier's cost information was private, we allowed each supplier to disclose it to the other players by clicking a button. We provide a screenshot of the matching stage with this disclosure option in Appendix B. Lastly, as mentioned previously, in the exogenous treatments retailer-supplier pairings were randomly assigned at the beginning of each round such that they skipped the matching stage and began directly in the bargaining stage.

After any potential matching, participants proceeded to the bargaining stage. In this stage, each retailer-supplier pair was given five minutes to negotiate a contract which consisted of two terms, a wholesale price, w , and a quantity, q . During this time, retailers and suppliers were permitted to make offers at any point and to make as many offers as they desired. If a pair was unable to reach an agreement after five minutes then both players would receive a payoff of zero. If the pair reached an agreement (which occurred when one player accepted the other player's most recent offer) then demand would be realized and players would receive feedback that included realized profits.

While bargaining, we allowed participants to provide feedback about the most recent offer received. In particular, they could 'reject' any of the proposed terms through a button for each contract term, which they could click at any time for the most recent offer received. This feedback would then be displayed on the proposer's screen. Note that a participant could later accept the offer even if they signaled disapproval with it, so long as a more recent offer was not received. We opted for this type of feedback to simulate a more natural bargaining process, while also allowing us to monitor offers and feedback. Lastly, offers were not required to improve upon a previous offer and only the most recent offer could be accepted. We chose the former because we did not want to inform subjects what constitutes a better offer, while the latter keeps bargaining straightforward.

To reduce complexity throughout the experiment, in both the matching stage (if applicable) and the bargaining stage, we provided participants with a decision support tool. In this tool they could enter hypothetical values for w and q , which would generate a graph showing the profit for both players as a function of demand. This is also seen in the screenshot available in Appendix B.

Overall, subjects participated in six rounds. For each of the five treatments we ran three sessions, each of which had 12 or 18 subjects.⁴ The experimental software was programmed in z-Tree (Fischbacher 2007), and all sessions took place in the experimental laboratory at a large northeast university. Sessions took between 60 and 75 minutes, with average earnings of \$37, a maximum of \$90, and a minimum of \$7. Subjects were compensated for all rounds of decisions. Sample instructions and additional screenshots are available upon request.

⁴ For the End-D-F treatment, we also had a fourth session of six subjects to balance all endogenous treatments at 54 participants.

Table 2 Experimental Predictions

(a) Full Information (Exo-F, End-F-F, End-D-F)

	Retailer/Supplier Profit			Wholesale Price (w)			Quantity (q)		
	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$
$c = 3$	122.50	145.45	168.75	7.31	7.86	8.40	70.00	72.73	75.00
$c = 4$	90.00	111.36	133.33	7.86	8.43	9.00	60.00	63.64	66.67
$c = 5$	62.50	81.82	102.08	8.33	8.94	9.53	50.00	54.55	58.33

(b) Private Information (Exo-P, End-D-P)

	Supplier Profit			Wholesale Price (w)			Quantity (q)		
	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$
$c = 3$	149.17	178.79	207.64	7.89	8.58	9.23	70.00	72.73	75.00
$c = 4$	99.17	124.24	149.31	7.98	8.63	9.26	50.00	54.55	58.35
$c = 5$	69.17	87.88	107.64	8.59	9.06	9.58	30.00	36.36	41.67

Note: The *ex ante* expected profits of the retailer under private information (i.e., before learning, via the bargaining mechanism, which cost supplier the retailer is bargaining with) coincide with the highest cost type supplier.

4.1. Predictions and Hypotheses

In Tables 2a and 2b we provide point predictions based on our previous theoretical analysis and experimental parameters. Table 2a depicts the point predictions when the suppliers's costs are full information while bargaining (Exo-F, End-F-F, End-D-F), whereas Table 2b illustrates the point predictions when the suppliers' costs should be private information while bargaining (Exo-P, End-D-P). A combination of these metrics and our propositions in §3 lead us to the following experimental hypotheses:

HYPOTHESIS 1. *Under full information, 100% efficiency is achieved for every (p, c) combination, and retailers and suppliers earn 50%/50% splits of total supply chain expected profit.*

HYPOTHESIS 2. *Under private information:*

- (i) *100% efficiency is only achieved for the pair with the lowest cost supplier.*
- (ii) *Suppliers earn at least 50% of the total supply chain expected profit.*
- (iii) *The agreed wholesale price is always higher compared to when there is full information.*

HYPOTHESIS 3. *Under endogenous matching and suppliers have the option to disclose their costs, but their costs will be known during bargaining (End-D-F), the two lowest cost suppliers should disclose their costs.*

HYPOTHESIS 4. *When there is endogenous matching and suppliers' costs may remain private while bargaining (End-D-P), no supplier type should disclose her cost.*

5. Results

We present our experimental results in three subsections. In §5.1 we investigate how our data compares to the experimental predictions and hypotheses from §4.1. In §5.2, because the bargaining solutions do not provide details pertaining to the process itself, we analyze the bargaining dynamics in our data. In §5.3 we investigate detailed behavior during the matching stage. For all hypothesis tests we use a matching group of six as an independent observation, and run all regressions with random effects and clustered standard errors at the matching group level.

Before proceeding to our detailed results, we provide a snapshot of some key insights. First, we reject nearly all of the normative point predictions for the contract parameters in Tables 2a and 2b. For example, wholesale prices are consistently below the equilibrium values, in both full and private information, and quantities tend to gravitate towards mean demand. Second, supply chain efficiency is roughly 90% in all treatments, whereas it should always be 100% under full information and 100% for ($c = 3$) under private information. Third, suppliers earn significantly less than the predicted 50% (or more) of the expected supply chain profit, in both full and private information. This is especially true for high cost suppliers under private information, where they only earn between 13.99% and 21.95% of total profits. Fourth, under endogenous matching, matching is partially assortative, with higher (resp. lower) priced retailers frequently matching with lower (resp. higher) cost suppliers. This increases the variance in earnings, with high quality retailers and suppliers earning more and low quality retailers and suppliers earning less under endogenous matching than under exogenous matching. Fifth, under private information, high-cost suppliers earnings are much lower than predicted by theory – so much so that that it is actually advantageous for them to disclose their cost during matching to be able to credibly demand a higher wholesale price. Sixth, when supplier costs may remain private while bargaining, a substantial portion of suppliers choose to disclose their costs while matching. As just stated, this is actually empirically optimal for higher-cost suppliers but is (weakly) disadvantageous for the lowest-cost supplier. Seventh, regardless of whether supplier costs are full or private information, subjects are susceptible to ‘superficial fairness’ and anchoring biases during bargaining. This is consistent with past studies, which documented such biases under full information.

5.1. Comparison to Predictions and Hypotheses

The average agreement rates while bargaining in the five experimental treatments were similar to one another: 93.06% in Exo-P, 90.28% in Exo-F, 88.89% in End-F-F, 90.12% in End-D-F, and 90.12% in End-D-P. As a consequence, we will report all summary statistics conditional on agreement in this section.

5.1.1. Contract Parameters We first compare the agreed upon contract parameters to the predictions in Tables 2a and 2b. To this end, Tables 3a and 3b depict the average wholesale prices and quantities in the full information treatments (Exo-F, End-F-F, and End-D-F) and private information treatments (Exo-P and End-D-P), for each combination of c and p . One can recognize that there are deviations between the actual contract terms and the normative predictions. Regarding wholesale prices, for every combination of c and p , the wholesale price is significantly different – and lower – than the normative predictions under both full and private information (t -tests, all $p < 0.01$). Moreover, contrary to Hypothesis 2(iii), which states that the wholesale price is always higher under private information versus full information, there is no difference in wholesale prices between full and private information. In fact, for only one of the nine combinations of (p, c) , $(p = 10, c = 3)$, is the difference statistically significant in the direction predicted by theory ($p < 0.05$).

Theory also predicts that the agreed wholesale price should increase in the suppliers' costs. The data are supportive of this prediction, but the magnitude is less than theory. For example, if $p = 10$, and c increases from $c = 3$ to $c = 5$, then predicted wholesale prices should increase by 0.70 ($w = 7.89$ to $w = 8.59$). Yet for our data in this scenario, the change in wholesale prices is only 0.46 ($w = 7.17$ to $w = 7.63$). The fact that wholesale prices are not higher under private information, suggests that suppliers earn less than theory, while this result implies that the difference is particularly large for the highest-cost suppliers.

Continuing with the agreed upon quantities in Tables 3a and 3b, one can also discern a number of deviations with respect to the predictions in Tables 2a and 2b. In general, compared to the normative benchmarks, the observed quantities are often closer to the mean demand of 50. We will explore anchoring in both wholesale prices and order quantities in more detail later. Overall, these results lead to the following:

Result 1 *Under both full and private information wholesale prices are significantly lower than the normative predictions. Also contrary to theory, there is no difference in average wholesale prices between full and private information. Under private information, increases in wholesale prices are flatter than predicted with respect to increases in supplier costs. Regarding quantities, under both full and private information, there is bias towards the mean demand of 50.*

5.1.2. Efficiency and Distribution of Profits We now focus on Hypotheses 1–2, which pertain to supply chain efficiency and distribution of expected profits under full and private information. In both the full and private information conditions, observed channel efficiency is nearly

Table 3 Wholesale Prices and Quantities, Conditional on Agreement

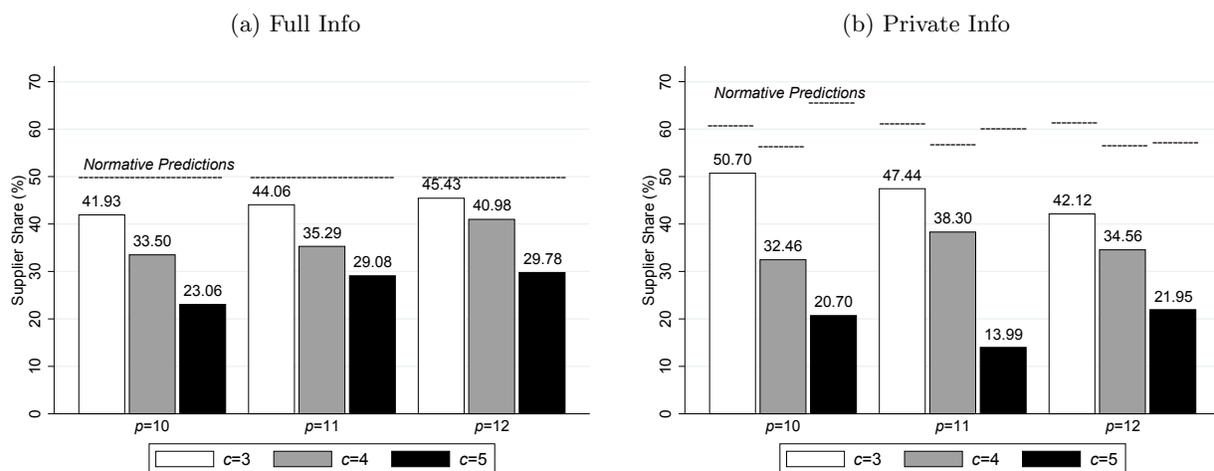
	(a) Full Info						(b) Private Info					
	Wholesale Price (w)			Quantity (q)			Wholesale Price (w)			Quantity (q)		
	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$
$c = 3$	6.72 [‡]	7.25 [‡]	7.82 [‡]	57.72 [‡]	56.66 [‡]	58.90 [‡]	7.17 [‡]	7.41 [‡]	7.53 [‡]	53.67 [‡]	53.67 [‡]	57.37 [‡]
	(.47)	(.50)	(.68)	(15.64)	(13.13)	(12.88)	(.74)	(.62)	(.65)	(10.79)	(11.78)	(9.60)
$c = 4$	7.18 [‡]	7.66 [‡]	8.23 [‡]	55.78	58.08*	54.96 [‡]	7.31 [‡]	7.72 [‡]	7.89 [‡]	53.62	53.82	55.84
	(.50)	(.69)	(.68)	(14.08)	(14.51)	(10.27)	(.87)	(.61)	(.98)	(17.41)	(16.20)	(13.44)
$c = 5$	7.69 [‡]	8.27 [‡]	8.61 [‡]	53.46	50.55	52.27	7.63 [‡]	7.76 [‡]	8.38 [‡]	53.50 [‡]	54.43 [‡]	52.58 [‡]
	(.52)	(.45)	(.60)	(14.64)	(11.52)	(15.83)	(.71)	(.60)	(.56)	(10.68)	(12.85)	(15.40)

Note: Standard deviations (based on matching group averages) are reported in parentheses below each mean. Significance of t-tests versus the normative theory given by [‡] $p < 0.01$, [†] $p < 0.05$, and * $p < 0.10$.

90%, with a minimum of 88.97% and a maximum of 93.09% across all eighteen (information, c , p) scenarios. In all instances where efficiency is predicted to be 100% (all full information scenarios and $c = 3$ under private information), we strongly reject the theoretical prediction (t-tests, all $p < 0.01$). For the private information case, when $c = 4$, the observed channel efficiencies are also significantly less than the normative prediction ($p < 0.01$ for $p = 10$; $p < 0.05$ for $p = 11$; and $p < 0.10$ for $p = 12$). As we have mentioned, and will discuss in greater detail below, these results appear to be driven by an anchoring bias in order quantities.

For the distribution of profits, the normative theory predicts a 50-50 split between the two parties in the full information treatments. In Figure 1a, which depicts the supplier's share of total supply chain expected profit, we observe that suppliers earn significantly less than 50%, with a minimum share of 23.06% and a maximum share of 45.43% (eight t -tests, $p < 0.01$, and one t -test, $p < 0.05$). Combined with the above-mentioned results on efficiency we can reject Hypothesis 1. Turning to private information, depicted in Figure 1b, the normative prediction is that suppliers should earn more than 50% of the total supply chain expected profit. Yet the differences between the actual supplier share of profits versus the predictions are even more stark than the full information scenario. Thus we reject Hypothesis 2(i)–(ii).

One can also discern, in both Figures 1a and 1b, that as c increases, suppliers earn a disproportionately low split of the supply chain expected profits (e.g., supplier share is between 13.99% and 29.78% when $c = 5$). In fact, when supplier's costs are private information, high cost suppliers only earn between 13.99% and 21.95% of the total supply chain expected profit. This extremely low share is driven by two previously noted results. First, under private information, suppliers do not receive the predicted higher wholesale price than under full information. Second, the increase in agreed wholesale price as supplier cost increases is flatter than predicted. We will further explore the driver of these wholesale prices when we investigate the bargaining data.

Figure 1 Supplier Share (%) of Supply Chain Expected Profit, Conditional on Agreement

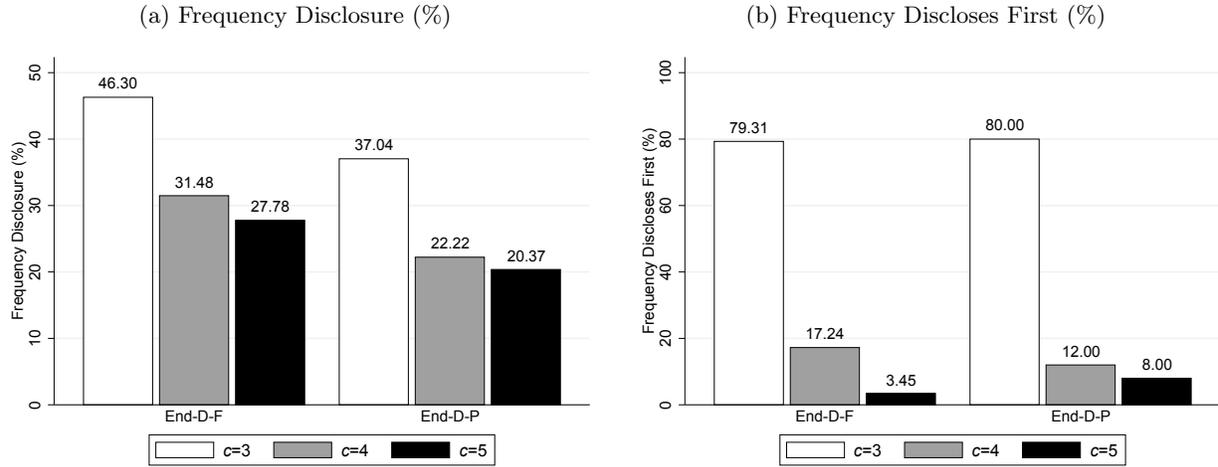
We can summarize these results as follows:

Result 2 *We reject Hypotheses 1 and 2. Under both the full and private information channel efficiency is generally less than predicted. Also, because of unfavorable wholesale prices suppliers earn less – especially higher cost suppliers – than their predicted split of supply chain profits, whereas retailers earn more. In addition, high cost suppliers under private information earn the lowest split of supply chain profits.*

5.1.3. Disclosure and Endogenous Matching We now turn our attention to Hypotheses 3–4, which concern cost information disclosure by suppliers and endogenous matching. Figure 2(a) provides the frequency of disclosure by each cost type, and shows that decisions do not perfectly conform to the predictions in the End-D-F or End-D-P treatments. In particular, in End-D-F a supplier with $c = 3$ discloses 46.30% of the time and $c = 4$ discloses 31.48% of the time, which is non-negligible but less than the prediction of 100%. On the other hand, in End-D-P, we see that all suppliers disclose more than theoretical prediction of 0%. This latter result could be because suppliers do not anticipate that the bargaining advantage of private information should outweigh the matching benefits of disclosure (at least for low-cost suppliers). Indeed, our earlier results for suppliers' share of profits under private information suggest that this may not be an irrational strategy, particularly for higher cost suppliers, as they seem to earn lower profits when their costs are private. Lastly, in Figure 2(b) we observe that the lowest cost suppliers are the first to disclose: roughly 80% of the time in both the End-D-F and End-D-P settings. Thus we have the following result:

Result 3 *We reject Hypotheses 3 and 4. Suppliers disclose between 20.37% - 46.30% in the End-D-F and End-D-P treatments, where theory predicts the two lower cost suppliers should disclose 100% in End-D-F, and no supplier should ever disclose in End-D-P (i.e., 0%). Low cost suppliers disclose most frequently and are most likely to be the first to disclose.*

Figure 2 Frequency of Disclosure Overall and Frequency of Disclosing First by Cost Type



Note: We count a subject as having disclosed if the other two suppliers disclosed their cost, thereby automatically revealing the remaining player's cost. As predicted by the theory, with one exception, this affects only the highest cost supplier.

Next we consider the realized impact of disclosure on supplier expected profits. Our theoretical predictions were derived assuming that matching and bargaining would conform to the equilibrium. However, we have already seen clear deviations from the normative theory such that suppliers' disclosure decisions might be empirically rational. Table 4 examines the impact of disclosure for different supplier cost types, where supplier expected profit is the dependent variable in a random effects regression. As can be seen, for the $c = 3$ supplier, disclosure is weakly profitable under full information (i.e., End-D-F) while it is quite harmful for the $c = 4$ and $c = 5$ suppliers. In contrast, under private information, disclosure harms the $c = 3$ supplier (but not significantly so) and is beneficial for both the $c = 4$ and $c = 5$ suppliers. Although this contradicts the theory for our parameterization, it is consistent with our experimental result that high cost suppliers earn a disproportionately low split of total supply chain profits under private information. That is, under private information, the high cost supplier may wish to disclose her cost to credibly convey her "need" for a relatively high wholesale price.

Table 4 Effects on Supplier Expected Profits: Private Information, Disclosure, Endogenous Matching

	$c = 3$		$c = 4$		$c = 5$	
Disclosed	13.249 [‡]	(7.522)	-31.055 [†]	(12.956)	-97.921 [†]	(39.930)
Private Treatment	9.529	(6.516)	-7.282	(13.204)	-10.496	(7.649)
Disclosed \times Private Treatment	-21.341	(17.993)	58.046 [†]	(27.930)	89.767 [†]	(45.480)
End-F-F Treatment	2.299	(8.525)	8.161	(8.322)	4.929	(8.177)
Constant	118.833 [‡]	(4.555)	77.634 [‡]	(7.109)	42.764 [‡]	(4.818)
R^2	0.016		0.033		0.148	
N	238		233		229	

Note: Significance given by [‡] $p < 0.01$, [†] $p < 0.05$, and * $p < 0.10$.

Table 5 Assortative Matching Details

Treatment	Matching of Subjects						p -value
	$\{(3,12), (4,11), (5,10)\}$	$\{(3,12), (4,10), (5,11)\}$	$\{(3,11), (4,12), (5,10)\}$	$\{(3,11), (4,10), (5,12)\}$	$\{(3,10), (4,12), (5,11)\}$	$\{(3,10), (4,11), (5,12)\}$	
End-F-F	40.74	9.26	22.22	1.85	9.26	16.67	0.030
End-D-F	20.37	22.22	20.37	14.81	11.11	11.11	0.249
End-D-P	27.78	25.93	16.67	7.41	12.96	9.26	0.000

Note 1: The p -value is from a joint test that all coefficients in a regression of frequency on indicator variables for each matching (where we cluster at the matching group level). Under random matching, all frequencies would be equal and equal to $1/6$.

Note 2: The highlighted column indicates fully assortative matching.

Result 4 *Under full information, disclosure is beneficial for the lowest cost supplier and detrimental to the higher cost suppliers. Under private information, the effects are reversed such that higher cost suppliers benefit from disclosing their costs.*

We now turn our attention to endogenous matching. Table 5 shows the frequency that subjects were matched assortatively (first column) as well as the frequency of all other combinations (columns 2–6). The frequency of fully assortative matching is significantly higher than the ($1/6$) random chance of occurring in the End-F-F treatment. Thus, endogenous matching, by itself, facilitates assortative matching, though the rates of assortative matching are well below 100%. For the two disclosure treatments, neither rates of assortative matching are significantly different from random chance, though for the End-D-P treatment, we strongly reject that matching is random. These insights lead to the following result:

Result 5 *Matching is partially assortative in the End-F-F treatment, but below 100%. In addition, the rates of fully assortative matching in both disclosure treatments (End-D-F and End-D-P) are not significantly different from random chance.*

Table 6 reports a series of random effects regressions where the dependent variable is the retailer

price that each supplier type is matched with, and the explanatory variables are indicators for whether each supplier type disclosed. Disclosure by the $c = 3$ supplier significantly increases the quality of retailer that she is matched with (i.e., higher retailer p) and significantly decreases the quality of retailer that the other two supplier types are matched with. Disclosure by any other supplier type does not significantly influence match quality.

Table 6 Effects on Matching with Better Retailers: Supplier Disclosure

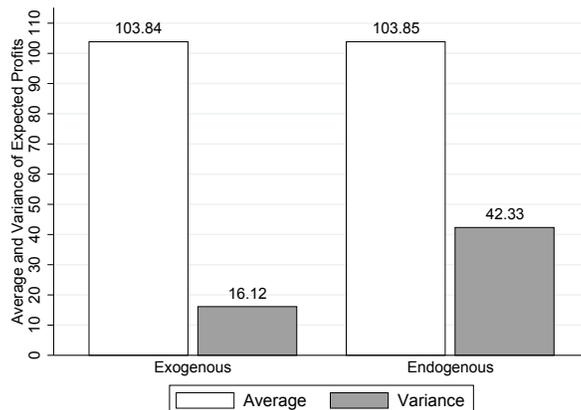
	$c = 3$		$c = 4$		$c = 5$	
$c = 3$ Disclosed	0.686 [‡]	(0.150)	-0.409 [†]	(0.187)	-0.332 [‡]	(0.122)
$c = 4$ Disclosed	-0.125	(0.193)	0.248	(0.287)	-0.036	(0.204)
$c = 5$ Disclosed	-0.084	(0.277)	-0.004	(0.233)	0.037	(0.190)
Constant	11.038 [‡]	(0.101)	11.056 [‡]	(0.101)	10.925 [‡]	(0.131)
R^2	0.157		0.050		0.042	
N	108		108		108	

Note: Dependent variable is the price of the retailer that supplier gets matched with. Significance given by [‡] $p < 0.01$, [†] $p < 0.05$, and * $p < 0.10$.

Finally, we consider more global consequences of endogenous matching and disclosure. Since endogenous matching facilitates best-with-best and worst-with-worst matching, and since there complementarities from such matching, a final prediction of our theory on matching is that the variance of earnings should be higher under endogenous matching. In line with this prediction, Figure 3 shows that the average profits were virtually identical between the exogenous and endogenous treatments (103.84 versus 103.85), but the variance increases from 16.12 to 42.33 when allowing retailers and suppliers to endogenously match (one-sided test based on matching group averages, $p = 0.025$). Thus we have:

Result 6 *As predicted by theory, endogenous matching does not change the average earnings but does significantly increase the variance of earnings.*

5.1.4. Superficial Fairness and Anchoring Previous research has shown that when a retailer and supplier engage in a more natural back-and-forth bargaining process, subjects tend to anchor on a superficially fair wholesale price and insufficiently adjust to account for asymmetries in exposure to risk (Davis and Hyndman (2017) and Davis and Leider (2017)). However, these studies are somewhat limited because they each consider only one (p, c) combination and assume full information, whereas our study has nine such combinations and also considers both full and private cost information. We can also better test for anchoring the order quantity on mean demand; in our private information treatments there are cases where the optimal order quantity is less than

Figure 3 Average and Variance of Profits for Exogenous and Endogenous Settings, Conditional on Agreement

50. The next result demonstrates anchoring on both superficially fair wholesale prices and the mean demand in our study.

Result 7 *There is evidence of anchoring for both wholesale prices – with anchoring on the superficially fair price of $(p+c)/2$ – and order quantities, with anchoring on mean demand of 50.*

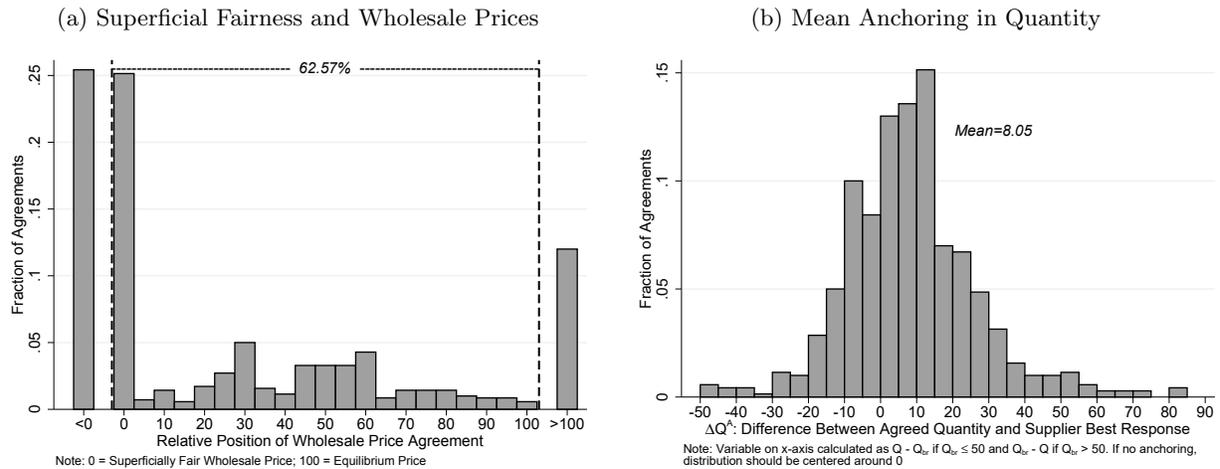
Support for this result can be seen in Figure 4, with panel (a) showing agreed wholesale prices, normalized so that 0 is the superficially fair wholesale price of $(p+c)/2$ and 100 is the equilibrium price. If the theoretical prediction was correct, then we would expect the distribution to be centered around 100. However, the data clearly show that this prediction is not born out. Fully 25% of agreed wholesale prices are exactly at $(p+c)/2$, and 62.57% are in the superficially fair inclusive region between $(p+c)/2$ and w^* . Furthermore, another 25% of agreements actually have wholesale prices less than $(p+c)/2$, which would give suppliers less than half the surplus *even in the absence of risk*. A t -test that the mean is equal to 100 is rejected at $p < 0.01$.

To show anchoring in order quantities, we define the variable:

$$\Delta Q^A = \begin{cases} Q - Q_{br}, & Q_{br} \leq 50 \\ Q_{br} - Q, & Q_{br} > 50 \end{cases},$$

where Q_{br} represents the supplier's optimal quantity given the agreed wholesale price.⁵ If anchoring is not present, then we would expect the distribution depicted in panel (b) to be centered on 0, while evidence of mean anchoring would manifest as a rightward shift of the distribution. As one can see, such a rightward shift is present and the mean is 8.05. Moreover, a t -test that ΔQ^A equals zero is rejected at $p < 0.01$.

⁵ Strictly speaking, in the bargaining solution, the order quantity need not be a best response to the wholesale price. For example, in the full information case, the order quantity is set to maximize channel surplus, which is different from the quantity that would maximize the supplier's expected profits given the agreed wholesale price. A similar figure, based upon the theoretical predictions is qualitatively similar.

Figure 4 Superficial Fairness in Wholesale Prices and Mean Anchoring in Quantities, Conditional on Agreement

While order quantities are closer to the mean demand, the mechanism is not necessarily the same as in traditional newsvendor experiments. Since the retailer is not exposed to inventory risk, her expected profits are strictly increasing in the order quantity. Therefore, when negotiating, she should try to push the agreement to higher order quantities. Indeed, if we consider separately those cases where $Q_{br} < 50$ and $Q_{br} > 50$, then we see very strong evidence of anchoring in the former case, but almost no evidence in the latter case. This suggests that the retailer is able to exacerbate any anchoring bias that the supplier may have for low optimal order quantities and to mitigate the bias for high optimal order quantities.

5.2. Bargaining Dynamics

The previous subsection documented outcomes which suggest that anchoring biases might be present when bargaining. In an effort to better understand how these outcomes were achieved, we now turn our attention to bargaining dynamics. Specifically, providing results on bargaining duration, the anchoring effect of first offers, and the concession process over time.

5.2.1. Bargaining Duration

Our first result is:

Result 8 *Bargaining takes longer when the supplier's cost is private information.*

Support for this result is in Table 7 which shows the average time remaining when an agreement was reached. As one can see, agreements are reached with less time remaining when suppliers' costs are private information. This is true for both the Exo-P treatment and for the End-D-P treatment (for those suppliers who did not disclose). Both random-effects regressions and t -tests based on matching group averages indicate that the result is statistically significant ($p < 0.01$).

Thus, although the agreements do not differ substantially depending on whether the supplier's cost is known or not, it takes longer to reach an agreement. It is also interesting to note that bargaining duration does not appear to be influenced either by the retailer's price or the supplier's cost (results available upon request).

Table 7 Time Remaining (in seconds) When Agreement is Reached

Treatment	Supplier's Cost	
	Full	Private
Exo-F	93.65	
End-F-F	88.81	
End-D-F	86.84	
End-D-P	124.59	55.94
Exo-P		58.90

5.2.2. First Offers and Anchoring Opening offers are of interest for two reasons. First, in the presence of private information, if different cost suppliers make different opening offers, it serves to partially reveal their private information to retailers. Second, first offers have been shown to have an anchoring effect on negotiations (Galinsky and Mussweiler 2001), ultimately influencing the final agreement that is reached. Table 8 depicts two random effects regressions with first offers for wholesale prices as the dependent variable for retailers and suppliers, and documents the following result:

Result 9 *Suppliers' first offers for wholesale prices are the same whether their cost is full or private information, while retailers' first offers for wholesale prices become more aggressive under private information.*

Table 8 Effects on First Offers for Wholesale Prices by Role

	Suppliers		Retailers	
$c = 4$	0.361 [‡]	(0.102)	0.554 [‡]	(0.096)
$c = 5$	0.505 [‡]	(0.083)	1.001 [‡]	(0.070)
Private Cost	0.116	(0.186)	0.102	(0.183)
$(c = 4) \times (\text{Private Cost})$	-0.110	(0.151)	-0.556 [‡]	(0.140)
$(c = 5) \times (\text{Private Cost})$	0.040	(0.146)	-0.914 [‡]	(0.123)
$p = 11$	0.673 [‡]	(0.070)	0.267 [‡]	(0.069)
$p = 12$	1.183 [‡]	(0.086)	0.587 [‡]	(0.105)
Constant	7.544 [‡]	(0.096)	5.860 [‡]	(0.102)
R^2	0.180		0.115	
N	753		756	

Note: Significance given by [‡] $p < 0.01$, [†] $p < 0.05$, and * $p < 0.10$.

In Table 8 for the full information case, both the suppliers' and retailers' first offers are increasing in both the supplier's cost and the retailer's price. Of course, suppliers' first offers are nearly 2 units higher than retailers, observed by comparing the intercept (Constant) term between suppliers and retailers. The main distinction between retailers and suppliers arises when we consider private information. Suppliers' first wholesale price offers under private information are statistically indistinguishable from those under full information (e.g., coefficients on the three Private Cost terms are insignificant for the supplier). The implication is that, upon observing the opening wholesale price, retailers can update their belief about the type of supplier they are matched with. In contrast, for retailers, their first offer under private information is always identical to the opening offer made to a $c = 3$ supplier under full information. For instance, for retailers, the coefficient on $c = 4$ is 0.554 and for $c = 5$ it is 1.001 under full information. Under private information, the interaction terms (-0.556 for $c = 4$ and -0.914 for $c = 5$) completely wash away the effect. This, combined with our next result on the anchoring effect of first offers, goes a long way to explain why the high cost suppliers earn a disproportionately small share of the supply chain surplus, particularly under private information.

Table 9, which shows a series of random effects regressions with agreed upon contract terms as the dependent variable by supplier and retailer, documents the following result:

Result 10 *Final agreements, for both the wholesale price and the order quantity, are significantly influenced by first offers.*

Table 9 Effects on Agreed Terms: Anchoring on First Offers

	Wholesale Price				Order Quantity			
	Suppliers		Retailers		Suppliers		Retailers	
First w Offer	0.367 [‡]	(0.048)	0.307 [‡]	(0.034)				
First q Offer					0.539 [‡]	(0.043)	0.361 [‡]	(0.046)
$c = 4$	0.142 [†]	(0.062)	0.229 [‡]	(0.050)	-0.374	(1.229)	-1.002	(1.286)
$c = 5$	0.452 [‡]	(0.070)	0.488 [‡]	(0.064)	-1.568*	(0.936)	-2.273*	(1.358)
Private Cost	-0.137*	(0.079)	0.136	(0.113)	0.274	(1.317)	-2.377	(1.996)
$p = 11$	0.222 [‡]	(0.051)	0.339 [‡]	(0.059)	0.148	(1.301)	0.786	(1.223)
$p = 12$	0.420 [‡]	(0.082)	0.664 [‡]	(0.071)	0.488	(1.331)	0.251	(1.481)
Constant	4.211 [‡]	(0.348)	5.060 [‡]	(0.224)	28.628 [‡]	(2.328)	34.078 [‡]	(2.783)
R^2	0.498		0.434		0.458		0.218	
N	680		683		680		683	

Note: The dependent variable is the agreed wholesale price for the first two regressions and the agreed order quantity for the last two regressions. Significance given by [‡] $p < 0.01$, [†] $p < 0.05$, and * $p < 0.10$.

In Table 9, for both the wholesale price and order quantity, the final agreements are significantly

and positively associated with each party’s first offer. For both contract parameters, the coefficient on the first offer is larger for the supplier, which indicates that their first offer is more determinative of the final outcome, but this difference is only significant for the order quantity (wholesale price 0.367 versus 0.307, $p = 0.15$; order quantity 0.539 versus 0.361, $p < 0.01$). This is not surprising because, given that they are exposed to inventory risk and that they generally earn less than half of the surplus in our data, they have more to gain by sticking more closely to their initial demands. It also speaks to the importance of making a “good” initial demand, which we now turn to.

Because players negotiate over both the wholesale price and order quantity, we can evaluate the expected profits of each offer to both players. Figure 5 depicts the suppliers’ average share of the total supply chain profit by offer number for those negotiations in which a player made at least five offers and an agreement was eventually reached. We provide three plots, one for each supplier cost type.⁶ As can be seen, for each supplier cost type, the retailer’s first offer provides very little – in two cases even negative – expected profit for the supplier. In contrast, suppliers’ first offer demands between 56% and 66% of the surplus. What is interesting to note is that for $c = 4$ and $c = 5$, suppliers eventually concede, on average, more than half the surplus to the retailer. Remarkably, for the $c = 5$ supplier this actually happens at the *second* offer. While retailers generally improve their offers, the average share of surplus to suppliers never exceeds 40% and for $c = 5$, it is not even 10%.

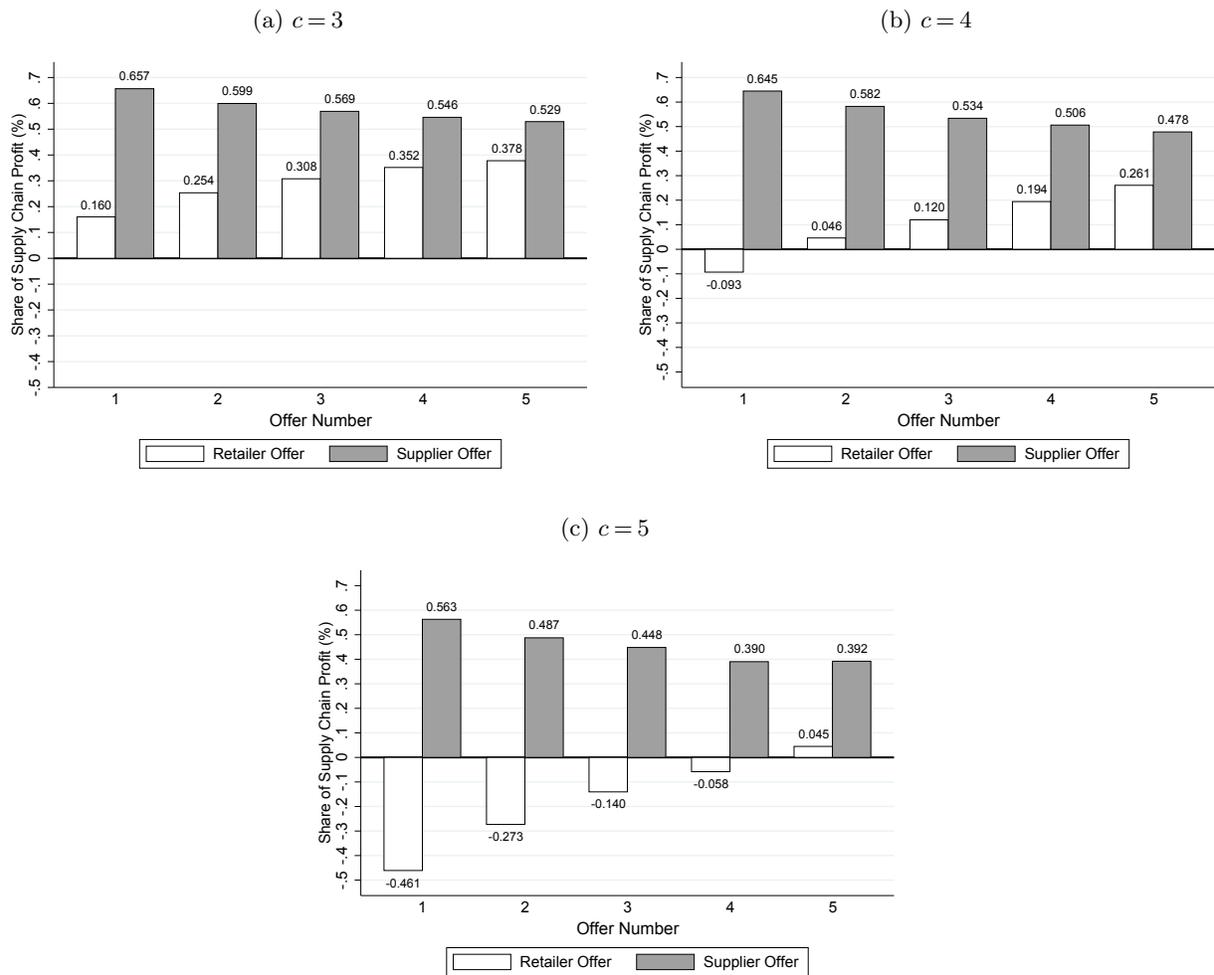
5.3. Matching Dynamics

We now turn our attention to the process by which matchings were formed in our endogenous matching treatments. The process itself was unrestricted except that, after 150 seconds, any players unmatched would be randomly matched to a player of the opposite role who was also unmatched. Specifically, a retailer of type $x \in \{10, 11, 12\}$ could propose to a supplier of type $y \in \{3, 4, 5\}$, denoted by $x \rightarrow y$ and vice-versa, denoted by $y \rightarrow x$. In the two disclosure treatments, supplier type y could disclose, denoted by Dy , $y \in \{3, 4, 5\}$. Lastly, a proposed matching could be accepted, either by the retailer or supplier. This is denoted by $A - (y, x)$, where $A \in \{R(etailer), S(upplier)\}$.⁷ We define each such proposal, disclosure decision, or matching, to be a ‘matching event.’

In Figure 6 we plot the frequency of each type of matching event, restricting attention to the first three such events in each (matching group, period). Panel (a) provides the results for the End-F-F

⁶ We also generated plots for each of the nine (p, c) combinations but no additional insights arise so we omit them in the interest of space.

⁷ We also allowed proposed matchings to be rescinded. These were relatively rare and so we omit them from our discussion to avoid clutter.

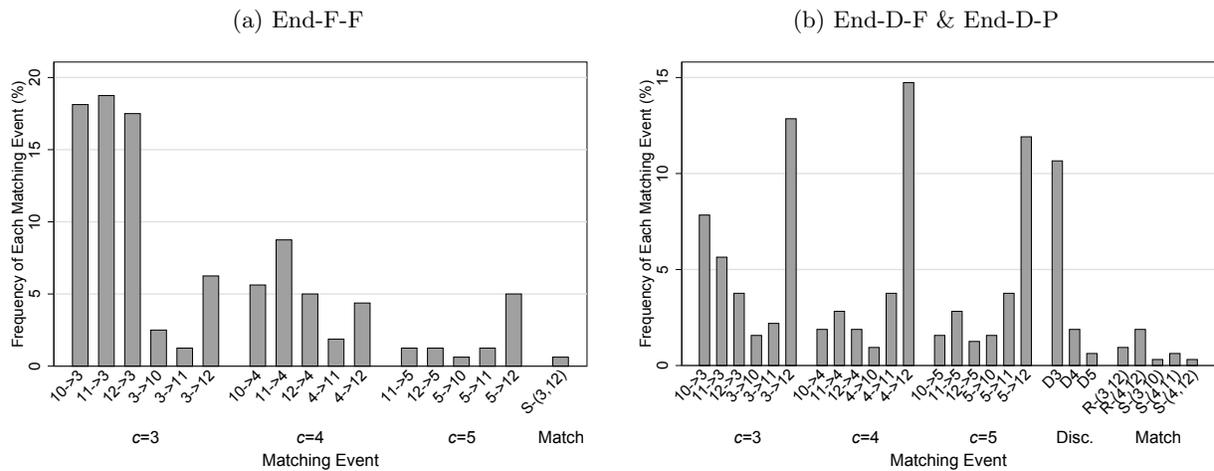
Figure 5 The Evolution of Surplus Division: Share of Supply Chain Expected Profit to Suppliers (%)

Note: Includes subject-periods in which 5 or more offers were made.

treatment. There are two interesting results: first, the process, at least at the start, is driven by retailers proposing to suppliers. Second, as one might expect, the modal proposal is to the lowest cost supplier. The latter result should not be too surprising since all retailer types benefit from being matched to a low cost supplier. It is also the case that the modal matching proposal by all supplier cost types is to the highest price retailer.

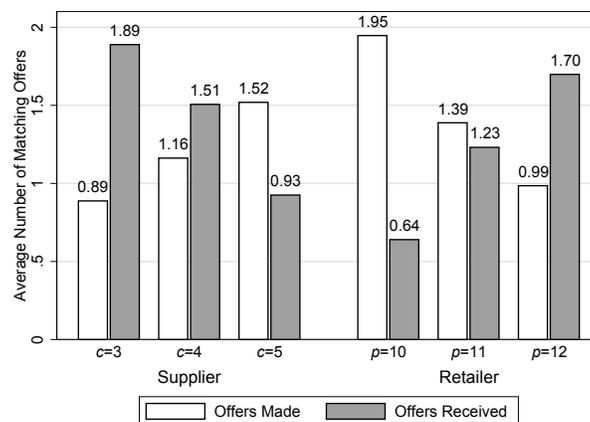
In the two disclosure treatments, we see an opposite pattern with matching proposals being driven by the suppliers, which makes sense because supplier costs are private information unless they choose to disclose. As before, we see that the modal supplier proposal is to the highest price retailer. Supporting earlier results, we also see that the lowest cost supplier has the greatest frequency of disclosure among suppliers over the first three matching events.

Figure 6 Distribution of Matching Events (First 3 Events, %)



In Figure 7, we focus only on proposals to match and we report the average number of proposals each player type made and received. There is a clear monotone relationship in all four possible comparisons. In particular, the “better” the player type (i.e., lower cost supplier or higher price retailer), the fewer proposals made but the more proposals received. Non-parametric trend tests easily reject that the average number of proposals made/received are the same across retailer and supplier types. Thus, the more desirable (in terms of supply chain surplus) of a match a player type is, the more flexibility he/she has to choose the partner that she wants to be matched with. Conversely, less desirable partners must make more proposals and are at the mercy of the other player role.

Figure 7 Average Number of Matching Offers Made and Received



Finally, in Table 10, we look at the timing at which the possible matchings form, reporting

both the average time remaining when each matching was formed and the frequency that each particular matching is the first to form in a (matching group, period). For the latter we report overall frequencies as well as the frequencies over the last half of the experiment. As can be seen, the best matching – (3, 12) – forms earliest on average and is the first matching to form nearly 40% overall and over 50% of the time in the last half of the experiment. The next earliest matching to form is (4, 11), which is next in the assortative matching chain, occurring approximately 2.5 seconds later, on average. Thus, it appears that the formation of the (3, 12) matching sets off a chain of events, frequently leading to assortative matching.⁸ We summarize this discussion as:

Result 11 *Retailers (resp. suppliers) are more likely to propose matching to the best quality supplier (resp. retailer). Assortative matches – in particular, (3, 12), form earlier on average, and are more likely to be the first matching to form. There is a tendency towards assortative matching over the last half of the experiment.*

Table 10 Time and Order of Matching

Matching	Average Time	Frequency First To Occur	
	Remaining	Overall	Last Half
(3, 10)	102.16	8.02	8.64
(3, 11)	105.13	12.35	12.35
(3, 12)	126.73	39.51	51.85
(4, 10)	103.00	2.47	0.00
(4, 11)	124.15	10.49	9.88
(4, 12)	105.84	14.20	4.94
(5, 10)	97.86	2.47	1.23
(5, 11)	98.86	4.94	6.17
(5, 12)	101.48	5.56	4.94

Note: The shaded cells are those matchings which are consistent with assortative matching.

6. Discussion and Concluding Remarks

In this study we investigate private cost information and endogenous matching in a two-stage supply chain with dynamic bargaining. In practice it is common for buyers in a B2B setting to have only a rough estimate of their supplier’s cost. It is also natural that retailers and suppliers can choose with whom to contract with. Our study is unique in evaluating this setting, where suppliers also have the option to disclose their private cost information.

⁸ Although not shown in the table, (4, 11) is most frequently the second matching to form.

We first examine this setting theoretically and find a number of predictions. For instance, given our experimental parameters, so long as costs remain private information while bargaining, suppliers should opt to keep their cost information private during matching because the informational rents from private information outweigh any gain from matching with a better partner due to disclosure. However, despite the vastly different predictions on disclosure depending on whether or not costs remain private information, disclosure patterns did not differ in these two treatments. At least part of this was likely due to important deviations from the theoretical predictions during bargaining, which saw suppliers earning a disproportionately small share of the surplus – particularly under private information and even more so for high-cost supplier types. Given these deviations, we showed that it was actually in higher-cost suppliers’ best interest to disclose their costs and credibly convey the need for a more equitable wholesale price.

As previously mentioned, much of the existing experimental supply chain literature exogenously matches retailers and suppliers into pairs. Therefore, we consider our study an important methodological step in understanding the implications that endogenous matching has on overall supply chain efficiency and distribution of profits. One key result we observe relating to this is that endogenous matching does not lead to significant differences in average expected profits. However, in terms of second order effects, we find that endogenous matching leads to a higher variance in profits: lower cost (i.e., higher quality) suppliers often choose to contract with higher priced (i.e., higher quality) retailers, and vice versa. Although in our experiment, subject types were drawn independently each period, in reality supplier costs and retailer quality are likely persistent. Thus endogenous matching may have important long-run consequences in the overall market, with gains being concentrated amongst the very best. This is an interesting avenue for future research.

Aside from these main results, we also observed a number of other decisions and outcomes that differed from the normative theory. For instance, supply chain efficiency was below the predicted values, wholesale prices were consistently lower than the normative predictions, and quantities were anchored towards mean demand. One advantage of our experimental design is that we were able to track various proposals and feedback, in both the bargaining and matching stages. This allows us to better understand the mechanisms that lead to any outcomes. Our analyses of these data suggest that superficial fairness, defined as the tendency to anchor wholesale prices on the midpoint between the retailer’s price and supplier’s cost and the equilibrium prediction, exists in our full information treatments. More importantly, our study shows that superficial fairness persists even in the absence of a salient supplier cost value, i.e., when a supplier’s cost is private information.

Despite providing extensive decision support in both the matching and bargaining stages, some of our results are indicative of bounded rationality. For instance, disclosure decisions in End-D-F and End-D-P did not significantly differ from one another, whereas the normative theory predicts that lowest cost suppliers should always disclose in the former and never in the latter. However, as we noted in our theoretical analysis, when a supplier chooses not to disclose and their costs remain private, the predictions for disclosure are somewhat nuanced: for our experimental parameters no supplier should disclose, but certain parameters exist such that all suppliers should disclose. Thus, it is not entirely surprising that human participants did not conform to these disclosure predictions. In addition, while bounded rationality is a plausible reason for observing deviations relative to normative theory, it is unlikely to be the primary explanation for differences across treatments. In particular, bounded rationality is probably present to a similar extent in all treatments.

While we believe superficial fairness and anchoring are plausible drivers for our results, we admit that other behavioral biases may be present as well. Some of these, but not all, can be ruled out in our data. For example, social preferences are unlikely to be a driver in that the full information treatments predict equal splits of expected profits between the two parties, whereas we observed retailers earning significantly more than suppliers. Davis and Hyndman (2017) discusses this in the context of full information. Nevertheless, it may be interesting to investigate how such biases may interact with endogenous matching and private information.

In summary, we find that suppliers do not always benefit from private information while bargaining. Instead, we find that lower quality suppliers actually benefit from revealing their cost structures to retailers, in an effort to achieve more equitable gains while bargaining. Further, our study demonstrates that endogenous matching is an important feature of experiments that can affect outcomes such as the variance of profits. Specifically, higher quality suppliers and higher quality retailers benefit from endogenous matching, whereas lower quality suppliers and lower quality retailers are disadvantaged by it. As discussed, this may have important consequences in the market over the long run. Overall, our study provides important insights for retailer and suppliers, depending on whether they are high or low quality with respect to their competition.

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Appendix

A. Bargaining with Private Information

For this analysis we specialize to the case of $a = 0$ and $b = 100$, to avoid any extraneous algebra. The expected profits of the retailer can be written as:

$$\pi_r(p, c, w, q) = \frac{p - w}{200} (200q - q^2),$$

while the expected profits of the supplier can be written as:

$$\pi_s(p, c, w, q) = \frac{w}{200} (200q - q^2) - cq.$$

A.1. Two Supplier Cost Types

We first consider the case in which there are two equally likely supplier types indexed by their cost of production, $c_1 < c_2$. This is less computationally intensive and so is useful to build intuition. It is also relevant because, in order to say whether suppliers will disclose their cost in End-D-P (where we have three supplier cost types), we require predictions for private information bargaining if only one supplier type discloses. Following Myerson (1984), a mechanism, M , assigns a contract, (w_i, q_i) , for each possible report c_i , $i \in \{1, 2\}$ of the supplier. We can set up the objective function as:

$$\max_{q_i, w_i} \lambda \pi_s(p, c_1, w_1, q_1) + (1 - \lambda) \pi_s(p, c_2, w_2, q_2) + \frac{1}{2} (\pi_r(p, c_1, w_1, q_1) + \pi_r(p, c_2, w_2, q_2))$$

subject to the incentive compatibility constraint that the low cost-supplier does not mimic the high-cost supplier:

$$\pi_s(p, c_1, w_1, q_1) \geq \pi_s(p, c_1, w_2, q_2).$$

Substituting in for the profit expressions, we can express the Lagrangean as:

$$\begin{aligned} \mathcal{L} = & \lambda \left(\frac{w_1}{200} (200q_1 - q_1^2) - c_1 q_1 \right) + (1 - \lambda) \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_2 q_2 \right) \\ & + \frac{1}{2} \left(\frac{p - w_1}{200} (200q_1 - q_1^2) + \frac{p - w_2}{200} (200q_2 - q_2^2) \right) \\ & + \alpha \left(\frac{w_1}{200} (200q_1 - q_1^2) - c_1 q_1 - \frac{w_2}{200} (200q_2 - q_2^2) + c_1 q_2 \right) \end{aligned}$$

We can now rearrange to group those factors involving the contract for the low- and high-type supplier respectively. Doing so, we obtain:

$$\begin{aligned} \mathcal{L} = & \frac{1}{2} \left(2(\lambda + \alpha) \left(\frac{w_1}{200} (200q_1 - q_1^2) - c_1 q_1 \right) + \frac{p - w_1}{200} (200q_1 - q_1^2) \right) \\ & + \frac{1}{2} \left(2(1 - \lambda) \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_2 q_2 \right) - 2\alpha \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_1 q_2 \right) + \frac{p - w_2}{200} (200q_2 - q_2^2) \right) \end{aligned}$$

Note that the expression is linear in w , which means that it effectively acts as a transfer payment between retailer and supplier. Therefore, we know that $\lambda + \alpha = 1/2$.

Solving for q_1 and q_2 yields:

$$q_1^* = \frac{100(p - w_1 + 2(\lambda + \alpha)(w_1 - c_1))}{p + (2(\alpha + \lambda) - 1)w_1}$$

and

$$q_2^* = \frac{100(p - 2c_2 + w_2(1 - 2(\alpha + \lambda)) + 2\alpha c_1 + 2\lambda c_2)}{p + w_2(1 - 2(\alpha + \lambda))}.$$

If we substitute these expressions into the objective function and impose the constraint that $\lambda = 1/2 - \alpha$, then the dual problem becomes:

$$\min_{\alpha \in [0, 1/2]} \frac{50((4\alpha^2 + 1)c_1^2 - 2(2\alpha + 1)c_2(2\alpha c_1 + p) + (2\alpha c_2 + c_2)^2 + 2(2\alpha - 1)c_1 p + 2p^2)}{p}$$

Observe that the derivative of this expression with respect to α is (ignoring the p in the denominator):

$$50(8\alpha c_1^2 - 4(1 + 2\alpha)c_1 c_2 + 4c_2(c_2 + 2\alpha c_2) + 4c_1 p - 4c_2(2\alpha c_1 + p)).$$

Setting the expression equal to 0 and solving for α yields:

$$\alpha^* = \frac{p - c_2}{2(c_2 - c_1)}.$$

Observe that for the parameters of the experiment, the smallest that this can be is $5/4 > 1/2$. Therefore, the minimum of this constrained optimization problem occurs at $\alpha = 1/2$.⁹

Using $\alpha = 1/2 - \lambda$ and plugging into the values for q_1 and q_2 , yields:

$$q_1 = \frac{100(p - c_1)}{p}$$

and

$$q_2 = \frac{100(p - 2c_2 + c_1 + 2\lambda(c_2 - c_1))}{p}.$$

The optimized objective function is:

$$\frac{25(p - c_1)^2}{p} + \frac{25(p - 2c_2 + c_1 + 2\lambda(c_2 - c_1))^2}{p}.$$

The warrant conditions imply that:

$$\begin{aligned} (\lambda + 1/2 - \lambda)W_1 &= \frac{1}{2} \frac{25(p - c_1)^2}{p} \\ (1 - \lambda)W_2 - (1/2 - \lambda)W_1 &= \frac{1}{2} \frac{25(p - 2c_2 + c_1 + 2\lambda(c_2 - c_1))^2}{p}. \end{aligned}$$

Solving yields:

$$\begin{aligned} W_1^* &= \frac{25(p - c_1)^2}{p} \\ W_2^* &= -\frac{25(2c_2^2(\lambda - 1) + 2c_2(-2c_1\lambda + c_1 + p) + c_1^2(2\lambda - 1) - p^2)}{p}. \end{aligned}$$

Finally, we can solve for w_1 , w_2 and λ . For λ interior, we have the following system:

$$\begin{aligned} \frac{w_1}{200} (200q_1 - q_1^2) - c_1 q_1 &= \frac{25(p - c_1)^2}{p} \\ \frac{w_2}{200} (200q_2 - q_2^2) - c_2 q_2 &= -\frac{25(2c_2^2(\lambda - 1) + 2c_2(-2c_1\lambda + c_1 + p) + c_1^2(2\lambda - 1) - p^2)}{p} \end{aligned}$$

⁹ Note that this is, indeed, the minimum, because the second derivative is everywhere positive, making this a strictly convex function.

$$\frac{w_1}{200} (200q_1 - q_1^2) - c_1q_1 = \frac{w_2}{200} (200q_2 - q_2^2) - c_1q_2,$$

where we use the expressions for q_1 and q_2 above. The solution to this is:

$$\begin{aligned} \lambda &= -\frac{p + 2c_1 - 3c_2}{3(c_2 - c_1)} \\ w_1 &= \frac{p(p + 3c_1)}{2(p + c_1)} \\ w_2 &= \frac{3p(3p + c_1)}{2(5p + c_1)}. \end{aligned}$$

This requires $\lambda \in (0, 1/2)$, which is equivalent to: $p \in (0.5(3c_2 - c_1), 3c_2 - 2c_1)$.

Note that this is never the case for the experimental parameters used in this paper. The relevant region for is $p \geq 3c_2 - 2c_1$, in which case $\lambda = 0$ and we must solve:

$$\begin{aligned} \frac{w_1}{200} (200q_1 - q_1^2) - c_1q_1 &\geq \frac{25(p - c_1)^2}{p} \\ \frac{w_2}{200} (200q_2 - q_2^2) - c_2q_2 &= -\frac{25(2c_2^2(\lambda - 1) + 2c_2(-2c_1\lambda + c_1 + p) + c_1^2(2\lambda - 1) - p^2)}{p} \\ \frac{w_1}{200} (200q_1 - q_1^2) - c_1q_1 &= \frac{w_2}{200} (200q_2 - q_2^2) - c_1q_2. \end{aligned}$$

This yields:

$$\begin{aligned} w_1 &= \frac{p(-7c_1^2 + 10c_1c_2 - 6c_2^2 + 2c_2p + p^2)}{2(p^2 - c_1^2)} \\ w_2 &= \frac{p(c_1^2 + 2c_1c_2 - 6c_2^2 + 2c_2p + p^2)}{2(-c_1^2 + 4c_1c_2 - 4c_2^2 + p^2)} \end{aligned}$$

Note that the inequality above is satisfied so long as:

$$\frac{50(c_2 - c_1)(2c_1 - 3c_2 + p)}{p} \geq 0,$$

which is equivalent to $p \geq 3c_2 - 2c_1$, which is the case we are considering.

In Table A.1, we provide the theoretical predictions on wholesale prices, order quantities and expected profits for the three combinations of supplier cost types and the three different retailer prices.

A.2. Three Cost Types

We can set up the objective function as:

$$\begin{aligned} \max_{q_i, w_i} &= \lambda_1 \pi_s(p, c_1, w_1, q_1) + \lambda_2 \pi_s(p, c_2, w_2, q_2) + (1 - \lambda_1 - \lambda_2) \pi_s(p, c_3, w_3, q_3) \\ &+ \frac{1}{3} (\pi_r(p, c_1, w_1, q_1) + \pi_r(p, c_2, w_2, q_2) + \pi_r(p, c_3, w_3, q_3)) \end{aligned}$$

subject to the incentive compatibility constraint that the supplier type c_i does not mimic the supplier type c_{i+1} for $i = 1, 2$:

$$\begin{aligned} \pi_s(p, c_1, w_1, q_1) &\geq \pi_s(p, c_1, w_2, q_2) \\ \pi_s(p, c_2, w_2, q_2) &\geq \pi_s(p, c_2, w_3, q_3). \end{aligned}$$

The Lagrangean, rewritten as in the two-type case to collect certain terms, is:

$$\mathcal{L} = \frac{1}{3} \left(3(\lambda_1 + \alpha_1) \left(\frac{w_1}{200} (200q_1 - q_1^2) - c_1q_1 \right) + \frac{p - w_1}{200} (200q_1 - q_1^2) \right)$$

Table A.1 Theoretical Predictions For Two Supplier Cost Types

(a) Supplier Cost Types: {3, 4}			
Retailer's Price			
Cost	10	11	12
3	(7.75, 70.00, 142.50)	(8.35, 72.73, 168.18)	(8.93, 75.00, 193.75)
4	(7.80, 50.00, 92.50)	(8.36, 54.55, 113.64)	(8.92, 58.33, 135.43)

(b) Supplier Cost Types: {3, 5}			
Retailer's Price			
Cost	10	11	12
3	(7.53, 70.00, 132.50)	(8.25, 72.73, 163.64)	(8.93, 75.00, 193.75)
5	(8.73, 30.00, 72.50)	(9.17, 36.36, 90.91)	(9.66, 41.67, 110.42)

(c) Supplier Cost Types: {4, 5}			
Retailer's Price			
Cost	10	11	12
4	(8.21, 60.00, 105.00)	(8.85, 63.64, 129.55)	(9.47, 66.67, 154.17)
5	(8.28, 40.00, 65.00)	(8.86, 45.45, 84.09)	(9.44, 50.00, 104.17)

Note: The numbers in each triple (x, y, z) correspond to the predicted wholesale price, order quantity and supplier expected profits, respectively. The expected profits of the retailer coincide with the high cost type supplier's expected profits.

$$\begin{aligned}
& + \frac{1}{3} \left(3(\lambda_2 + \alpha_2) \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_2q_2 \right) - 3\alpha_1 \left(\frac{w_2}{200} (200q_2 - q_2^2) - c_1q_2 \right) + \frac{p - w_2}{200} (200q_2 - q_2^2) \right) \\
& + \frac{1}{3} \left(3(1 - \lambda_1 - \lambda_2) \left(\frac{w_3}{200} (200q_3 - q_3^2) - c_3q_3 \right) - 3\alpha_2 \left(\frac{w_3}{200} (200q_3 - q_3^2) - c_2q_3 \right) + \frac{p - w_3}{200} (200q_3 - q_3^2) \right)
\end{aligned}$$

Observe that the linearity in w implies that $\lambda_1 + \alpha_1 = 1/3$ and $\lambda_2 + \alpha_2 - \alpha_1 = 1/3$. The next step is to optimize with respect to q_i .

This yields:

$$\begin{aligned}
q_1 &= \frac{100(p - w_1 + 3(\lambda_1 + \alpha_1)(w_1 - c_1))}{p - w_1 + 3(\lambda_1 + \alpha_1)w_1} \\
q_2 &= \frac{100(p - w_2(3(\lambda_2 + \alpha_2 - \alpha_1) - 1) - 3(\lambda_2 + \alpha_2)c_2 + 3\alpha_1c_1)}{p + w_2(3(\lambda_2 + \alpha_2 - \alpha_1) - 1)} \\
q_3 &= \frac{100(p + w_3(3(1 - \lambda_1 - \lambda_2) - 3\alpha_2 - 1) - 3(1 - \lambda_1 - \lambda_2)c_3 + 3\alpha_2c_2)}{p + w_3(3(1 - \lambda_1 - \lambda_2) - 3\alpha_2 - 1)}.
\end{aligned}$$

With these values for quantities and also using the relationship between the α and λ variables, we obtain the value of the objective function (as a function of the λ s):

$$\frac{50}{3} \left(\frac{(p - c_1)^2}{p} + \frac{(p + c_1 - 3\lambda_1c_1 + c_2(3\lambda_1 - 2))^2}{p} + \frac{(p + c_2(2 - 3\lambda_1 - 3\lambda_2) - 3c_3(1 - \lambda_1 - \lambda_2))^2}{p} \right)$$

The warrant conditions imply that:

$$\begin{aligned}
(\lambda_1 + \alpha_1)W_1 &= \frac{1}{2} \frac{50}{3} \left(\frac{(p - c_1)^2}{p} \right) \\
(\lambda_2 + \alpha_2)W_2 - \alpha_1W_1 &= \frac{1}{2} \frac{50}{3} \left(\frac{(p + c_1 - 3\lambda_1c_1 + c_2(3\lambda_1 - 2))^2}{p} \right) \\
(1 - \lambda_1 - \lambda_2)W_3 - \alpha_2W_2 &= \frac{1}{2} \frac{50}{3} \left(\frac{(p + c_2(2 - 3\lambda_1 - 3\lambda_2) - 3c_3(1 - \lambda_1 - \lambda_2))^2}{p} \right).
\end{aligned}$$

Table A.2 Equilibrium Predictions Under Private Information (Three Cost Types)

	Supplier Profit			Wholesale Price (w)			Quantity (q)		
	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$	$p = 10$	$p = 11$	$p = 12$
$c = 3$	149.17	178.79	207.64	7.89	8.58	9.23	70.00	72.73	75.00
$c = 4$	99.17	124.24	149.31	7.98	8.63	9.26	50.00	54.55	58.35
$c = 5$	69.17	87.88	107.64	8.59	9.06	9.58	30.00	36.36	41.67

This yields:

$$W_1 = \frac{25(p - c_1)^2}{p}$$

$$W_2 = \frac{25(p^2 + c_1^2(1 - 3\lambda_1) + c_2^2(2 - 3\lambda_1) - 2c_1c_2(1 - 3\lambda_1) - 2c_2p)}{p}$$

$$W_3 = \frac{25(c_1^2(3\lambda_1 - 1)(3\lambda_1 + 3\lambda_2 - 2) - 2c_1c_2(3\lambda_1 - 1)(3\lambda_1 + 3\lambda_2 - 2) + c_2^2(18\lambda_1^2 + 3\lambda_1(9\lambda_2 - 8) + 9\lambda_2^2 - 18\lambda_2 + 8))}{3p(1 - \lambda_1 - \lambda_2)} + \frac{25(-6c_2c_3(3\lambda_1^2 + \lambda_1(6\lambda_2 - 5) + 3\lambda_2^2 - 5\lambda_2 + 2) + 3(\lambda_1 + \lambda_2 - 1)(3c_3^2(\lambda_1 + \lambda_2 - 1) + 2c_3p - p^2))}{3p(1 - \lambda_1 - \lambda_2)}.$$

It remains to solve for λ_1 , λ_2 , w_1 , w_2 and w_3 . To do this, we use the expressions for W_i , where we impose that W_i is greater than or equal to the expected profits for supplier type i (with equality if λ_i is interior) and the incentive compatibility constraints (which must be satisfied with equality if $\alpha_i > 0$). This leads to many cases to consider.

Using the values that we implemented in the experiment, the relevant case is $\lambda_1 = \lambda_2 = 0$. This yields the following contract parameters for each possible price of the retailer (which was always known with certainty) depicted in Table A.2.

As we discuss in the main text, one can use the results in Tables A.1 and A.2, to conclude that suppliers will not disclose their cost in the End-D-P treatment.

B. Sample Experimental Screenshot

Figure B.1 Screenshot of the Matching Stage for the Endogenous Treatments

Round 1
 You are **supplier 992**
 Your cost is 3
 Time remaining 118

Supplier Reveal Info

Reveal your cost? Reveal

Supplier	Reveal	Cost
122	No	-
427	No	-
992	No	-

Test Inputs and Graph

Your manufacturing cost: 3
 Test retail price (10,11,12):
 10
 11
 12
 Test wholesale price:
 Test quantity:
Test

Retailers You Want to Match With

Retailer	Price	Propose	Rescind	Proposed
217	11	Propose	Rescind	No
649	12	Propose	Rescind	Yes
886	10	Propose	Rescind	No

Retailers Who Want to Match With You

Retailer	Price	Proposed	Accept
217	11	No	Accept
649	12	No	Accept
886	10	No	Accept