Procurement for Assembly Under Asymmetric Information: Theory and Evidence

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Abstract. We study an original equipment manufacturer (OEM) purchasing two inputs for assembly from two suppliers with private cost information. The OEM can contract with the two suppliers either simultaneously or sequentially. We consider both cases in which the OEM has relatively equal bargaining power (the dynamic bargaining institution) or substantial bargaining power (the mechanism design institution). For the dynamic bargaining institution, we show that in sequential bargaining, the supply chain profit is higher, the OEM earns a lower profit, the first supplier earns a higher profit, and the second supplier may earn a higher or lower profit, than compared with simultaneous bargaining. For the mechanism design institution, we show that all players’ profits are the same in simultaneous and sequential contracting. We also benchmark against a case where the OEM procures both inputs from a single integrated supplier (a dyadic supply chain). We then test these predictions in a human-subjects experiment, which supports many of the normative predictions qualitatively with some deviations: an OEM with relatively equal bargaining power weakly prefers to contract with suppliers simultaneously, whereas an OEM with substantial bargaining power prefers to contract with suppliers sequentially. In addition, the OEM’s profit and supply chain efficiency are higher in the dyadic supply chain than the assembly system.

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1. Introduction

In today’s global marketplace, original equipment manufacturers (OEMs) rely more than ever on sourcing inputs from external suppliers rather than producing inputs in-house (Fung et al. 2008). For instance, to assemble its 787 Dreamliner, Boeing procures engines from Rolls Royce and nacelles from Goodrich Corp. (Tang et al. 2009). Assembly supply chains relate to a number of manufacturing industries such as transportation equipment, electronics and computers, and machinery (which generated $1.73 trillion in shipments in the United States in 2018; U.S. Census Bureau 2020). In most of these cases, suppliers have private cost information. As such, an OEM is interested in extracting this information to help maximize its own profit. Because OEMs often source inputs from multiple suppliers, one lever they have at their disposal is to contract with suppliers simultaneously or sequentially. In this study, we investigate the procurement problem of an OEM purchasing two inputs from suppliers who both have private cost information, and the OEM can contract with the suppliers simultaneously or sequentially.

We analyze this three-party assembly supply chain, where an OEM contracts with suppliers simultaneously or sequentially, under two different levels of bargaining power. When the OEM has relatively equal bargaining power with its suppliers, they engage in a back-and-forth dynamic bargaining process, whereas if the OEM has considerably more bargaining power, then they make take-it-or-leave-it ultimatum offers to suppliers. For both levels of bargaining power, we aim to address the following research question: in an assembly supply chain, should OEMs contract with suppliers simultaneously or sequentially?

Although OEMs often require specialized components, necessitating multiple suppliers, there are times when OEMs may have the ability to sole source their needs as well. For example, Volkswagen procured
both the light source and control module for its head-
lamps in the Volkswagen Golf VI from a single suppli-
er but opted for separate suppliers in the Volkswagen
Golf VII (Chen et al. 2021). As another example, road
and mountain bike assemblers such as Trek, Giant,
and Cannondale often choose between purchasing all
or some of the components for a bike’s drivetrain from
a single supplier or multiple suppliers, such as Shimano
or SRAM. Therefore, a second research question is
as follows: how does a three-party assembly setting
compare with a dyadic supply chain, where both inputs
are sourced from a single integrated supplier, in terms
of OEM, supplier, and supply chain profit? Even if an
OEM cannot choose between an assembly system or a
dyadic supply chain, studying the dyadic setting
serves as a useful benchmark to understand the
unique characteristics of the assembly system.

Because human managers are integral to procure-
ment decisions, we answer these research questions
theoretically and experimentally. Using both methods
is advantageous because the former generates norma-
tive predictions, and the latter identifies whether hu-
mans conform to those predictions. There are a num-
ber of experimental studies which demonstrate that
human-decisions makers deviate from the normative
theory in settings such as supply chain contracting,
auctions, and forecasting. Neglecting to recognize such
deviations can lead to erroneous managerial recom-
mandations and negatively impact profits. Ultimately,
by developing and testing the normative theory for as-
sembly supply chains, we can identify when the theo-
y is validated versus those instances where there are
deviations, which translates into more useful insights
for managers.

To this end, we begin by deriving a number of theo-
retical predictions for the assembly setting in which
the OEM procures two different inputs: one each from
two suppliers who possess private cost information.
The OEM must reach agreements with both suppliers
regarding the price and quantity. For the case of equal
bargaining power between the OEM and suppliers
(the dynamic bargaining institution), we use the solution
concept of Myerson (1984a). The solution is an
incentive-efficient mechanism satisfying individual ra-
tionality, incentive compatibility, and Pareto optimali-
ty. In this framework we show that, although the total
supply chain profit is higher when bargaining sequen-
tially, the OEM actually prefers to bargain simulta-
aneously. This is because when bargaining sequentially,
the OEM needs to transfer an outsized fixed payment
to the first supplier in order to reduce incentive distor-
tion in the second bargaining stage, leading to lower
OEM profit. In contrast, for the powerful OEM case
(the mechanism design institution), we demonstrate an
equivalence between simultaneous and sequential con-
tracting in terms of OEM (and supplier) profit.

In both institutions, the contracting process effec-
tively separates high- and low-cost suppliers. The dif-
ference is that in the mechanism design case, we as-
sume that the OEM can make a menu of contract
proposals: one that is optimal for each supplier cost
type, and in the dynamic bargaining case, that this sepa-
ration of supplier types occurs in the process of bar-
gaining. We also analyze a dyadic supply chain where
the OEM procures the two inputs from an integrated
supplier, which helps shed light on the impact of the
assembly structure.

We then report the results of a human-subjects ex-
pertiment. In particular, we use our main theoretical re-
sults as benchmarks that our experiment rigorously
tests. Turning to our design, we conduct a 2 × 3
between-subjects experiment with 396 participants.
The first factor manipulates the institution, dynamic
bargaining, or mechanism design, and the second fac-
tor varies the supply chain structure and contract tim-
ing: assembly with simultaneous contracting, assembly
with sequential contracting, or dyadic supply chain.

Our experimental results confirm that, at a high level,
the broad comparative static predictions of the theory
hold. However, we also document some managerially
relevant deviations. First, OEMs with considerable bar-
gaining power earn higher profit under sequential con-
tracting than simultaneous contracting. Second, in as-
sembly systems under sequential contracting, the first
supplier earns more than the second supplier, for both
the bargaining and mechanism design institution. Third,
whereas theory predicts that the OEM and suppliers
will earn unequal profits, we observe that these differ-
ences are more equal than predicted. Fourth, our dyadic
supply chain setting achieves higher agreement rates
and, even conditional on agreement, higher supply
chain profit, than an assembly system. Last, we observe
that OEMs often neglect to successfully screen suppliers.

2. Related Literature

The research most related to our study are those pa-
pers which investigate procurement in supply chains,
dynamic bargaining between parties, and asymmetric
information. Early theoretical research regarding pro-
curement in supply chains typically considers a dyadic
relationship with one buyer and one supplier under asym-
metric information settings (Corbett et al. 2004,
Yang et al. 2009, Li et al. 2013). Regarding procure-
ment in assembly supply chains, there are a few recent
papers studying the aspects of managing information
asymmetry, including the OEM with private informa-
tion about demand (Kalkanci and Erhun 2012) and the
suppliers with private information about production
costs (Fang et al. 2014, Hu and Qi 2018, Li et al. 2019).
These papers consider one stakeholder with strong
bargaining power to make take-it-or-leave-it offers to
other stakeholders; none of them consider the scenario with relatively equal bargaining power among the OEM and the suppliers, as studied in this paper, which calls for a solution to a multilateral bargaining problem with asymmetric information.

There has also been theoretical research on bargaining among stakeholders since the seminal paper by Nash (1950). In the operations management literature, bargaining with symmetric information has been studied (Nagarajan and Sošić 2008, Lovejoy 2010, Kuo et al. 2011, Feng and Lu 2012). None of these papers evaluate the impact of asymmetric information on bargaining. When the stakeholders have private information, Myerson (1984a) extends the Nash bargaining solution to accommodate multiple players. For a more recent review on bargaining with asymmetric information, we refer the reader to Ausubel et al. (2002). In operations management, bargaining with asymmetric information between two players has been analyzed. For example, Feng et al. (2014) study the dynamic bilateral bargaining problem between one seller and one buyer privately informed of the demand information. Both stakeholders are impatient and make alternating offers until an agreement is reached. They characterize the perfect Bayesian equilibrium of the bargaining game. Bhandari and Secomandi (2011) consider an infinite-horizon revenue management problem in which the seller is privately informed of his inventory level, discount factor, and the arrival probability of buyers, and engages in bilateral bargaining with each buyer. They compare the seller’s performance under four bargaining mechanisms: buyer posted price, seller posted price, a neutral bargaining solution, and the split-the-difference mechanisms. In contrast with these two papers, the assembly supply chain we investigate imposes a unique challenge because bargaining is multilateral, involving multiple stakeholders. In addition, the potential contracting timing, simultaneous or sequential contracting, between the OEM and the two suppliers imposes another challenge: whereas simultaneous bargaining can be solved using the solution concept by Myerson (1984a), sequential bargaining requires us to extend the concept to accommodate the change in the informational structure during the bargaining process.

There has been considerable experimental research studying procurement through supply chain contracts. Many of these studies include three assumptions: (1) only two parties contract, most commonly a buyer and supplier; (2) the two parties interact through a proposing party making an ultimatum offer to the responding party; and (3) there is full information of all cost, price, and demand parameters (for a summary, see Chen and Wu 2019). In contrast, we investigate a three-party assembly supply chain, dynamic bargaining, and private cost information.

Some recent experimental studies in operations management have begun to relax the aforementioned assumptions. For instance, Johnsen et al. (2019) study a context where a retailer has private forecast information and investigate whether preset screening contracts are effective at separating supplier types. They find that certain biases play a role in supplier decisions, most notably bounded rationality and fairness (Fehr and Schmidt 1999, Bolton and Ockenfels 2000). In many ways, our work extends their research in that we too find evidence of these behavioral drivers. However, we consider a three-party assembly supply chain, dynamic bargaining, and allow OEMs to endogenously set contract terms. Leider and Lovejoy (2016) deviate from ultimatum offers and allow a retailer to interact with more than one supplier through chat-box communication. However, after communicating with multiple suppliers, the retailer then contracts with a single supplier. Davis and Leider (2018) and Davis and Hyndman (2019) explore back-and-forth negotiations, similar to our study, albeit under full information in a two-party supply chain. Also, an important feature of our assembly supply chain is that an OEM may contract with suppliers simultaneously or sequentially. The only operations management experiment that we are aware of which investigates simultaneous or sequential offers to responding parties is Ho et al. (2014). They consider full information where a supplier makes ultimatum wholesale price offers to two retailers, whereas we consider dynamic bargaining in an assembly supply chain with private information.

There is also much literature on bargaining from experimental economics. We refer the interested reader to Camerer (2003) but highlight some important aspects here. In particular, much of the experimental economics research on bargaining focuses on relatively simple environments, most notably ultimatum and dictator games, where the surplus is fixed and where a proposer makes an ultimatum offer to a responder. A robust finding is that human participants exhibit fairness preferences, where proposers offer more than the normative prediction and responders reject many offers that are actually quite profitable (Camerer 2003, chapter 2). Expanding social preferences further, Ho and Su (2009) extend the standard ultimatum game so that there is one proposer and two responders and show that peer induced fairness among responders plays a role in accept/reject decisions as well. Importantly, although fairness is a robust finding in these papers, they consider environments with full information. As we will show in Section 6, our experiment builds on this literature by finding that fairness is also useful in explaining profit outcomes under one-sided private information for all settings we investigate.

Our study contributes to the literature in the following ways. First, we study an assembly supply chain
where an OEM interacts with two suppliers (simultaneously or sequentially). We believe that this is an important missing feature in the extant literature: in practice, OEMs usually require multiple inputs from multiple suppliers. Second, we consider a dynamic bargaining environment that mimics a more realistic bargaining interaction. Third, we allow for suppliers to have private information, which is common in industry but has not been studied extensively in the literature.

3. Theory

We consider an OEM sourcing two different inputs respectively from two individual suppliers (indexed 1 and 2) and then assembles the final product from a unit of each input at zero assembly cost. For simplicity, we assume the two inputs and suppliers to be symmetric, namely that ex ante they have identical parameters; the analysis for asymmetric inputs and suppliers is similar. Suppliers are typically better informed regarding their own production costs than the OEM. We assume the two inputs and suppliers to be symmetrically have high or low unit input costs, which we denote by $c_{HL}$ and $c_{L}$, respectively. Each supplier’s two possible production costs and the prior probability of its cost being high, $p$, are common knowledge. We define $\bar{p} = 1 - p$, and $\Delta = c_{HL} - c_{L} > 0$. Each supplier is privately informed of its actual cost (type). Without loss of generality, we assume that each supplier and the OEM have reservation profit zero. As discussed in the Introduction, the assembly setting is widely seen in industries, and sourcing from two individual suppliers perfectly complementary inputs (i.e., having one without the other yields no value) poses unique challenges.

Depending on the bargaining power of the OEM and suppliers, we consider two bargaining institutions: dynamic bargaining and mechanism design. Under the dynamic bargaining institution, when the OEM and suppliers have comparable bargaining power, the three parties engage in dynamic back-and-forth bargaining with incomplete information, which is explored in Section 3.1. Under the mechanism design institution, when the OEM has dominant bargaining power over the suppliers, the OEM can make a take-it-or-leave-it ultimatum contract offer to suppliers, which is explored in Section 3.2. Under each institution, because the OEM needs to contract with two suppliers, it is faced with the issue of contracting timing: the OEM can contract with both suppliers simultaneously or sequentially. Therefore, a total of four models must be analyzed.

The outcome under each institution, if transactions occur, is a set of contracts signed by both the OEM and the suppliers, which effectively specifies the monetary transfer $P_i$ from the OEM to Supplier $i$, and the quantity of input $Q_i$ supplied by the corresponding supplier; $i = 1, 2$. The total output quantity by the OEM is $Q = \min\{Q_1, Q_2\}$ because in an assembly system both inputs are needed to produce the output. We assume that the OEM faces market-clearing price $a - Q/2$ for outputting $Q$ units. We also assume that $a$ is above a threshold ($\bar{a}$, defined in Online Appendix A), to ensure positive optimal outputs and rule out other less interesting cases.

Following Hu and Qi (2018), we implement equilibrium bargaining outcomes and optimal mechanisms in the form of two-part tariff contracts. A two-part tariff contract $(w_i, f_i)$, where $w_i$ specifies a wholesale price and $f_i$ specifies a fixed payment, allows the OEM to choose any purchase quantity $Q_i$ from Supplier $i$ while obliging the OEM to pay $w_iQ_i + f_i$ to the latter. Given $(w_1, f_1)$ and $(w_2, f_2)$, it is straightforward to see that the OEM’s optimal order quantity for both inputs is $a - w_1 - w_2$, with which the OEM’s profit is $(a - w_1 - w_2)^2/2 - f_1 - f_2$, and each Supplier $i$’s profit is $(w_i - c_i)(a - w_1 - w_2) + f_i$, where $x_i \in \{L, H\}$ represents Supplier $i$’s type. Hu and Qi (2018) show that the two-part tariff implementation has a major advantage. They find that optimal mechanisms implemented in the original quantity-payment terms $(Q_i, P_i)$ may be contingent, namely that the contract terms offered to one supplier may depend on another supplier’s choices, whereas two-part tariff implementations of optimal mechanisms do not contain contingency and are also simpler in form. Contingent contracts are challenging to implement in practice or in a laboratory. For these reasons, we implement equilibrium bargaining outcomes and optimal mechanisms in the form of two-part tariff contracts so that the experimental participants find them intuitive and relatable.

3.1. Dynamic Bargaining in Assembly

When the OEM and suppliers have comparable bargaining power, the three stakeholders engage in dynamic back-and-forth bargaining. In the assembly setting, the lack of cooperation of any party results in nontrading and zero profit for everyone. Therefore, when there is no information asymmetry, the Shapley value would predict that the three stakeholders cooperatively maximize their total profit and equally share the profit three ways. Myerson (1984a) generalizes the Shapley value to allow private information. The high-level idea of the generalization is to find an incentive-efficient mechanism which is incentive compatible (IC), individually rational (IR), and Pareto optimal (PO); under the incentive-efficient mechanism, the stakeholders obtain equitable profit shares that are fair in the sense of a virtual utility capturing the impact of the IC and IR constraints. We adopt the framework of Myerson (1984a) in solving our dynamic bargaining models. For readability, we relegate all technical
analyses to Online Appendix A and only present formulations, results, and intuitions in the main text.

3.1.1. Simultaneous Bargaining. Consider that the OEM simultaneously bargains with the two suppliers. Let $P_{1XY}$, $Q_{1XY}$ be the payment to and purchase quantity from Supplier $i$, respectively, given that Supplier 1 has cost type $X$ and Supplier 2 has cost type $Y$. It is straightforward that any efficient outcome must have $Q_{1XY} = Q_{2XY}$, and thus we denote the equal order quantity by $Q_{XY}$ henceforth. For convenience we denote the expected payment for Supplier 1 of type $X$ (respectively, Supplier 2 of type $Y$) as $P_{1X} = pP_{1XH} + pP_{1XL}$ (respectively, $P_{2Y} = pP_{2YH} + pP_{2YL}$).

A bargaining solution $(P_{1XY}, P_{2XY}, Q_{XY})$ should first be individually rational and incentive compatible, namely that it satisfies IR constraints for both the OEM and the suppliers of each type (i.e., they need to receive nonnegative expected profits), and IC constraints for the suppliers (i.e., they need to be willing to reveal their true types). An example of the IR and IC constraints for Supplier 1 is provided in Online Appendix A.1.

A bargaining solution should also be Pareto optimal for all stakeholders. Myerson (1984a) shows that incentive-efficient mechanisms, that is, mechanisms that are IR, IC, and PO, must solve the following primal bargaining problem, where $\lambda_i \in [0, 1]$, $i = 1, 2$ are some weights of the high-type suppliers’ profits and $\overline{\lambda}_i = 1 - \lambda_i$ are those on the low-type suppliers’ profits:

$$\max_{p, Q} p^+ \left[ (a - Q_{HH}/2)Q_{HH} - P_{1HH} - P_{2HH} \right]$$

$$+ \overline{\lambda}_1 \left[p(P_{1LH} - c_1Q_{LH}) + \overline{\lambda}_1P_{1LL} - c_1Q_{LL} \right]$$

$$+ \overline{\lambda}_2 \left[p(P_{2LH} - c_2Q_{LH}) + \overline{\lambda}_2P_{2LL} - c_2Q_{LL} \right]$$

s.t. IR, IC for all stakeholders and their types.

Solving the problem with the approach by Myerson (1984a), we find the following two-part tariff bargaining solutions; recall that we focus on cases with sufficiently large $a$. The free parameter $\delta$ is a transfer between the wholesale prices and fixed payments that, although technically arbitrary, is likely to be zero in practice, which leads to the most intuitive contract. For any value of $\delta$, the expected payments and quantities are the same. Thus, the two-part tariff bargaining solutions are effectively unique. For simplicity of presentation, we slightly abuse the terminology and refer to the outcome with $\delta = 0$ as the simultaneous bargaining outcome. The detailed analysis is relegated to Online Appendix A.1.

**Proposition 1** (Simultaneous Bargaining Solution). The following two-part tariff mechanisms implement the simultaneous bargaining outcome, with $\delta$ being any real number. The wholesale prices and the fixed payments are as follows:

$$w_{1H}^* = c_H + \frac{p}{p} \Delta - \delta, \ w_{1L}^* = c_L - \delta,$$

$$w_{2H}^* = c_H + \frac{p}{p} \Delta + \delta, \ w_{2L}^* = c_L + \delta,$$

$$f_{1H}^* = \frac{a^2 + 2ac_H - 4c_H^2}{6} - \frac{2c_H^2}{3p} + \Delta \frac{pa - (3 + 5p)c_L}{3p}$$

$$- 2\Delta \frac{1 + p}{3p} - w_{1H}^*(a - w_{1H}^* - p\omega_{1j}^* - p\omega_{1H}^*),$$

$$f_{1L}^* = \frac{(a - 2c_L)(a + 4c_L)}{6} + \Delta \frac{a - 5c_L}{3} - 2\Delta \frac{1 + p}{3p}$$

$$- w_{1L}^*(a - w_{1L}^* - p\omega_{1j}^* - p\omega_{1H}^*), \ i, j \in \{1, 2\}, i \neq j.$$

3.1.2. Sequential Bargaining. Consider without loss of generality that the OEM first bargains and enters a contract with Supplier 1, in the process learning its private information, before bargaining with Supplier 2. Because the trade requires all stakeholders’ participation, we assume that the OEM’s initial contract with Supplier 1 is tentative, and Supplier 1 retains the veto power over the contract during the OEM’s bargaining with Supplier 2, although no change of the contract terms is allowed. The key feature of sequential bargaining is that the OEM when bargaining with Supplier 2 is equipped with the private information of Supplier 1, and the bargaining involves double-sided private information. Similar to the simultaneous bargaining case, the bargaining solution in the sequential bargaining is also an incentive-efficient mechanism that guarantees the equitable share of all stakeholders on the virtual utility scale.

To find the bargaining solution, we first analyze the OEM’s bargaining with Supplier 2. We also directly assume the two-part tariff format from now on. We present an outline of the analysis and key results in the main text; the detailed analysis is relegated to Online Appendix A.2.

3.1.2.1. Second-Stage Bargaining. Assume that the OEM and Supplier 1 have reached the temporary agreement with a menu of two-part tariff contracts $(w_{1X}^i, f_{1X}^i)$, where $X$ is Supplier 1’s type. In what follows, we use subscript $2XY$, $X, Y = H, L$ to denote the bargaining outcome with Supplier 2 of type $Y$ given
Supplier 1’s type being \( X \), and define \( w_{2X} , f_{2X} = w_{2XH} , \)
\( w_{2XL} , f_{2XL} , X = H , L \). Similar to Section 3.1.1, we present the following primal bargaining problem, where \( \lambda_i \in [0,1] \) is the weight of the high-type Supplier 2’s profit, and \( \lambda_i \in [0,1] \) is the weight of the high-type OEM’s (i.e., an OEM having learned that Supplier 1 is of the high type) profit; \( \lambda_i = 1 - \lambda_i , i \in \{2,o\} \), are, respectively, the weights of the low-type profits:

\[
\max_{w_{2H} , f_{2H} , w_{2L} , f_{2L} , \lambda} \left\{ \lambda_1 \left[ \frac{(a - w_{1H} - w_{2LH})^2}{2} - f_{1H} - f_{2LH} \right] + \lambda_2 \left[ \frac{(a - w_{1L} - w_{2LH})^2}{2} - f_{1L} - f_{2LH} \right] \right. \\
+ \lambda_1 \left[ \frac{(a - w_{1H} - w_{2LH})^2}{2} - f_{1H} - f_{2LH} \right] \\
+ \lambda_2 \left[ \frac{(a - w_{1L} - w_{2LH})^2}{2} - f_{1L} - f_{2LH} \right] \right\} \\
\text{s.t.} \text{ IR, IC constraints for both OEM and Supplier 2 and their types.}
\]

By simplifying the constraints, defining virtual utilities, and solving for equitable shares in the dual problem, we find a bargaining outcome subject to the OEM’s IC constraint where the expected fixed payment to Supplier 2 of type \( Y = H , L \) is \( f_{2H} = p_{2H} + \phi f_{2L} \):

\[
w_{2HH} = c_H + \frac{\phi}{p} \Delta, \quad w_{2HL} = c_L, \quad w_{2HH} = c_H + \frac{\phi}{p} \Delta, \quad w_{2HL} = c_L\]

\[
f_{2H} = (a - c_L)^2 + \frac{(4 - 3p)\Delta^2}{4p^2} - \frac{(2 - p)\Delta}{2p} \\
\times (a - c_L - pw_{1H}^t - pw_{1L}^t) \\
- \frac{p}{2}[f_{1H}^t + w_{1H}^t(a - c_L - w_{1H}^t/2)] \\
- \frac{p}{2}[f_{1H}^t + w_{1L}^t(a - c_L - w_{1L}^t/2)] \\
+ \frac{3\Delta^2}{4} + \frac{\Delta}{2}(2 - a - pw_{1H}^t - pw_{1L}^t) \\
- \frac{p}{2}[f_{1H}^t + w_{1H}^t(a - c_L - w_{1H}^t/2)] \\
- \frac{p}{2}[f_{1L}^t + w_{1H}^t(a - c_L - w_{1L}^t/2)].
\]

Additionally, for this outcome to satisfy the OEM’s IC constraint, we need to require

\[
f_{1H}^t - f_{1H}^t \geq \frac{1}{2} (w_{1H}^t - w_{1L}^t)(2a - 2c_H - w_{1H}^t - w_{1L}^t), \quad (\text{IC}^t_{OL})
\]

for the first-stage bargaining outcome.

Comparing the bargaining outcome above to the simultaneous bargaining solution in Proposition 1, we note that, although the OEM also has private information, there is no additional distortion in the wholesale price for Supplier 2 (and the resulting sourcing quantity). For the bargaining outcome to be feasible, the fixed payment difference between the low-type and high-type Supplier 1 should be sufficiently large, which is reflected by the IC^t_{OL} constraint.

3.1.2.2. First-Stage Bargaining. The first-stage primal bargaining problem incorporates the anticipated second-stage bargaining outcome where the sum of the first four terms in the objective function represents the expected total virtual utility of the OEM and Supplier 2 in the second-stage bargaining, including the anticipated condition (IC^t_{OL}) required by the second-stage outcome:

\[
\max_{w_{1H} , f_{1H} , w_{1L} , f_{1L} , \lambda} \left\{ \lambda_1 \left[ \frac{(a - w_{1H} - w_{2H})^2}{2} - f_{1H} \right] + \lambda_2 \left[ \frac{(a - w_{1L} - w_{2L})^2}{2} - f_{1L} \right] \\
+ p_{2H} \left[ (a - w_{1H} - w_{2L})^2 - f_{1H} \right] \\
+ (w_{2HL} - c_L)(a - w_{1H} - w_{2L}) \right\} \\
\text{s.t.} \text{ IR, IC constraints for all stakeholders and their types, IC^t_{OL}.}
\]
By simplifying the constraints, defining virtual utilities, and solving for equitable shares in the dual problem, we find a bargaining outcome as summarized in the following proposition.

**Proposition 2** (Sequential Bargaining Solution). The first-stage bargaining outcome is

\[
\begin{align*}
\text{Proposition 2:} & \quad w_{1H}^* = \gamma_H, \quad w_{1L}^* = \gamma_L, \\
& \quad f_{1H}^* = \frac{1}{3} \left( \frac{p \cdot (a - 2c_H - \frac{p}{2} \Delta)}{2} + p \cdot (a - c_H - c_L) \right), \\
& \quad f_{1L}^* = \frac{1}{3} \left( \frac{p \cdot (a - 2c_L - \frac{p}{2} \Delta)}{2} + p \cdot (a - c_H - c_L) \right) + \frac{1}{2} (c_H - c_L)(2a - 3c_H - c_L).
\end{align*}
\]

The second-stage bargaining outcome is

\[
\begin{align*}
\text{Proposition 2:} & \quad w_{2HH}^* = \gamma_H + \frac{p}{2} \Delta, \quad w_{2LL}^* = \gamma_L, \quad w_{2HL}^* = \gamma_L, \quad w_{2LH}^* = \gamma_H + \frac{p}{2} \Delta, \\
& \quad f_{2H}^* = \frac{(a - 2c_H)^2}{12} + \frac{\Delta(a - 2c_L)(3p^2 + p - 6)}{6p} \\
& \quad + \frac{\Delta^2(3p + 21p - 11)}{12p}, \quad f_{2L}^* = \frac{(a - 2c_L)^2}{12} + \frac{\Delta(a - 2c_H)(3p + 1)}{6} + \frac{\Delta^2(4 - 7p)}{4} - \frac{11\Delta^2}{12p}.
\end{align*}
\]

The most notable finding in the solution process is that constraint IC_{2L} is binding, whereas Supplier 1’s IC constraint is not binding because it is implied by the former. As a result, there is no distortion in the wholesale price paid to Supplier 1, and the supply chain efficiency is higher compared with the simultaneous bargaining case. The intuition is that anticipating the second stage bargaining outcome, for the OEM not to introduce additional incentive distortion in the second-stage bargaining, the fixed payment difference between the low-type and high-type Supplier 1 should be sufficiently large, which is achieved by increasing the supply chain efficiency by reducing the distortion of the wholesale price paid to Supplier 1 and at the same time, increasing the fixed payment to Supplier 1.

The following proposition compares the simultaneous and sequential bargaining outcomes.

**Proposition 3** (Simultaneous vs. Sequential Bargaining). Compare the outcomes under simultaneous and sequential bargaining for assembly. The sequential bargaining yields (1) a lower profit of the OEM, (2) a higher profit of Supplier 1, (3) a higher profit of Supplier 2 if \(3 - \sqrt{3} \leq p \leq 3 + \sqrt{3}\), and a lower profit for Supplier 2 otherwise, and (4) a higher profit of the supply chain.

Sequential bargaining leads to less distortion on the wholesale prices, resulting in a higher supply chain profit. Also observe that sequential bargaining leads to a higher fixed payment to Supplier 1, who is better off under sequential bargaining. The OEM must pay more to the suppliers under sequential bargaining and earns a lower profit. For Supplier 2, whether it will earn a higher or lower profit depends on the difference between the increased supply chain profit and the increased payments to Supplier 1. When the suppliers’ types are more ambiguous (i.e., \(3 - \sqrt{3} \leq p \leq 3 + \sqrt{3}\)), Supplier 2 receives more information rent, benefits more from the increased supply chain profit, and earns a higher profit under sequential bargaining.

### 3.2. Mechanism Design in Assembly

When the OEM has dominant bargaining power over the suppliers, it can offer a menu of take-it-or-leave-it contracts to suppliers. The mechanism design institution represents the limiting case of alternating offer bargaining when the OEM has all the power (Wang 1998). We keep all other assumptions and parameters unchanged from Section 3.1 and analyze the OEM’s optimal contracting mechanism with the suppliers. Unlike the dynamic bargaining institution, under the mechanism design institution, the OEM’s dominant power allows it to extract most profits of the suppliers except for the information rents warranted by the suppliers’ private information. That said, the informational structure difference between simultaneous and sequential decision making in mechanism design remains similar to that in dynamic bargaining. In sequential mechanism design, when the OEM designs a menu of contracts for Supplier 2 after contracting with Supplier 1, it is equipped with the private information of Supplier 1, making the OEM an *informed principal* in the second-stage contracting process.

The simultaneous and sequential mechanism design problems have been studied by Hu and Qi (2018) in a more general form. Here, we present relevant results from their work (adapted to our notation and special cases) and relegate the formulations to Online Appendix B. The optimal simultaneous mechanism is presented in the following proposition.

**Proposition 4** (Optimal Simultaneous Mechanism). The following two-part tariff mechanisms implement the optimal simultaneous mechanism, with \(\delta\) being any real number: the OEM offers the menu \((w_{iH}^S, f_{iH}^S), (w_{iL}^S, f_{iL}^S)\) to Supplier \(i, i = 1, 2\), where

\[
\begin{align*}
w_{1L}^S &= c_L + \Delta, \quad w_{1H}^S = c_L + \Delta + \Delta/p, \quad w_{2L}^S = c_L - \Delta, \\
w_{2H}^S &= c_L - \Delta + \Delta/p, \quad f_{1H}^S = (-\Delta + \Delta/a - 2c_L - \Delta - \Delta^2/p, \quad f_{1L}^S = (-\Delta + \Delta/a - 2c_L - \Delta - \Delta^2/p, \quad f_{2H}^S = -\Delta^2/p - \delta)(a - 2c_L - \Delta - \Delta/p), \quad f_{2L}^S = -\Delta^2/p - \delta)(a - 2c_L - \Delta - \Delta/p).
\end{align*}
\]
Similar to the simultaneous bargaining solution, all values of $\delta$ lead to the same expected profit for the suppliers and the OEM. Therefore, the two-part tariff optimal simultaneous mechanisms are effectively unique. Although the parameter $\delta$ is technically arbitrary, $\delta = 0$ leads to the most intuitive contract that is most likely to be used in practice. For simplicity, we slightly abuse the terminology and refer to the mechanism with $\delta = 0$ as the optimal simultaneous contracting mechanism. The optimal sequential mechanism is presented in the following proposition.

**Proposition 5 (Optimal Sequential Mechanism).** The following two-part tariff mechanism implements the optimal sequential mechanism: in the first stage the OEM offers the menu $\{(w_1^0, f_1^0), (w_2^0, f_2^0)\}$ to Supplier 1, where

$$w_1^0 = c_l + \frac{\Delta}{p}, f_1^0 = \Delta(a - 2c_l - \Delta) - \frac{\Delta^2}{p},$$

$$w_2^0 = c_l, f_2^0 = -\Delta(a - 2c_l - \Delta)\bar{p} + \Delta^2\bar{p}^2/p^2.$$

If Supplier 1 is revealed to have high (respectively, low) costs, then in the second stage the OEM offers the menu $\{(w_{1H}^0, f_{1H}^0), (w_{2H}^0, f_{2H}^0)\}$ (respectively, $\{(w_{1L}^0, f_{1L}^0), (w_{2L}^0, f_{2L}^0)\}$) to Supplier 2, where

$$w_{1H}^0 = c_l + \frac{\Delta}{p}, f_{1H}^0 = \Delta(a - 2c_l - \Delta) - \frac{\Delta^2}{p},$$

$$f_{2H}^0 = -\Delta(a - 2c_l - \Delta)\bar{p} + \Delta^2\bar{p}^2/p^2;$$

$$w_{1L}^0 = c_l, f_{1L}^0 = -\Delta(a - 2c_l - \Delta)\bar{p} + \Delta^2\bar{p}^2/p^2;$$

$$w_{2L}^0 = c_l, f_{2L}^0 = \Delta(a - 2c_l) - \frac{\Delta^2}{p},$$

$$f_{2L}^0 = -\Delta(a - 2c_l)\bar{p} + \Delta^2\bar{p}^2/p^2.$$

By observing Propositions 4 and 5, one can immediately arrive at the following conclusion.

**Proposition 6 (Optimal Simultaneous vs. Sequential Mechanisms).** The optimal simultaneous and sequential procurement mechanisms for assembly yield equal expected profits for the OEM and each supplier. In addition, the OEM and both suppliers are indifferent regarding the contracting sequence in sequential contracting.

The revenue equivalence between optimal simultaneous and sequential mechanisms is notable. Although the two contracting sequences have different informational structures, namely that, under sequential contracting, the OEM learns Supplier 1’s cost before contracting with Supplier 2, this difference does not result in a profit difference for the OEM. It suggests that the OEM need not worry about contracting timing. Proposition 6 is in direct contrast with Proposition 3. These observations will constitute our experimental predictions for the assembly setting in Section 3.4.

### 3.3. Benchmark: Dyadic Supply Chain with an Integrated Supplier

A key premise of our analysis is the assembly setting. The need for the OEM to contract with both suppliers creates unique challenges, as noted previously. For a basis of comparison, we now analyze a dyadic supply chain where the OEM procures the two inputs from one supplier, who possesses private cost information about both inputs. That is, we analyze optimal mechanism design and dynamic bargaining if the two suppliers were integrated into one. Because the integrated supplier provides two symmetric inputs whose costs may each be high or low, the supplier has three possible types: $HH$ for high-high (when both costs are high), $LL$ for low-low (when both costs are low), and $HL$ for high-low (when one cost is high and the other is low). The prior probabilities are $p_{HH} = p^2$, $p_{LL} = p^2$, and $p_{HL} = 2p\bar{p}$. All other assumptions and parameters remain the same.

The mechanism design problem is formulated and solved following a standard approach, and we relegate all details to Online Appendix C.1. Comparing the profits of all the stakeholders with those derived in Propositions 4 and 5, one can immediately arrive at the following conclusion.

**Proposition 7 (Dyadic vs. Assembly Supply Chains Under Optimal Mechanisms).** Comparing the OEM’s, suppliers’, and supply chain’s profits between the assembly and dyadic supply chains under the optimal mechanisms yields:

1. The OEM’s profit is higher under a dyadic supply chain.
2. The suppliers’ (total) profit is higher under an assembly supply chain.
3. The supply chain’s profit is higher under an assembly supply chain.

The bilateral dynamic bargaining problem is formulated and solved following Myerson (1984b). Similar to Davis and Hyndman (2020), although the problem is numerically solvable, the analytical solutions are algebraically cumbersome and intractable. Thus, we provide the formulation and the key steps to compute the bargaining solution in Online Appendix C.2, which is used to derive the normative prediction of the bargaining outcome in the dyadic supply chain in the next section.

### 3.4. Experimental Predictions

As described in the Introduction, it is important to test the theory with a behavioral lens for our assembly setting. To this end, our experiment consisted of a $2 \times 3$ between-subject design aimed to coincide with the six settings outlined previously. The first factor manipulated the institution type: the OEM interacts with the supplier(s) through a dynamic bargaining process (Barg) or by offering a menu of take-it-or-leave-it offers (Mech). The second factor manipulated the supply chain structure: an assembly supply chain in which the OEM contracts with two independent suppliers (i) simultaneously (Sim) or (ii) sequentially
Experimental Predictions: Assembly Setting

<table>
<thead>
<tr>
<th></th>
<th>Barg-Sim</th>
<th>Barg-Seq</th>
<th>Mech-Sim</th>
<th>Mech-Seq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex ante OEM expected profit</td>
<td>370.83</td>
<td>354.17</td>
<td>1112.5</td>
<td>1112.5</td>
</tr>
<tr>
<td>Ex ante supplier expected profit</td>
<td>545.83</td>
<td>(604.17, 554.17)</td>
<td>175</td>
<td>175</td>
</tr>
<tr>
<td>Ex ante supply chain expected profit</td>
<td>1,462.5</td>
<td>1,512.5</td>
<td>1,462.5</td>
<td>1,462.5</td>
</tr>
<tr>
<td>Wholesale price low ($w_l$)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Wholesale price high ($w_H$)</td>
<td>25</td>
<td>(15, 25)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Fixed fee low ($f_L$)</td>
<td>720.83</td>
<td>(854.17, 754.17)</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Fixed fee high ($f_H$)</td>
<td>20.83</td>
<td>(354.17, -45.83)</td>
<td>-350</td>
<td>-350</td>
</tr>
</tbody>
</table>

Notes. For pairs of numbers, (A, B), A represents the contract term to Supplier 1, whereas B represents the contract term to Supplier 2. If there is only one number, then it applies for both suppliers.

(Seq), and (iii) a baseline dyadic supply chain (Dyad) in which the OEM contracts with a single integrated supplier who supplies both inputs.

In all treatments, we set $a = 75$. The four assembly settings set: $c_L = 5$, $c_H = 15$, $p_L = \frac{1}{2}$, and $p_H = \frac{1}{2}$. In the two dyadic settings, the integrated supplier had three costs, $c_{LL} = 10$ (w.p. 0.25), $c_{HL} = 20$ (w.p. 0.5), and $c_{HH} = 30$ (w.p. 0.25), which mimics the cost distribution in the assembly treatments and ensures a fair comparison. The experimental predictions for our design are in Tables 1 and 2. Although Proposition 7 provides the predicted differences between assembly and dyadic supply chains under the optimal mechanism, we use this table to generate predictions between assembly and dyadic supply chains under dynamic bargaining:

1. The OEM’s profit is higher under a dyadic supply chain.
2. The suppliers’ (total) profit is higher under an assembly supply chain.
3. The supply chain profit is higher under an assembly supply chain.

4. Experimental Methodology

As noted, our experiment consisted of a $2 \times 3$ between-subject design aimed to coincide with the six settings outlined in Section 3. Each assembly treatment included 72 participants, whereas each dyadic treatment included 54 participants for a total of 396 participants, depicted in Table 3.

Table 2. Experimental Predictions: Dyadic Setting

<table>
<thead>
<tr>
<th></th>
<th>Barg-Dyad</th>
<th>Mech-Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex ante OEM expected profit</td>
<td>598.64</td>
<td>1,181.25</td>
</tr>
<tr>
<td>Ex ante supplier expected profit</td>
<td>846.77</td>
<td>237.50</td>
</tr>
<tr>
<td>Ex ante supply chain expected profit</td>
<td>1,445.4</td>
<td>1,418.75</td>
</tr>
<tr>
<td>Wholesale price low ($w_{LL}$)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Wholesale price med ($w_{LM}$)</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Wholesale price high ($w_{HH}$)</td>
<td>56.21</td>
<td>60</td>
</tr>
<tr>
<td>Fixed fee low ($f_{L}$)</td>
<td>1,268.75</td>
<td>650</td>
</tr>
<tr>
<td>Fixed fee med ($f_{M}$)</td>
<td>518.75</td>
<td>-100</td>
</tr>
<tr>
<td>Fixed fee high ($f_{H}$)</td>
<td>88.30</td>
<td>-450</td>
</tr>
</tbody>
</table>

Participants were first assigned a role of an OEM, Supplier 1, or Supplier 2 (in the four Assembly treatments), which remained fixed for the duration of the session. Nine (six) participants comprised a single cohort in the Assembly (Dyadic) treatments, yielding eight cohorts in each treatment. In each round, within a cohort, one participant of each role was randomly placed into a triad/dyad, and this random rematching process was repeated every round. Furthermore, at the beginning of each round each supplier’s cost was randomly and independently drawn from the relevant cost distribution (which differed between the Assembly and Dyadic treatments). All treatments consisted of eight rounds. We automated the quantity decisions so that $q = 75 - w_1 - w_2$ and provided all participants with decision support where they could enter test values of fixed fees and wholesale prices and observe the profits for themselves and the other player(s) in their triad/dyad.

Turning to the specifics of each treatment, in the three dynamic bargaining treatments, the parties engaged in a back-and-forth negotiation (although to be sure, one player could make multiple offers in a row without waiting for their bargaining partner to make a counteroffer). To create this environment, we used a protocol similar to one that has been used in recent operations bargaining studies. Specifically, the parties were given a fixed amount of time to negotiate contract terms. During this time, they could make as many offers as they would like, where each offer was comprised of a fixed fee and wholesale price. A receiving party could send feedback about the most recent offer they received by clicking a button and rejecting the fixed fee, the wholesale price, or both. This information would then be shown to the proposing party.

<table>
<thead>
<tr>
<th></th>
<th>Sim(ultaneous)</th>
<th>Seq(uential)</th>
<th>Dyad(ic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing and supply chain structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bargaining</td>
<td>72</td>
<td>72</td>
<td>54</td>
</tr>
<tr>
<td>Mechanism</td>
<td>72</td>
<td>72</td>
<td>54</td>
</tr>
</tbody>
</table>

Table 3. Experimental Design and Number of Participants
(the receiving party could still accept the offer if it was still the most recent offer received). Overall, this protocol mimicked a more natural bargaining process while allowing us to observe offers and feedback over time.

In the Barg-Sim condition, the OEM bargained with Supplier 1 and Supplier 2 simultaneously (six minutes in rounds 1 and 2 and four minutes in rounds 3–8). The OEM could make a fixed fee and wholesale price offer to Supplier 1 and/or a separate fixed fee and wholesale price to Supplier 2. Each supplier could also make their own offers to the OEM. Each supplier could not see the negotiation details taking place between the OEM and the other supplier. If a supplier chose to accept an offer or the OEM chose to accept an offer from a specific supplier, then an agreement was made between those two parties, and the OEM and remaining supplier continued to negotiate. If the OEM came to an agreement with both suppliers in the allotted time, then all three parties earned their profits; otherwise, the triad earned a profit of zero. The Barg-Seq treatment was identical except that in each round the OEM first bargained only with Supplier 1 (four minutes in rounds 1 and 2 and 2.5 minutes in rounds 3–8). If they came to an agreement, then the OEM and Supplier 2 bargained. If the OEM and Supplier 2 agreed on a specific offer, then all three earned their respective profits; otherwise, they earned a profit of zero. The Dyadic bargaining treatment, Barg-Dyad, followed the same protocol as Barg-Sim and Barg-Seq except that the OEM bargained with a single integrated supplier (please see Section 3.4 for detailed parameters). If they could not come to an agreement within the allotted time, then they both earned a profit of zero.

In the Mech-Sim condition, each round began with the OEM making a take-it-or-leave-it offer consisting of two wholesale price and fixed fee pairs, \((w_1, f_1), (w_2, f_2)\) to both suppliers simultaneously. Each supplier then chose to accept one of the two sets of contract terms or reject both. If either supplier chose to reject then all three players in the triad earned a profit of zero; otherwise, they earned their respective profits.

The Mech-Seq treatment was identical except that decisions were made sequentially: the OEM first made a set of contract offers to Supplier 1, Supplier 1 then made their decision to accept one of the two sets of offers or reject both, if Supplier 1 accepted an offer then the OEM made a set of offers to Supplier 2, and Supplier 2 then made the accept/reject decision. The Dyadic mechanism design condition, Mech-Dyad, was the same except that the OEM made a take-it-or-leave-it offer of three wholesale price and fixed fee pairs to a single supplier (see Section 3.4), who then made an accept/reject decision.

As mentioned previously, to ensure a fair comparison between all treatments, the cost distribution of the single integrated supplier in the Dyadic treatments was engineered such that it was equivalent to the Assembly setting with two suppliers. Last, the experimental interface was designed using z-Tree (Fischbacher 2007) and took place at a large northeast university. Sessions took between 60 and 90 minutes, with average earnings of roughly $28. Subjects were compensated for all rounds.

5. Experimental Results

Because the theory that we have developed is rich, rather than presenting several hypotheses, in Tables 4–7 we provide the theoretical directional predictions along with whether they are validated in our experimental data. To organize this information, we have tables investigating the Assembly treatments and whether theory predicts an equivalence or a difference, along with comparing the Assembly and Dyadic treatments to each other. Furthermore, the predictions are color-coded according to whether they pertain to OEM profit, supplier profit, or agreements and supply chain profit (Tables 4–7). In the next three sections, we provide details for each colored category, which generally follow our research questions: the OEM (Section 5.1), suppliers (Section 5.2), and agreements and supply chain profit (Section 5.3). Unless otherwise noted, profits are conditioned on agreement. Given that our study is one of the first to experimentally investigate screening contracts in

Table 4. Table of Key Directional Predictions and Summary of Results: Assembly (Theory Predicts Equivalence)

<table>
<thead>
<tr>
<th>Prediction</th>
<th>No significant difference</th>
<th>Significant difference</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM profit is equal b/w Mech-Seq/Seq</td>
<td></td>
<td>✓ ((p = 0.077))</td>
<td>Seq higher</td>
</tr>
<tr>
<td>Supplier (total) profit is equal b/w Mech-Seq/Seq</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier 1 profit is equal to Supplier 2 in Mech-Seq</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes. The predictions are divided into three categories: (1) OEM (light gray), (2) suppliers (medium gray), and (3) agreements and supply chain profit (dark gray). We adopt a conservative approach to testing. Specifically, when theory predicts no difference, we mark the result as significantly different if the \(p\) value is 0.10 or lower, and we note the direction of the difference. On the other hand, when theory predicts a difference, we mark it as “Correct Dir. (‘Sig.’) if the \(p\) value is 0.05 or lower.
operations management, we also focus on screening and signaling in Section 5.4.

Before proceeding, in Tables 4–7, one can see that a number of directional predictions are validated in our data. This is especially true for predictions regarding the OEM and supplier profits. However, although the theory is affirmed in these directional cases, few of the specific point predictions (from Tables 1 and 2) are confirmed. While we discuss these in more detail in Section 6, for now we note that across all six of our experimental treatments, theory predicts a larger difference in profits between the OEM and suppliers, than what we observe in the data.

Last, in what follows we devote more attention to those results which yield particularly meaningful managerial insights. We include all eight rounds of data in our analysis. Unless otherwise noted, all hypothesis tests are t tests, where a single cohort of nine (Assembly) or six (Dyadic) participants, averaged over all rounds, represents an independent observation. Regressions are run with random effects and clustered standard errors at the cohort level to account for repeated observations.

5.1. Analysis of the OEM

We begin with the OEMs, who deserve special emphasis because they have a choice as to approach suppliers simultaneously or sequentially in an assembly setting (i.e., our first research question). Beginning with the Assembly treatment in the mechanism design institution, in Table 8, we see that the OEM earns a higher profit when approaching suppliers sequentially (650.69 versus 554.30; \( p = 0.077 \)), where theory predicts that there should be no difference. Under the bargaining institution and assembly, the OEM weakly prefers simultaneous bargaining, which is consistent with theory, although the difference is not significant (445.57 versus 394.35; \( p = 0.493 \)). The remaining comparisons are supportive of the theoretical predictions, including those which focus on our second research question. In particular, the OEM earns a significantly higher profit in the dyadic supply chain compared with an assembly supply chain (\( p \ll 0.01 \)).

**Result 1.** In an assembly system under the mechanism design institution, an OEM earns a higher profit by contracting with suppliers sequentially. Furthermore, the OEM earns significantly higher profit in a dyadic supply chain with an integrated supplier versus a three-party assembly system.

There appear to be interesting bargaining power dynamics vis-à-vis the bargaining and mechanism institutions and also comparing dyadic supply chains and assembly. Specifically, in all three dynamic bargaining treatments, OEMs earn more than the theoretical predictions (Barg-Sim, 445.57 > 370.83; Barg-Seq, 394.35 > 354.17; Barg-Dyad, 720.62 > 598.64). On the other hand, in all three mechanism design treatments, we observe that OEMs earn less than predicted (Mech-Sim, 554.30 < 1,112.50; Mech-Seq, 650.69 < 1,112.50; Mech-Dyad, 842.23 < 1,181.25). This suggests that OEMs are unable to fully exploit their bargaining

### Table 5. Table of Key Directional Predictions and Summary of Results: Assembly (Theory Predicts Difference)

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Correct dir. (* Sig.)</th>
<th>Incorrect dir.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM profit is higher in Barg-Sim than Barg-Seq</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Supplier 1 profit is higher than Supplier 2 in Barg-Seq</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Supplier (total) profit is higher in Barg-Seq than Barg-Sim</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Supply chain profit is highest in Barg-Seg</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

**Notes.** The predictions are divided into three categories: (1) OEM (light gray), (2) suppliers (medium gray), and (3) agreements and supply chain profit (dark gray). We adopt a conservative approach to testing. Specifically, when theory predicts no difference, we mark the result as significantly different if the \( p \) value is 0.10 or lower, and we note the direction of the difference. On the other hand, when theory predicts a difference, we mark it as “Correct Dir. (*Sig.)” if the \( p \) value is 0.05 or lower.

### Table 6. Table of Key Directional Predictions and Summary of Results: Dyadic vs. Assembly (Theory Predicts Equivalence)

<table>
<thead>
<tr>
<th>Prediction</th>
<th>No significant difference</th>
<th>Significant difference</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agreement rates equal between Dyadic and Assembly</td>
<td>✓ (( p = 0.033 ))</td>
<td>Dyadic higher</td>
<td></td>
</tr>
</tbody>
</table>

**Notes.** The predictions are divided into three categories: (1) OEM (light gray), (2) suppliers (medium gray), and (3) agreements and supply chain profit (dark gray). We adopt a conservative approach to testing. Specifically, when theory predicts no difference, we mark the result as significantly different if the \( p \) value is 0.10 or lower, and we note the direction of the difference. On the other hand, when theory predicts a difference, we mark it as “Correct Dir. (*Sig.)” if the \( p \) value is 0.05 or lower.
power when they have it (as in the mechanism design institution) and vice versa. Moreover, in the bargaining institution, the gap between observed and predicted OEM earnings is larger (and positive) in the dyadic supply chain than in the assembly system. Similarly, in the mechanism institution, the gap between observed and predicted OEM earnings is smaller (and negative) in the dyadic supply chain than in the assembly system. Both differences suggest that the relative bargaining power of the OEM appears to be higher in a dyadic supply chain than an assembly system. We will explore potential drivers of these outcomes in Section 6.

**Result 2.** OEMs do not fully take advantage of their bargaining power in the mechanism design institution but earn a higher profit than theory in the dynamic bargaining institution. Moreover, in a three-party assembly system, the OEM’s bargaining power is diminished compared with a dyadic supply chain with an integrated supplier, relative to theory.

### 5.2. Analysis of Suppliers

Table 9 depicts average supplier profits in our experiment, which are generally supportive of the theoretical predictions, at least directionally (Tables 4, 5, and 7). To highlight some results: (1) total supplier profit is higher in the Assembly treatments (average, 879.87) compared with the Dyadic treatments (average, 675.61), for both the bargaining and mechanism institutions; (2) Supplier 1 earns significantly more than Supplier 2 in the Barg-Seq treatment, where a difference is predicted \((p = 0.034)\); and (3) in Mech-Seq, Supplier 1 earns more than Supplier 2, but the difference is not significant \((p = 0.130)\), and it is not predicted to be.

Continuing in Table 9, although the combined supplier profits under assembly are higher than the lone supplier’s profits in the dyadic system (point (1)), the normative prediction is also validated in that any individual supplier who supplies only one input earns a lower profit compared with the lone supplier in dyadic. For instance, the highest individual supplier profit among the four Assembly treatments is 534.68, whereas the integrated supplier’s profits in the two Dyadic treatments are 717.27 and 633.94. Again, this is consistent with the theoretical prediction but is interesting in that both an OEM and a supplier earn a higher profit in a dyadic supply chain.7

As noted in points (2) and (3), in the sequential versions of both institutions, Supplier 1 earned more than Supplier 2 (534.68 and 431.81 in Barg, 428.34 and 371.19 in Mech). More importantly, in the bargaining institution, this difference is double the theoretical prediction and weakly significant (predicted profits,

### Table 7. Table of Key Directional Predictions and Summary of Results: Dyadic vs. Assembly (Theory Predicts Difference)

<table>
<thead>
<tr>
<th>Prediction</th>
<th>Correct dir. (Sig.)</th>
<th>Incorrect dir.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM profit is higher in Dyadic (Barg.)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>OEM profit is higher in Dyadic (Mech.)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Supplier (total) profit is higher in Assembly (Barg.)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Supplier (total) profit is higher in Assembly (Mech.)</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Supply chain profit is higher in Assembly (Barg.)</td>
<td>✓ (p = 0.090)</td>
<td></td>
</tr>
<tr>
<td>Supply chain profit is higher in Assembly (Mech.)</td>
<td>✓ (p = 0.05)</td>
<td></td>
</tr>
</tbody>
</table>

**Notes.** The predictions are divided into three categories: (1) OEM (light gray), (2) suppliers (medium gray), and (3) agreements and supply chain profit (dark gray). We adopt a conservative approach to testing. Specifically, when theory predicts no difference, we mark the result as significantly different if the \(p\) value is 0.10 or lower, and we note the direction of the difference. On the other hand, when theory predicts a difference, we mark it as “Correct Dir. (Sig.)” if the \(p\) value is 0.05 or lower.

### Table 8. OEM Profits (Conditional on Agreement)

<table>
<thead>
<tr>
<th>Institution</th>
<th>Sim</th>
<th>Seq</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>445.57 (114.84)</td>
<td>394.35 (170.49)</td>
<td>720.62 (45.55)</td>
</tr>
<tr>
<td>Mech</td>
<td>554.30 (105.15)</td>
<td>650.69 (96.56)</td>
<td>842.23 (93.17)</td>
</tr>
</tbody>
</table>

**Note.** Standard deviations, based on the cluster averages are in parentheses.

### Table 9. Supplier Profit (Conditional on Agreement)

<table>
<thead>
<tr>
<th>Institution</th>
<th>Sim</th>
<th>Seq</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>948.67 (126.08)</td>
<td>966.50 (134.85)</td>
<td>717.27 (70.67)</td>
</tr>
<tr>
<td>Mech</td>
<td>804.78 (177.43)</td>
<td>799.53 (90.38)</td>
<td>633.94 (51.39)</td>
</tr>
</tbody>
</table>

**Panel B: Supplier 1 profit**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Sim</th>
<th>Seq</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>474.34 (63.04)</td>
<td>534.68 (99.59)</td>
<td>717.27 (70.67)</td>
</tr>
<tr>
<td>Mech</td>
<td>402.39 (88.72)</td>
<td>428.34 (51.39)</td>
<td>633.94 (81.33)</td>
</tr>
</tbody>
</table>

**Panel C: Supplier 2 profit**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Sim</th>
<th>Seq</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>474.34 (63.04)</td>
<td>431.81 (90.98)</td>
<td>n/a</td>
</tr>
<tr>
<td>Mech</td>
<td>402.39 (88.72)</td>
<td>371.19 (76.63)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

**Notes.** Standard deviations, based on the cluster averages are in parentheses. In the simultaneous treatments, profits are pooled across Suppliers 1 and 2. Hence, Supplier 1 and 2 profit in panels (b) and (c) is exactly half (modulo rounding) the total supplier profit in panel (a). In the Mechanism institution, both suppliers received the same set of offers, while in the Bargaining institution, the OEM’s opening offers to Suppliers 1 and 2 were virtually identical.
604.17 and 554.17). In the mechanism institution, whereas the difference is not significant, theory predicts that the two suppliers earn exactly the same profit. This anomaly deserves more attention, which we will provide in Section 6.

**Result 3.** The directional predictions for supplier profits are largely borne out in the data. One notable finding is that the observed difference in profits between Supplier 1 and Supplier 2 is larger than theory predicts (i.e., Supplier 1 earns a disproportionately higher profit than Supplier 2, relative to theory), in both Barg-Seq and Mech-Seq.

### 5.3. Analysis of Agreements and Supply Chain Profit

Table 10 illustrates the details on agreements. Agreement rates are below 100% in both the Assembly and Dyadic treatments. Moreover, they are significantly lower ($p = 0.033$) in the Assembly treatments (73.96%–79.03%) than in the Dyadic treatments (83.33%). Not surprisingly, although contrary to theory, this suggests that it is more difficult for the relevant parties to come to an agreement in an assembly supply chain compared with a dyadic setting with an integrated supplier.

Looking at agreements in the four Assembly treatments, there is some variation, but the differences are not significant either on the Barg versus Mech or Sim versus Seq dimensions ($p \gg 0.1$ in both cases). In Tables 11 and 12, we see that, in contrast to the theoretical prediction, disagreements are more likely to occur when a supplier has a higher cost (in all cases $p < 0.038$). This suggests that the parties use the possibility of disagreement to distinguish between cost types, which is common in more structured bargaining environments. As we show later, this is likely because OEMs are poor at separating between supplier types.

We depict supply chain profit, conditional on agreement, in Table 13. Recall in Table 7, that supply chain profit should be higher in the Assembly treatments than in the corresponding Dyadic treatments. However, in contrast to these predictions, supply chain profit is actually higher in the Dyadic treatments for both the bargaining and mechanism institutions (and nearly significantly so, $p = 0.090$ in Barg and $p = 0.105$ in Mech). Thus, an important managerial insight is that agreements are not only more likely when an OEM negotiates with a single integrated supplier, but the supply chain profit is also higher, conditional on an agreement being reached, compared with a three-party assembly setting where an OEM must negotiate with two suppliers. Combining these effects by including disagreements (i.e., zero profit), the difference between the supply chain profit of the Dyadic and Assembly treatments is even larger: 1,195.70 Dyadic versus 1,042.86 Assembly in Barg ($p < 0.019$), and 1,226.35 Dyadic versus 1,095.58 Assembly in Mech ($p = 0.061$).

**Result 4.** Agreement rates and supply chain profit, conditional on agreement, are higher in a dyadic supply chain with an integrated supplier versus a three-party assembly setting, for both the bargaining and mechanism institutions.

### 5.4. Screening and Signaling

Our experiment supports many of the theoretical predictions in terms of comparative statics. In addition, observed supply chain profits are quite close to the theoretical point predictions (within 7.1% in all cases)

---

**Table 10. Agreement Rates (%): Overall**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Sim</th>
<th>Seq</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>77.08 (10.45)</td>
<td>73.96 (9.64)</td>
<td>83.33 (7.51)</td>
</tr>
<tr>
<td>Mech</td>
<td>79.03 (12.88)</td>
<td>77.96 (11.34)</td>
<td>83.33 (10.21)</td>
</tr>
</tbody>
</table>

*Notes.* In the sequential treatments, the OEM and Supplier 2 would not bargain unless an agreement was reached between the OEM and Supplier 1. Hence, the agreement rates for Supplier 2 are conditional on an agreement with Supplier 1. Standard deviations, based on the cluster averages are in parentheses.

**Table 11. Agreement Rates (%): Dyadic Treatments**

<table>
<thead>
<tr>
<th></th>
<th>$c = 10$</th>
<th>$c = 20$</th>
<th>$c = 30$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>93.85 (10.22)</td>
<td>82.90 (9.86)</td>
<td>73.33 (21.91)</td>
</tr>
<tr>
<td>Mech</td>
<td>98.15 (5.56)</td>
<td>93.52 (10.02)</td>
<td>53.17 (26.89)</td>
</tr>
</tbody>
</table>

*Notes.* In the sequential treatments, the OEM and Supplier 2 would not bargain unless an agreement was reached between the OEM and Supplier 1. Hence, the agreement rates for Supplier 2 are conditional on an agreement with Supplier 1. Standard deviations, based on the cluster averages are in parentheses.

**Table 12. Agreement Rates (%): Assembly Treatments**

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Institution</th>
<th>$c = 5$</th>
<th>$c = 15$</th>
<th>$c = 5$</th>
<th>$c = 15$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>Barg-Sim</td>
<td>89.67 (6.25)</td>
<td>81.90 (9.16)</td>
<td>89.67 (6.25)</td>
<td>81.90 (9.16)</td>
</tr>
<tr>
<td></td>
<td>Barg-Seq</td>
<td>92.94 (9.60)</td>
<td>76.94 (15.00)</td>
<td>92.41 (9.93)</td>
<td>82.01 (8.16)</td>
</tr>
<tr>
<td></td>
<td>Mech-Sim</td>
<td>96.38 (5.83)</td>
<td>77.32 (13.58)</td>
<td>96.38 (5.83)</td>
<td>77.32 (13.58)</td>
</tr>
<tr>
<td></td>
<td>Mech-Seq</td>
<td>98.86 (3.21)</td>
<td>85.74 (11.82)</td>
<td>100.00 (0.00)</td>
<td>68.45 (16.46)</td>
</tr>
</tbody>
</table>

*Notes.* In the sequential treatments, the OEM and Supplier 2 would not bargain unless an agreement was reached between the OEM and Supplier 1. Hence, the agreement rates for Supplier 2 are conditional on an agreement with Supplier 1. Standard deviations, based on the cluster averages are in parentheses.

**Table 13. Supply Chain Profit (Conditional on Agreement)**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Sim</th>
<th>Seq</th>
<th>Dyad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barg</td>
<td>1394.25 (72.52)</td>
<td>1360.85 (97.61)</td>
<td>1437.90 (75.56)</td>
</tr>
<tr>
<td>Mech</td>
<td>1359.08 (108.58)</td>
<td>1450.21 (97.25)</td>
<td>1476.17 (83.21)</td>
</tr>
</tbody>
</table>

*Note.* Standard deviations, based on the cluster averages are in parentheses.
except Barg-Seq, where the difference is 10%). However, the theory is based on the notion that the OEM can differentiate between different types of suppliers, and we have already seen a hint that this is not the case with our finding that disagreements are more likely for high-cost suppliers. In this section, we now look more closely at screening and signaling.

We begin by studying the agreed contract terms. Although suppliers’ costs were private information, we can analyze the agreed contract parameters by supplier cost. The results are shown in Tables 14 and 15. In the Assembly treatments, average agreed wholesale prices are always above 15, even for low-cost suppliers (where they should be 5). In the Dyadic treatments, average agreed wholesale prices are between 27.78 and 39.09. Although it is true that average wholesale prices increase with supplier cost, the differences are much smaller than theory predicts (e.g., predicted wholesale prices for the three cost types in Dyadic are 5, 25, and 56.21/60; see Tables 1 and 2). Regarding the average observed fixed fee, they generally decrease in supplier cost (there are exceptions in Barg-Seq and Mech-Dyad), but the differences are again smaller than theory predicts.

We turn now to the issue of whether OEMs were able to successfully differentiate between supplier types. The fact that the agreed contract terms are similar across different costs is suggestive that it was difficult to separate suppliers. Beginning with the mechanism institution, Figure 1 shows the frequencies that the menu of contracts separated suppliers by their type, induced pooling (in which all supplier cost types are indistinguishable). However, consistent with Figure 1, attempts at screening were minimal. Less than half of the offers in which \( w < 15 \) were such that \( w < w_l \leq w_m \leq w_h \). In the Dyadic treatment, one can see that 69.35%–80.11% of contract menus offered by OEMs should induce pooling by suppliers on the same contract, whereas only 16.13%–24.07% of menus successfully separate supplier cost types, either partially or fully. In fact, in the Dyadic setting, there was only one proposal that fully separated all three cost types, whereas another 23.61% of contract menu proposals were partially separating. Observe that explicitly pooling offers (with the two wholesale price offers \( w_A = w_B \) were rare, occurring between 9% and 19% of the time. However, consistent with Figure 1, attempts at screening were minimal. Less than half of the offers in which \( w < 15 \leq w_l \leq w_h \) were such that \( w < w_l \leq w_m \leq w_h \). In the Dyadic treatment, only 2.3% of offers make a minimal attempt to separate the three types with \( w_l < 20 \leq w_m < 30 \leq w_h \), where \( l, m, \) and \( h \) subscripts indicate the lowest, middle, and highest wholesale price offer, respectively.

Last, for the mechanism institution, one might wonder whether OEMs who made separating contract offers earned more than OEMs who did not. Although there is no significant difference in Mech-Sim and Mech-Dyad, separating contract proposals in Mech-Seq did generate significantly higher earnings for the OEM.

| Table 14. Average Agreed Contract Parameters: Assembly Treatments |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Wholesale price low (\( w_{ll} \)) | 17.17 | (19.06, 16.14) | 17.44 | (16.41, 15.50) |
| Wholesale price high (\( w_{lh} \)) | 20.18 | (20.18, 18.18) | 18.48 | (17.41, 16.64) |
| Fixed fee low (\( f_{l} \)) | 163.27 | (211.45, 179.19) | 153.61 | (150.36, 132.22) |
| Fixed fee high (\( f_{h} \)) | 157.21 | (224.22, 166.78) | 127.67 | (142.15, 116.82) |

| Note. For pairs of numbers, \((A,B)\), \( A \) represents the contract term to Supplier 1, and \( B \) the contract term to Supplier 2. |

| Table 15. Average Agreed Contract Parameters: Dyadic Treatments |
|-----------------|-----------------|-----------------|-----------------|
| Wholesale price low (\( w_{ll} \)) | 29.12 | 27.78 |
| Wholesale price med (\( w_{ml} \)) | 34.94 | 33.19 |
| Wholesale price high (\( w_{mh} \)) | 39.09 | 34.74 |
| Fixed fee low (\( f_{l} \)) | 229.74 | 267.12 |
| Fixed fee med (\( f_{m} \)) | 142.53 | 74.43 |
| Fixed fee high (\( f_{h} \)) | 128.52 | 123.54 |

| Note. For pairs of numbers, \((A,B)\), \( A \) represents the contract term to Supplier 1, and \( B \) the contract term to Supplier 2. |
screening by proposing \( w < 15 \) early in the bargaining period with the idea that high-cost suppliers will be more willing to hold out for a wholesale price \( w' \geq 15 \) than low-cost suppliers. Therefore, we can look at initial offers by the OEM. Additionally, we can also look at initial offers of suppliers by cost type in order to see if they signal their type with their initial offer. The results of this analysis are in Table 16.

As one can see, the average OEM initial wholesale price offer is always below 15, and between 53.17% and 59.19% of initial OEM wholesale price offers are below 15, which suggests that most OEMs do attempt to screen between suppliers cost types. For suppliers, the average initial wholesale price offer is always higher than 15, where the initial offers of high-cost suppliers are higher than low-cost suppliers. Moreover, a small but nonnegligible fraction of initial offers by low-cost suppliers, 11.59%—12.85%, are for wholesale prices \( w < 15 \), which should be a strong signal that the supplier has a low cost, whereas high-cost

<table>
<thead>
<tr>
<th>Player making offer</th>
<th>Wholesale price</th>
<th>Fixed payment</th>
<th>% ( w &lt; 15 )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panel A: Barg-Sim</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEM</td>
<td>12.67 (2.47)</td>
<td>31.81 (198.75)</td>
<td>58.29 (16.49)</td>
</tr>
<tr>
<td>Low-cost supplier</td>
<td>22.87 (3.43)</td>
<td>329.37 (87.20)</td>
<td>11.59 (15.62)</td>
</tr>
<tr>
<td>High-cost supplier</td>
<td>26.09 (2.48)</td>
<td>333.32 (62.10)</td>
<td>1.90 (2.68)</td>
</tr>
<tr>
<td><strong>Panel B: Barg-Seq</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEM to Supplier 1</td>
<td>13.49 (3.89)</td>
<td>68.22 (133.84)</td>
<td>53.17 (21.46)</td>
</tr>
<tr>
<td>Low-cost Supplier 1</td>
<td>24.57 (4.76)</td>
<td>303.27 (78.24)</td>
<td>12.23 (19.81)</td>
</tr>
<tr>
<td>High-cost Supplier 1</td>
<td>27.16 (2.54)</td>
<td>317.10 (85.31)</td>
<td>0.00 (0.00)</td>
</tr>
<tr>
<td>OEM to Supplier 2</td>
<td>12.67 (3.42)</td>
<td>38.00 (123.22)</td>
<td>59.19 (21.05)</td>
</tr>
<tr>
<td>Low-cost Supplier 2</td>
<td>21.73 (2.28)</td>
<td>358.64 (138.24)</td>
<td>12.85 (15.18)</td>
</tr>
<tr>
<td>High-cost Supplier 2</td>
<td>27.37 (2.94)</td>
<td>374.73 (141.70)</td>
<td>2.08 (5.89)</td>
</tr>
</tbody>
</table>

Note: Standard deviations, based on the cluster averages are in parentheses.
suppliers almost never propose an initial wholesale price less than 15 (0.00%–2.08%). This suggests that there is some attempt at screening by OEMs and some signaling by low-cost suppliers, but it is by no means the dominant behavior.

A slightly different perspective on screening in the bargaining institution can be seen in Figure 2, which shows a histogram of the time remaining at which OEMs’ wholesale price offers to a supplier is 15 or higher for the first time.12 As one can observe, there is a great deal of variation, and 15% and 20% of the time, OEMs never propose a wholesale price of 15 or higher. However, we also see a large mass over the first 30 seconds of bargaining in which OEMs propose a wholesale price of 15 or higher. Consistent with Table 16, this suggests that there is a great deal of heterogeneity in OEMs’ willingness to engage in temporal screening.

Result 5. OEMs engage in limited attempts to screen between high and low-cost suppliers, particularly in the mechanism institution. In the bargaining institution, OEMs attempt temporal screening about half the time, but most eventually give up and offer a wholesale price greater than 15.

6. Discussion

In this section we seek to provide a discussion of the underlying behavioral drivers of our experimental results and to summarize how our results fit within the broader literature.

6.1. Behavioral Drivers: Bounded Rationality and Fairness

We believe that there are two biases that are influencing outcomes in our setting: bounded rationality and fairness. At a high level, bounded rationality relates to the notion that decision makers are limited in their cognitive abilities and are therefore prone to errors. When designing our experiment, we aimed to minimize the role that bounded rationality played in explaining any differences across treatments (by providing decision support), but it is still likely that a certain degree of bounded rationality is present. This is especially true given the complexity of decisions in our experiment, resulting in participants potentially making errors or opting for simpler alternatives. This would not be without precedent. For instance, multiple supply chain experiments have found that decision makers are rarely able to leverage the benefits of more complicated contracts and end up preferring simpler contracts (Kalkanci et al. 2011, Cui et al. 2020).

Turning to fairness, there is an extensive literature showing that when one party is predicted to earn significantly more than another party, the observed magnitude of this difference is often less than predicted (Fehr and Schmidt 1999, Bolton and Ockenfels 2000). In addition to this distributional fairness, more recent research has shown that peer-induced fairness can also affect decisions. For example, in a three-player ultimatum game with one proposer and two responders, Ho and Su (2009) show that distributional fairness can exist (between responders and the proposer) simultaneously with peer-induced fairness (between responders). In our setting, there are a couple of reasons why fairness is plausible. In all our treatments, one party is predicted to make considerably more than the other. If distributional fairness is present then we should see more equitable payoffs between OEMs and suppliers, along with the rejection of profitable offers by responding parties. Also, because our assembly environment involves two suppliers, it is possible
that peer-induced fairness may influence outcomes (e.g., this may explain why the OEM’s bargaining power appears weaker in the assembly versus dyadic setting). Last, it is important to note that fairness, in conjunction with bounded rationality, has been observed in a number of related contracting experiments (Kalkanci et al. 2014, Johnsen et al. 2019).

We believe that bounded rationality and fairness can rationalize our key experimental results. First consider Result 5, which states that OEMs often set pooling contracts. One can show (see Online Appendix D) that separating contracts are not robust to bounded rationality. The reason is that when the OEM deviates from the contractual terms of the optimal separating contract, the supplier may choose the contract intended for a different type or not participate at all. In either case, the OEM earns a lower profit. A pooling contract is more robust because the OEM may only suffer from a supplier not participating, but never from it choosing a contract for a different type (because there is only one contract). In addition, a pooling contract is cognitively less demanding for the OEM to design than separating contracts, and thus one may expect the OEM to less likely make mistakes in designing the contract. In short, if OEMs are prone to errors, they may be better off setting a pooling contract than a poorly designed contract which attempts to separate supplier types. Moreover, observe that the optimal pooling contract generates more equitable payoffs than the optimal separating contract, which is consistent with our result that more powerful parties do not fully exploit their bargaining power (Result 2).

This observation is also consistent with related supply chain experiments, which find that bounded rationality can lead to more equitable outcomes (Gurnani et al. 2014). To provide further support for the role of fairness, consider Figure 3, which plots the difference between actual and predicted profits for the OEM and suppliers for each treatment. A positive (negative) number indicates that the party earns more (less) than theory predicts. As can be seen, for all the Mech treatments, the OEM consistently earns less than theory and suppliers consistently earn more than theory. On the other hand, for all the Barg treatments, the reverse is true. We also see evidence of fairness when we look at rejections, where we observe suppliers rejecting positive expected value (but unequal) offers.13

We also believe that fairness and bounded rationality can explain our two results about sequential contracting. Specifically, recall that Supplier 2 earned a lower profit than Supplier 1 under sequential contracting (Result 3), which is because of the OEM making less favorable offers to Supplier 2. This is of particular interest for the Mech-Seq setting, because theoretically, both suppliers should get equivalent offers (in Barg-Seq, the normative theory predicts that Supplier 2 ends up with less favorable terms than Supplier 1). If Supplier 2 incorrectly believes, a form of bounded rationality, that she is getting the same contract terms as Supplier 1, and if she is motivated by peer-induced fairness, she may be willing to accept the OEM’s offer, even though it actually leads to a lower profit than Supplier 1. This can also explain the experimental result that the OEM prefers sequential contracting in the mechanism design.
institution (Result 1), because the OEM can more easily exploit Supplier 2’s bounded rationality and fairness concerns in such a setting. Last, fairness and bounded rationality can explain both the higher agreement rate and the higher supply chain profit in the dyadic supply chain than assembly system (Result 4). For example, uncertainty about what constitutes a fair deal may lead to disagreement and, if fairness ideals are heterogeneous (and independent), then the likelihood of disagreement is higher with three parties. Regarding supply chain profit, first observe while the supply chain profit is lower in a dyadic supply chain, assuming the use of separating contracts, the optimal pooling contract achieves the same profit in a dyadic supply chain as in assembly. Thus, the fact that most contracts are pooling removes the penalty to the dyadic supply chain. To see how supply chain profit can be higher under a dyadic supply chain, we appeal to fairness. In our setting, the optimal pooling contract in both the dyadic and assembly settings gives the OEM the same profit. The difference is that under assembly, the amount left over must be divided across two suppliers. Therefore, the difference between each supplier’s profit and the OEM’s profit is greater under assembly. To compensate for this, we see that OEMs offer higher total wholesale prices in assembly (i.e., \( w_1 + w_2 \)) than the dyadic supply chain (i.e., \( w \)), which reduces the efficiency of the assembly system relative to the dyadic system.\(^{14}\)

### 6.2. Connection to Literature

We now distinguish between those results that we believe are entirely new versus those that have been observed in related experiments and therefore extend to our setting. Although our discussion focuses on the experimental findings, we stress that our theoretical analysis of dynamic bargaining in assembly with private information is novel to the literature. Importantly, certain aspects of it are validated experimentally as well, such as many qualitative profit predictions. With that, we believe that there are two important and new experimental results, which correspond to our research questions. First, powerful OEMs earn higher profits by contracting with suppliers sequentially. Second, moving from a dyadic supply chain to an assembly system comes at a cost, both in terms of more frequent disagreement and lower supply chain profit conditional on agreement.

The remaining experimental results can be considered as extensions of previous research, including the presence of bounded rationality and fairness. First, more equitable profit distributions between proposers and responders have been observed in various supply chain experiments with a single supplier (Kalkanci et al. 2014). Second, Supplier 2, earning a lower profit than Supplier 1 under sequential contracting, echoes a result first found in Ho et al. (2014). In particular, they find that in a game between a powerful supplier and two (responding) retailers, with full information and ultimatum offers, the second retailer earns less than the first. Third, the low prevalence of screening contracts, notably in the presence of bounded rationality and fairness, has been observed in related private information studies with ultimatum offers (Johnsen et al. 2020).

### 7. Concluding Remarks

In this paper, we study the contracting problem of an OEM who needs to procure two distinct inputs, which it then assembles into a final product. Our main focus/contribution is to consider an assembly system in which the OEM procures one input from each supplier, each of which is privately informed of its cost. In this basic setting, we seek to understand whether the timing of contracting, either simultaneously or sequentially, matters and how this assembly system compares with a dyadic supply chain in which the OEM sources both inputs from the same supplier.

We provide theoretical results for both the case in which the OEM is powerful and can make take-it-or-leave-it offers to suppliers (mechanism design) and for the case of more balanced bargaining power between the OEM and suppliers (dynamic bargaining), with the latter case being a novel contribution to the literature. Our experiment then sought to test the predictions generated by our theoretical analysis, many of which are borne out with some deviations. As discussed in the previous section, we believe that bounded rationality and fairness concerns can explain the key findings. Indeed, we believe that future research could extend our work by explicitly aiming to investigate these behavioral drivers in an assembly system in order to gain further insights.

Our analysis generates managerial insights regarding how an OEM should approach negotiating with suppliers and, if possible, building their supply chain. We structure these insights around our two primary research questions. First, regarding the timing of contracting, our theoretical analysis finds that the OEM, when they have considerable bargaining power, should be indifferent between approaching suppliers simultaneously or sequentially. Yet, our experimental analysis indicates that, empirically, the OEM prefers sequential contracting. Furthermore, when the OEM has relatively equal bargaining power with suppliers, our experiments support our theoretical prediction that the OEM has a weak preference for simultaneous negotiations. Turning to our second research question, we find empirical support for our theoretical prediction that the OEM suffers when moving from a dyadic supply chain to an assembly system.

Our paper is not without limitations. First, we assumed that suppliers are symmetric. It would be
interesting to consider supplier heterogeneity. For example, although Apple likely has significant power over many of its suppliers, its relationship with Samsung is almost surely more balanced. Investigating such a setting might be an exciting, and challenging, avenue for future work. Second, in our dyadic setting we assumed that only one supplier could provide the required inputs. It would be interesting to explore competition among suppliers, where multiple suppliers can provide all required inputs for the OEM.

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Endnotes
1 The assumption is relevant for the off-equilibrium threat that Supplier 1 may impose in the negotiation process. In the equilibrium bargaining solution, Supplier 1 will not use its veto power after reaching agreement with the OEM in the first-stage bargaining.
2 Because of a technical issue, one cohort of nine in Mech-Seq only completed six rounds.
3 When applicable, players would see the suppliers’ profits for \( c_i \) and \( c_H \) (\( c_{HL}, c_{HH} \) in the Dyadic treatments).
4 We explore learning later, but here note that nearly all of our results outlined in Tables 4-7 are confirmed even when dropping the first half of the data. There are three times when significance changes that are worth detailing: (a) OEM profit in Mech-Seq is still higher than Mech-Sim (\( p = 0.077 \) to \( p = 0.125 \)), (b) agreement rates in Dyad are still higher than Assembly (\( p = 0.033 \) to \( p = 0.314 \)), and (c) supply chain profit in Dyad-Mech is no longer significantly higher than Assembly-Mech (\( p = 0.869 \)). Given that the experiment consisted of only eight rounds and that we base our analysis on cohort averages, focusing on the last half of the experiment leads to noisier data and should be evaluated with caution. In Online Appendix E.1, we examine time trends with regressions.
5 Our conclusions are unchanged if we used the nonparametric alternative to the parametric \( t \) test. For example, of the tests reported in Tables 4-7, only in row 2 of Table 5 does the significance change, dropping to 0.109. Also, Randomization checks on supplier costs detected no evidence that suppliers’ costs varied across conditions. Put differently, variation in supplier cost realizations across treatments is small and insignificant, and, therefore, not a driver of our results.
6 To be sure, this overlooks other factors that might be important in determining whether it is better to source both inputs from the same supplier or each input separately. Future work should study this more carefully.
7 The lack of significance in the mechanism institution could be caused by a lack of power. Indeed, taking a less conservative approach using subject averages, rather than cohort, the difference is marginally significant at \( p = 0.051 \).
8 In some cases, a contract may be neither separating nor pooling if the actions are not consistent with beliefs. For example, under the assumption of pooling, one supplier type may prefer to take the nonpooling contract, whereas under the assumption of separation, one supplier type may prefer to mimic the other type.
9 In some cases, a contract may be neither separating nor pooling if the actions are not consistent with beliefs. For example, under the assumption of pooling, one supplier type may prefer to take the nonpooling contract, whereas under the assumption of separation, one supplier type may prefer to mimic the other type.
10 However, this may not represent a lack of understanding as OEMs used the decision support feature to test the profit implications of many potential contracts. For example, in Mech-Sim, OEMs tested an average of 6.49 contracts per period, and in Mech-Seq, they tested an average of 9.34. Moreover, a strong majority of the time, an OEM tested at least one contract pair that involved one wholesale price less than 15 and the other 15 or higher.
11 There are a few instances in which an OEM never proposes a wholesale price of 15 or higher, but they accepted such a wholesale price offer made by a supplier. In these instances, we take the time when such an offer was accepted.
12 The Mech-Dyad treatment is best suited to this analysis. More than 75% of rejected offers would have generated positive profit to the supplier. However, they also heavily favored the proposer. In the Barg-Dyad treatment, in the case of eventual disagreement, final offers were also quite unequal (in favor of the proposer), despite frequently providing the other player with a positive profit. In the assembly environment, it is more difficult to say that an offer would have led to positive expected profit because the expected profit calculation relies on the supplier’s beliefs about the agreement between the OEM and the other supplier. However, with a plausible assumption on beliefs (that suppliers receive the same offers) then most disagreements would have led to positive profit for all parties in the assembly environment as well.
13 To be sure, the OEM could have increased compensation to suppliers via the fixed payment, without reducing efficiency. The fact that they did not is another indication of bounded rationality.

References


