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Working Paper 2004-28
November 2004

WORKING PAPER SERIES

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Abstract: We provide substantial evidence that the futures market for West Texas Intermediate crude oil increased the short-term volatility of the cash price of crude oil. We show that the variability of prices increased using both published posted prices and transaction prices for producers. This increased volatility in the price of crude oil may reflect information aggregated into the price, an increase the variance of shocks to the price of crude oil, or noise in the futures price that affects the cash price. We present evidence from experiments consistent with the interpretation that information aggregation not feasible in a posted-price market can explain at least part of the increase in variance. This evidence supports the proposition that information not previously aggregated into the cash price for crude oil is at least part of the reason for the greater variability of the cash price after the opening of the futures market and provides at least one example in which a futures market increased the volatility of the cash market, and prices became more efficient.

JEL classification: G130, G140

Key words: crude oil, futures, posted price, experiments, experimental finance, price discovery, information aggregation

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The authors appreciate helpful comments from Lucy Ackert, Raymond C. Battalio, Peter Bossaerts, David Dubofsky, Donald House, Peter Locke, Shyam Sunder, Robert van Order, Paula Tkac, and participants in seminars at the Commodity Futures Trading Commission, George Washington University, and in sessions at the Economic Science Association and Financial Management Association meetings. Some of Dwyer's initial work on this paper was completed while he was a visiting financial economist at the Commodity Futures Trading Commission. Gillette's initial work on this paper was completed while she was a visiting scholar at the Federal Reserve Bank of Atlanta and the College of Business Administration at Georgia State University. They also appreciate assistance by two crude oil producers who provided invoices and contracts. Qian Li, Nancy Lucas, Shalini Patel, Gwendolyn Penneywell, Anand Venkateswaran, and Wei Yu provided research assistance, and Linda Mundy provided editorial assistance. The views expressed here are the authors' and not necessarily those of the Federal Reserve Bank of Atlanta or the Federal Reserve System. Any remaining errors are the authors' responsibility.

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Trading Institutions and Price Discovery:
The Cash and Futures Markets for Crude Oil

Does a futures market increase the variability of cash market prices, and if it does, is that good or bad? Futures markets can affect spot markets by allowing producers to hedge, providing liquidity to holders of the commodity, providing information about the future price, and facilitating coordination of producers' decisions about future production. Most of these changes are likely to lower the variance of cash prices after a futures market is introduced, although information about the future price can increase the variance of cash prices. On a less positive note, there have been long-standing claims that futures markets adversely affect spot markets by increasing the variance of spot prices because speculators in futures markets are, practically speaking, merely uninformed gamblers. A very large number of empirical studies have found mixed results on whether spot market prices vary more when there are futures markets (Mayhew 2000), and it remains an open question.

The volatility of cash prices for crude oil increased after futures on West Texas Intermediate crude oil began trading on March 30, 1983. Researchers have attempted to identify the specific cause of the increased volatility in the crude oil spot price, including inventory changes and speculative trading behavior in the futures market (Pindyck 2002; Smith 2002). The source of the dramatic increase in price volatility in the crude oil market after the introduction of the futures, however, remains an open question. The evidence on the increased volatility of the cash market is based on posted prices. A first thought might be that these posted prices are mere list prices, but we show that actual prices from invoices as well as the average price received by producers in Texas are closely related to posted prices.

Trading in the futures market is a possible reason for the increasingly frequent changes in the posted price and the associated higher variance of prices and price changes. One explanation is that trading on the futures market aggregates information in the futures price that previously was not apparent to refiners who post prices. Because of this information aggregation, refiners can infer the information from the futures market, arbitrage can force the posted price to respond to information in the futures price, or both, and the posted price may now reflect this information and change more frequently than before. Another explanation for the increased frequency of price changes is that a successful futures market depends on risk to be allocated. More volatility in demand and supply in 1983 and later years may explain both the success of the futures market and the higher frequency of price changes in those years. A third explanation is less positive for the evaluation of the futures market and is consistent with common complaints about futures markets – the futures market may merely introduce people who want to gamble into determining the price for crude oil.

What is the evidence from other futures markets introduced into other posted-price cash markets? Unfortunately, a long search has not turned up solid evidence that any other futures market has been introduced into a posted-price cash market. NYMEX has begun trading a contract for coal which has the potential of having similar effects to the market for crude oil, but this innovation is recent and the success of the futures market is uncertain.[1] One possible market with a posted-price

[1] Bonskowski (1999, p. 19; 2002) summarizes recent trends in coal cash-market contracts and suggests that higher price volatility undermining long-term contracts is one reason why coal futures are being introduced into an industry in which prices had been determined by long-term contracts between electric utilities and coal mines. This contract may well fail – trading was nonzero only on two days in December 2003.

cash market is the market for onions, which is interesting because the futures market was quite controversial and futures in onions were outlawed in 1958.

While more comparisons before and after futures start trading would be interesting, such comparisons would be hard pressed to disentangle increased volatility that creates an opportunity to open a futures market and increased volatility due to the futures market. Furthermore, any attempt to identify information aggregation in the futures market's price and noise due to uninformed speculation by traders in futures inevitably would be based on specific identifying assumptions that would be fragile and contentious.[2]

We use controlled experiments to provide evidence on the effect of introducing a futures market into a posted-price cash market, which avoids the problems associated with before-and-after comparisons. These experiments provide evidence in addition to the data from the crude oil market, which suggested the hypothesis, that the introduction of the open-outcry futures market can explain the increased variability of the posted cash price. Experiments make it possible for us to examine an environment in which the direction of causation is clear. We hold constant the shocks to the experimental economy; hence greater variability of shocks does not explain the existence of the futures market or greater variability of the price. Furthermore, we know the shocks to the economy and we can examine whether more variable cash prices are reflecting those shocks or speculative gambling.

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[2] While it would not resolve the choices among alternatives, it would be helpful to construct a theoretical model of the markets, which then could be seen to imply the observed behavior. This is not trivial. Existing theoretical models such as the Glosten and Milgrom model (1985) are not well developed enough to characterize the behavior of the agents across these markets and the Kyle model (1985) assumes impersonal competition, which is not appealing as a complete theoretical characterization of agents' behavior when prices are posted on the cash market. As a result, we compare the experimental results to highly stylized theoretical predictions.

Earlier experimental research has examined posted-price markets and the effects of futures markets on auction spot markets. The evidence on posted-price markets quite clearly shows that auctions can aggregate information more quickly than a posted-price market (Davis and Holt 1993, pp.173-87). The evidence on the effects of a futures market on the volatility of the spot price and on allocative efficiency is mixed (Forsythe, Palfrey and Plott 1984; Friedman, Harrison, and Salmon 1984).[3]

Our experimental results show that a futures market increases the volatility of the posted cash price because the futures market aggregates information that is not otherwise reflected in cash prices. Without a futures market, the prices posted by buyers do not reflect information about the state of supply. With a futures market, the posted price can reflect information about supply held by individuals even though no individual buyer can know the information other than by observing the futures price. As a result, the cash market can have a more variable price precisely because it is more informationally efficient.

This experiment provides evidence that the futures market for crude oil contributed to the increased variability of cash prices. This evidence, of course, does not rule out the possibility that greater expected variability in demand and supply explains the timing of the introduction of the futures market, the futures market's success, and some of the increased variability in prices.

Surprisingly little analysis of the effects of futures markets has examined or even mentioned how cash prices are determined. Our evidence indicates that, at least in the case of crude oil, the way

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[3] Krogmeier, Menkhaus, Phillips and Schmitz (1997) investigate price discovery in forward and spot markets, examining seller's risk associated with markets based on advanced production versus production to order.

Besides institutional differences, these experiments concerning futures markets generally are more easily interpreted as ones in which agents are learning about the market or markets rather than applying stationary expectation functions such as rational expectations: a more plausible interpretation than learning after the futures market has existed for twenty years.

in which prices are determined in the cash market – the cash market's microstructure – is very important for understanding the effects of the futures market on the cash market.

In the next section, we examine the cash market for West Texas Intermediate Crude Oil and contrast price behavior before and after the introduction of the futures market. In the following section, we present the experimental evidence, which is followed by a brief conclusion.

I. Posted Prices, Futures Prices and Prices Received by Producers

In this section, we examine the behavior of the prices in the spot market and the futures market for crude oil. The data show that the posted price is closely related to transaction prices and that the posted price changes more frequently after the introduction of the futures market, with the frequency of price changes gradually increasing from a couple of times a year to three or four days a week.

A. *Posted Price of Crude Oil*

The posted price of crude oil changed relatively infrequently before the introduction of the futures market. Figure 1 shows the nominal posted price for West Texas Intermediate Crude Oil (WTI) at the beginning of the month for January 1946 to December 2003.[4] These are prices posted by the refiners for pickups of crude oil from producers. This nominal price changes little in many years. For example, from June 1959 to June 1964, the nominal price is constant at $2.97, then falls to $2.92 until August 1966.

Schwartz and Smith (2000) and others have found evidence that the price of crude oil has a unit root component and a mean reverting component. As is evident in Figure 1, before the late 1970s or early 1980s, the price of crude oil generally was constant, although changes tended to be permanent when they occurred; the transitory or mean reverting component of the price was zero for all practical

[4] The posted price is for Amoco from January 1946 to December 1982 and Sunoco afterwards. The prices are from posting sheets provided by the firms.

purposes. In the 1990s, this transitory component of price changes is substantial and the frequency of price changes has increased substantially. Absent any other information, one obvious explanation is an increased variance of shocks to demand and supply in more recent years.

The frequency of price changes in earlier years is low in one sense: the nominal price is constant for extended periods. While it is difficult if not impossible to define the term *sticky price* with any precision, these data indicate that the posted nominal price of crude oil did not change very often in some periods and the relative price fell for extended periods at the rate of inflation.[5] It would be surprising to see a pattern of changes in supply and demand that produce a relative price falling at the rate of inflation, but it is possible.

B. *Invoice Prices for Crude Oil*

It is natural to suggest that the problem is with the data. Perhaps these posted prices reflect prices associated with explicit long-term contracts and the underlying transactions prices vary substantially more. Contracts between refiners and two producers that are available to us and the producers' invoices for crude oil sold provide no support for such a supposition. These contracts between producers and refiners are terminable at will by either party with thirty day's notice. The price received by the producer is not specified in the contract, but with occasional premiums or discounts, the contracts specify that the producer will receive the posted price. There are adjustments for the crude oil's gravity but these are standardized and change infrequently.[6]

We have data based on invoices sent and received for two producers in the 1980s. For one producer, the data cover 1985 through 1987. For the other producer, the data cover 1984 through

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[5] The existence of such stickiness in other markets has been noted by, e.g., Carlton (1986), Bils and Klenow (2002) and Levy and Young (2004).

[6] These adjustments, while not completely uniform across refiners, are similar across refiners, are the same across producers selling to a given refiner, and change even less frequently than posted prices.

October 1988. These data are from the firms' files and are based on essentially free access to the firm's records. Our underlying data are the actual prices per barrel for each pickup of crude oil by a tanker truck.[7]

The data for these two producers are consistent with posted prices and actual transactions prices being quite similar. Figure 2 shows daily values of these transaction prices for one of the two producers, the posted price for Sunoco and the differences between these two prices. The figure indicates that the variation in the price received by the producer is almost entirely the same as the variation in the posted price. The overall variability of the price received by the producer and the posted price are quite similar. The standard deviation of the price received by the producer is $5.41 and the standard deviation of the posted price is $5.44 for those same days. The deviations between the price received by the producer and Sunoco's posted price are minor in one respect: the mean deviation of $0.16 is small relative to the standard deviation of the prices but the standard deviation of the mean difference is only $0.018, indicating that the mean difference is quite unlikely to be zero. The range of deviation is relatively large, with the minimum value being -$2.415 and the maximum value being $1.60. The deviation of -$2.415 is associated with non-synchronous price changes when the price received by the producer fell by $2.00 in one day and the price posted by Sunoco fell in steps by $2.50 in nine days. The deviation of $1.60 occurs for one day when Sunoco's posted price fell by $1.50 one day and the price received by this producer fell by the same amount on the next day.

Average prices received by Texas crude oil producers indicate that these producers' data are representative of data for other producers. Figure 3 shows the average posted price for each month from January 1983 through December 2003 for Sunoco and the average price reported by all

[7] On some days, there is no pickup of crude oil and on other days there are multiple pickups.

producers to the Texas Comptroller of Public Accounts through August 2003. This figure indicates that the average price reported by all producers quite closely tracks the posted price for Sunoco.

Overall, we conclude that transactions prices track the posted price reasonably closely and that both posted and transactions prices change infrequently before the introduction of the futures market.

C. *Futures Price of Crude Oil*

The futures price makes it possible to give substantially more precision to the observation that the posted price changes infrequently. In the early years after the introduction of the futures market in 1983, the posted price varies relatively little compared to the futures price. Figure 4 shows the futures price at expiration for WTI on the New York Mercantile Exchange (NYMEX) and the average posted price during the delivery month. This graph includes data from the inception of the futures market through December 2003. In the early years, the posted price varies substantially less than the futures price. From April 1983 through October 1984, the monthly average posted price is constant at $30. In later months, the monthly average posted price is the same in two consecutive months only three times.[8] That said, there is a close relationship between the average posted price during the delivery month and the futures price at expiration. The R^2 of a regression of the posted price on the futures at expiration is 0.88 with a slope coefficient of 0.94 and a constant term of -0.09 dollars.

The number of months with a constant price suggests that the frequency of price changes increased a few years after the introduction of the futures market, but daily changes in the posted price tell a more complete story. Table 1 shows the daily frequency of price changes by year since 1983. Price changes were rare in the early 1980s: In both 1983 and 1984, the posted price changed only twice. In 1986 – the year of the crash in oil prices – posted prices changed on 10.3 percent of

[8] The consecutive months with the same average prices are only February and March 1985, November and December 1985, and October and November 1986

weekdays, a record number of changes at that time, which can be compared to price changes on 84 percent of the weekdays in 12003. Since 1993 prices have changed on more than half the weekdays, and prices have changed on at least 60 percent of weekdays since 1996.

It is extremely unlikely that the frequency of price changes has not increased. From 1983 through 1987, there were price changes on 4.3 percent of the weekdays – 56 price changes on 1304 weekdays; from1999 through 2003, there were price changes on 80.1 percent of the weekdays – 1,045 price changes on 1,304 weekdays. The probability of observing price changes on 4.3 percent of weekdays is virtually zero if the true probability of a price change is 80.1 percent; the probability of observing price changes on 80.1 percent of weekdays is virtually zero if the true probability is 4.3 percent. Similarly, if the average for the whole period were the correct frequency, the low frequency of price changes in the first five years in the table and the high frequency in the last five years would be extremely unlikely. There is no doubt that the underlying frequency of price changes has increased since the introduction of the futures market.

The standard deviation of the posted price and its changes, also included in Table 1, is another way of seeing that the variability of prices has increased since futures in crude oil started trading. While the standard deviation arguably is less informative in the early years because of the infrequency of price change, this measure of price volatility supports the same conclusion: the volatility of the posted price of crude oil is higher after the futures market opened. The standard deviation of the posted price is 4.5 times higher in 2003 than in 1983, and the standard deviation of price changes is 8.5 times higher in 2003 than in 1983. While the changes in the standard deviation have been much less uniform than the changes in the frequency of price changes themselves, the volatility in recent years was not evident in the early years of the futures market for crude oil.

There is no reason to think that the futures market has increased the variability of innovations to the permanent part of the posted price. Figure 1 visually and Table 1 indirectly suggest that there has been an increase in the variance of relatively permanent changes in the posted price since the introduction of the futures market, and evidence is consistent with such a component of the price (Schwartz and Smith 2000). It is hard to imagine that permanent changes in demand and supply are not eventually reflected in the price, whether or not there is a futures market.

The futures market may account for the increased transitory variation in the posted price though. On general grounds, we would expect the futures price to be related to the expected posted price because there is a substantial amount of delivery at the futures price, and transitory variation in the futures market may be reflected in transitory variation in the posted price. We conjecture that the combination of an auction futures market and a posted-price cash market explains much of the increased transitory variation in the posted price of crude oil. Posted prices are posted by refiners, and futures prices are determined in auction markets by open outcry. Experimental evidence indicates that posted prices tend to change less frequently and be less efficient than auction prices (Plott 1986), and this greater stickiness may be a real phenomenon. As a result, the auction futures price may be more variable than the posted spot price without a futures market because the futures market price aggregates information about transitory changes in demand and supply.

II. EXPERIMENT

In this section, we run an experiment to examine whether the introduction of a futures market can increase the variability of a posted spot price due to information aggregation in the futures market and traders who participate in both markets. If so, then there is some ground for thinking that the futures market in crude oil has increased the variability of the cash price.

A. *Overview of Experiment*

The experimental design has two institutional treatments: Treatment 1 has a posted-bid spot market, and Treatment 2 extends the environment of Treatment 1 by adding a futures market organized as a double oral auction. Both treatments include transitory, random supply shocks in the markets. Several sequences of these cost shocks are used to examine the behavior of the spot market price in sessions with and without a futures market.

Our experiment focuses on the effect of trading in the two markets and possible information aggregation in the futures market that informs spot market buyers' bids in today's spot market. Our choice of experimental design is motivated by the nature of the spot and futures markets for crude oil and is guided by previous experimental research. The contractual arrangements in the crude oil spot market can be characterized as a posted-bid market. Refiners set prices at which they will buy and producers decide how much they will sell at those prices. We use a double oral auction to characterize the futures market, the same experimental market used in prior studies of futures markets (Forsythe, Palfrey and Plott, 1984; Friedman, Harrison, and Salmon, 1984).[9] In contrast to our study, however, these studies also use double oral markets in the spot market with all participants trading in both the spot and futures markets.[10] The transactions in their spot markets frequently go to zero after

[9] Sunder (1995, pp. 464-67) provides a judicious summary of this research.
It might seem that a futures market organized as a posted-bid market would also suffice to aggregate this information and relay it to the spot market traders in a timely fashion, but previous experimental market research indicates otherwise. A variety of controlled experiments in a stationary demand and supply environment have shown that a double-oral auction aggregates information more quickly and converges to competitive levels faster compared to a posted-bid market. Davis and Holt (1993, pp. 183-187), and Holt (1995) provide detailed summaries of this evidence. Of particular interest is a study by Plott and Smith (1978) which compares a posted market and a one-sided oral bid auction with repeated bids possible in a period that are otherwise the same. They find inferior average performance in the posted market and conclude that this difference is primarily due to slower convergence to competitive predictions.

[10] We ran a session with a spot market organized as a double oral auction for a robustness check because we know of no prior experimental studies that compare a posted-bid market and a double oral auction with supply shocks. A comparison of the two institutions, presented in Appendix D, confirms prior experimental evidence of better information aggregation in a double oral auction.

participants gain experience in the two markets. Because of the increased complexity of our design introduced by the different trading rules in the posted-bid spot market and the double-oral futures market and because transactions regularly occur in the spot market for crude oil, most of the buyers and sellers participate in only one of the two markets in our sessions that include both the spot and futures markets. We do have two traders who trade in the futures market and can sell in the cash market after taking delivery of the good. Using largely different participants in the spot and futures market also results in a stronger test of our research question: Does the introduction of the futures market affect the behavior of the buyers posting bids in the spot market?

Prior research gives some reason to think that these experimental institutions, which map into the market institutions for crude oil, can be associated with observations similar to those in the market for crude oil. The closeness of a double oral auction to demand and supply in terms of both price and efficiency is one of the most stylized facts of experimental economics.[11] Slow convergence in posted price markets to a stationary posted price also is well documented.[12] Even so, the results of our particular experiment is not obvious. Prior studies of the effects of futures markets provide conflicting evidence. Prior studies do not provide subjects with information about the exogenous shocks affecting the market, which may affect the conclusions, and this is especially so when buyers and sellers in the cash market observe the futures market but do not participate in it. We add arbitrageurs, but this is

[11] Many researchers have argued that the superior performance of the double oral auction is directly related to the sequential aspect of trading, which makes it possible to revise prices and haggle over units. Furthermore, when the good cannot be carried across periods, there is a strong incentive to make price concessions at the end of the period to buy or sell marginal units. The inability of buyers in posted markets to revise prices and the absence of opportunity to haggle over the price during a trading period appear to be important parts of the explanation of the differences between these institutions. In a posted-bid market, mistakes in the form of overly low prices posted in one trading period by buyers cannot be corrected until the following period; consequently, units remain unsold when the period ends and the number of unsold units becomes the statistic that reflects the current period's information instead of the prices. In decentralized markets such as the spot crude oil market, the number of unsold units in the market is not likely to be estimable with much accuracy.

[12] This slower convergence of the posted-bid market to competitive levels is more exaggerated in nonstationary environments (Davis, Harrison and Williams 1991).

different than allowing all participants to trade in either market, if nothing else because trading in the cash market cannot be supplanted by trading in the futures market. Consistent with complaints about futures markets, the futures market price could reflect substantial noise which overwhelms the futures market's usefulness as a signal for behavior in the cash market.

B. *The Traders and Markets*

All participants are informed about the trading rules in the markets, the number of different types of participants, the cost and redemption schedules, and the probability distribution of the cost states. Because we wish to examine differences in buyers' bids across the two treatments and not how quickly a rational expectations equilibrium is attained, all participants are given the two different redemption schedules and the three possible cost-state schedules for that session.[13] This information is given to everyone at the same time to maximize the likelihood that the information will be common knowledge. The instructions are neutral in language. In particular, the experimenter and the instructions never mention the words futures or spot market, instead referring to them as Markets X and Y. We discuss the incentives and trading rules in the spot market followed by the futures market because the spot market is common to both treatments.

Posted-bid Market Without a Futures Market – In a posted-bid market, buyers post prices and sellers respond to these bids by deciding how much to sell. Buyers are given a redemption schedule with the values at which they can redeem units of the good at the end of each period. There are two types of buyers distinguished by their redemption value schedules which differ by a relatively small amount.[14] The number of buyers with each redemption schedule is known, although their identities are not. If a buyer purchases a unit for less than its redemption value, he makes a profit on that unit; if a buyer

[13] The instructions are included as Appendix A.

[14] Appendix B shows the redemption value schedules for each parameter set used in the experiments.

purchases a unit for more than its redemption value, he has a loss on that unit; and if a buyer purchases nothing, he earns nothing. Sellers are given a cost schedule with the cost paid for each unit sold. All sellers have the same cost schedule and are told this. If a seller sells a unit for more than its cost, he makes a profit on that unit; if a seller sells a unit for less than its cost, he has a loss on that unit; and if a seller sells nothing, he earns nothing.

The same sequence of events is followed each period. First, each buyer records on a sheet a price at which he will buy the good and a maximum quantity that he will buy at that price. Monitors then collect the buyer sheets from the buyers. After all these sheets have been collected, the experimenter records the bids and maximum quantities next to each buyer's number on a transparency, which is then displayed to all participants at the front of the room.

After buyers' bids have been determined, sellers are given the period's pre-drawn cost schedule. Providing the cost state to the seller after prices are determined makes it impossible for the sellers to inadvertently transfer information about the cost state to buyers. The randomness in the experiment occurs through this state-dependent cost schedule given to sellers each period. The cost schedule for each period is drawn from a simple distribution: The distribution's probabilities are 25 percent for a low-cost state, 50 percent for a middle-cost state and 25 percent for a high-cost state. The shock is drawn independently each period and any earlier shock has no effect on this period's price – an extreme version of a mean-reverting component. In the experimental instructions for each session, participants are told the distribution and that the pre-drawn cost schedule in each period is the same for all sellers.

After distribution of the actual cost state, units are bought and sold. First, a seller is chosen at random to select the buyer and the quantity he wishes to sell. The seller is allowed to sell up to the amount that the chosen buyer wants to buy. A second seller then is selected, and so on. In the event

that a seller wants to sell more units than his chosen buyer wants to buy, the seller is given the opportunity to sell more units after all other sellers make their initial sales if unsatisfied demand remains.[15]

It is a simple matter to show that the price in a rational expectations competitive equilibrium with risk-neutral traders in this market is the price's unconditional expected value. This unconditional expected value is constant across periods and is the same as the equilibrium's expected value conditional on all participants knowing that the cost state is the middle cost state.

Posted-bid Market With a Futures Market – The posted cash market operates essentially the same with a futures market, with the exception that two traders who can buy and sell in both markets replace one seller in the spot market. In a rational expectations competitive equilibria with risk-neutral traders, the unconditional expected value of the cash price equals the expected value not conditional on the cost state with a futures market and traders, as it does without a futures market.

The futures market is organized as a double-oral auction with all trades in the futures market in a period occurring before prices are posted on the spot market. This is similar to the relationship between the cash and futures markets in crude oil on a daily basis, because the price on the cash market is set after the close of trading on the futures market.[16] The futures market can aggregate

[15] Myopically optimal selling behavior is typical in posted-bid markets, and for this reason, seller behavior is often computer simulated. Simulated sellers eliminate any strategic multi-period behavior by sellers. In posted-offer markets, Brown-Kruse (1991) conclude that strategic buyer behavior generally induces conservative pricing on the part of sellers, and this leads to a faster convergence to competitive levels. Likewise, in posted-bid markets we would expect strategic sellers to withhold units which would induce buyers to post higher prices. As a result, we think that the human sellers in our posted-bid markets facilitate convergence to competitive levels.

[16] Delivery of course does not occur on a daily basis, but delivery every N trading periods with N greater than one would complicate the experiment substantially because such delivery would add the complexity of an asset market to the experiment. We do not think that this is an important issue for our purpose, but the experiment can be thought of as being closest to the crude oil futures market on the last day of trading of a contract.

information and reveal the state, although it need not, and that information may or may not be reflected in the cash price.

In the experiment, futures traders are arranged in a circular fashion around an overhead projector where bids and offers are recorded – an arrangement similar to trading in the pits at the NYMEX and other futures markets. Each contract is for one unit. Sellers in the futures market are given the cost state before the futures market opens. Buyers verbally call out bids for a unit and sellers call out offers for a unit at any time. Once there is an outstanding offer or bid, subsequent offers and bids must be improving, i.e., a bid-ask improvement rule is in effect. Buyers can accept the best offer at any time, and sellers can accept the best bid at any time. Each period of trading in the futures market lasts eight minutes. If a minute had elapsed without a new bid or offer being made, then the market would have been shut down prior to the eight-minute maximum, but this termination rule never applied.

The participants' incentives are such that buyers in the spot market have higher earnings if they post prices conditional on the cost state, sellers in the spot market have higher earnings if they buy when the price is greater than their cost, and traders have higher earnings if they buy in the futures market and sell in the cash when they expect positive earnings. Buyers and sellers in the futures market are given the same redemption and cost schedules as buyers and sellers in the spot market. To allow for traders purchasing in the futures and later selling in the cash market, we drop one buyer in the futures market and one seller in the cash market, replacing them by the two traders who can operate in both markets. The futures market has five sellers, four buyers and two traders and the

posted-bid spot market has four sellers, five buyers and two traders. We use two traders instead of one to allow for the possibility that one might go bankrupt and have to leave the experiment.[17]

Traders receive positive earnings by buying at a lower price in the futures and selling at a higher price in the spot market. To reduce their execution risk, the traders were selected in the spot market to sell before the other sellers in the spot market.[18] In addition, the traders could sell any desired quantity to the experimenter at a price of 1.25 cents (five francs), which is slightly less than the lowest cost in the lowest cost state.[19] The traders received initial endowments of funds for transaction purchases, just as an actual trader is required by the exchange to have capital before trading.[20] A trader would be asked to leave the experimental session if at any point he lost his cumulative endowment or if his one-period loss exceeded the maximum, as indicated on the cumulative record sheet for traders in Appendix A.[21] The incentive structure faced by the traders is a discontinuous function. From the initial endowment of 1,200 francs to a cumulative loss of 510 francs (more than the maximum one period loss) traders earnings and losses are one to one. A

[17]In two double-oral auction markets with "speculators" operating in both markets, Plott and Uhl (1981) find that convergence to competitive equilibrium is not affected by the number of speculators, who act as if they solve the implicit coordination problem.

[18] This rule was implemented to avoid the possibility of one or more buyers on the cash market posting very low prices that occasionally generate very high profits by catching a trader who has paid for units on the futures market and effectively has a zero marginal cost of the good.

[19] To avoid the appearance of asymmetry, both traders and the posted-bid market sellers were permitted to sell to the experimenter, although it would never be profitable for a seller to produce to sell to the experimenter and none did.

[20] Because trading can lead to negative payoffs for participants, it is common for experimental researchers to give these types of traders an endowment. Recently, both experimental economics and psychology literatures have begun to question whether subjects behave differently when they receive these up-front payments. This has been referred to as the "house money" or "small unexpected windfall gains" effect. However, in a standard voluntary contribution experiment, Clark (2002) finds no support for a "house money" effect. If a house money effect is present in our experiments, it should increase risk taking by the traders.

[21] In pilot experiments, at least one trader had to leave the session due to exceeding the cumulative losses. Realizing that successful traders are a rare breed in the laboratory as well as in the real world, we imposed a maximum loss to continue trading in a period. This constraint can be interpreted as similar to the exchange practice of requiring active traders to maintain minimum capital margins.

breakpoint occurs at a cumulative 510 franc loss, where until the total endowment is lost or his earnings reduce his cumulative loss sufficiently, the trader earns a flat fee for trading. This flat incentive range provided a buffer for risk taking by traders and was intended to suggest a reevaluation of their trading strategy. None of the traders in our sessions ever faced cumulative losses large enough to place them in this flat incentive range. Although all market participants were told the traders' incentive structure, the values of the initial endowments and loss breakpoints were private information.

Participants in the spot market could listen to the bids and offers being made in the futures market and they could see the posted contract prices on a blackboard at the front of the room as they occurred. Participants in the spot market were not given information about the cost shocks while the futures market was trading. After futures trading ended, buyers in the spot market posted their prices and submitted their buyer sheets to a monitor as in the posted-bid market in Treatment 1. The producers in the spot market then were given the period's cost state and trading followed the same sequence as in Treatment 1. After trading, the experimenter informed participants of the cost state.

C. *Experimental Details*

The participants were undergraduate and graduate students at a large state university. To ensure participants understood the rules of the game and how their earnings would be determined, the experimenter read the instructions aloud and participants worked through worksheets. Participants' roles in all sessions were randomly assigned. Different parameter sets and randomly pre-drawn cost state sequences were used across the sessions. Table 2 presents details of the experimental design. Treatment 1 has only the posted-bid spot market, and Treatment 2 has a posted-bid spot market and a double-oral futures market. The monetary unit in the experimental sessions is a franc to allow the desired divisibility in prices between different cost state equilibria. At the end of the experiment,

participants are given 2.5 cents per franc earned. Salient earnings were paid: average payments across treatments and experience levels varied between $26.28 and $41.30 in sessions lasting two to three hours.

We ran both Treatments 1 and 2 with inexperienced and experienced participants. An *inexperienced* session is one in which the participants have not participated in that particular treatment before. An *experienced* session is one in which the participants previously participated in a prior session of that particular treatment. Prior to participating in an experienced Treatment 2 session, all participants moved sequentially through an inexperienced Treatment 1 session to an experienced Treatment 1 session and then to an inexperienced Treatment 2 session. Participants were not kept in exact cohorts as they moved through the treatments, but about 50 percent of the participants in the experienced Treatment 2 sessions had participated together in the same inexperienced Treatment 2 session.[22] The experimenter made participants in the experienced Treatment 2 sessions aware that all other participants had previously been in the same sequence of inexperienced and experienced sessions by having participants raise their hands if they had participated in the sequence of sessions. There are some purposeful design differences between the inexperienced and experienced Treatment 1 sessions. To facilitate learning about decision making in the posted markets, participants in the inexperienced Treatment 1 sessions switched roles: Buyers became sellers and sellers became buyers midway through the planned number of periods in a session.[23] Participants did not switch roles in the inexperienced Treatment 2 sessions because 1. all subjects had experience in both roles in the posted-

[22] Participants from pilot sessions with the same parameter sets and draws of cost sequences as the sessions analyzed in this paper were included in experienced Treatment 2 sessions to provide the necessary number of participants in the Treatment 2 sessions after dropouts from cohorts. These pilot experiments were the same as the experiments in the paper except that traders had different payoffs. These "fill-in" participants had at least as much experience as the remaining members of the cohort--an inexperienced Treatment 1 session, an experienced Treatment 1 session and an inexperienced Treatment 2 session.

[23] Many experimental studies with posted market designs give participants experience in both roles.

bid market in Treatment 1; 2. the primary objective of the inexperienced Treatment 2 session is to acclimate participants to the more complex trading environment with two markets; and 3. experimental evidence indicates that participants acclimate to trading roles in a double oral auction quickly.

The inexperienced sessions of Treatment 1 (labeled Treatment 1A) ran for 12 or 20 periods and lasted about two hours, while the experienced sessions of Treatment 1 (labeled Treatment 1B) ran for 12 or 15 periods and lasted about an hour and a half. The addition of the futures market in Treatment 2 reduces the number of periods that can be completed in a session.[24] The inexperienced sessions of Treatment 2 (labeled Treatment 2A) ran nine periods lasting three hours, while the experienced sessions of Treatment 2 (labeled Treatment 2B) ran ten periods lasting three hours.[25]

III. EXPERIMENTAL FINDINGS

The parameterization of cost schedules for each of the three cost states implies a different rational expectations competitive equilibrium price conditional on the cost state. To help discern whether variation in bids reflects noise or a price associated with a different cost state, the conditional equilibrium prices are separated by 100 francs (see Appendix B).[26] Experimental results are discussed

[24] It is fairly widely accepted in experimental economics that the attention span for participants is about three hours, and thus lengthening the sessions beyond three hours would require a significant break. We did not wish to give the participants in a session the opportunity to discuss strategy and it is difficult to recruit participants for a longer time span; hence, we capped our sessions at three hours.

[25] In the inexperienced session 10 of Treatment 2A, each period of the double oral futures market lasted ten minutes resulting in only five periods in a three hour period. In the remaining two sessions for Treatment 2A, we reduced the auction period time to eight minutes, and consequently, nine periods were completed in each of the sessions 11 and 12.

[26] The discrete nature of supply-and-demand step functions often results in a vertical overlap or price tunnel, (Davis and Holt 1993, p. 131). Our price tunnel at each equilibrium price is ten francs.

only for the experienced sessions for both treatments because the qualitative results of the inexperienced and experienced sessions are similar within a treatment.[27]

To simplify further discussion, the reference equilibrium prices are called simply the *unconditional equilibrium price* and the *conditional equilibrium price*, both of which are based on equilibria with rational expectations by risk neutral participants in perfectly competitive markets. The unconditional equilibrium price is not conditional on the cost state; the conditional equilibrium price is conditional on participants knowing the cost state. Figure 5 shows the equilibria in the posted-bid market conditional on the buyers knowing the cost state.

A. *Posted-Bid Spot Market (Treatment 1)*

How do buyers bid in this posted-bid market environment in which they only know the probability distribution of the cost states before placing their bids? Our hypothesis is that buyers will bid the unconditional equilibrium price, which is the same as the conditional equilibrium price in the middle cost state which has a 50 percent probability in any period.

Figure 6 shows the distribution of prices of actual trades in the posted price sessions without a futures market. The actual prices generally range between prices in the middle cost state and the low cost state, but there is no evident relationship between the prices and the cost states, an impression confirmed by a statistical analysis.

The average prices in the posted-bid market are less than the unconditional equilibrium price, but average prices in each period never are as low as the conditional equilibrium price in the low-cost state. Table 3 summarizes the bid behavior for the sessions with only a posted-bid market. The average bids each period range from about 547 to 572 francs. An F-test rejects the null hypothesis that the average bids in the three sessions are the same with an F-value of 8.459 and a p-value $< 10^{-3}$. For

[27] Appendix C presents the data for the inexperienced sessions.

each of the three sessions, t-tests are inconsistent with the hypothesis that the average bid is equal to the unconditional competitive equilibrium price of 595 (p-values < 10^{-3}). In two of the three sessions, the modal bid is 570, and the interquartile range highlights that the large majority of bids never reach the conditional equilibrium prices implied by the low cost state or the high cost state.[28]

There is no apparent relationship between bids and the cost state in Treatment 1. Across sessions, the correlations of the bids with the conditional equilibrium prices range from -0.14 to 0.19. An F-test for each session cannot reject that the means of the bids in the low cost, middle cost and high cost states are the same, with p-values of 0.077 for Session 7, 0.891 for Session 8, and 0.392 for Session 9. Hence, in the posted-bid markets sessions without a futures market, variability in bidding behavior is observed but it is not related to the cost state because none of the participants were told the cost state prior to prices being posted.

2. *Spot and Futures Market (Treatment 2)*

When observing prices in another market responding to similar forces and with traders who can operate in both markets, does the price in the other market aggregate the information sufficiently well that buyers's prices in the spot market are similar to what they would be if buyers knew the cost state? Our hypothesis is that prices in the double-oral auction futures market will track the conditional equilibrium price, that bids in the posted-bid market will be more consistent with the conditional equilibrium price and that the variance of the cash price will increase.

Figure 7 shows the prices in the futures market and the posted prices in the cash market for each session. While the trade prices in the futures market are not exactly equal to the conditional

[28] As Davis and Holt (1993, p. 181) point out, the asymmetry of buyers' and sellers' roles in posted-bid markets is a likely explanation for the generally lower prices than in the more symmetric double-auction markets. Buyers posting prices apparently try to set low prices since sellers in a posted-bid market tend to make all profitable sales. In typical designs with nonstochastic supply and demand, prices start below the competitive level and rise over time.

equilibrium prices in each period, we see some relationship between the two. Furthermore, it is clear that the range of cash prices is greater – for example, they sometimes are close to the conditional equilibrium price in the high-cost state, which never was true in the absence of a futures market.

Details about the prices with both a futures market and a posted-bid market are explored in Table 4. Panel A of Table 4 summarizes the prices for the combined sessions, while Panel B summarizes them by individual session. As Figure 7 suggests, the futures market prices are correlated with the equilibrium prices conditional on the cost states, 0.85 for all sessions and 0.98, 0.75, and 0.84 for sessions 13, 14 and 15 respectively. In contrast to the posted-bid market without a futures market, the posted-bid markets with a futures market have a high correlation of the posted bid with the conditional equilibrium price. The correlations are 0.88 for all of the sessions and 0.96, 0.95 and 0.75 for sessions 13, 14 and 15 respectively, similar to the correlations of the futures market prices with the conditional equilibrium prices. The correlations of the last futures price with the average posted bid of 0.95 for all of the sessions and 0.99, 0.98 and 0.89 for sessions 13, 14 and 15 respectively, suggest that the high correlations of posted bids with competitive equilibrium prices is associated with the transactions prices in the futures market.[29] In further contrast to Treatment 1, the data for the posted-bid markets are inconsistent with the hypothesis that the mean bids in the low cost, middle cost and high cost periods are equal: an F-statistic of this hypothesis has a p-value less than 10^{-3}.[30]

The absolute value of the difference between each price and the conditional equilibrium price, a price tracking measure, provides further evidence that the futures and spot market prices track the periods' cost states. In the futures market, the aggregated sessions' average price tracking measure

[29] The correlations of the average futures prices with the average posted bids are 0.96 for all sessions and 0.97, 0.97 and 0.93 for sessions 13, 14 and 15 respectively.

[30] This hypothesis also is inconsistent with the data for the futures markets with a p-value less than 10^{-3}.

is 20.50; in the posted-bid spot markets, it is 17.81. The value of 17.81 is much lower than the average of 62.9 in the posted-bid spot market without a futures market, indicating prices closer to the conditional equilibrium prices.

3. Comparison of Posted-Bid Spot With and Without a Futures Market

In this section, we compare the prices in the posted-bid spot market without a futures market and with a futures market. To facilitate a direct comparison of the posted-bid spot markets across Treatment 1 without a futures market and Treatment 2 with a futures market, the parameter set and randomly pre-drawn cost state sequence used in a Treatment 1 session also were used in a Treatment 2 session. The experienced sessions with a futures markets ran ten periods, and, only the first ten periods of the posted-bid spot market sessions without a futures market are used in the statistical analysis.[31]

Our hypothesis is that the average bids in the posted-bid markets without a futures market will not track the cost states, and the average bids in the posted-bid spot market with a futures market will. Figure 8 shows the sequences of posted prices in the sessions with and without a futures market. Visually, these average accepted bids appear to be consistent with our hypothesis. Table 5 summarizes bids for the spot market data for each treatment. Panel A indicates that the mean bid and the standard deviation are higher in Treatment 2 with a futures market than without one. A t-test of the null hypothesis that the mean bids across the two treatments of the posted-bid markets are the same is inconsistent with the data at a p-value less than 10^{-3}.

[31] The Treatment 1 sessions were run prior to the Treatment 2 sessions. Not knowing exactly how many Treatment 2 periods could be obtained in the three hour session, we ran more periods in the Treatment 1 sessions in which there was less of a time constraint to maximize the possible number of observations. There are no qualitative differences in the data or hypothesis tests when using all periods instead of the first ten periods.

The price tracking measure provides further support for the proposition that the spot market price with a futures market reflects the period's cost state. Panel B in Table 5 examines the differences in the treatments by cost state. In all cost states, the spot markets with a futures market more closely track the conditional equilibrium price. In particular, the average price tracking measure respectively for posted-bid spot markets without and with a futures market, in the low cost state are 61.66 and 40.26, in the middle cost state 34.98 and 11.66, and in the high cost state 127.94 and 9.43. The presence of the futures market has the greatest impact on bid behavior when the cost state is high, which translates into a marked difference in the quantity transacted.

The variation in posted prices is higher with a futures market. The standard deviation of bids in the posted-bid market with a futures market is 74.39, more than double the standard deviation of 34.11 without a futures market. In terms of variances, this is four times greater and a standard F-test indicates that the probability that these two variances are the same is much less than 10^{-3}. This higher volatility is not just noise, because the mean bids are different in the three cost states with a futures market and not different without a futures market.

We examine whether this higher variance is due to bids more closely tracking cost states using a simple statistical analysis of differences in means.[32] The most general equation estimated allows for differences across cost states, sessions and the combination of the two. This estimated equation for the average bid price in period i in session s, P_{is}, is

$$P_{is} = \sum_{s} \mu_s + \sum_{c,s} \delta_{cs} + \varepsilon_{is}, \qquad \sum_{c} \delta_{cs} = 0, \quad s = 7,8,9,13,14,15 \quad c = l,m,h, \quad (1)$$

[32] This analysis is essentially the same as an Analysis of Variance but it is set in a regression context to make it clearer.

where i is the index for periods in a particular session, s the subscript for a session, and c is the subscript for a cost state. The summation restrictions are identifying restrictions, not restrictions on possible values of the data. The parameters μ_s are the means in the six sessions across all conditions. Because the unconstrained mean values for the sessions allow for possibly different means across sessions, it is possible to estimate only the deviations from those means in the three possible cost states in each session. Hence, we impose the identifying restriction that the sum of the coefficients across cost states for each session must be zero. The deviation for each cost state c from the overall session mean for session s, δ_{cs}, potentially can differ for each session. The generality of this equation is most evident by comparison with the most restrictive equation estimated:

$$P_{is} = \mu_c + \mu_f + \delta_{lf} + \delta_{mf} + \delta_{hf} + \varepsilon_{is}, \;\; \delta_{lf} + \delta_{mf} + \delta_{hf} = 0, \qquad (2)$$

where μ_c and μ_f are the means in the posted-bid markets without a futures market and in the posted-bid markets with a futures markets, and δ_{lf}, δ_{mf} and δ_{hf} are the deviations from the mean prices in the posted-bid markets with a futures market. Equation (2) imposes the restrictions on equation (1) that all posted-bid sessions without a futures market are the same, that all posted-bid sessions with a futures sessions are the same, and that the deviations from the mean prices in the posted-bid sessions without a futures market are not predictably different than the overall mean.

Table 6 presents the coefficients and related statistics for the unrestricted equation (1). While our hypotheses are best tested using F-tests, it is noteworthy that the t-tests are exactly consistent with information revelation by the futures market. None of the sessions without a futures market has an average bid in any cost state that is different than the overall session average. Every session with a futures market has average bids in high and low cost states that are different than the session average.

Table 7 presents F-statistics for testing restrictions on the estimated equation (1). Since the selection of participants is random, it is natural to analyze the data assuming that the participants are not reliably different. Even though we also analyze the data under that restriction, the first F-values in Table 7 examine the null hypothesis that the deviations of average prices from the session means are zero in the three cost states allowing the session means to differ. The hypothesis that the average deviations are zero is quite consistent with the data for the posted-bid markets without a futures market and quite inconsistent with the data for the posted-bid markets with a futures market. This is precisely the same as the rough conclusion from the t-values in Table 6.

The second set of F-values examines whether the sessions are heterogeneous, testing whether the data are consistent with combining all sessions and separately combining the sessions without a futures markets and sessions with a futures markets. The p-value for the sessions without a futures market, Treatment 1, is 0.046 and the p-value for the sessions with a futures market, Treatment 2, is 0.140. We interpret this as suggesting that the posted-bid markets without a futures market are different, but not conclusively so.

The most important issue is whether the effect of a futures market on the posted-bid market continues to hold when we impose the restriction that the sessions in the two treatments are the same. This restriction that the mean bids are the same across cost states has a p-value of 0.854 for sessions without a futures market and a p-value of less than 10^{-3} for the sessions with a futures market. Whether or not the sessions in each treatment are the same, the evidence is crystal clear that the futures market is associated with spot market prices that reflect the cost state.

Figure 8 and Table 6 suggest that mean bids increased with a futures market and Table 7 confirms that impression. At any usual significance level, the mean bids across the posted-bid markets

without a futures market are different statistically than the mean bids with a futures market. The introduction of the futures market increased average bids in the posted-bid market.

Table 8 summarizes the quantities traded with and without a futures market. The futures market in general increases the efficiency of the posted-bid market by increasing the quantity traded, which is to be expected since the bids in the posted-bid market reflect the cost state. Table 8 shows that the average quantity traded in the posted-bid market without and with a futures market are 10.7 and 10.9 units in the low cost state, 5.8 and 7.6 units in the middle cost state and 0 and 4.3 units in the high cost state. The presence of a futures market has the biggest effect on trades in the high cost state. In the high cost state, the unconditional equilibrium quantity traded is zero because the unconditional equilibrium posted bids are lower than the lowest cost units in that state, a prediction that is borne out. The increase in quantity traded is not as large as predicted by the theory in the other cost states, perhaps partly because of the discreteness of the cost schedule.

Table 9 examines the traders' behavior. Compared to the markets without a futures market, two traders who can buy in the futures market and sell in the cash market are added and one buyer is removed from the futures market and one seller is removed from the spot market in Figure 5. Although none of the traders went bankrupt, traders in two different sessions had to sell one unit to the monitor in the spot market. Across all sessions, the traders on average purchased less than the conditional equilibrium number of units in all cost states. The percentage of conditional equilibrium units carried over to the spot market on average is greater in the high cost state, but even that is only 57 percent of the quantity predicted by the simple conditional equilibrium. There is quite a bit of variability in traders' behavior across sessions.[33] For example, in the high cost state, traders in Session

[33]Traders in the experienced session of Treatment 2 had previously participated in the full set of possible roles in the inexperienced sessions: trader, seller in posted market, buyer in posted market, seller in futures market and buyer in futures market. All of the traders earned at least average profits relative to others in those roles; hence, there is no

13 always carried over the predicted number of conditional equilibrium units while the traders in Session 15 never carried any units over to the posted-bid market in this cost state.

III. Conclusion

The variance of the cash price is higher with a futures market in both the crude oil market and in the experimental market. Based on data for the crude oil futures and cash, it would be hard if not impossible to provide compelling evidence that the higher variance of the cash price is due to the futures market. The experimental markets make it possible to present strong evidence that a futures market can increases the variance of a cash market with posted prices. It is clear that the cash price with a futures market in the experimental markets reflects information aggregation, not noise trading or some kind of speculative frenzy.

We conclude that the increase in the transitory variation of the cash price for crude oil can be explained by improved information aggregation in the cash market. It does not follow that a futures market necessarily increases the variance of a cash price.

The market institutions in the cash market are an important, if not crucial, contributor to the higher variance of the cash price with a futures market. The posted-price cash market without a futures market fails to aggregate information because a posted-price market has difficulty doing so, a difficulty that is both plausible and well documented by experimental evidence. The futures market aggregates information better because it is an auction market. If the cash market for crude oil had been an auction market, there is every reason to think that the cash market would have aggregated the information. Quite simply, this means that market microstructure – often treated as a detail even by the very careful Working (1960) who at least discusses how prices are determined – is very important for properly understanding the effect of a futures market on the cash market. This does not mean that

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reason to view any of the traders as relatively "slow learners" of the markets.

information about market microstructure would resolve all issues in the literature on the effects of futures markets on cash markets. On the other hand, we have presented strong evidence that market microstructure and information aggregation is important for understanding the effects in the market for crude oil.

Looking forward in a different direction, our experiment includes two ways that information can be transmitted between the two markets – observation of information in related markets by participants and trading in both markets. Extraction of information from a related market and its consequent reflection in another market is an analytical device introduced by Lucas (1972) into macroeconomics in island economies. No-arbitrage conditions are the fundamental basis of asset pricing, introduced by Black and Scholes (1979) and Harrison and Kreps (1979). While the information transmission between markets may well reflect both connections, the relative importance of these two contributions to efficiency is an issue that has substantial implications for financial theory and is on our research agenda.

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Table 1
Frequency of Changes in the Posted Price by Year
1983 through 2003

Year	Number of Weekdays with Price Changes	Fraction of Weekdays with Price Changes	Standard Deviation of Price	Standard Deviation of Price Changes
1983	2	0.008	0.581	0.088
1984	2	0.008	0.473	0.069
1985	8	0.031	0.518	0.088
1986	27	0.103	3.835	0.345
1987	17	0.065	0.985	0.181
1988	23	0.088	1.481	0.197
1989	55	0.212	1.091	0.231
1990	122	0.467	6.465	0.992
1991	87	0.333	1.925	0.744
1992	126	0.481	1.290	0.254
1993	154	0.590	1.819	0.286
1994	162	0.623	1.782	0.328
1995	136	0.523	0.891	0.242
1996	191	0.729	2.168	0.563
1997	167	0.640	1.944	0.382
1998	164	0.628	1.695	0.418
1999	197	0.755	4.509	0.435
2000	215	0.827	2.920	0.837
2001	214	0.820	3.620	0.672
2002	200	0.766	3.222	0.555
2003	219	0.839	2.599	0.747

The computations are restricted to weekdays because price changes on weekends are quite rare: There are eight price changes on the 2,200 days on weekends from January 1, 1983 through December 28, 2003.

Table 2
Experimental Design

Session	Date	Session Type	Average Payment	Session Length	Experienced Subjects	Parameter Set	Number Periods	Cost Shock	Number Subjects
				Treatment 1 (Posted-Bid Spot Market Only)					
1	4/18	1A	$41.30	2 hours	No	2	20	1	14
2	4/19	1A	$41.20	2 hours	No	2	20	2	14
3	10/2	1A	$34.68	2 hours	No	2	12	1	14
4	10/3	1A	$33.32	2 hours	No	2	12	1	14
5	10/4	1A	$33.44	2 hours	No	2	12	1	12
6	10/8	1A	$33.42	2 hours	No	2	12	1	12
7	4/22	1B	$33.00	1.5 hours	Yes	4	15	3	10
8	10/9	1B	$26.85	1.5 hours	Yes	4	12	2	10
9	10/10	1B	$32.70	1.5 hours	Yes	4	12	4	10
				Treatment 2 (Posted-Bid Spot Market with Double Oral Futures Market)					
10	4/25	2A	$26.28	2 hours	No	3	5	4	20
11	10/25	2A	$40.99	3 hours	No	3	9	3	20
12	10/30	2A	$40.58	3 hours	No	3	9	3	20
13	5/23	2B	$36.63	3 hours	Yes	4	10	3	20
14	12/6	2B	$44.69	3 hours	Yes	4	10	2	20
15	12/13	2B	$49.18	3 hours	Yes	4	10	4	20
				Robustness Treatment (Double Oral Auction Spot Market)					
16	10/24	3	$26.50	3 hours	No	4	10	2	10

This table presents the experimental design for all sessions. Columns 1 through 10 detail for each session the session number, session date in 2002, treatment type, average subject payoff, session length, experience level, parameter set, number of periods, cost shock sequence draw, and number of subjects. The average payoff includes fees of $5 for showing up on time and $3 for an end-of-session questionnaire that collected basic demographic and treatment experience data.

Table 3
Posted-Bid Spot Market Without a Futures Market—Treatment 1

	Mean Bid (Std. Dev.) N	Mode Bid (Interquartile Range)	Correlation of Cost State with Bid	Mean Bid Conditional on Low-Cost State (Std. Dev.) N	Mean Bid Conditional on Middle-Cost State (Std. Dev.) N	Mean Bid Conditional on High-Cost State (Std. Dev.) N
			All Sessions			
	558.47	570	0.05	553.29	560.57	558.26
	(36.49)	(545-580)		(47.42)	(32.29)	(33.79)
	195			45	115	35
			Individual Sessions			
Session 7						
	547.35	575	0.19	525.53	553.62	550.33
	(42.20)	(530-575)		(52.50)	(37.88)	(38.75)
	75			15	45	15
Session 8						
	572.4	590	0.03	568.70	573.45	571.90
	(27.69)	(565-591)		(33.13)	(25.33)	(33.58)
	60			10	40	10
Session 9						
	558.45	570	-0.14	566.40	553.80	556.50
	(32.00)	(545-571)		(41.75)	(26.61)	(23.11)
	60			20	30	10

The unconditional competitive equilibrium bid range is 590-600 francs. The conditional competitive equilibrium bid ranges are 490-500 in the low-cost state, 590-600 in the middle-cost state, and 690-700 in the high-cost state.

This table presents characteristics of the bid behavior for the three experienced sessions of Treatment 1, the posted-bid spot market without a futures market. Columns 1 through 8 detail for each session and for all sessions within an experience level, the session number, the mean bid, the standard deviation, number of observations, the mode bid and the interquartile range, the correlation of the cost state with the bids, the average bid conditional on the respective low, middle and high-cost states.

Table 4
Posted-Bid Spot Market With a Futures Market—Treatment 2

Market	Mean Bid (Std. Dev.) N	Modal Bid (Interquartile Range)	Correlation of Cost State with Bid	Mean of Price Tracking Measure	Mean Bid Conditional on Low-Cost State (Std. Dev.) N	Mean Bid Conditional on Middle-Cost State (Std. Dev.) N	Mean Bid Conditional on High-Cost State (Std. Dev.) N
				All Sessions			
DA Futures	574.04	595	0.853	20.50	515.90	591.36	696.92
	(64.84)	(530-600)			(50.61)	(15.58)	(2.97)
	238				91	121	26
Posted-Spot	589.67	595	0.88	17.81	498.51	586.34	688.43
	(74.39)	(564-601)			(56.01)	(28.58)	(24.39)
	150				35	80	35
Correlation (Last Futures Price, Avg. Post Bid) = 0. 95							
Correlation (Mean Futures Price, Avg. Post Bid) = 0.96							
				Individual Sessions			
Session 13							
DA Futures	571.16	595	0.98	11.31	465.96	591.32	698.86
	(80.55)	(493-595)			(29.51)	(4.62)	(2.14)
	87				26	47	14
Posted-Spot	597.54	696	0.96	10.98	466.70	590.04	697.27
	(84.14)	(570-695)			(39.98)	(21.06)	(2.79)
	50				10	25	15
Correlation (Last Futures Price, Avg. Post Bid) = 0.99							
Correlation (Mean Futures Price, Avg. Post Bid) = 0.99							
Session 14							
DA Futures	583.23	600	0.75	27.28	545.41	590.36	695.00
	(51.64)	(550-600)			(45.81)	(21.95)	(2.52)
	80				29	44	7
Posted-Spot	595.60	695	0.95	10.88	520.00	588.83	691.50
	(57.72)	(569-602)			(29.45)	(11.55)	(11.08)
	50				10	30	10
Correlation (Last Futures Price, Avg. Post Bid) = 0.98							
Correlation (Mean Futures Price, Avg. Post Bid) = 0.97							
Session 15							
DA Futures	567.21	500	0.84	24.13	528.19	592.87	694.20
	(55.67)	(510-600)			(39.43)	(15.89)	(1.30)
	71				36	30	5
Posted-Spot	575.86	595	0.75	31.58	505.40	579.64	672.10
	(78.23)	(545-600)			(70.21)	(44.89)	(40.94)
	50				15	25	10
Correlation (Last Futures Price, Avg. Post Bid) = 0.89							
Correlation (Mean Futures Price, Avg. Post Bid) =0.93							

The unconditional competitive equilibrium bid range is 590-600 francs. The conditional competitive equilibrium bid ranges are 490-500 in the low-cost state, 590-600 in the middle-cost state, and 690-700 in the high-cost state.

This table summarizes the bids for all sessions and for each individual experience*d* sessions of Treatment 2 with a double oral auction futures market and a posted-bid spot market. Parameter set 4 was used in all sessions. Each session ran for ten periods. Session 13 used the cost state sequence 2, Session 14 used the cost state sequence 3, and Session 15 used the cost state sequence 4. Columns 1 through 8 presents for each session the average bid, standard deviation, and number of observations, the modal bid and the interquartile range, the correlation of the cost state with the bids, the mean of the price tracking measure and the average bid conditional on the respective low, middle and high-cost states. The correlation of the last future price with the average posted market bid and the correlation of the mean futures market bid with the average posted market bid are presented beneath the other information.

Table 5
Comparison of Posted-Bid Spot Markets

	Treatment 1 Posted-Bid Market Only	Treatment 2 With Futures Markets
	All Sessions and Cost States	
Mean Bid	556.83	589.67
(Std. Dev.)	(34.11)	(74.39)
N	150	150
Modal Bid	570	595
(Interquartile Range)	(544 – 576)	(564 – 601)
Correlation (Cost State, Bid)	0.10	0.88
Correlation (Last Futures Price, Avg. Post Bid)	NA	0.95
Correlation (Mean Futures Price, Avg. Post Bid)	NA	0.96
Mean of Price Tracking Measure	64.95	17.81
	All Sessions Conditional on the Cost State	
Low Cost State (CE Bid = 495)		
Mean Bid	548.09	498.51
(Std. Dev.)	(42.51)	(56.01)
N	35	35
Interquartile Range	520 – 575	460 – 535
Mean of Price Tracking Measure	61.66	40.26
Middle Cost State (CE Bid = 595)		
Mean Bid	560.04	586.34
(Std. Dev.)	(29.66)	(28.58)
N	80	80
Interquartile Range	550 – 580	587 – 598
Mean of Price Tracking Measure	34.99	11.66
High Cost State (CE Bid = 695)		
Mean Bid	558.26	688.43
(Std. Dev.)	(33.79)	(24.39)
N	35	35
Interquartile Range	540 – 575	694 – 697
Mean of Price Tracking Measure	136.74	9.43

This table compares bid behavior in the posted-bid spot market across the experienced treatments with (Treatment 2) in column 2 and without (Treatment 1) a futures market in column 3. To make a cleaner comparison with the numbers in Treatment 2 only periods 1-10 are used in this table for Treatment 1. Panel A presents data across all cost states and Panel B presents the data conditional on the cost state. The same parameter set 4 and the same three pre-drawn cost states sequences are used in the two treatments. The competitive equilibrium bid range for parameter set 4 given the respective cost states are: Low 490-500, Medium 590-600, High 690-700.

Table 6
Posted Bids With and Without A Futures Market

Variable		Coefficient	Standard Deviation	P-value for Coefficient
Session 7		539.59	6.84	$<10^{-3}$
Session 8		571.99	7.27	$<10^{-3}$
Session 9		553.91	6.84	$<10^{-3}$
Session 13		584.67	6.84	$<10^{-3}$
Session 14		600.11	7.27	$<10^{-3}$
Session 15		585.71	6.84	$<10^{-3}$
Session 7	Low-cost state	-22.79	10.71	0.039
Session 7	Middle-cost state	12.05	8.60	0.169
Session 7	High-cost state	10.74	9.60	0.269
Session 8	Low-cost state	-3.29	10.99	0.766
Session 8	Middle-cost state	3.38	8.69	0.699
Session 8	High-cost state	-0.09	10.99	0.994
Session 9	Low-cost state	1.29	9.60	0.894
Session 9	Middle-cost state	-3.87	8.60	0.655
Session 9	High-cost state	2.59	10.71	0.810
Session 13	Low-cost state	-117.97	10.71	$<10^{-3}$
Session 13	Middle-cost state	5.37	8.60	0.536
Session 13	High-cost state	112.60	9.60	$<10^{-3}$
Session 14	Low-cost state	-80.11	10.99	$<10^{-3}$
Session 14	Middle-cost state	-11.28	8.69	0.201
Session 14	High-cost state	91.39	10.99	$<10^{-3}$
Session 15	Low-cost state	-80.31	9.60	$<10^{-3}$
Session 15	Middle-cost state	-6.07	8.60	0.484
Session 15	High-cost state	86.39	10.71	$<10^{-3}$

s_e	20.19
R^2	0.9991
F	2708.48
p-value	$<10^{-3}$

This table presents the mean values by session and the session's deviations of the average bids in each cost state from the overall mean. The notation s_e indicates the standard deviation of the residuals, R^2 is the fraction of variation explained, F is the F-value for the equation and p-value is the probability that the F is zero. Note that the equation does not have a constant term. Sessions 7, 8 and 9 are posted-bid markets standing alone and sessions 13, 14 and 15 are posted bid markets with a futures market preceding the posted-bid market.

Table 7
Tests Whether Bids Reflect The Cost State in Sessions With and Without A Futures Market

Hypothesis	F	df	p-value
Is the average bid equal in all cost states conditional on sessions different?			
All sessions	26.576	12	$<10^{-3}$
Posted-bid sessions without a futures market	0.837	6	0.549
Posted-bid sessions with a futures market	52.320	6	$<10^{-3}$
Is the average bid equal in periods with the same experimental condition and cost state?			
All sessions	2.044	12	0.044
Posted-bid sessions without a futures market	2.367	6	0.046
Posted-bid sessions with a futures market	1.720	6	0.140
Is the average bid equal in all cost states conditional on average bids being equal in periods with the same experimental condition and cost state?			
All sessions	63.400	4	$<10^{-3}$
Posted-bid sessions without a futures market	0.158	2	0.854
Posted-bid sessions with a futures market	127.403	2	$<10^{-3}$
Is the average bid equal in posted-bid sessions without a futures market and with a futures market?			
Posted-bid sessions without a futures market and with a futures market	32.797	1	$<10^{-3}$

The first three tests are tests whether the average bids differ across cost states, as are the last three. The first three tests allow the average bids in the three cost states to differ across sessions. The last three tests are conditional on the bids in the three cost states being the same in sessions without a futures market (Treatment 1) and the same in sessions with a futures market (Treatment 2), respectively, but not necessarily the same in Treatment 1 and 2 of course. The fourth, fifth and sixth tests are tests whether the average bids in the three sessions without a futures market (Treatment 1) are equal in the same cost states and tests whether the average bids in the three sessions with a futures market (Treatment 2) are equal in the same cost states. In short, are the sessions in a given treatment the same, or do the three sessions differ? Test results for each treatment are presented conditional on the other treatment not having the same average bid in the same cost state. Tests results conditional on the other treatment having the same average bid in the same cost state are only marginally different. The tests are F-tests with F-statistics "F" with degrees of freedom "df" and p-values given in the table.

Table 8
Comparison of Quantities Traded in Posted-Bid Spot Markets

Cost State	Equilibrium		Without Futures Market		With Futures Market	
	Unconditional Quantity	Conditional Quantity	Average Actual Quantity Traded Per Period	Average Posted Maximum Quantity Per Period	Average Actual Quantity Traded Per Period	Average Posted Maximum Quantity Per Period
Low						
Mean	10	15	10.71	11	10.86	12.29
(Std. Dev.)			(0.49)	(0.58)	(1.95)	(2.21)
Median			11	11	11	12
Mode			11	11	13	12
Interquartile Range			(10.5-11)	(11-11)	(9.5-12.5)	(12-13.5)
Middle						
Mean	10	10	5.81	10.56	7.62	9.56
(Std. Dev.)			(0.98)	(0.51)	(1.20)	(0.63)
Median			5	11	8	10
Mode			5	11	8	10
Interquartile Range			(5-7)	(10-11)	(7-8.25)	(9-10)
High						
Mean	0	5	0	10.57	4.29	5.14
(Std. Dev.)			0	(0.53)	(0.79)	(0.38)
Median			0	11	5	5
Mode			0	11	5	5
Interquartile Range			(0-0)	(10-11)	(4-5)	(5-5)

This table shows equilibrium quantities traded in the unconditional and conditional equilibria and the actual average quantities traded by cost state. The conditional equilibrium quantity traded is the full information benchmark. The unconditional equilibrium quantity traded is the quantity traded sellers could transact at the bids for a given cost state made by the uninformed buyers where the profit maximizing bid for the uniformed buyers should be the middle cost state equilibrium price. Under this pricing behavior, in the low cost state periods sellers will only be able to sell two units each to the buyers (10 units for the market period) because that is the maximum number of units demanded at that price. In the middle cost state, each seller should be able to sell two units (10 units for the market period), but in the high cost state sellers will not sell any units (0 units) for the market period at that price. The conditional equilibrium quantities traded are 3, 2, and 1 in the low cost, middle cost and high cost states for total quantities traded of 15, 10 and 5 units respectively.

Table 9
Traders' Actions

Cost State	Average Number of Units that Traders Purchased in Future Market	Average Number of Units that Traders Sold to Posted-Bid Spot Market	Competitive Equilibrium Units Conditional on the Cost State	Percentage of Competitive Equilibrium Units Brought to Spot Market
		All Sessions		
Low	1.21	1.14	3	40.3
Middle	0.75	0.75	2	37.5
High	0.57	0.50	1	57.0
		Individual Sessions		
Session 13				
Low	0.50	0.50	3	16.7
Middle	1.00	1.00	2	50.0
High	1.00	0.83	1	100
Session 14				
Low	1.75	1.5	3	58.3
Middle	0.83	0.83	2	41.5
High	0.50	0.50	1	50.0
Session 15				
Low	1.33	1.33	3	44.3
Middle	0.40	0.40	2	20.0
High	0.00	0.00	1	0.00

This table presents data on the traders' actions. Each session averages over the two traders. Columns 1 through 5 give the cost state, average number of units purchased in the futures market, average number of units sold in the posted-bid spot market, the competitive equilibrium units one buyer in the futures market would of purchased conditional on the cost state, and the percentage of competitive equilibrium units that the traders bought on average in the futures market in a period given the cost state.

Figure 1

Posted Price from January 1946 through December 2003

Beginning of Month

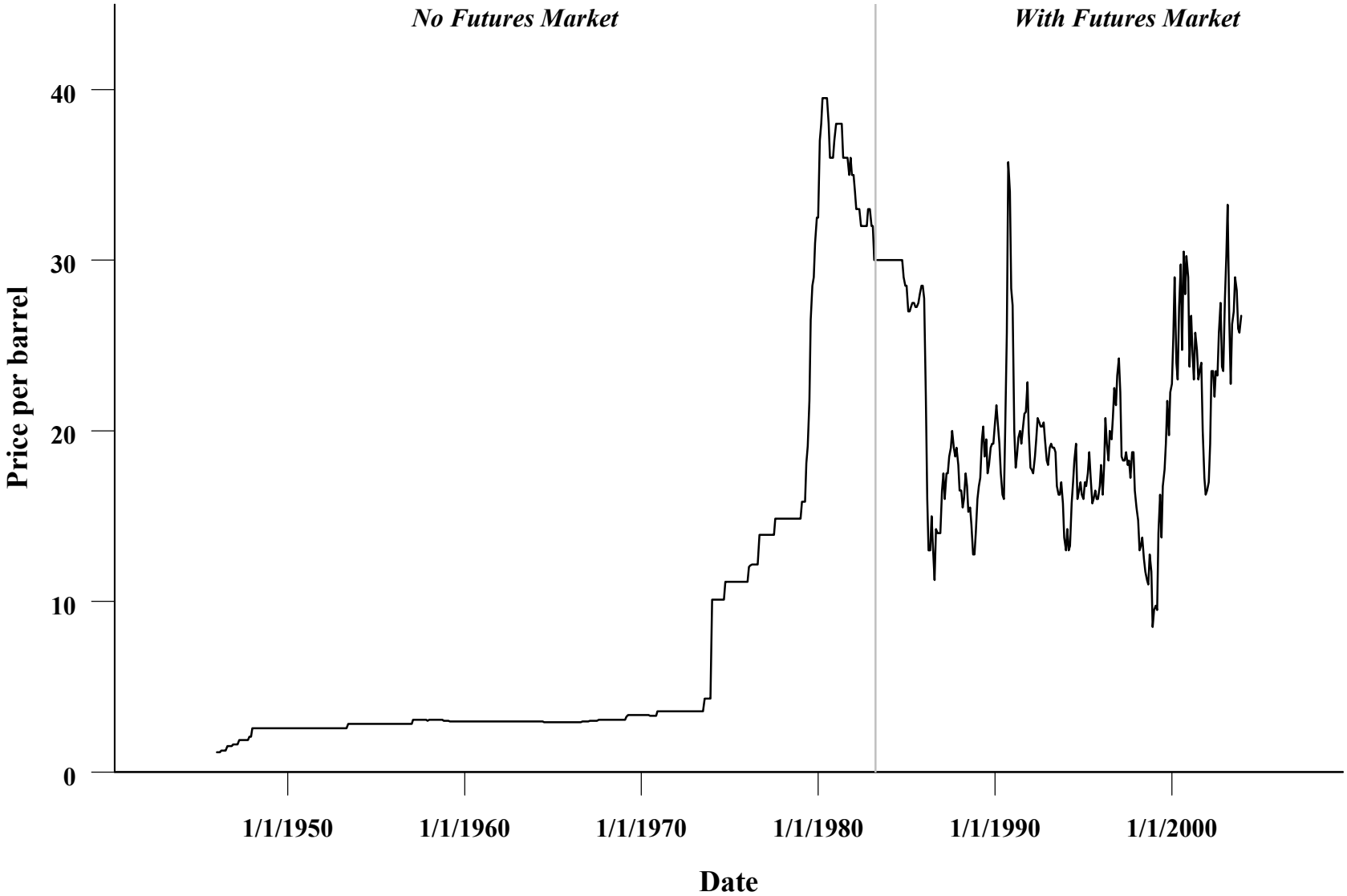
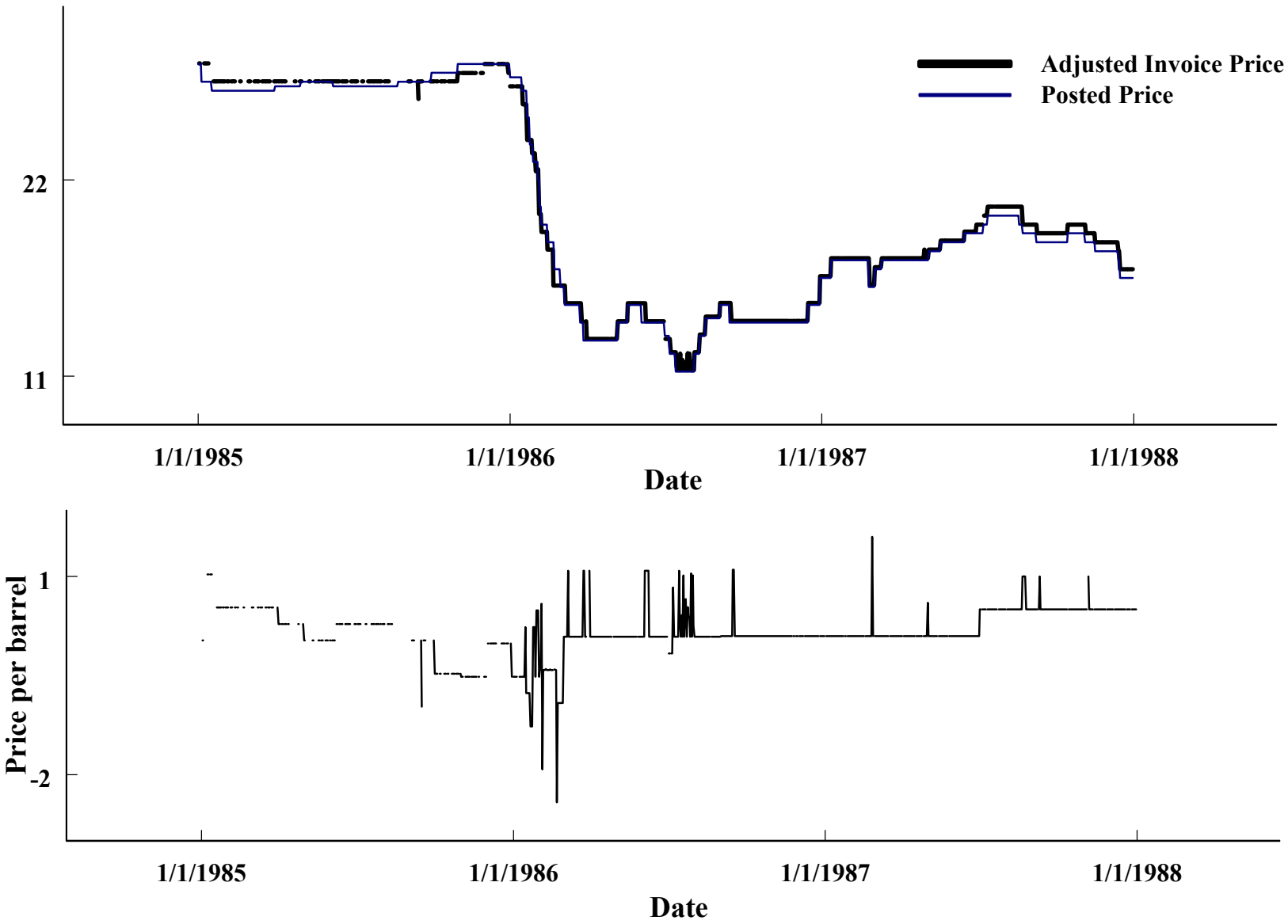


Figure 1 shows the nominal post of crude oil posted by producers. The vertical line is drawn as of the beginning of trading of West Texas Intermediate crude oil on March 30, 1983.

Figure 2
Adjusted Invoice Price and Posted Price
Daily 1985 through 1987



The top graph in Figure 2 shows daily values of Sunoco's posted price and transaction prices for a producer of crude oil on the days that oil was collected. The prices received by the producer are adjusted for relatively minor gravity deviations that occasionally apply to the oil from these wells. Such adjustments determine the net price actually received by producers, are typical, change very seldom and are similar if not the same across refiners. The bottom graph shows the difference between the adjusted invoice price and the posted price.

Figure 3

Posted Price and Comptroller's Reported Price - Averages

January 1983 to December 2003

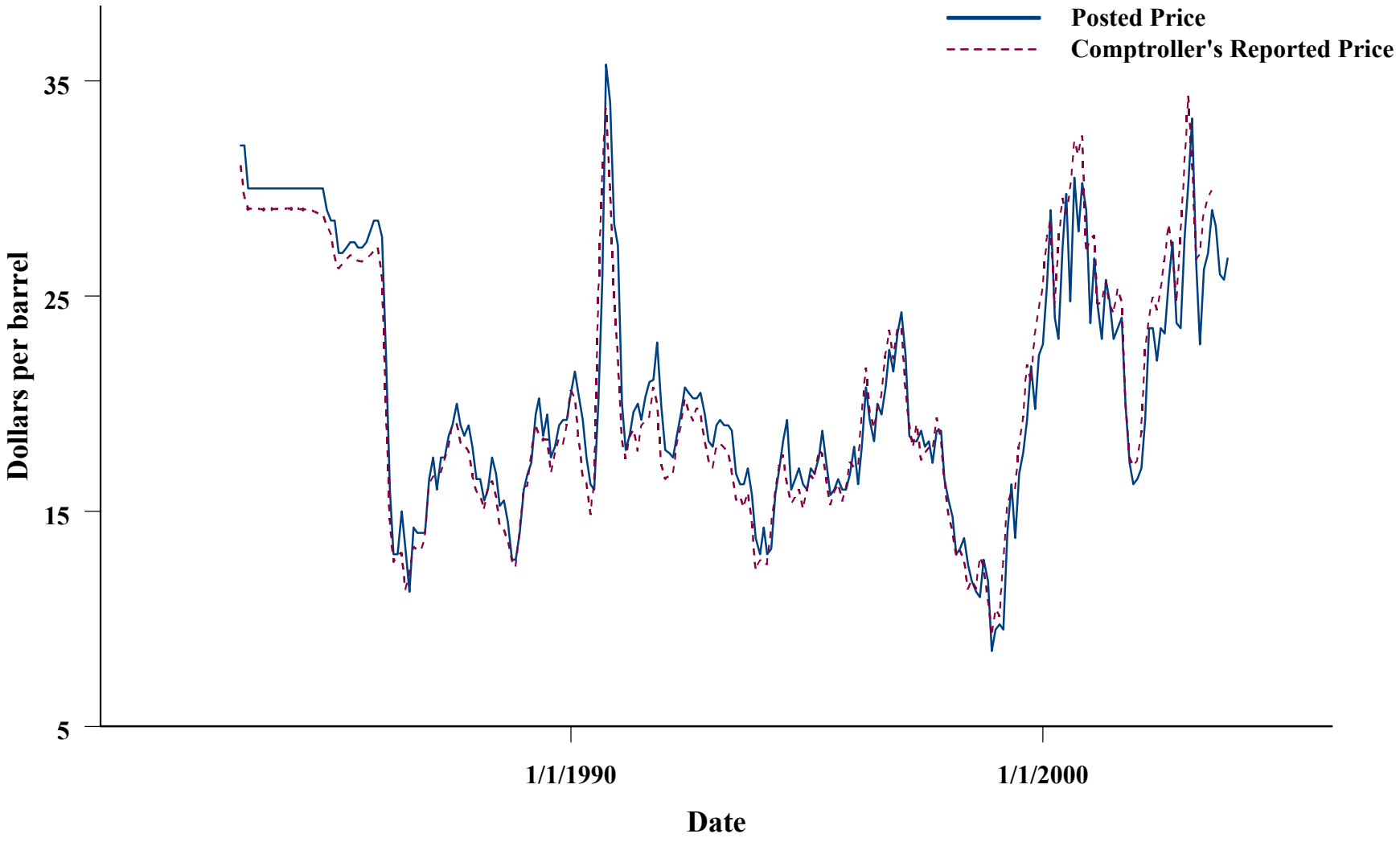


Figure 3 shows the monthly average posted price for Sunoco and the average price reported by all producers to the Texas Comptroller of Public Accounts for severance tax purposes.

Figure 4

Delivery Price and Average Posted Price

December 1983 to December 2003

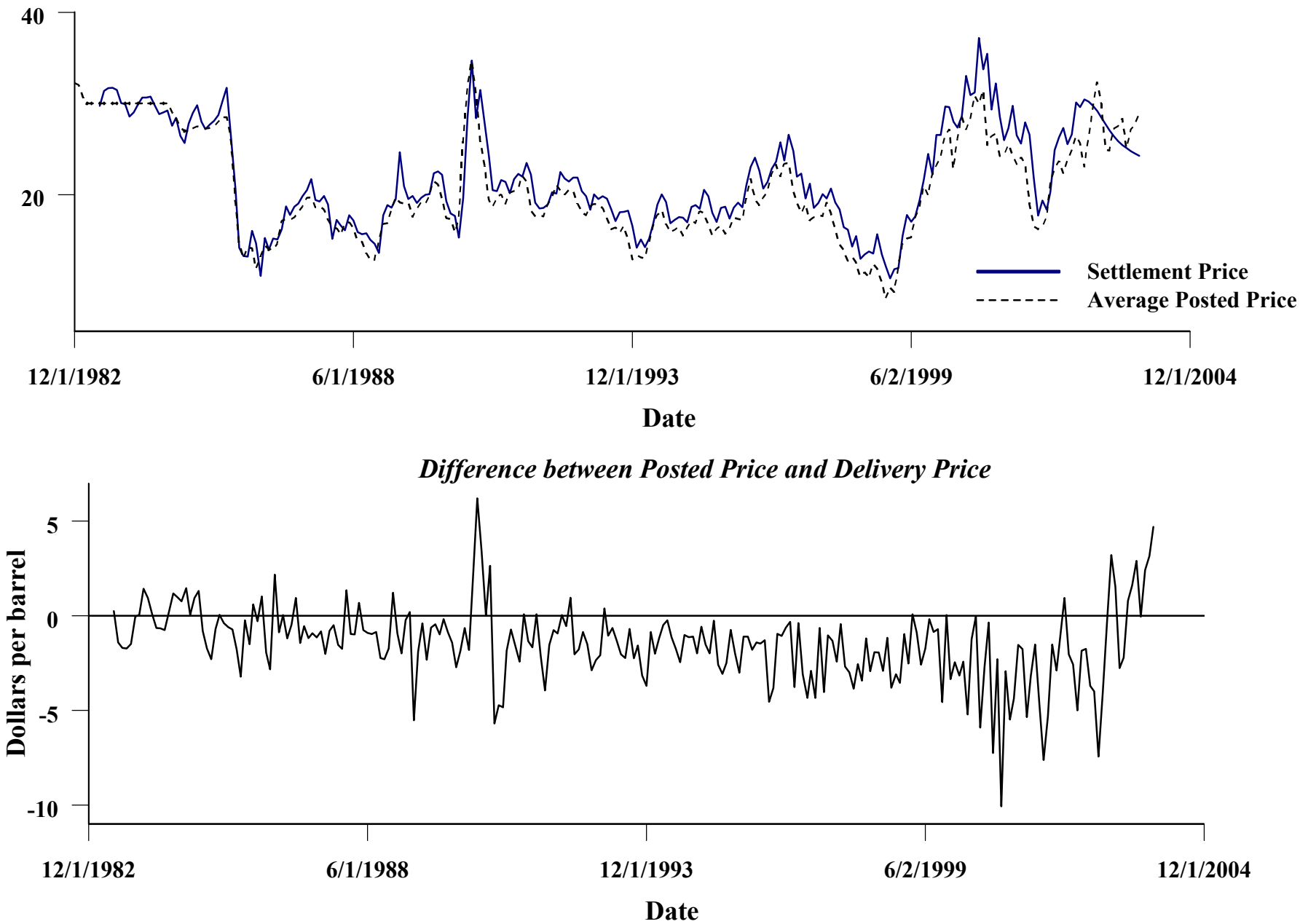


Figure 4 shows the monthly futures price at expiration for WTI crude oil on the New York Mercantile Exchange and the average posted price during the delivery month. This graph includes data from the inception of the futures market through December 2003. The graph is dated by the delivery month, which is all that is known at expiration because the delivery day for a particular contract is during the month after expiration of the futures contract and is determined by the NYMEX.

Figure 5

Market Demand and Supply

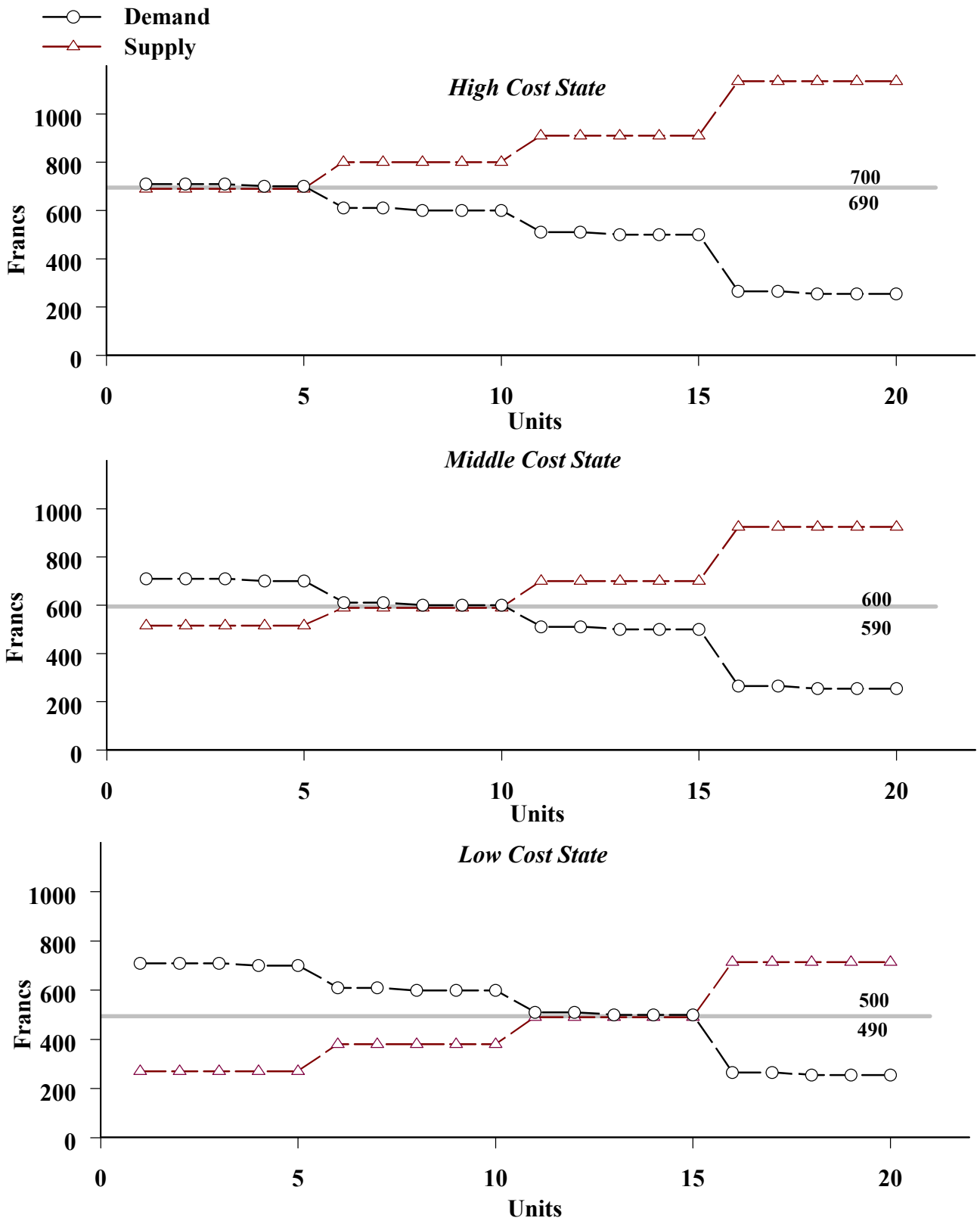


Figure 5 shows the equilibria in the posted-bid market conditional on the buyers knowing the cost state. The figure shows the market demand and supply curves. The horizontal line in each of the three graphs indicates the equilibrium price range in each of the cost states conditional on buyers and sellers knowing the cost state. The values are given by the numbers above and below this line, e.g. 490 to 500 in the low cost state. The equilibrium prices range from 490 to 500 in the low cost state, from 590 to 600 in the middle cost state and from 690 to 700 in the high cost state.

Figure 6

Cash Prices without Futures Market

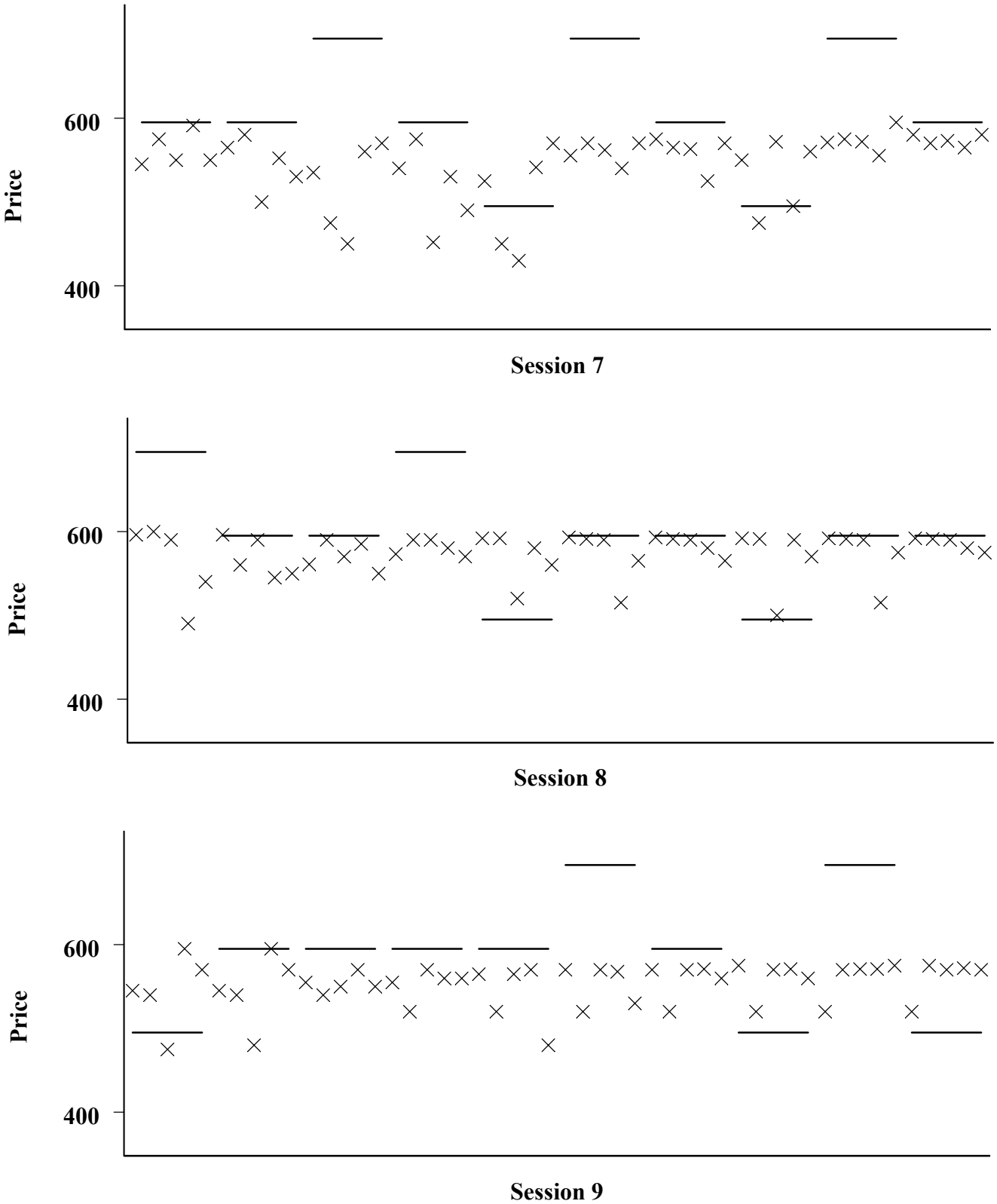


Figure 6 shows the posted prices in each period in the sessions without a futures market, i.e., Treatment 1, sessions 7, 8 and 9. The solid lines indicate the median conditional equilibrium prices in each period. The *X*s indicate the price that each buyer posted. The prices are ordered by buyer, so that the same buyer's price is listed first for every period. Sales by a buyer in some periods, especially in the high cost states, could be zero at the posted price.

Figure 7
Futures Prices and Posted Prices

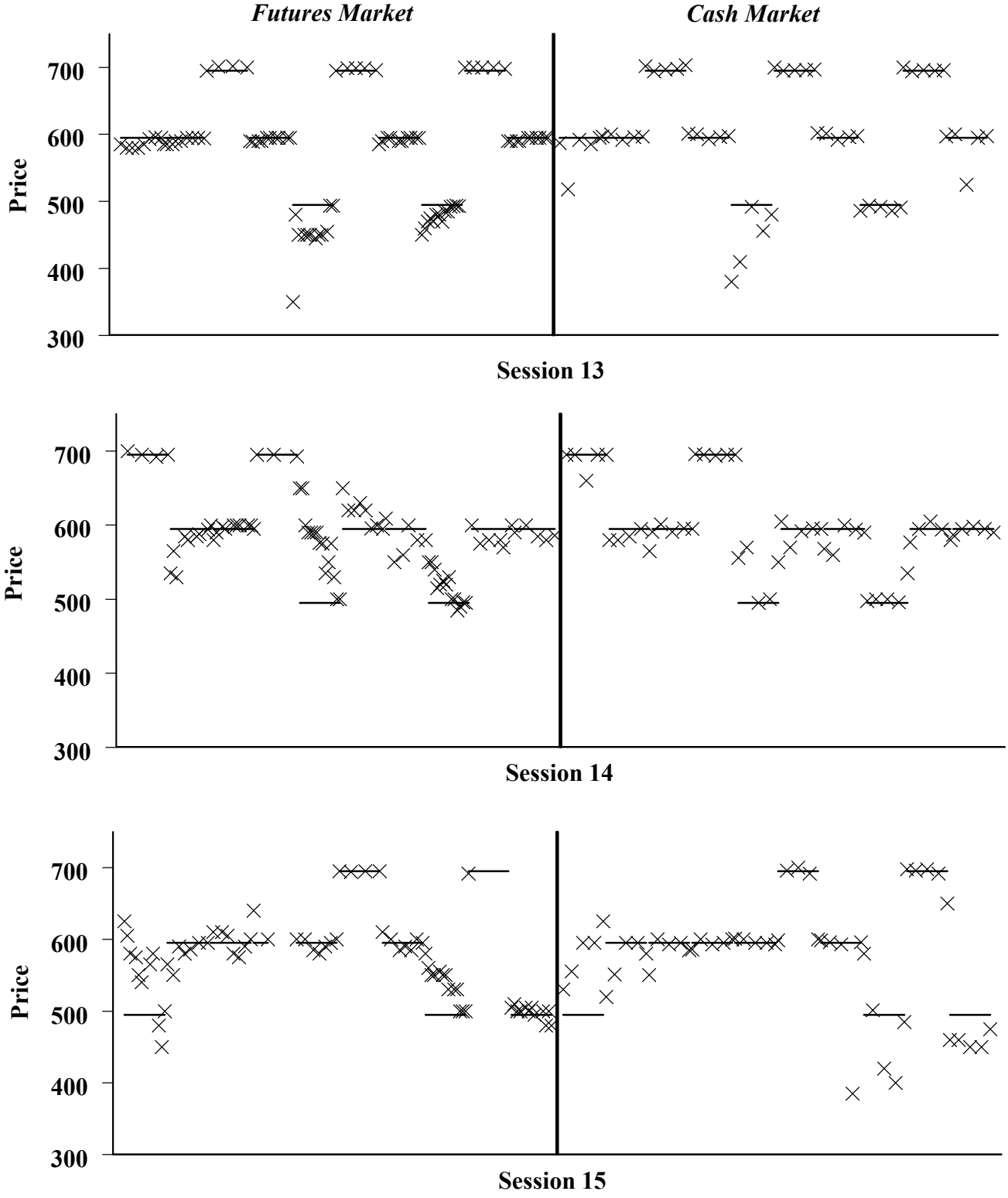


Figure 7 shows the sequences of trade prices in the futures market and posted prices in the posted price market. Each graph shows the trade prices in the futures market and the posted prices in the posted price market for one of the three sessions. The solid horizontal lines indicate the conditional equilibrium price for that period. The unconditional equilibrium price is the same as the conditional equilibrium price in the middle cost state. For the futures markets, each *X* represents a trade of one unit: the number of units traded in each transaction. For the cash markets, each *X* represents a posted price for a buyer.

Figure 8

Average Posted Prices in Experimental Sessions

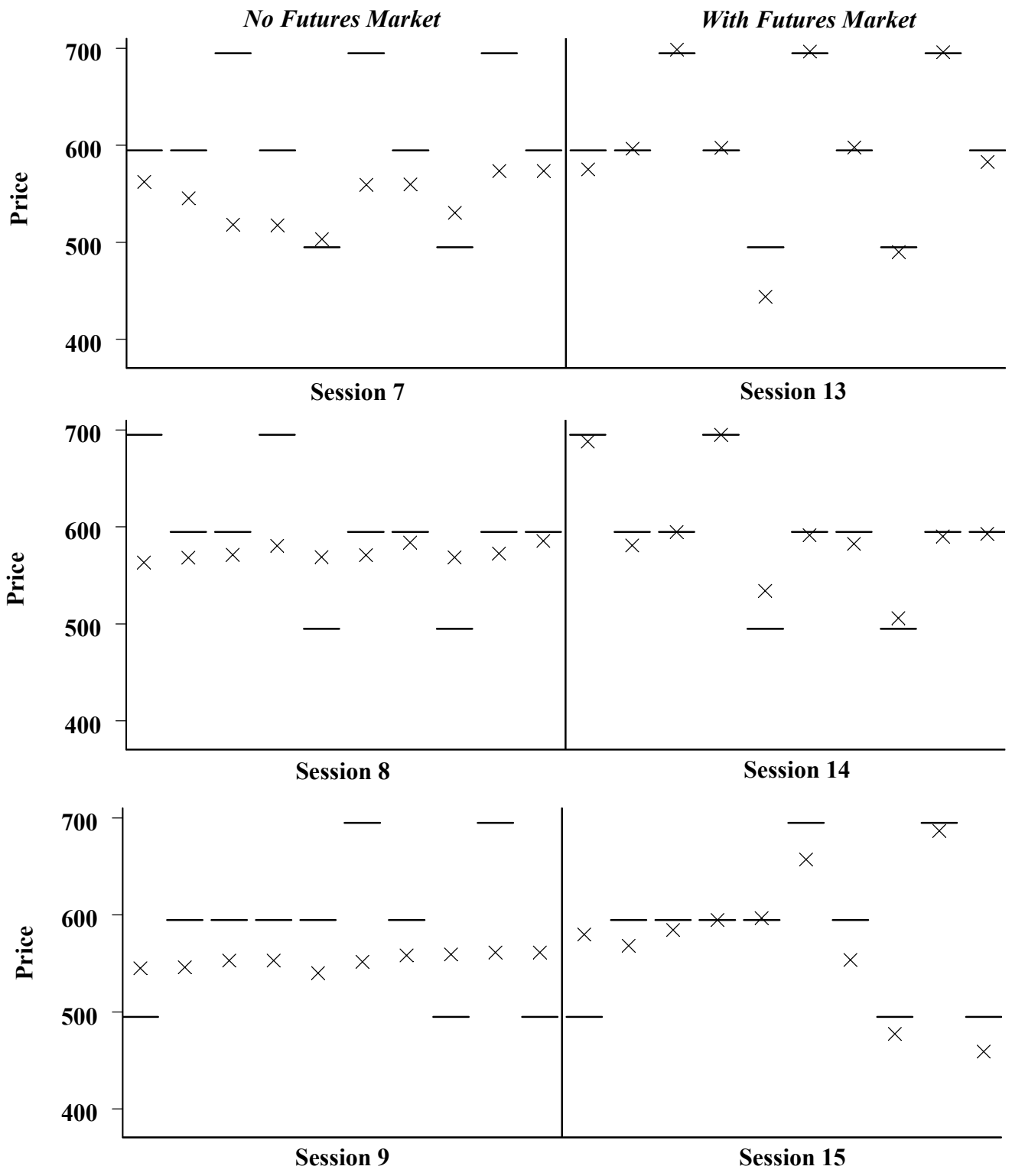


Figure 8 shows the average posted prices in each session without a futures market and with a futures market. The solid lines indicate the median conditional equilibrium prices in each period. Each *X* indicates the average of the bids by buyers in the period. Each panel of the figure shows the averages in the posted price markets without and with a futures market. By design the sequences of cost shocks are the same in both posted price markets in a panel. The left hand side of each panel shows the conditional equilibrium prices and the average posted prices without a futures market. The right hand side of each panel shows the same conditional equilibrium prices and the average posted prices with a futures market.

Appendix A
Instructions for Market Sessions *With* a Futures Market

Note: Instructions for the posted-bid Market only sessions are similar with the appropriate omissions, such as descriptions of Market X and trader's roles.

GENERAL

This is an experiment in the economics of market decision making. The instructions are simple and if you follow them carefully and make good decisions, you might earn a considerable amount of money that will be paid to you in cash. The currency in these markets is francs. Each franc is worth .025 dollars, thus 100 francs is worth $2.50 to you.

In this experiment we are going to conduct two markets in a sequence of market trading periods. In each period, Market X participants will trade and then Market Y participants will trade. The prices that you negotiate in each trading period will determine your earnings. Attached with the instructions you will find a sheet labeled Buyer, Seller or Trader Record Sheet, which describes the value to you of any decisions that you might make. It is your own private information. *You are not to reveal this information to anyone*. Also, please note your identification number at the top of this sheet; this is how you will identify yourself during the trading process.

Specific Instructions for Buyers:

You will only participate in one of the markets and you will always be a buyer. During each market period you are free to purchase from any seller or trader as many units as you might want. For the first unit that you buy during a trading period you will receive the amount listed in row (1) marked *1st unit Redemption Value*; if you buy a second unit you will receive the additional amount listed in row (2) marked *2nd unit Redemption Value*; etc. The profits from each

purchase (which are yours to keep) are computed by taking the difference between the redemption value and the purchase price of the unit bought. That is

Buyer Earnings = [Redemption Value – Purchase Price].

Note that, if you buy a unit at a price *above* your redemption value for that unit, you will make a *loss on that transaction* and this *will* reduce your earnings.

Importantly, a buyer does not receive the redemption value for a unit unless the unit is purchased. Thus, the earnings for each unit not purchased in a period is zero. If you are a buyer, the first unit you purchase during a trading period is your "1st unit," regardless of whether or not other buyers have previously bought units in that trading period. ***You cannot buy your second unit before you buy your first unit, and therefore you will move down a column during a trading period***. The blanks on your Record Sheet will help you record your profits. The purchase price of the unit(s) you buy during the period should be recorded *at the time of purchase*. You should then record the cumulative profits for that period on the last row on the page, and then transfer this amount onto your Cumulative Profit Sheet. Subsequent trading periods should be recorded similarly.

Specific Instructions for Sellers:

You will only participate in one of the markets and you will always be a seller. During each market period you are free to sell to any trader or buyer as many units as you might want. The first unit that you sell *during a trading period* will cost you the amount listed on the sheet in row (1) marked *cost of 1st unit*; if you sell a second unit you incur the cost listed in the row (2) marked *cost of the 2nd unit*; etc. The profits from the sale of each unit (which are yours to keep) are computed by taking the difference between the price at which you sold the unit and your cost

for that unit. *Additionally, sellers may sell units to the monitor at the end of the period for 265 francs*. That is

Seller Earnings = [Sale price of unit – Cost of unit].

Note that, if you sell a unit at a price *below* the cost to you for that unit, you will make a *loss* on that transaction and this *will* reduce your earnings.

Importantly, a seller does not incur the cost for a unit unless the unit is sold. Thus, earnings for each unsold unit in a period is zero. If you are a seller, the first unit you sell during a trading period is your "1st unit," regardless of whether or not other sellers have previously sold units in that trading period. ***You cannot sell your second unit before you sell your first unit, and therefore you will move down a column during a trading period***. The blanks on your Record Sheet will help you record your profits. The sale price of the unit(s) you sell should be recorded on the respective row *at the time of the sale*. You should then record the cumulative profits on the last row of the page for that trading period and then transfer this amount onto your Cumulative Profit Sheet. Subsequent trading periods should be recorded similarly.

Specific Instructions for Traders:

You will be able to trade in *both* markets. You will be a buyer in Market X but a seller in Market Y. Note that you do not have any units to begin with, that is, you do not have a redemption value schedule or a cost schedule. For every unit that you buy in Market X you will be given a card. You may resell this *card unit* in Market Y. *For every unit you take to Market Y that you do not sell to a buyer, you may sell to the monitor for 265 francs*. Thus, your total earnings in each period are determined by:

Total Trader Period Earnings = [Price *Sold* in Market Y – Price *Paid* in Market X].

Note that, if you sell a unit at a price *below* the price you paid for that unit, you will make a loss on that transaction and this *will* reduce your earnings. You should then record the cumulative profits on the last row of the page for that trading period and then transfer this amount onto your Cumulative Profit Sheet. Subsequent trading periods should be recorded similarly.

Traders have also been given an initial endowment of francs for which a certain portion must be given back at the end of the experimental session. This endowment is listed on your Cumulative Record Sheet and is your own private information. Please look at this information now. *If a trader falls below this initial endowment in earnings at any point in the experiment, then they will cease trading for the remainder of the experiment*.

MARKET ORGANIZATION

The two markets X and Y will run sequentially in a given period. The way in which transactions occur in the two markets is organized somewhat differently. *Participants in Market X will begin and complete trading prior to the opening of trading in Market Y.* It is important for you to understand how both markets work.

Market X:

I will begin each *eight-minute* trading period with an announcement that the market is open. Any buyer or trader is free at any time during the period, to raise his/her hand and, when called on, make a verbal bid to buy *one unit* of the commodity at a specified price. Any seller is free, at any time during the period, to raise his/her hand and, when called on, make a verbal offer to sell *one unit* of the commodity at a specified price. *All bids and offers pertain to one unit: it is not possible to sell two units as a package.* Anyone wishing to sell is free to accept or not accept the bid of anyone wishing to buy and anyone wishing to buy is free to accept or not accept the

offer of anyone wishing to sale. If a bid is accepted, then a binding contract has been closed for a single unit and the respective buyer and seller will record the contract price.

All participants should use their identification numbers when making a bid or offer. When making an offer to buy, the participant should use the word, "bid," and sellers should use the word "sell." For example, participant 1 wants to make a bid of 120 francs, then this person would raise his/her hand and, when recognized, say "Participant 1 bids 120." I will repeat the participant's number and the bid to give the person at the overhead projector time to record it. Similarly, if Seller 5 decides to offer a unit for sale at 250 francs, this seller should raise his/her hand and, when recognized, say "Seller 5 sells 250." I will repeat this information while it is recorded, and the overhead will appear

Bids	Offers
B1 120	S5 250

We ask you to help us enforce a bid/ask improvement rule: before a contract is made, subsequent bids and offers must be improving. That is, all bids must be higher than the highest outstanding bid, should one exist, and asking prices must be lower than the lowest outstanding offer, should one exist. So, bids must be increasing and offers must be declining. In the example above, the next bid must be above 120 francs and the next offer must be below 250 francs.

For example, suppose participant 1, the next person recognized raises his/her own bid from 120 francs to 130 francs, and then Seller 4 is called on and asks 165 francs. Suppose then that Participant 3 bids 160 francs, and that Seller 5 will accept this bid. Seller 5 raises his hand and saying, "Seller 5 accepts Participant 3's bid". Participant 3 and Seller 5 will then have a contract at a price of 160. (These numbers are illustrative only).

Bids		Offers	
B1	120	S5	250
B1	130	S4	165
B3	160	S5	Accepts

Participant 3 and Seller 5 have a binding contract for a single unit at the price of 160 francs, and this price for the particular unit should *be* immediately recorded. **As contracts are made in Market X, the contract prices will be recorded on the board at the front of the room, where participants in both markets can view them.**

After a contract is made a line will be drawn, indicating that all previous bids and asks will automatically be withdrawn before any new ones can be made. Initial bids and offers *can start at new levels*—but again, subsequent bids and offers must be improving. Any ties in bids or acceptances will be resolved by random choice. ***If a minute elapses and there are no new bids to buy or asks to sell, then Market X will go ahead and close down for that period.*** Except for bids, asks, and their acceptances, you are expected not to speak to any other person, even if there are many bids and offers that are not accepted.

Market Y:

At the beginning of the period each *buyer* decides on a purchase price (bid) and the *maximum* number of units he is willing to purchase at that price (***the buyer must buy all units at the same price***). He will then write the bid and maximum quantity on one of the cards provided. A monitor will collect the cards and then post *simultaneously* the bids and quantities for each buyer on the overhead projector.

Offers to sell will be made as follows: randomly a *trader* will be called upon (by drawing a seller trader identification number from a deck of cards), and he/she will state the quantity that

he wishes to sell and the buyer to whom he wishes to sell to. If the first buyer will not purchase all units the trader wants to sell, then that trader can get back in the line to sell after the other trader and sellers have had an opportunity. When the first trader has made all his contracts, the other trader will be selected to make his desired sales. After the traders have made their sells, then randomly the sellers of Market Y will be chosen to make their desired sells. Again, if the first buyer will not purchase all units the seller wants to sell, then that seller can get back in the line to sell after the other sellers have had an opportunity. This process will be continued until there are either no more offers to sell or no more buyers willing to purchase units.

Supply Shocks:

Please look at your sheet labeled Schedule Sheet that displays redemption schedules for buyers and cost schedules for sellers. Notice that there are two types of buyers. Each buyer will remain the same type, that is, will keep the same redemption value schedule throughout the entire experimental session. In each market there will be both types of buyers. Unlike the buyers, sellers will receive a new cost schedule every period, which will be one of the three cost schedules shown on the Schedule Sheet. ***All* sellers in *both* markets will receive the *same* cost schedule that was drawn for that period.**

For each period cost state, a random drawing was held from a bucket of chips with the following distribution:

25% chance of the Low Cost Schedule (Blue Chip)

50% chance of the Medium Cost Schedule (White Chip)

25% chance of the High Cost Schedule (Red Chip).

That is, every period all sellers have a 25% chance of receiving the Low Cost Schedule, a 50% chance of receiving the Medium Cost Schedule, and a 25% chance of receiving the High

Cost Schedule. After the draw in each period, the drawn chip was placed back in the bucket before the next period draw. Thus, each period's cost schedule is drawn from the original distribution of chips. For example, if the high cost schedule was drawn in the previous two periods, the probability that the next period will have a high draw is still 25%.

[Please stop for a demonstration of how the period cost schedules were drawn.]

At the end of each period, the cost schedule that was drawn will be announced to all participants in both markets.

Please raise your hand if you have any questions at this time?

Worksheet

Please work through this worksheet to make sure you understand how earnings are calculated. Note these numbers are *illustrative only* and not related to the numbers you are likely to see in the experiment. If you have any questions please raise your hand and a monitor will come by to assist you.

A. Suppose you are a buyer and you have the following redemption value schedule. Please fill in the buyer record sheet and calculate your period franc earnings if you buy *four* units at 2,050 francs each.

Buyer Record Sheet

Row	Unit	Redemption Value (Column 3)	Purchase Price (Column 4)	Earnings per Unit (Column 3 – Column 4)
1	1st	3,050		
2	2nd	2,500		
3	3rd	2,055		
4	4th	1,890		

Total *franc* earnings for this period: _____

Suppose you are a seller and you have the following cost schedule. Please fill in the seller record sheet and calculate your period franc earnings if you sell *three* units, the 1st unit at 4,250 francs, the 2nd unit at 3,950 francs, and the third unit for 3,886 francs.

Seller Record Sheet

Row	Unit	Sale Price *or* to the Monitor (Column 3)	Unit Cost (Column 4)	Earnings per Unit (Column 3 – Column 4)
1	1st		2,900	
2	2nd		3,000	
3	3rd		4,050	
4	4th		6,990	

Total trading earnings for this period: _____

Suppose you are a trader and you purchase 5 units in Market X for the following prices: 1550, 1600, 1670, 1610 and 1600. You resell one unit in Market Y for 1700 and three units for 1650 each. You also sell one unit to the monitor. What are your period earnings?

Trader Record Sheet

Card Units	**Price *Sold* in Market Y *or* to the Monitor (Column 2)**	**Price *Paid* in Market X (Column 3)**	**Earnings Per Unit (Column 2 – Column 3)**
1			
2			
3			
4			

Total *franc* trading earnings for this period: _____

Once the experiment begins, remember the following:

1) At the beginning of a period, individual pre-drawn computer randomized cost schedules will be handed out to the sellers. Traders, Market X Buyers and Market X Sellers will trade. A trading period will last ten minutes or less if a minute has elapsed without a bid or offer. Traders and sellers are free to make verbal bids and offers for 1 unit at a time. When trading has ended in Market X then trading begins in Market Y. Market Y Buyers will post prices and maximum quantities. Traders and then Market Y Sellers will be randomly drawn to choose the buyer(s) they wish to sell to. Also, traders and sellers can sell units to the monitor for a price of 20 francs. Profits will be calculated. This process will repeat itself in subsequent periods.
2) Buyers (sellers) *restart each trading period* with the 1st unit redemption (cost) values in their respective schedules. Traders have no units at the beginning of each period.
3) Recall the only way for a buyer to earn money on a unit is to purchase it for a price below its redemption value. The only way for a seller to earn money on a unit is to sell it for a price that exceeds its cost. The only way for a trader to earn money on *card* units is to sell them at a higher price than what they paid for it. If you earn a loss on a transaction it will reduce your earnings.
4) You are free to make as much profit as you can. Please make sure that you keep accurate records for each transaction. A monitor will come by to double-check your calculations.
5) Try to ensure that you do not need to leave the room until the session is over.
6) It is very important that you do *NOT* talk, signal, or make noises to others in the experiment.

THIS IS THE END OF THE INSTRUCTIONS. IF YOU HAVE ANY QUESTIONS PLEASE RAISE YOUR HAND AT THIS TIME.

Schedules Sheet

Buyers			*Sellers*		
Redemption Values			**Cost Values**		
			25%	**50%**	**25%**
Unit	**Type1**	**Type2**	**High**	**Medium**	**Low**
1	700	710	690	515	270
2	610	600	800	590	380
3	510	500	910	700	490
4	265	255	1,135	925	715

Cumulative Profits for Traders

Participant No. _____

Note*: If at anytime* you loose *500 francs* in a given period or your *cumulative loss* is *1,200 francs* then you will *cease trading*, and *earn only $10.00* for the experimental session.

	Profits in Francs
Period 1	
Period 2	
Period 3	
Period 4	
Period 5	
Period 6	
Period 7	
Period 8	
Period 9	
Period 10	
Total francs net cumulative earnings	

Earnings Calculation:

(1) Note*: If at anytime* you loose *500 francs* in a given period or your *cumulative loss* is *1,200 francs* then you will *cease trading*, and *earn only $10.00* for the experimental session.

(2) Otherwise, your total franc earnings will be the *maximum of*:

1,200 francs + net cumulative trading earnings of _____ = _____ .

or

690 francs total.

Total franc trading earnings _____ x 0.25 = _____Total $ Trading Earnings + $5.00 show up fee =

Total $ _____

Appendix B

Parameter Set Schedules

Parameter Set 1:

	Buyers Redemption Values		*Sellers* Cost Values		
			25% (Blue)	**50% (White)**	**25% (Red)**
Unit	Type1	Type2	High	Medium	Low
1	590	600	580	370	160
2	500	490	690	480	270
3	400	390	800	590	380
4	155	145	1,025	815	605

Parameter Set 2:

			25% (Blue)	**50% (White)**	**25% (Red)**
Unit	Type1	Type2	High	Medium	Low
1	590	600	580	405	160
2	500	490	690	480	270
3	400	390	800	590	380
4	155	145	1,025	815	605

Parameter Set 3:

			25% (Blue)	**50% (White)**	**25% (Red)**
Unit	Type1	Type2	High	Medium	Low
1	460	470	450	275	30
2	370	360	560	350	140
3	270	260	670	460	250
4	25	15	895	685	475

Parameter Set 4:

			25% (Blue)	**50% (White)**	**25% (Red)**
Unit	Type1	Type2	High	Medium	Low
1	700	710	690	515	270
2	610	600	800	590	380
3	510	500	910	700	490
4	265	255	1,135	925	715

Cost Shock Schedules

Pre-drawn Random Cost Shock Schedules				
Period	**1**	**2**	**3**	**4**
1	M	H	M	L
2	M	M	M	M
3	H	M	H	M
4	L	H	M	M
5	M	L	L	M
6	L	M	H	H
7	M	M	M	M
8	M	L	L	L
9	M	M	H	H
10	L	M	M	L
11	M	M	M	M
12	L	M	M	L

Appendix C

Posted-Bid Spot Market *without* a Futures Market
Treatment 1A (*Inexperienced* Participants)

Parameter Set 2
CE Bid Range: (480 - 490)
Conditional Bid Range: Low (380-390), Middle (480-490), and High (580-590)

Session Number	Mean Bid (Std. Dev.) N	Mode Bid (Interquartile Range)	Correlation of Cost State with Bid	Mean Bid Conditional on Low Cost State (Std. Dev.) N	Mean Bid Conditional on Middle Cost State (Std. Dev.) N	Mean Bid Conditional on High Cost State (Std. Dev.) N
1	410.94	450	0.13	404.34	406.02	441.57
	(77.01)	(410-453)		(79.52)	(81.57)	(41.17)
	140			35	84	21
2	437.39	450	0.03	439.29	432.71	444.86
	(65.31)	(407-475)		(65.66)	(60.63)	(74.57)
	140			35	70	35
3	462.18	481	0.08	454.14	466.57	463.57
	(59.94)	(460-485)		(68.15)	(58.13)	(36.15)
	84			28	49	7
4	442.36	450	-0.05	449.61	436.82	452.14
	(52.0)	(425-474)		(37.15)	(61.31)	(23.07)
	84			28	49	7
5	418.56	450	-0.01	428.17	408.33	451.67
	(59.64)	(410-459)		(57.57)	(62.77)	(18.07)
	72			24	42	6
6	450.25	450	-0.15	460.58	446.98	431.83
	(56.67)	(423-481)		(54.95)	(60.57)	(25.06)
	72			24	42	6
All 1A	434.63	450	0.02	437.71	430.31	445.78
(1-6)	(66.39)	(415-475)		(65.19)	(69.30)	(54.78)
	592			174	336	82

This table presents characteristics of the bid behavior for the six *inexperienced* sessions of Treatment 1, the posted-bid spot market *without* a futures market. The number of observations across sessions varies due to differences in the number of periods run per session, and also the number of participants in the inexperienced sessions, see Table 2 for details. Columns 1 through 8 detail for each session and for all sessions within an experience level, the session number, the mean bid, the standard deviation, number of observations, the mode bid and the interquartile range, the correlation of the cost state with the bids, the average bid conditional on the respective low, middle and high cost states.

Appendix D

Comparison of Posted-Bid with Double-Oral Auction Spot Markets

	Session 8 Posted-Bid Market Only	Session 16 Double Oral Auction
Panel A. Bid Behavior		
Mean Bid	573.3	582.6
(Std. Dev.)	(26.56)	(54.58)
N	50	95
Mode Bid	590	592
Correlation (Cost State, Bid)	0.04	0.93
Interquartile Range	564 – 591	545 – 595
Mean of Price Tacking Measure	51.2	13.7
Average Volume	6.2	9.5
Panel B. Conditional on the Cost State		
Low Cost State **(CE Bid = 495)**		
Mean Bid	568.7	519.2
(Std. Dev.)	(33.13)	(24.32)
Mean of Price Tracking Measure	73.7	25.6
Average Volume	11.0	14.5
Middle Cost State **(CE Bid = 595)**		
Mean Bid	575.4	596.9
(Std. Dev.)	(22.11)	(18.65)
Mean of Price Tracking Measure	19.7	9.6
Average Volume	6.7	9.5
High Cost State **(CE Bid = 695)**		
Mean Bid	571.9	695.9
(Std. Dev.)	(33.58)	(2.37)
Mean of Price Tracking Measure	123.1	1.3
Average Volume	0.0	4.5

This table compares spot markets with the same random pre-drawn cost shocks and the same number of periods--ten. Session 8 is organized as a posted-bid market, and Session 16 is organized as a double-oral auction market. These two sessions are used for the comparison since they both use parameter set 4 and cost state sequence draw 2. Panel A presents data on the bid behavior across all cost states while Panel B presents data conditional on the cost state.