Asymmetric Information Undermines Coasian Bargaining in Common (Oil) Pool Resources

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ABSTRACT

This paper provides an experimental analysis of bargaining under imperfect information, molded by the circumstances found in oil field unitization. The purpose of the study is to test whether differences in regulation are causally related to variation in the rate of oil-field unitization observed across states. We design lab experiments that implement the information conditions implied by differences in state regulatory environments. This allows us to isolate the effect of regulation on the pattern of negotiated shares and contractual failure in unitization. The results show that regulatory differences alone can account for much of the observed variation in unitization rates, and suggest a new interpretation of how imperfect information molds sharing rules and undermines unitization contracting. The analysis then reexamines the field data and shows how the analysis sheds new light on field evidence.

JEL Classification C90, D23, D70, Q30

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Section 1. Introduction

This paper provides an experimental analysis of bargaining under imperfect information, shaped by the circumstances found in oil field unitization. Under unitization, a single agent carries out the recovery of oil from the field so as to maximize field value. Land owners for a given field negotiate to determine the division of net revenues from the field. The net revenues from subsequent production are then shared among the various firms according to a negotiated sharing formula.

Unitization offers extremely high gains, substantially increasing the value of the field. The purpose of this study is to test whether differences in regulation are causally related to variation in the rate of oil-field unitization observed across states. We develop an experimental model of oil-field unitization negotiation that captures key elements of the negotiation environment, and then we implement the information conditions implied by different state regulatory environments in a series of experimental treatments. The experiments allow us to provide a more in-depth analysis of how asymmetric information affects negotiated shares and contractual failure in unitization. The results strongly support the hypothesis that regulatory differences are responsible for cross-state variation in unitization rates, and suggest a new interpretation of how imperfect information molds sharing rules and undermines unitization contracting. This interpretation is highly consistent with the focal point theory of bargaining previously proposed by Roth (1985), and a related behavioral theory of distribution by Güth (1988, 1992), as well as prior experimental research on negotiation (Babcock and Loewenstein, 1997). The analysis then reexamines the field data and shows how the laboratory results shed new light on field evidence.

Oil field unitization is a classic application of Coasian contracting, with large, documented returns to contracting (Libecap and Wiggins (1984, 1985)). When multiple firms access reserves on common oil pools, each firm has an incentive to stimulate oil migration from neighboring leases
by rapid production, increasing output on an individual lease as oil is drained from neighboring areas. In the aggregate, however, rapid production raises marginal extraction costs and lowers ultimate recovery (Wiggins and Libecap (1985)). Wiggins and Libecap show that potential gains normally reach into the tens or hundreds of millions of dollars on individual fields; gains are typically shared among a few bargaining parties—often only five or ten. Hence unitization provides a classic example of Coasian bargaining with substantial gains to successful contracting.

Yet, Wiggins and Libecap (1985) show that in practice the success of unitization is highly varied. In some areas, unitization works poorly. In Texas, for example, less than twenty percent of production is unitized; unitization bargaining is protracted, acrimonious, and commonly ends in failure. Elsewhere, unitization can be highly successful. In Wyoming, more than eighty percent of production is unitized, and negotiations are short, harmonious, and rarely end in failure. The large returns to successful bargaining and the empirical variation in success make unitization a unique setting in which to study the factors that affect multilateral negotiations, contracting success, and failure.

Wiggins and Libecap theoretically and empirically examine unitization bargaining, and conclude that a major factor affecting contractual failure is asymmetric information. Specifically, the operators of producing leases have better information about the value of their leases than do outsiders. This information difference leads to a ‘lemons’ problem during negotiations; parties

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1 In particular, rapid production prematurely dissipates pressure by raising the amount of natural gas produced early in a field’s life. Natural gas is lighter than oil and under conditions of rapid production, gas leaves solution with the oil and travels more rapidly through the reservoir to well bores. This premature depletion of gas leaves the oil more viscous and harder to move, and dissipates the pressure needed to propel the oil to well bores. Such dissipation requires the subsequent costly re-injection of natural gas and water to restore pressure and enhance recovery. Even these costly measures, however, ultimately leave significant pockets of oil permanently trapped.

2 For similar conclusions regarding the existence of asymmetric information, see Meade, et al. (1984) and Hendricks and Porter (1988). Interpretations of available information may also be self-serving, enhancing the impact of information asymmetries. Babcock and Loewenstein (1997) review negotiation experiments and show that subjects tend to adopt focal points or fairness norms that favor their own payoffs.
with favorable private information reject formulas based on public information, just as those with
good cars withhold them from the market. These problems undermine negotiations.\(^3\) Wiggins and
Libecap then present substantial empirical evidence to support this hypothesis.

The problem with these analyses is that the empirical record in the field data is incomplete. Exact public or private estimates of the value of individual leases are unavailable, which means that one cannot analyze the differential effect of public and private value estimates on observed sharing rules. The absence of such estimates also means that there is little direct evidence regarding how differential information affects parties’ bargaining behavior, how such behavior affects proposed sharing rules, or how sharing rule offers lead to contractual failure. Hence there is much to be learned from additional data regarding the role of information in unitization-style bargaining.

This study uses laboratory experimental methods to provide such data. The paper analyzes multilateral bargaining under laboratory conditions that parallel those found in oil field unitization. Experimental methods allow direct measurement of information levels, and a degree of control over the bargaining environment unavailable in field data. These improvements provide major new insights into unit negotiations, and complement analysis using field data.

The key treatment variable in this study is the nature of the information that parties have on the value of one another’s leases. Behavioral theories of bargaining indicate that such information will affect bargaining outcomes. For example, research by Roth and his associates points to a focal-point theory of bargaining, where these focal points are determined at least in part shared distributional norms rather than the usual strategic data.\(^4\) Güth (1988, 1992) has also used

\[^3\] Accordingly, states that have high unitization rates are ones where regulation encourages unitization before asymmetric information emerges during field development. States with low unitization rates mandate unitization after field development. For an in-depth analysis of the political economy underlying the differences in state unitization policies, see Libecap and Wiggins (1985).

\[^4\] They found that when bargainers in a binary lottery setting did not know one another’s payoffs, bargaining outcomes clustered around an equal division of probability of winning. When payoff information was provided, bargaining outcomes clustered around equal expected payoffs. Thus variation in the information held by bargainers can be used
social-psychological theories of distribution to develop a behavioral theory of bargaining, predicting that bargainers will use the contribution standard that most fully utilizes the available information on a bargainer’s contribution to joint surplus. These behavioral theories suggest that the reliability of information determines the nature of unitization agreements and the extent of their successes.

We find that when information on individual “lease” values is common knowledge, subjects in successful negotiations allocate shares according to these values. Per-capita allocations play little or no role in successful unitization agreements when information is known by all. Allocation rules change when information on individual lease values becomes imperfect and asymmetric -- that is, bargainers know their own lease value, but other bargainers only have a public estimate. In this situation, we find that parties discount these public value estimates in assigning shares, and also assign a substantial portion of shares equally, on a per-capita basis. Hence discounting of value estimates and per capita share assignments are absent when value estimates are known with certainty, but emerges and plays a major role in bargaining when public value estimates are uncertain and bargainers have private information about the value of their own lease values. The implication is that the uncertainty of value estimates affects whether parties discount value estimates-- and also place weight on per-capita allocations -- in assigning shares.\(^5\)

The discounting of public lease value estimates appears to play a significant role in bargaining failures under imperfect information. When bargaining fails, the failure occurs because subjects refuse to accept discounts of their value estimates in their assigned shares. Instead, the

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\(^5\) The analysis here does not attempt to isolate whether risk aversion is the underlying cause of this discounting. Experimental data presented in Murnighan, Roth and Schoumaker (1988) suggest that the focal point effects are likely to dominate any effects due to risk preference differences among experimental subjects.
relationship between final share requests and value is nearly identical to the same relationship in successful bargains under perfect information. The refusal of these offers, as evidenced by the failure to agree, suggests that observed bargaining failures emerge because of a disagreement over focal points. Specifically, the issue is a disagreement over the weight attached to value versus a per capita equal division. The key point is that this disagreement appears to undermine bargaining only when value estimates are uncertain. These problems then complement the role of simple asymmetric information in explaining contractual failure.

Section 6 reexamines the contractual failures from the primary fields in the original Wiggins and Libecap study. This reexamination suggests that information discounting plays a significant role in contractual failure in the field.

Section 2. Background

The experiments are designed to capture the important stylized facts about the unitization bargaining environment identified by Wiggins and Libecap. According to their analysis, information is the key variable that influences the degree of contracting success. Accordingly, it is useful to briefly summarize that empirical evidence. It is also important to describe other features of the unitization bargaining environment that theory suggests might complicate bargaining, but that the evidence suggests is unimportant in unitization. In the interest of space, however, the interested reader is referred to Wiggins and Libecap (1985) for a discussion of the theory.6

Wiggins and Libecap present a variety of evidence suggesting that asymmetric information is key to the frequent failure of unitization. One key piece of evidence is the considerable variation in the success of unitization across states. In Wyoming, unitization works well, while in Texas and

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6 For an excellent in-depth discussion of the relevant theoretical issues, see Mailath and Postlewaite (1990).
Oklahoma it works poorly. In Wyoming the federal government has, since the 1980s, encouraged unitization prior to production, and such unitization works well. More than eighty percent of Wyoming production is unitized, and negotiations take an average of only a few months to complete. Unitization in Wyoming is effective despite numerous potential limiting factors. Specific problems include heterogeneities in firm size, potential small-firm hold-outs, and repeat contact of firms over time. Each of these might well complicate negotiations and lead to failure. The empirical evidence, however, suggests that they do not.

In contrast, unitization in Texas and Oklahoma works poorly, and negotiations commonly end in failure. Less than twenty percent of production in Texas and forty percent in Oklahoma comes from unitized fields. Negotiations that reach agreements, moreover, average seven years to complete, dissipating many of the benefits to unitization.

The apparent difference between these states and Wyoming is information. Texas Railroad Commission and Oklahoma Corporation Commission rules prohibit unitization until after field development. Field development, however, generates substantial private information regarding the value of individual leases (Wiggins and Libecap (1985), Meade, Moseidjord, and Sorenson (1984), and Hendricks and Porter (1988)). This private information, according to Wiggins and Libecap, becomes a central obstacle leading to unitization failure. Most successful contracting, moreover, occurs late in field life after production has resolved informational asymmetries.

The plausibility of the information explanation is reinforced because the complicating

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7 It should be noted that the federal government does offer some exemptions to acreage leasing limitations and does monitor unitization on federal lands. The important point, however, is that unitization on federal lands is only effective when it takes place prior to production, before private information is generated (see Libecap and Wiggins (1985) and below). Hence these incentives are not the primary factor encouraging unitization on federal lands.

8 The Oklahoma figure is higher than Texas because Oklahoma State Corporation Commission rules allow compulsory unitization. When there is agreement on a sharing rule by sixty three percent of the interests in a field, the remainder of the firms can be forced to enter the agreement.

9 The political economy of the reasons underlying the Texas (and Oklahoma) rule that unitization take place ex post is discussed in Libecap and Wiggins (1985).
factors referred to above are similar across the states. These factors include variation in firm size, potential small-firm hold-outs, repeat firm contacts, and others, all of which are seen across all states. Since these complicating factors are similar across states, the evidence suggests that they are not the key determinants of success or failure. Hence data from contractual failure across states points toward information as central to contractual failure.

Another type of evidence pointing toward information comes from individual fields in Texas. When unitization fails, a common response is for subsets of similar leases (with possibly correlated private information), to withdraw from a field-wide unit to form a ‘partial unit’ covering only a portion of the field. Highly productive leases are a primary example of such withdrawal. Partitioning fields in this way sacrifices considerable gains to coordinated recovery. Yet the repeated claim in the minutes of negotiating sessions is that participants with these high value leases will not be treated equitably under proposed field-wide sharing rules (Wiggins and Libecap (1985), p. 378). Statistical tests show that there is more likely to be significant private information for leases that hold out, supporting the asymmetric information explanation.

A third type of evidence pointing toward information is that late in field life, unitization is much more successful in Texas. As production from a field dwindles, parties will often be able to negotiate a successful unitization, whereas earlier they could not. The apparent reason for success is that late in field life, lease values have been revealed through actual production. The implication is that asymmetric information no longer stands in the way of successful bargaining. Wiggins and Libecap argue that these data together suggest strongly that information, and in particular private information, plays a key role in the failure of unitization.

10 The unitization experience in Oklahoma is generally unsuccessful, just as in Texas, and apparently for the same reasons. Oklahoma, however, has a compulsory unitization law, which complicates the analysis, and so the original study of private contractual failure focused on Texas fields.
Limitations in field data prevent the full analysis of the effect of information on contracting. The problem with the field data is that they are incomplete, and do not provide either public or private value estimates, nor direct measures of private information. The absence of such measures means there is no direct evidence regarding how information molds bargaining, how it influences accepted and rejected shares, or how exactly it leads to contractual failure.

The experimental analysis below surmounts these problems by directly manipulating information. The analysis focuses on the three information conditions that lead to considerable variation in the success of contracting. The first treatment is a “Wyoming condition.” In Wyoming, unitization occurs before development, and so the primary relevant information is the acreage of individual leases. The second treatment is a “Texas private information” treatment. In Texas, unitization is attempted after field development and there is substantial public and private information about relative lease values, and unitization generally fails. The third treatment is the “Texas complete information” treatment, corresponding to unitization late in field life where production has defined relative lease values, and unitization is more often successful.

In addition to these information treatments other elements of the laboratory environment were molded to capture the important stylized facts regarding the unitization process. Unitization takes place among producing firms with tracts in a productive field. Some tracts are large, others small, and there is repeat contact in bargaining across fields. Yet entire groups are sufficiently large and diverse that the same group of bargainers is rarely reassembled.

Firms begin negotiations by appointing an “Engineering Committee” to compile known facts about leases and the field, including information like past production, number of wells, and

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11 Seismographs and other information are generally useful at helping to identify potential reservoirs – areas that might be unitized – but appear highly unreliable at distinguishing among leases. To the best of our knowledge, such seismographs are not used in negotiations, and do not affect assigned sharing rules.
remaining reserves. They do not, however, include any direct value estimates. The engineering committee reports its findings to the “Operators’ Committee,” which then conducts actual negotiations. Negotiations are free-wheeling, and there is no particular sequence to offers or counter-offers. Message spaces are unlimited, and parties are free in principle to reveal any information they feel appropriate. The negotiations focus on achieving a sharing rule, generally using the lease characteristics compiled by the Engineering Committee, but parties can focus on any factor as they see fit. Specific elements of the experimental environment, described below, mirror these characteristics.

Before proceeding, it is important to note the relationship between the analysis here and the extant experimental work on bargaining. Güth’s work linking Roth’s focal-point theory with social-psychological theories of distribution offers some testable hypotheses and some puzzles relevant to this study. In the Wyoming information treatment, parties know one another’s lease acreage, and since acreage is at least weakly informative of lease value, parties are predicted to allocate the joint return proportionately with lease acreage rather than on a per-capita basis. In the Texas compete information treatment, both acreage and actual lease values are known, and here parties are predicted to allocate the joint return proportionately with lease values rather than acreage. The puzzle has to do with how the parties incorporate uncertain public estimates of lease value in the Texas private information treatment. This treatment is a key element of the experimental investigation, as in the field.

It is also important to note that the control conditions here mimic a unitization-style bargaining environment, and so the experimental approach differs to some extent from that found in most extant experimental work on bargaining. We feel that the appropriate place to begin experimental analysis of unitization bargaining is to preserve the basic institutional features of
such bargaining as closely as possible. Accordingly we preserve a substantial ability for participants to communicate preferences and opinions, repeat contact, and heterogeneities in firm size in the basic design, to which we now turn.

Section 3. Laboratory Experimental Design

3.1. The Laboratory Setting

The experimental design is based on the oil field unitization problem. Sessions contained 3-4 bargaining groups, all of which shared the same induced “lease” characteristics. Each subject in a group was assigned one of six “color” profiles. Each color profile consisted of a set of specific set of lease characteristics and information. The number of white and blue chips associated with a particular color was randomly determined each period. To avoid identification of subjects across periods, subjects were reassigned colors randomly each period.

The bargaining groups were then created by randomly assigning a subject from each color group to a six-person bargaining groups. The groups always contained one member of each color profile, but the groups were reassigned each round. A session contained three or four bargaining groups, depending on the number of subjects who turned up (18 or 24), thus participants encounter each other multiple times. This procedure creates multiple bargaining groups each round with identical compositions of color types and therefore chips. In each group, the members’ holdings collectively represent a productive area (field) that contains a valuable, non-renewable common pool resource (oil). Motivated by conditions in the industry, this method also creates a design where subjects repeatedly encounter one another, but where entire groups very rarely reassemble.

At the start of each round the subjects received their holdings, represented electronically by virtual “bags” of (poker) chips. The cost of each bag depended on its size, and subjects were
charged a cost $.03 per chip in the bag allocated to them. As in the field data, these bags varied in size and individual subjects held anywhere from 4 to 40 percent of the total area, and bore 4 to 40 percent of these “lease” costs.

The ‘productivity’ of ‘leases’ varied by including both white and blue chips in the bags. White chips represented unproductive areas of a lease and had a redemption value of $0. Blue chips represented productive areas and could be redeemed at the end of the bargaining round (see below). The sum of the blue chips times their value (depending on the outcome of the negotiation) then represented the total productive potential of the common pool. As in the field data, individual subject holdings of valuable blue chips varied, both in terms of the percentage of chips within their own bag and in percentage of total blue chips in the common pool. The mean percentage of valuable blue chips to total chips in the individual bags was thirty-five percent, with a standard deviation of sixteen percent and a range from eight to eighty-four percent. Individual subjects also held a mean of 16.67 percent of the total number of valuable blue chips, but this percentage also varied widely from two to thirty-eight percent (Std. Dev. = 8.3 percent). This variation was chosen by the experimenters to allow us to examine how size and “productivity” influenced bargaining outcomes. The numbers of total chips, blue chips and white chips and their assignment to color profiles varied each period. However, the distributions used were constant across sessions. That is, the orange profile in period 5 had the exact same number of chips in all sessions.

The incentive for a bargaining agreement was to increase the value of blue chips. Each blue chip had a redemption value of ten cents if no unitization contract was formed. This value increased to eleven cents when an agreement was reached.

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12 The purpose of the payment was to force subjects to purchase their leases, and so to confound simple efforts to "split-the-pie evenly" as a bargaining solution. Subjects did not have the choice of buying or not buying chips, nor could they select a particular bag of chips to buy, though these restrictions are potentially important.
The order of events in each round is illustrated in Table 1. After purchasing their virtual bag of chips, subjects in individual color groups were randomly assigned to bargaining groups. They were then given information according to one of the three information treatments. In all treatments, subjects knew their own and others’ bag sizes (total chips). Treatment 1 corresponds to information conditions in Wyoming, and so total bag size was the only information available. Treatment 2 corresponds to asymmetric information conditions found in Texas (and Oklahoma). Each subject was privately told his number of valuable chips, and other subjects were provided with an unbiased public estimate of this number. The public estimate was a random variable drawn from on the discrete uniform distribution with range 30, centered around the number of actual blue chips (i.e., [actual blue chips - 15, actual blue chips + 15]). Treatment 3 corresponds to conditions late in field life in Texas and Oklahoma, where production has revealed private information, creating symmetric information regarding actual lease values; all subjects were told the actual number of valuable chips held by each party.

Following typical procedures of Engineering Committees, each relevant variable was presented to subjects both in raw numbers and in percentages of totals for easy reference during negotiations. Hence subjects had available mean value estimates and the range of values, both in absolute and in percentage terms. As in unitization, parties were free in bargaining to use or not use any of this information.

Figure 1 provides the experimental interface (programmed using z-tree software, Fischbacher, 2007) a subject would observe during the Texas private information treatment. The leftmost column identifies the subject’s color, current earnings, and holdings in his/her virtual bag of chips. The bottom left corner calculates for the subject his/her earnings if no agreement is reached.

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13 In very rare cases the actual chips were less than 15, in which case the public estimate was drawn from a uniform distribution from 0 to the actual chips + 15.
reached and an estimate of earnings should an agreement be reached. The table on the right shows each group member’s number of total chips and estimate for blue chips (with corresponding percentages of holdings). The lowest and highest possible number of blue chips a subject could be holding given the estimate is also disclosed. In Treatment 1, with incomplete, symmetric-information all values under blue and white chips would be replaced by “?” symbols. In the complete “Texas” information treatment, the values would contain actual numbers.

The interface also provided the method of bargaining. Subjects had the opportunity to request a percentage share of the total amount of blue chips. Once the request was made it was visible to all other subjects in the group (rightmost column in the table in Figure 1). A subject could withdraw a request at any time and then submit a new request. If all six subjects simultaneously had outstanding requests that totaled less than or equal 100%, they would be informed of that fact and asked to confirm the group proposal. If all six subjects confirmed the proposal, an agreement would be reached. If any subject withdrew an offer rather than confirming a proposal, the bargaining round would continue. Subjects also could utilize a chat window (shown in the middle of figure 1) to aid bargaining. Bargaining ended at agreement or when time ran out.

The experiment featured a within-subject design, so that subjects would encounter all three treatments within the fixed twelve bargaining periods. In the first three periods, each experiment followed the private information treatment. In the next nine periods, the experiment would follow three successive periods of each of the three treatments. The order of the three treatments was randomized. Treatments are summarized in Table 1.

3.2. Procedures

Subjects were Texas A&M undergraduate students recruited from a campus wide database (econdollars.tamu.edu) using ORSEE software (Greiner, 2015). After subjects arrived, written
instructions were distributed and read aloud by the experimenter (see the Appendix), questions were answered, and the first bargaining round began. Bargaining stages across sessions all featured the same time limits: 10 minutes for period 1, 7 minutes for periods 2-6, and 5 minutes for the remaining periods. In each period, after bargaining had concluded, subjects were asked to rate each other’s bargaining behavior on a scale from minus four (highly disagreeable) to four (highly agreeable).

At the end of experiment, subjects answered an open-ended question about the reasoning behind their decisions. They also filled out a questionnaire consisting of demographics information, a non-incentivized risk-preference elicitation (similar to Eckel and Grossman, 2008), and the Cognitive Reflection Test (Frederick, 2005). Subjects were then paid based on their total earnings over all periods plus a five-dollar show-up payment. Subjects earned on average $27.93 for a 2.5-hour session.

Seven experimental sessions were run at the Economic Research Laboratory at Texas A&M University over a two-week period in October 2015. Five (two) sessions used 24 (18) subjects, a total of 156 subjects.14

Section 4. Theory and Predictions

We model this six-agent bargaining problem in terms of a cooperative bargaining solution (e.g., Nash, 1950; Kalai and Smordinsky, 1976). The most straightforward application is to the full information treatment (Treatment 3), but we will also model at the treatments with symmetric, complete information (Treatment 1) and asymmetric information (Treatment 2).

14 Two sessions (42 subjects) featured the treatment ordering incomplete-asymmetric-complete for the last nine periods. One session of 18 subjects featured the treatment ordering incomplete-complete-asymmetric. The four other possible orderings were run once each in separate sessions of 24 subjects.
4.1 Complete Information

Define each agent $i \in \{1, 2, 3, 4, 5, 6\}$ with blue chip holdings $b_i$. Let $B$ denote the sum of all blue chip holdings, $\sum b_i = B$. Let the value of a blue chip to an individual be $m$ and $m'$ be the value of the blue chip if unitization is reached. By assumption $m' > m$, so groups reaching agreement is always efficient. Each agent has a utility function $u_i$ for money that is increasing and weakly convex.

The axiomatic bargaining approach utilizes utility sets to explain the bargaining problem. The utility possibility set $U \subset \mathbb{R}^6$ contains every possible 6-tuple utility realization than can be achieved under a bargain for the group of six agents. The 6-tuple $u^*$ is the vector of utility realizations should agreement not be achieved. We define the two elements as

$$u^* = (u_1(mb_1), u_2(mb_2), u_3(mb_3), u_4(mb_4), u_5(mb_5), u_6(mb_6)),$$

and

$$U = \left(u_1(m'\beta_iB), ..., u_6(m'\beta_iB)\right)$$

where $\sum \beta_i \leq 1$.\(^{15}\)

It follows that $u^* \in U$ because $\sum \frac{mb_i}{m'B} < 1$.

A bargaining solution may be defined as $f(U, u^*)$ that selects a solution $f(U, u^*) \in U$ for every bargaining problem $(U, u^*)$. Bargaining solutions vary by the specific axioms they impose on $f(U, u^*)$. The axiom most crucial for our purposes is individual rationality, that is, that each individual does as least as well under the bargain than in the fallback point. Formally, we write $f(U, u^*) \geq u^*$. Nash (1950) includes individual rationality among several specific axioms for a bargaining solution and shows the solution must satisfy

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\(^{15}\) The assumption of free disposal $\sum \beta < 1$ is both a crucial assumption of axiomatic bargaining theory, and feasible—though it was never utilized—under our design.
\[
\max_{f(U,u^*) \in U} \prod_i u_i(m'\beta_iB) - u_i(mb_i).
\]

In the simplest case, where agents have identical linear utility functions, maximization requires each \(m'\beta_iB - mb_i\) to be equal. Then for each \(i\) the Nash bargaining solution is \(\beta_i^* = \frac{mb_i}{mB} + \frac{1-m}{6}\). In our experiment, \(\frac{m}{m} = \frac{10}{11}\), so \(\beta_i^* = \frac{10}{11} \frac{b_i}{B} + \frac{1}{66}\).

4.2 Incomplete Symmetric Information

In the incomplete information treatment (Treatment 1), all subjects only possess common information about total chips. Each total chips may be either blue or white with some unspecified probability, \(p_b\).\(^{16}\) Suppose agent \(i\) has holdings of total chips \(t_i\) with the group total of \(T\).

Following expected utility, we define the elements of a bargaining solution as

\[
V^* = \left(\int_0^T P(b|t)u_i(mb)db, \ldots, \int_0^T P(b|t)u_i(mb)db\right),
\]

and

\[
V = \left(\int P(B|T)u_i(m'\beta_1B)dB, \ldots, \int P(B|T)u_i(m'\beta_6B)dB\right), \text{where } \sum \beta_i \leq 1.
\]

The point \(V^* \in V\) because \(\sum \frac{mb_i}{m'\beta_iB} < 1\) and each \(u_i\) is increasing and weakly concave. Then we may define a bargaining solution \(f(V, V^*) \in V\). Under equal, linear utility functions for each agent, the Nash bargaining solution is \(\beta_i^* = \frac{mt_i}{mT} + \frac{1-m}{6}\), which is \(\beta_i^* = \frac{10}{11} \frac{t_i}{T} + \frac{1}{66}\) under the parameters of our experiment.

4.3 Asymmetric Information

Under the asymmetric information treatment (Treatment 3), agents know their own chip

\(^{16}\) No explicit distributions were given regarding the number of blue chips in Treatment 1. Prior to encountering any Treatment 1 round, subjects have at least played three rounds so they know that on average roughly 30% of total chips are blue.
totals, $b_i$, but only observe a public signal $\hat{b}_j \in [b_j - c, b_j + c]$ about the other agents’ blue chips. Define $\hat{B}_i = b_i + \sum_{i \neq j} \hat{b}_j$, agent $i$’s inference of group total chips. Because agents know their own chip holdings, the fallback point is identical to the full information case,

$$u^* = (u_1(mb_1), u_2(mb_2), u_3(mb_3), u_4(mb_4), u_5(mb_5), u_6(mb_6)).$$

However, the set of bargaining possibilities more closely resembles the incomplete information case.

$$V' = \left( \int P(B|\hat{B}_1)u_i(m'\beta_1B)dB, \ldots, \int P(B|\hat{B}_6)u_i(m'\beta_6B)dB \right),$$

where $\sum \beta_i \leq 1$.

It is not clear whether the point $u^* \in V'$. First if the functions $u_i$ are sufficiently concave, we find no $v' \in V'$ such that $v' \geq u^*$. In this case risk aversion has kept agents at their certain fallback rather than risking a bargain with uncertain payoffs. However even under the case of linear $u_i$, agreement may not be reached. Consider a case where $B \gg m' \sum \hat{b}_i$. To satisfy individual rationality, we require that $u_i(mb_i) \leq \int P(B|\hat{B}_i)u_i(m'\beta_iB)dB$ for all $i$ which implies $mb_i \leq \beta_i \hat{B}_i m'$ for all $i$. If the latter condition is true, we must have $m' B \leq \sum \beta_i \hat{b}_i \approx \sum \hat{b}_i$, which would not be satisfied in our example.

Thus, in cases where the total number of blue chips greatly exceeds the total of the signals, cooperative bargaining outcomes may not be reached. A similar argument shows in cases where the total number of blue chips is far fewer than the total of the signals, agreement is easily reached. The reason is that agents correctly know their blue chip holdings but only have some information on total blue chips. When that information is biased upward, they incorrectly infer a small share of total production is necessary to compensate them for entering an agreement. The reverse is true when the information is biased downward.  

\[17\] There is the likely possibility that some true information will leak out during bargaining so that agents might have a more informed idea about chip totals than just the signals. This case could be modelled with the term $\tilde{b}_i = ab_i + b_i$. 

The property produces a lemons-like result where agreement is most likely in the states where it is least profitable and least likely in the states where it is most profitable (recall the gains to agreement are simply a percentage of total blue chips, so higher blue chip totals mean more efficiency gains.)

4.4 Predictions

**Prediction 1.** Agreement will occur more often in Treatment 1 and Treatment 3 than in Treatment 2.

**Prediction 2.** Within Treatment 2, agreement will occur more often when the total of signals exceeds the total of chips than in the reverse case.

The preceding analysis shows that bargaining solutions that satisfy individual rationality are always possible in complete and incomplete information treatments. They may not be possible in the asymmetric information treatment. In that treatment we should expect to see more agreements when the total of public signals greatly exceeds the total of blue chips than when the reverse is true.

Further, because discussion may be required for asymmetric information to leak out and inform the group and because not all solution concepts are feasible in every bargaining game of asymmetric information (agents may need to take time to discover what is feasible) we expect agreements in Treatment 2 to take longer than in the other two Treatments.

**Prediction 3.** Considering only groups that reach agreement, time to agreement will be greatest in the asymmetric information treatment (Treatment 2).

**Prediction 4.** Share totals in Treatment 1 and 3 will follow the symmetric, linear Nash $(1 - \alpha)\tilde{b}_t$. As long as $\alpha < 1$, in which case the analysis of the complete information game would apply, the results here would hold with $\tilde{b}_t$ replaced by $\tilde{b}_t$. 
bargaining solution. In the event it is individually rational by all parties, Treatment 2 may feature a similar Nash bargaining solution using the public estimates.

The theory section provides the actual predicted bargained shares for Treatments 1 and 3. Specifically, each subject should receive $\frac{10}{11}$ of their chip share (either share of blue or total chips) plus $\frac{1}{66}$ (an equal division of the remaining surplus). It is not clear whether an equivalent share can be applied to the asymmetric information treatment.

In the asymmetric treatment, in the event all information is revealed, the complete information solution may apply. If no information is revealed $\frac{10}{11}$ of the share of the public estimate plus $\frac{1}{66}$ (an equal division of the remaining surplus) might be a bargaining solution provided it was individually rational (that is, no one’s true chip totals greatly exceed their estimate).

Section 5. Laboratory Results: Primary Treatment Effects on Bargaining Outcomes

The 7 experimental sessions contained a total of 26 bargaining groups for 12 periods. This provided 312 period/group level observations for analysis. Of these groups 156 were under the private information treatment, 78 were under the incomplete and complete symmetric information treatments, respectively. These groups reached agreement quite often under symmetric information. In Treatment 1, with symmetric, incomplete information, groups reached agreement in 54 of 78 (69%) cases. In Treatment 3, under complete information, groups reached agreement in 58 of 78 (74%) cases. In contrast and consistent with prediction 1, groups in Treatment 2, with private information, reached agreement in only in only 71 of 156 (46%) instances. This difference across treatments is significant if we pool symmetric information treatments and compare to the asymmetric information treatment (Fisher’s exact test, $p<0.001$), or compare each treatment
separately (Pearson chi-square, p<0.001). These results do not appreciably change if we exclude the first three periods from analysis and only compare treatments in rounds 4-12.

We can also use a regression to control for additional factors that might influence a group to reach agreement. Table 2 presents the results of a linear probability model that include session fixed effects and period dummy variables, with standard errors clustered at the period-group level. The complete and incomplete symmetric information are treated as separate variables. The results indicate that incomplete symmetric information and complete information are associated with a 22 and 24 point gain over asymmetric information in the probability of reaching agreement (p<0.01). The difference between the two symmetric information treatments is not statistically meaningful.

Another variable that measures the difficulty in bargaining is how long groups take to reach agreement. Restricting our analysis to the 183 groups that reached agreement, summary statistics reveal the time to reach agreement was 2.35, 3.67, and 2.38 minutes in treatments 1, 2, and 3, respectively. The results are not statistically different in treatments 1 and 3, but are at the 1% level for both comparisons with treatment 2. Regression analysis (table 3) shows similar findings. Treatments 1 and 3 are associated with roughly a one minute shorter time to reach agreement than the asymmetric information treatment.

The theoretical framework of bargaining when applied to this setting identified special cases with asymmetric information where bargaining would be most difficult. In cases where the difference between the total number of blue chips and total of the signals is large (i.e., total asymmetric information), we are most likely to expect disagreement with asymmetric information.

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18 An additional regression (not shown) repeated this specification with standard errors clustered at the session level under a wild cluster bootstrap regression (Cameron, Gelbach and Miller, 2008). The results remain significant at the 5%-level (see Table 2 note), suggesting within-session idiosyncrasies are not driving the main treatment effect. For more information on the analysis of possible session effects, see Frechette (2012).
(prediction 2). Summary statistics suggest this is the case. Agreement was reached in 56 of 95 (58.33%) where the total signal exceeded the total number blue chips, but only in 15 of 60 (25%) cases where the total signal was less than the total number of blue chips (p<0.01, Fisher’s exact test). The second regression in Tables 2 and 3 provides a coefficient for the variable Total Asymmetric Information, the difference between actual group totals of blue chips and the group total of signals. The coefficients suggest each chip increase in the difference between blue chip and signal totals is correlated with a drop of 0.5 percentage points in the likelihood of agreement and a 1.5 second (0.024 minute) increase in deliberation among groups that reach agreement.

5.1 Laboratory Results: Information, Focal Points, and Sharing Rules

A central focus of the analysis is how information affects sharing rules in successful bargains. We examine these focal point effects are shown in regression analyses reported in Table 3. The left-hand side variable is the bargained share, while the right-hand side variables reflect the information available in the various treatments. The baseline is Treatment 1 (incomplete, symmetric information), where subjects know only total chips. Hence information in this treatment is represented by subjects’ shares of total chips, and there is also a constant term. The remaining variables have a value of zero in this treatment and are introduced below. We provide regression results over all treatment observations as well as restricting to cases where subjects agree and fail to agree on an allocation rule. In the latter case the dependent variable reflects the last offer made by subjects when the bargaining round concluded.

5.2. Treatment 1: Incomplete Symmetric Information

With incomplete, symmetric information subjects focused on shares of total chips in
assigning final shares, and equal division also plays a role. To see how to interpret the coefficients, note that under agreements the shares sum to one so that the coefficient of total chips provides an unbiased estimate of the portion of bargained shares allocated on the basis of total chips.\textsuperscript{19} Further, the \textit{Intercept} term provides an unbiased estimate of the share assigned to \textit{each person} on a per capita basis -- that is, how much they would receive if their chip share were zero; the total per capita assignments are obtained by multiplying by six, the size of the bargaining group.

Observing the agreement data, the coefficient on \textit{Share of Total Chips} is .59 (p<0.01) which means that roughly three-fifths of the common-pool resource was allocated on the basis of total chips. Per capita allocations were significant; the point estimate is 41\% (6* .068). The constant is significant at the 1\%- level. Hence, both total chips and a per capita allocation were key determinants of bargained shares. This result was obtained when total chips were equally divided and when total chips were very unequally divided. In the unequal division cases, individual total chip holdings ranged from a low of nine percent to a high of twenty-five percent. The relatively small standard error (.058) implies that there was significant uniformity in the use of share of total chips in assigning bargaining shares. The implication is that the relationship between chips and assigned shares was not only positive, but that bargaining groups used the information in similar ways. Interestingly the results are a bit of a departure from the symmetric risk-neutral Nash bargaining solution (prediction 4) that would suggest a share should be determined by 10/11 (91\%) of the total chip share plus a constant of 1/66 (1.5\%).

5.3. Treatment 2: Asymmetric Information.

The sharing rule under the Treatment 2, the Texas private information treatment, differed

\textsuperscript{19} The mean values of the dependent variable (shown in Table 3) are quite telling here. When there is agreement the average bargained share is 0.167 meaning subjects’ totaled shares equal 1. When there is a disagreement, the average value is 0.186, meaning subjects, on average, were requesting shares that totaled to 1.12.
Parties concentrated on different focal points in bargaining as the new information available from the estimated number of blue chips supplanted total chips as the primary focal point.

In agreements, subjects primarily focused on the public share estimate. This variable was not available in Treatment 1, so the variable is equal to zero for observations from Treatment 1. The estimated coefficient of the Public Share Estimate variable is large (.71) and highly significant (p<0.01). Noting again that shares add to one hundred percent, seventy-one percent of the common-pool resource was allocated using this primary focal point. Hence public value estimates emerge as the major factor in assigning final shares.

A significant finding for unitization, as discussed below, is that subjects do not accord shares one-to-one with value, but instead discount the value estimates considerably. This discounting is reflected by the fact that the coefficient of the public estimate is significantly less than one. The implication is that a one percent increase in a subject’s estimated share generates significantly less than a one percent increase in assigned value.

The coefficient on Public Share Estimate also has a remarkably small standard error of about four and one half percent (.044). This small standard error reveals significant uniformity in how value estimates were incorporated in shares in successful bargains. A one percent increase in a subject’s share of the public estimate resulted in between a .61 and a .79 increase in assigned share in nearly all successful bargains. The implication is that in successful bargains, value discounting was a uniformly applied, dominant allocation rule.

A related finding is that value estimates replaced shares of total chips as the primary factor affecting bargained shares. The change in the influence of total chips is measured through an interaction term between the Private Information Dummy and Share of Total Chips, which measures total chip share in the private information treatment, but is zero otherwise. This variable
measures the reduced influence of total chips on shares in the private information treatment compared to the baseline where only total chips were known. The coefficient is large (−.569) and significantly negative (p<0.01). Accordingly, it can be added to the coefficient on Share of Total Chips to assess the effect of chips on final bargained shares under private information. Such addition yields .59 + (−.57) = .02 or 2 percent, and becomes insignificantly different from zero. Noting again that shares add to one, only a statistically insignificant two percent of the final shares were allocated according to total chips in Treatment 2 with private information. Hence, the bargainers’ total chip shares ceased to play a meaningful role in the outcomes.

Under the private information treatment, the per capita allocation becomes smaller, but remains important. A dummy variable was introduced to indicate observations from Treatment 2 (Private Information): its coefficient is −.024 and it is significant (p<0.05). The point estimate for the intercept obtained by adding this coefficient to the intercept of the regression, .068−.024 = .044, is large and significantly positive. With six subjects, roughly a quarter of the common-pool resource was allocated for mere participation, suggesting that the per capita allocation remains substantial.

These findings are significant for unitization. The evidence shows that subjects discount value estimates and chip shares in their share allocations, and allocate significant shares for mere participation. The discussion below links these findings to unitization, and to Roth’s earlier results.

Private information also plays an important role in bargaining. The essence of a ‘lemons’ story is that parties behave strategically with respect to their private information; car owners are more likely to sell when their private information is unfavorable and less likely to sell when it is favorable. Accordingly, the ‘lemons’ hypothesis is that favorable and unfavorable information have differential effects on bargaining. To separately measure favorable and unfavorable private

information, the regression analysis incorporated two interaction terms. We first create a variable measuring the *Difference* between public and private information by subtracting the public share estimates from the privately known actual share. We then interact this variable with dummy variables indicating whether private information was *Positive* (=1 if private > public), or *Negative* (=1 if private < public). The two interaction terms are then *Positive Private Information* (*Difference* x *Positive*) and *Negative Private Information* (*Difference* x *Negative*). When information was unfavorable and in other information treatments, *Positive Private Information* was zero. *Negative Private Information* was then zero when information was favorable and in other treatments.

The construction of these variables permits a ready interpretation of the impact of information on bargained shares. As public estimates and actual shares rise together, the coefficient of the public share estimate captures the impact on bargaining. To see this, simply note that when the public estimate equals the true value, the private information variables are zero, leaving the public estimate as the only factor affecting bargained shares. Holding the public share estimate constant, the private information coefficients then measure the impact of deviations from the public estimate.

‘Lemons’ reasoning addresses the coefficients of the private information variables. Strategic play would suggest that parties will attempt to reveal favorable private information for incorporation into bargained shares. The problem is that other parties may discount revelations since they are not verifiable. Similarly, ‘lemons’ reasoning suggests that parties should not reveal unfavorable private information, and so the coefficient for negative private information should be small, or even zero. The incentive not to reveal, however, is tempered by the fact that parties with unfavorable private information have a greater incentive to make concessions to ensure that a
bargain is reached. Finally, overall discounting of private information suggests that the coefficient of both private information variables will likely be smaller than the coefficient of the public share estimate.

The results are mixed; they suggest the discounting of private information found in the ‘lemons’ hypothesis, but they do not reflect a differential impact for favorable and unfavorable information. Specifically, the coefficient for favorable private information is .58 (p<0.01), while that for unfavorable information is .50 (p<0.01). Hence bargained shares reflect both types of private information, with favorable private information raising bargained shares and unfavorable information, which has negative values, reducing bargained shares. The coefficients for both private information variables are smaller than the coefficient of the public share estimates (.71). These differences are marginally statistically insignificant. Hence the results indicate that private information does become incorporated into bargained shares and that such information could reflect further information discounting. This discounting is particularly important because there is already heavy discounting of the public share estimate, and so private information is accorded a relatively low weight in share assignments.

The key results are that i) parties discount public share estimates when they are uncertain, ii) a significant portion of bargained shares are allocated on a per capita basis, iii) private information is potentially more heavily discounted, and iv) there appears to be little difference in the influence of favorable and unfavorable private information on bargained shares.

5.4. Treatment 3: Complete Information

Bargaining under full information differed markedly from bargaining in the limited information treatments. Once again, the change in information shifted parties bargaining behavior,
this time leading to a focus on subjects’ actual shares of valuable chips. More important, the changed information altered the discounting of share estimates, greatly reduced the role of total chip shares and eliminated the role of the per capita allocation in bargained shares.

The dominant focal point in bargaining became subjects’ actual shares of valuable blue chips. These shares determined virtually all of the share allocations in successful bargains. The coefficient estimate for share of valuable blue chips (Actual Shares) is .894, which is large and highly significant (p<0.01). Noting once again that shares sum to one, this factor accounts for roughly ninety percent of the assigned shares in successful bargains in Treatment 3. This coefficient also shows that there is nearly a one-to-one relationship between assigned shares and individuals’ shares of valuable chips. A one percent increase in share of valuable chips translates into a .894 percent increase in assigned shares. The numbers do not differ greatly from the symmetric risk-neutral Nash bargaining solution which predicts that a coefficient of 10/11 for blue chips and a constant of 0.015 (prediction 4).

A key finding is the contrast among the sharing arrangements across information treatments, particularly how value estimates are discounted. The near absence of information discounting under complete information differs sharply from the heavy discounting observed when information is low. This finding suggests that subjects discount public share estimates simply because they are estimates. Such discounting, as we shall see, plays a role in the failure to reach agreements.

A decline in fairness considerations can also be measured by examining changes in the per capita share assignments and in the effect of total chips on bargained shares. Accordingly, the regression includes a treatment dummy variable, Complete Information, to gauge the impact of the treatment on per capita assignments, and an interaction term, Complete Information x Share of
Total Chips, to capture the effect of the treatment in the influence of total chip allocation. The coefficient for Complete Information is negative, -.060 (p<0.01). To obtain the intercept under complete information, one adds this coefficient to the intercept of the regression to yield .068 + (-.060) = .008. The point estimate indicates the per capita allocation disappears under full information: This result contrasts sharply with the low and private information treatments where such allocation accounted for almost twenty-five to thirty-five percent of assigned shares.

Total chip shares similarly fade as a determinant of shares. The coefficient of the interaction term, Complete Information x Share of Total Chips, is -.54 (p<0.01). It shows that there is a highly significant difference in the effect of total chips on shares in this treatment compared to Treatment 1. To assess the absolute impact of total chip shares on bargained shares, this coefficient can be added to the baseline coefficient to yield .59 + (-0.54) = .05, which is not statistically significant from zero. The resulting coefficient shows that total chip shares receive virtually no weight in the bargained share assignments.

Private information, however, raises a new issue. When subjects’ estimated shares are discounted in bargained share assignments, subjects with large holdings have an incentive to reject the bargained share, leading to bargaining failure. We now turn to the general issue of bargaining failure and this issue in particular.

Section 6. Experimental Results: Contractual Failure

The analysis above shows how information affects observed sharing rules by determining the information parties use to assign shares in bargaining. These effects also play a significant role when bargaining fails. The data show that parties bargain differently as information changes, and there is a particular disagreement on the role of the per-capita share when private information and
public estimates are available in Treatment 2. This disagreement appears to be responsible for the reduced amount of agreements in that treatment.

We now turn to a discussion of a comparison of the last shares that subjects offered when the bargaining round expired vs. what they agreed to during the negotiations. Comparing the third and fourth columns of Table 3 investigates this issue. Examining Treatment 1 coefficients, we see that in disagreements there is less discounting of total chip amounts; the total chip coefficient is 0.866 (compared to 0.593 in agreements, significantly different \( p<0.001 \)) and the per-capita allocation is also smaller (the estimate is that only 22\% (0.037 x 6) of the allocation was assigned on a per capital basis, not significantly different from the 41\% (0.068 x 6) for agreements). To reach agreement, concessions need to be made to those with the smaller total chip holdings.

With private information in treatment 2—where disagreements occur 55\% of the time—we see a similar conflict. Subjects no longer focus on total chip estimates; the \( Private Information \times Share of Total Chips \) interaction variable is negative and nearly equal in magnitude to the \( Share of Total Chips Variable \). However, the \( Private Information \) variable is slightly less in disagreements than agreements. Most crucially, the sum of the \( Private Information \) and \( Constant \) variables, the share allocated to each individual regardless of holdings is much larger (0.044 vs. 0.69) in disagreements.

There appear to be two different focal points when subjects attempt to incorporate value estimates in assigning shares. The first focal point is that subjects discount value estimates and assign shares accordingly. In the second, subjects request shares assigned according to value. The dominant sharing rule under imperfect, asymmetric information is the one which discounts the public estimate of lease values and includes a weight on the per-capita standard. The reason this focal point appears to be dominant is that when agreements were reached, there was heavy
discounting of value estimates, small confidence intervals for the coefficients, and a large share allocated for mere participation. Still, not all subjects accept discounting, and this failure to accept discounting played a significant role in bargaining breakdowns.

Our pilot study suggested that favorable private information was another source of friction. Specifically, in disagreements parties with favorable private information were less willing to agree to bargains that did not reflect that information. We see very little confirmatory evidence of that hypothesis. In agreements, a one percent increase in favorable information generated a .58 percent increase in assigned share. In disagreements, such a one percent increase generated a .64 percent increase in the asked-for share. Similarly, unfavorable private information generated larger concessions when there were breakdowns. Specifically, a one percent decrease in private information generated a 0.50 percent decrease in shares in agreements vs. 0.57 with agreements. It is a bit surprising these coefficients are not greater, as those with negative (vs. positive) information have a less favorable outside option if an agreement is not reached, and so there is an incentive to make concessions to encourage more agreements.

In the complete information treatment (Treatment 3), where agreements occurred roughly 75% of the time, we once again see signs of the conflict between focal points. The per-capita share value is determined by the sum of the Constant and the Complete Information term. In agreements, the per capita share value is effectively 0 (0.068 - 0.06). In disagreements, it is roughly 7% (0.037 + 0.037).

One last insight into bargaining failures comes from the survey data. Recall at the end of every bargaining period subjects were asked to evaluate the likeability of every other player on a 9-point scale. Tables 4 provide similar regressions to Tables 3 except that the period average rating of likeability from the other five participants is used as the dependent variable. Unsurprisingly,
subjects like participants more after agreements than disagreements (a constant of 7.096 vs. 5.773). Regressors generally have little explanatory power. There is some evidence that those with more total chips are looked at more favorably under incomplete information, looked at less favorably under private information, and looked at roughly the same under complete information. This may indicate a willingness by the group to use the total chip numbers (albeit with a discount) under treatment 1, but not treatment 2.

Most predictive is the feelings of likeability towards those with positive and negative in Treatment 2. Those with positive (negative) private information are seen as much less (more) favorable on average. An increase of 5% share in positive (negative) information would be associated with an increase (decrease) of half (one-third) a point on the 9-point favorability scale. Thus, it would appear subjects blame those with positive private information for the failure of the group while crediting those with negative private information for being conciliatory. In reality, the former group is making real concessions while the latter is making illusionary ones.

Section 7. Disagreements and Bargaining Breakdowns in the Field Data

The experimental laboratory results provide new insight into the unitization field data and link contractual failure to the earlier findings of Roth, et al. In the field, a major element of the failure of unitization is that more productive leases are often withheld from units when they are formed (Wiggins and Libecap (1985)). This problem was originally identified by Raymond Myers (1967) who noted “frequent acrimony as to the respective shares to be given owners of interest in favorable parts of the structure and owners of interests in less favorable areas…” (p. 108). Wiggins and Libecap then present systematic data showing that productive leases are more likely to be withheld, at least in the three fields for which systematic data is available. Hence fields are
fragmented along productivity lines, sacrificing valuable gains to field-wide recovery efforts. Wiggins and Libecap explain this behavior primarily in terms of symmetric information.\textsuperscript{20} The experimental results support that hypothesis in that private information is heavily discounted in sharing rule assignments, leading to bargaining failures in some cases.

The experimental results, however, also show that discounting of value estimates provides another mechanism through which uncertain lease values can lead to contractual failure. The experimental findings show that when value estimates are uncertain, subjects discount these estimates in sharing rule assignments. In Treatment 2, with asymmetric information, this discounting reaches approximately thirty percent; a one-percent increase in estimated share only generates a seven-tenths of one percent increase in assigned share. In contrast, such discounting nearly vanishes when value estimates are known with certainty. In the full information treatment, a one percent increase in share of valuable chips generates a .89 percent increase in assigned share. The implication is that highly productive leases are more likely to be withheld under the private information treatment.

This interpretation indicates a need to reevaluate the field data. The experimental analysis suggests that bargaining failures may occur simply because insufficient weight is given to value estimates while excessive weight is given to non-value criteria -- the constant term, or total chips. In the field, such non-value criteria can include using a variety of factors that measure lease heterogeneities, but have little to do with productivity. The experiments suggest, moreover, that

\textsuperscript{20} To briefly summarize, when a unit is formed parties who withhold their leases will not subsequently be offered a more favorable share. This means that parties who decline to join must believe that their share operating alone is sufficiently greater than the offered share to more than offset the economies of joint production. The likelihood of such large differences increases with the uncertainty of the public estimate of lease value. Wiggins and Libecap show that public estimates of the value of more productive leases was more uncertain than such estimates for less productive leases. Hence they explain the hold-out of more productive leases by arguing that it is more likely that such leases have highly favorable or unfavorable private information. That earlier paper also argued that pure imperfections in information might be important in the failure of unitization, but did not address the discounting arguments analyzed here.
disagreements should focus on the weight attached to productivity and value.

This hypothesis is directly testable using data from sharing rules when fields fragment. When bargaining breaks down along productivity lines, there should be systematic differences in the sharing rules used by the more and less productive fragments. Highly productive areas should place more weight on value estimates, productivity, and so forth. Less productive areas should place weight on acreage and other factors unrelated to value.

To test this hypothesis, we investigated further the nature of the sharing rules and bargaining failures on the three primary fields contained in the original analysis by Wiggins and Libecap. These three fields were the Prentice, Cowden, and Goldsmith/Landreth fields (see the analysis of joinder decisions, Wiggins and Libecap (1985) Table 2, p. 378). When fieldwide unitization failed on each of these fields, the field fragmented into smaller, partial units.

To test the value discounting hypothesis, differences in sharing rules were examined. Specifically, the weight assigned to measures of value in the highly productive and less productive field fragments was examined. We contacted the operators of these units, and obtained the sharing rules for all of the units on the field.

The field data from those three fields suggests that value discounting may in fact have played a significant role in the failure of unitization. On the primary, less productive area in the

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21 Investigation of this hypothesis using more extensive field data is planned, but would carry us far from the current, more limited analysis. These fields were chosen simply because they had already been identified in the earlier study as reasonably representative examples of the nature of contractual failure in unitization.

22 As noted above, such partial unitization reaps some of the gains to coordinated recovery efforts, but sacrifices significant portions of the potential gains to fieldwide unitization and recovery. Such partial units are a widespread response to the failure of fieldwide units and account for roughly thirty percent of the production in Texas.

23 As footnote three suggests, an important role for purely imperfect information was considered in the original Wiggins and Libecap study. Pure discounting of value estimates, however, was not considered because there was no reason to suspect that such discounting would be created by imperfect value estimates.

24 This data was not collected in the original study because that study provided no specific hypotheses regarding how such sharing rules should differ. These data were gathered from firms, but are also available through the Texas Railroad Commission.
Prentice Field (Prentice Northeast), three factors were used to assign weights for tract participation in the sharing rule. These factors and their weights were: i) reservoir volume (67.5%), ii) output during the year before unitization (20%), and iii) cumulative past output (12.5%). On the residual unit (Prentice Central) formed the highly productive leases in the central portion of the field, the tract participation was based solely on output during the year before unitization.\(^{25}\)

The key difference in these formulas is the large weight attached to reservoir volume in the Prentice Northeast formula. To the extent that volume differs from output, however, it measures oil originally in place that is drained away by neighbors who (generally) lie downhill. The less productive areas in Prentice insisted on high weight for the size of the reservoir under their leases, reflecting “fairness.” The more productive leases gave all weight to output, ignoring “fairness.” Hence the sharing formulas on the two portions of the Prentice Field support the value of discounting hypothesis.

The second field considered by Wiggins and Libecap was Goldsmith/Landreth. Unit negotiations broke down on that field, as on Prentice, and two separate (partial) units were formed. Differences in the sharing formulas used for these partial units reflect disputes over the weight placed on current value estimates, though in a less pronounced way than in the Prentice Field. For the Goldsmith/Landreth Deep Unit, the sharing formula was i) current output (77.5%) and ii) productive acres (22.5%).\(^{26}\) To the extent that acreage differs from output, moreover, it affects a fairness criterion directly paralleling bag size in the experiments. The second fragment on the

\(^{25}\) As is common, the central unit used a two-phase sharing rule and the one reported in the text is the first phase. The second phase, which came into operation after 8.6 million barrels were produced, was 60 percent reservoir volume and 40 percent cumulative output.

\(^{26}\) The Goldsmith Field involved multiple formations and the weight attached to both output and acreage was broken down more finely in the sharing formula. This breakdown is immaterial for the analysis here, but was as follows: i) 15% current oil output from the 5600’ zone, ii) 3% current gas output from the 5600’ zone, iii) 49% current oil output from the Clearfork zone, iv) 10.5% current gas output from the Clearfork zone, v) 12% acres in the 5600’ zone, vi) 10.5% acres in the Clearfork zone. The San Andres Unit of the Goldsmith Field did not employ such detailed breakdowns.
Goldsmith Field, the San Andres Unit, placed all weight on value measures just like Prentice Central. Output over the year prior to unitization received eighty percent (80%) of the sharing weight. A second dimension of productivity-- producing wells which play a major role in determining Railroad Commission output quotas -- received the remaining twenty percent (20%) of the sharing weight. Hence on both Prentice and Goldsmith/Landreth, the sharing rules of the individual fragments show significant differences similar to those predicted by the value discounting hypothesis.

The third field in the Wiggins and Libecap study was the Cowden Field. The Cowden Field differs somewhat from the other two. Valuation and fairness were important in the disagreement, but the analysis is more complex than in the other two fields. In particular, the North Cowden Unit was formed first, and the leases in what eventually became the Wight Unit of the North Cowden Field were withheld. The North Cowden Unit formula weighted natural gas production and cumulative output much more heavily. Both units had a two-phase sharing formula. In the North Cowden Unit, the first phase gave one hundred percent of the weight to the preceding year’s oil and gas output and was in place for the first twenty-five million barrels produced. The second phase formula placed a one hundred percent weight on cumulative oil output, which measures well a lease’s historical ability to produce.

The North Cowden Wight Unit had a short first phase covering only two million barrels. The formula placed fifty percent weight on the preceding year’s oil production, and fifty percent on the same period’s oil and gas. Hence oil was emphasized over oil and gas. In the second phase, the formula gave thirty-five percent to the preceding year’s oil, forty percent to the preceding year’s oil and gas, but only twenty-five percent to cumulative oil output, contrasting sharply with the one hundred percent weight given this factor in the second phase of the North Cowden Unit
phase II sharing formula.

All of the differences reflect disagreement over dimensions of fairness and valuation. When leases are uphill (high) on a formation, they enjoy high production early in a field’s life. This production diminishes comparatively rapidly has heavier oil flows downhill to lower leases. Gas production, however, remains steady or even rises, as lighter gas flows uphill. Lower leases have longer-lived production and produce less gas.

In the Cowden Field, the production data indicate that the North Cowden Unit was uphill. Accordingly, their formula weighted gas more heavily and for a long time in Phase I; then in Phase II, the formula switched to total cumulative output. This is “fair” because the downhill Wight Unit leases were draining oil from their uphill neighbors. The Wight Unit leases, however, discounted past production and gas production in their sharing formula. Instead, they looked to current output and oil output, which in a significantly sloped field likely better measured future ability to produce.

The implication is that uncertainty over value estimates and fairness seems to have played a significant role in the breakdowns in all three fields. Uncertainty over the contribution of various leases to field value is pervasive in a field setting, and the sharing rules adopted suggest that there may be discounting of value estimates fieldwide unitization efforts. The weight attached to valuation criteria was much higher in the partial units formed from the leases withheld when attempts at fieldwide unitization broke down. The experimental results show how this result is similar to the discounting of “chips” found by Roth, Malouf, and Murnighan. The suggestion is that imperfect information, per se, affects focal points in bargaining, and this change in focal points can cause bargaining to break down. The field data lend support to this argument.

Section 8. Summary and Conclusion
The analysis above shows how information plays an important, multifaceted role in bargaining. The results provide two advances. The first is to show how imperfect information affects the weight placed on value criteria in bargaining. Roth, et al., showed that uncertain versus known prize values lead to sharply different focal points in bargaining. In particular, payoffs in “chips” of completely unknown value led to complete discounting of prize values in the bargaining, while dollar payoffs were incorporated fully into the bargaining outcomes.

Our results extend this result to partially uncertain payoffs. When subjects’ own shares of the value of a common pool are known with certainty, bargains assign shares on nearly a one-to-one basis with contributions. When subjects have unbiased estimates of shares of the value, but know their own values, subjects heavily discount valuation in assigned shares in successful bargains.

These partially uncertain payoffs, however, create new incentive for bargaining failure. When payoffs are in “chips” of completely uncertain relative values, as in Roth, et al., discounting chips affects all subjects symmetrically. Here, in contrast, parties whose values are discounted the most have an incentive to insist on giving full weight to the value estimate. This introduces a potential disagreement over focal points. This disagreement was reflected strongly in the final offers in unsuccessful bargains.

We also link the results directly to bargaining breakdowns unitization field data. Value discounting appears to play some role in the bargaining breakdowns in the three primary fields covered in the original Wiggins and Libecap study. Whether this effect is important for the failure of unitization more generally is an important issue for further research.
REFERENCES


Roth, Alvin E., and Michael Malouf: “Game-Theoretic Models and the Role of Information


<table>
<thead>
<tr>
<th>Treatment</th>
<th>Name</th>
<th>Information</th>
<th>Revealed to group</th>
<th>Revealed to individual only</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wyoming</td>
<td>Incomplete, Symmetric</td>
<td>Total Chips</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Texas Private</td>
<td>Asymmetric</td>
<td>Total Chips + Estimate</td>
<td>Blue Chips</td>
</tr>
<tr>
<td>3</td>
<td>Texas Complete</td>
<td>Complete, symmetric</td>
<td>Total Chips + Blue Chips</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Rounds 1-3 consisted of Treatment 1. Rounds 4-12 included three successive periods each of Treatments 1, 2, and 3 in random order.
TABLE 2
BARGAINING AGREEMENT BY TREATMENT
(Linear probability model, dependent variable = 1 if agreement is reached)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Parameter Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1: Incomplete (Wyoming) Information</td>
<td>0.218*** (0.071)</td>
<td>0.253*** (0.072)</td>
</tr>
<tr>
<td>Treatment 3: Complete (Texas) Information</td>
<td>0.245*** (0.072)</td>
<td>0.282*** (0.074)</td>
</tr>
<tr>
<td>Total Asymmetric Information</td>
<td>-0.005* (0.003)</td>
<td></td>
</tr>
<tr>
<td>(Total Blue Chips – Total Estimate, Treatment 2 only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period Dummy Variables</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Session Fixed Effects</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Total Number of Observations</td>
<td>312</td>
<td>312</td>
</tr>
<tr>
<td>Number of Subjects</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Number of Sessions</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>R-square</td>
<td>0.191</td>
<td>0.197</td>
</tr>
<tr>
<td>Dep Mean</td>
<td>0.587</td>
<td>0.587</td>
</tr>
</tbody>
</table>

Significance level: ***p<0.01, **p<0.05, *p<0.1.
*standard errors in parenthesis.
Note: Treatment 1 and 3 coefficients are not significantly different. The coefficients are jointly different from 0 at the 0.01 level. Clustering on session using a wild cluster bootstrap (Cameron, Gelbach and Miller, 2008) does not reduce the significance of the treatment 1 and 3 coefficients below the 5 percent level.
### TABLE 3

**BARGAINING DURATION BY TREATMENT (AGREEMENTS ONLY)**

(Linear regression model, dependent variable is minutes of bargaining)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter Estimate</th>
<th>Parameter Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1: Incomplete (Wyoming) Information</td>
<td>-0.892*** (0.301)</td>
<td>-1.159*** (0.340)</td>
</tr>
<tr>
<td>Treatment 3: Complete (Texas) Information</td>
<td>-0.707** (0.298)</td>
<td>-0.982*** (0.340)</td>
</tr>
<tr>
<td>Total Asymmetric Information (Total Blue Chips – Total Estimate, Treatment 2 only)</td>
<td></td>
<td>0.024* (0.014)</td>
</tr>
<tr>
<td>Period Dummy Variables</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Session Fixed Effects</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Total Number of Observations</td>
<td>183</td>
<td>183</td>
</tr>
<tr>
<td>Number of Subjects</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Number of Sessions</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>R-square</td>
<td>0.267</td>
<td>0.275</td>
</tr>
<tr>
<td>Dep Mean</td>
<td>2.873</td>
<td>2.873</td>
</tr>
</tbody>
</table>

Significance level: ***p<0.01, **p<0.05, *p<0.1.

*standard errors in parenthesis.

Note: Treatment 1 and 3 coefficients are not significantly different. The coefficients are jointly different from 0 at the 1-percent level. Clustering on session using a wild cluster bootstrap (Cameron, Gelbach and Miller, 2008) does not reduce the significance of the treatment 1 and 3 coefficients below the 5-percent level.
### TABLE 4: THE DETERMINANTS OF BARGAINED SHARES
(Linear regression, dependent variable defined on [0,1])

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall</th>
<th>Agreement</th>
<th>No Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.060***</td>
<td>0.068***</td>
<td>0.037***</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.009)</td>
<td>(0.019)</td>
</tr>
<tr>
<td>Share of Total Chips</td>
<td>0.670***</td>
<td>0.593***</td>
<td>0.866***</td>
</tr>
<tr>
<td></td>
<td>(0.057)</td>
<td>(0.058)</td>
<td>(0.117)</td>
</tr>
<tr>
<td>Private Information</td>
<td>-0.004</td>
<td>-0.024**</td>
<td>0.032</td>
</tr>
<tr>
<td>(Dummy variable =1 if Treatment 2)</td>
<td>(0.012)</td>
<td>(0.011)</td>
<td>(0.024)</td>
</tr>
<tr>
<td>Private Information x Share of Total Chips</td>
<td>-0.631***</td>
<td>-0.569***</td>
<td>-0.812***</td>
</tr>
<tr>
<td></td>
<td>(0.070)</td>
<td>(0.066)</td>
<td>(0.131)</td>
</tr>
<tr>
<td>Public Share Estimate</td>
<td>0.695***</td>
<td>0.711***</td>
<td>0.645***</td>
</tr>
<tr>
<td>(Treatment 2 only)</td>
<td>(0.046)</td>
<td>(0.044)</td>
<td>(0.075)</td>
</tr>
<tr>
<td>Positive Private Information</td>
<td>0.595***</td>
<td>0.574***</td>
<td>0.638**</td>
</tr>
<tr>
<td>(Private – Public Share Estimate if positive; 0 otherwise)</td>
<td>(0.171)</td>
<td>(0.095)</td>
<td>(0.291)</td>
</tr>
<tr>
<td>Negative Private Information</td>
<td>0.536***</td>
<td>0.495***</td>
<td>0.570**</td>
</tr>
<tr>
<td>(Private – Public Share Estimate if negative; 0 otherwise)</td>
<td>(0.146)</td>
<td>(0.105)</td>
<td>(0.252)</td>
</tr>
<tr>
<td>Complete Information</td>
<td>-0.034***</td>
<td>-0.060***</td>
<td>0.037</td>
</tr>
<tr>
<td>(Dummy variable =1 if Treatment 3)</td>
<td>(0.012)</td>
<td>(0.010)</td>
<td>(0.034)</td>
</tr>
<tr>
<td>Complete Information x Share of Total Chips</td>
<td>-0.663***</td>
<td>-0.536***</td>
<td>-0.962***</td>
</tr>
<tr>
<td></td>
<td>(0.071)</td>
<td>(0.064)</td>
<td>(0.153)</td>
</tr>
<tr>
<td>Complete Information x Actual Shares</td>
<td>0.858***</td>
<td>0.894***</td>
<td>0.764***</td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.029)</td>
<td>(0.056)</td>
</tr>
</tbody>
</table>

| Total Number of Observations                  | 1872        | 1098        | 774          |
| Number of Subjects                            | 156         | 156         | 156          |
| Number of Group Clusters                      | 312         | 183         | 129          |
| R-squared                                     | 0.470       | 0.810       | 0.310        |
| Dep Mean                                      | 0.175       | 0.167       | 0.186        |

Significance level: ***p<0.01, **p<0.05, *p<0.1.

Note: Fixed effects used at subject level. Standard errors clustered at group-period level.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall</th>
<th>Agreement</th>
<th>No Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>6.867***</td>
<td>7.096***</td>
<td>5.773***</td>
</tr>
<tr>
<td></td>
<td>(0.157)</td>
<td>(0.161)</td>
<td>(0.256)</td>
</tr>
<tr>
<td>Share of Total Chips</td>
<td>0.665</td>
<td>1.458**</td>
<td>1.957</td>
</tr>
<tr>
<td></td>
<td>(0.662)</td>
<td>(0.591)</td>
<td>(1.462)</td>
</tr>
<tr>
<td>Private Information</td>
<td>-0.279</td>
<td>0.261</td>
<td>0.129</td>
</tr>
<tr>
<td>(Dummy variable =1 if Treatment 2)</td>
<td>(0.207)</td>
<td>(0.220)</td>
<td>(0.303)</td>
</tr>
<tr>
<td>Private Information x Share of Total Chips</td>
<td>-1.596*</td>
<td>-1.935*</td>
<td>-3.429**</td>
</tr>
<tr>
<td></td>
<td>(0.841)</td>
<td>(1.000)</td>
<td>(1.458)</td>
</tr>
<tr>
<td>Public Share Estimate</td>
<td>0.215</td>
<td>0.182</td>
<td>-0.029</td>
</tr>
<tr>
<td>(Treatment 2 only)</td>
<td>(0.625)</td>
<td>(0.878)</td>
<td>(0.819)</td>
</tr>
<tr>
<td>(Private – Public Share Estimate if positive; 0 otherwise)</td>
<td>(2.634)</td>
<td>(3.649)</td>
<td>(3.079)</td>
</tr>
<tr>
<td>Negative Private Information</td>
<td>7.363***</td>
<td>6.988**</td>
<td>3.514</td>
</tr>
<tr>
<td>(Private – Public Share Estimate if negative; 0 otherwise)</td>
<td>(2.286)</td>
<td>(3.109)</td>
<td>(2.705)</td>
</tr>
<tr>
<td>Complete Information</td>
<td>0.288</td>
<td>0.156</td>
<td>0.858**</td>
</tr>
<tr>
<td>(Dummy variable =1 if Treatment 3)</td>
<td>(0.206)</td>
<td>(0.215)</td>
<td>(0.374)</td>
</tr>
<tr>
<td>Complete Information x Share of Total Chips</td>
<td>-0.663***</td>
<td>-0.536***</td>
<td>-0.962***</td>
</tr>
<tr>
<td></td>
<td>(0.071)</td>
<td>(0.064)</td>
<td>(0.153)</td>
</tr>
<tr>
<td>Complete Information x Actual Shares</td>
<td>0.211</td>
<td>1.280</td>
<td>-2.231*</td>
</tr>
<tr>
<td></td>
<td>(0.779)</td>
<td>(0.844)</td>
<td>(1.337)</td>
</tr>
<tr>
<td>Total Number of Observations</td>
<td>1859</td>
<td>1096</td>
<td>763</td>
</tr>
<tr>
<td>Number of Subjects</td>
<td>156</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Number of Group Clusters</td>
<td>312</td>
<td>183</td>
<td>129</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.108</td>
<td>0.032</td>
<td>0.094</td>
</tr>
<tr>
<td>Dep Mean</td>
<td>6.867</td>
<td>7.290</td>
<td>5.663</td>
</tr>
</tbody>
</table>

Significance level: ***p<0.01, **p<0.05, *p<0.1.
Note: Fixed effects used at subject level. Standard errors clustered at group-period level.
FIGURE 1

EXPERIMENTAL INTERFACE – TREATMENT 2 (I.E., ASYMMETRIC INFORMATION)