Chapter 62

ASYMMETRIC TWO-PERSON BARGAINING UNDER INCOMPLETE INFORMATION: STRATEGIC PLAY AND ADAPTIVE LEARNING

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The present chapter focuses on a series of experiments investigating decision behavior in single-stage, two-person bargaining over the exchange of a single commodity, where neither trader knows with precision the reservation value that the other places on the good or service being bought or sold. Uncertainty about the other trader's reservation value is represented by a commonly known probability distribution. We summarize the major behavioral regularities that have been observed in two computer-controlled bargaining experiments using the sealed-bid double auction mechanism (Daniel, Seale, and Rapoport, 1998; Rapoport, Daniel, and Seale, 1998). Under this mechanism, the buyer submits a bid anonymously over a computer network, and the seller submits an offer for the good she possesses. Bids and offers are submitted simultaneously. If the buyer's bid is at least as high as the seller's offer, then a transaction takes place at a price halfway between the offer and the bid. If not, then no trade occurs. Considerable theoretical progress has been made in analyzing these bilateral bargaining situations with two-sided incomplete information within the general framework of the Bayesian–Nash equilibrium (Chatterjee and Samuelson, 1983; Leininger, Linhart, and Radner, 1989; Linhart, Radner, and Satterthwaite, 1992). When both parties to the bargaining are assumed to be active, this theory typically permits a wide range of equilibrium bargaining behavior. Replicable behavioral regularities, to the extent that they can be found in the laboratory, can be combined with the theoretical results to choose between the multiple equilibria and, more importantly, construct a viable, descriptive theory of two-person bargaining under incomplete information. The following behavioral regularities appear to be particularly significant.

Handbook of Experimental Economics Results, Volume 1

DOI: 10.1016/S1574-0722(07)00062-5

1. Most Participants Behave Strategically in General Accordance with the Linear Equilibrium Strategy

The results of our experiments leave little doubt that most participants in the sealed-bid two-person bargaining game behave strategically. By this we mean that traders make offers and bids which are systematically different from their reservation values for the item being traded, and that these offers and bids are accounted for (with some systematic departures discussed below) by the linear equilibrium strategy (LES) constructed by Chatterjee and Samuelson (1983). Earlier experiments using the same mechanism iterated over time suggested this result (Radner and Schotter, 1989; Linhart, Radner and Schotter, 1990; Rapoport and Fuller, 1995), but were in varying degrees inconclusive either because the predictions of the LES and an alternative theory postulating truth telling (honest disclosure of the reservation values, which maximizes joint profit) made close predictions over large ranges of the reservation values, or because they used fixed pairs, thereby allowing for dependencies between successive iterations of the game and reputation building.

Figure 1 portrays the LES functions of the buyer and seller for two different cases. The upper panel pertains to the case where the buyer's reservation values are commonly known to be randomly drawn from a uniform distribution defined over the interval $[0, 200]$, and the seller's reservation values are commonly known to be drawn from a uniform distribution defined over the interval $[0, 100]$. In the lower panel, the buyer's distribution is the same, whereas the seller's uniform distribution is now defined over a considerably narrower interval $[0, 20]$. Truthful disclosure of the reservation values is depicted by the straight line with a slope of one. In both cases, the seller's LES function has an intercept of 50 and slope of $2/3$. The buyer's LES is a piecewise linear function with three connected segments. In both cases, the difference between truth telling and equilibrium play is seen to be substantial.

Figure 2 shows a representative sample of all fifty bids of three buyers from each of two independent experiments in which ten buyers were randomly paired, trial by trial, with ten sellers for a set of fifty periods (bargains). The reservation values in the first experiment by Daniel et al. were randomly selected from commonly known uniform distributions with a range of 0 to 200 for the buyer and 0 to 100 for the seller (see the LES functions for this case in the upper panel of Figure 1). The reservation values in the second experiment by Rapoport et al. were randomly selected from commonly known distributions with the same range of 0 to 200 for the buyer and a considerably smaller range from 0 to 20 for the seller (see the LES functions for this case in the bottom panel of Figure 1). In both experiments the payoff was contingent on performance. In both of them the buyer has an information advantage over the seller in the sense that the buyer's uncertainty about the seller's reservation value is smaller than the seller's uncertainty about the buyer's reservation value. This information advantage increases as the distribution of reservation values of one of the traders become narrower. One-sided uncertainty is obtained when the distribution of reservation values of one of the traders shrinks to a single point.

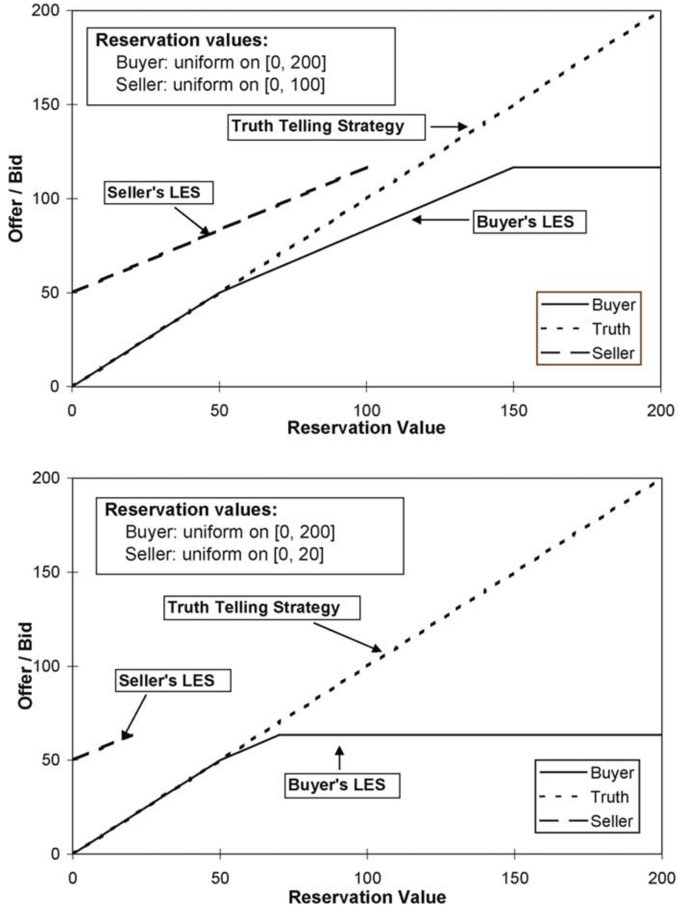

Figure 1. Linear equilibrium strategies (LES) for the buyer and seller in two different games.

Figure 2 displays all the fifty bids of each of the six buyers as a function of the corresponding reservation values. All the six panels exhibit bidding patterns very suggestive of the LES (Figure 1). See, in particular, the non-linear, piecewise-like behavior of the bids. No compelling case can be made for competing models predicting that buyers bid their reservation values or even some constant fraction of those values. To the extent that the results of both buyers and sellers depart from LES, they do so primarily in three ways. First, high bids which are closer to the reservation values than to the LES values typically occur early in the experiment and seldom after ten trials, indicating a learning process. Second, buyers bid slightly more aggressively (lower bids) than the theory would predict. Third, most of the sellers make less aggressive offers than predicted; their offers (not displayed here) typically fall on a straight line between the LES and

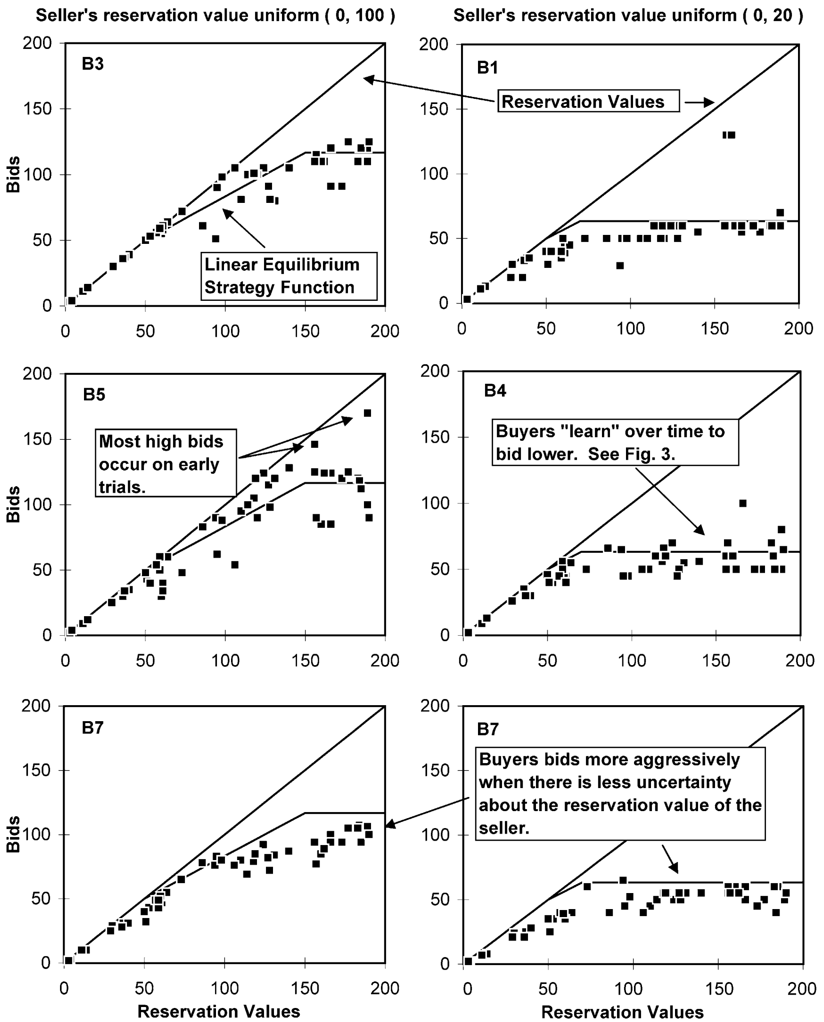

Figure 2. Buyer's bids vs their reservation values for two groups of sellers (for a sample of three buyers facing each type of seller). Over 50 trails, all buyers bid strategically (much closer to the linear equilibrium strategy values than to their reservation values).

truth telling linear functions. These small but systematic departures from the LES and their implications for the two traders are discussed below.

2. There is an Information Advantage Exceeding the Predictions of the LES

The two experiments manipulated the information structure by using a 2 by 2 between-subjects design to compare fixed vs random pairing of subjects and wide vs narrow

Table 1
Actual and potential profits of buyers and sellers (in experimental money units over 50 trials). Because of the information disparity, buyers should do a little better than sellers, if both played their equilibrium strategies (LES–LES). In actual play (A–A), buyers do much better than this and the sellers do much worse. If both revealed their true reservation values, both would profit (RV–RV). With fixed pairing over the 50 trials, the buyer's profit is higher than under random pairing of buyers and sellers

Reservation values				Sellers – uniform (0, 100) Buyers – uniform (0, 200)		
Random partners				Fixed partners		
Strategy	A–A	LES–LES	RV–RV	A–A	LES–LES	RV–RV
Buyer 1	1693	1519	1693	1199	1549	1582
Buyer 2	1262	1422	1442	971	1412	1546
Buyer 3	1779	1534	1737	1641	1463	1543
Buyer 4	1385	1395	1529	2064	1491	1624
Buyer 5	1589	1426	1526	1894	1409	1569
Buyer 6	1398	1345	1405	1749	1542	1604
Buyer 7	1437	1385	1476	1417	1416	1543
Buyer 8	1102	1389	1442	1088	1426	1553
Buyer 9	1394	1490	1524	2229	1474	1535
Buyer 10	1536	1488	1591	1501	1454	1564
Total buyers	14,573	14,392	15,363	15,751	14,635	15,662
Seller 1	1074	1256	1531	985	1309	1569
Seller 2	1074	1214	1381	1173	1389	1624
Seller 3	989	1502	1654	730	1388	1535
Seller 4	1274	1420	1728	346	1545	1604
Seller 5	827	1216	1367	864	1481	1582
Seller 6	961	1187	1472	1055	1234	1546
Seller 7	1177	1433	1640	1028	1345	1553
Seller 8	714	1074	1314	1248	1270	1543
Seller 9	1278	1554	1827	1316	1395	1564
Seller 10	909	1294	1451	1066	1319	1543
Total sellers	10,276	13,149	15,363	9811	13,675	15,663
Total all	24,849	27,541	30,725	25,559	28,310	31,325
% deals made	52%	53%	77%	52%	52%	76%

ranges of the seller's reservation values. This information structure was chosen so that the predictions of the LES would differ markedly from those that would have been obtained if the buyers bid and the sellers offered a fixed proportion of their reservation values. This information structure provided the buyers with an advantage which, if both traders bid their LES values, would have led to only modestly larger profits. Table 1 presents three sets of payoffs for each buyer and each seller in each of our two experiments, one (left panel) where pair members changed randomly from trial to trial (random pairing), and another (right panel) in which a fixed pairing of the buyer and seller was preserved for all fifty trials (fixed pairing). The payoffs in the column labeled A–A are those actually observed in the experiments; the ones in the column labeled LES–LES would have been obtained (with the reservation values actually generated in the experiments), if each trader had played according to the LES; and the payoffs in the column labeled RV–RV would have been obtained if each trader had simply reported his/her true reservation values. The LES–LES column illustrates the point made above – profits for the buyers were expected to be from 7 to 10 percent higher than those of the sellers. However, the actual payoffs (A–A) are strikingly different. The buyers made between 40 percent (under random pairing) and 60 percent (under fixed pairing) more profit. These results are mostly due to the aggressive behavior of the buyers who "pushed down" the sellers' offers particularly in the second half of the experiment. Experiments are currently under way to see if the mirror image of these results holds – 'Do sellers achieve equal or even higher profits when they hold a corresponding information advantage?'

3. Repeated Play with a Fixed Partner Enhances Strategic Advantages

A comparison of the left- and right-hand panels of Table 1 shows that any strategic advantage that a buyer has in a bargaining situation can be enhanced by being able to deal with the same seller over a relatively long sequence of transactions. The operative word in the preceding sentence is 'can.' Whereas the average buyer did eight percent better dealing with a fixed partner and the average seller did five percent worse, the standard deviation of the buyers' profits with fixed pairing of traders (not presented here) is more than twice that when bargaining under random pairing. Our results suggest that most of the gain accorded to the buyers when dealing with fixed partners comes from the ability of a few buyers to discover and then exploit weaknesses on the part of a few sellers. In general, the bidding behavior of both buyers and sellers in the fixed pairing case shows more commonality than difference with the bargaining behavior in the randomly matched design.

4. Explanation of the Findings in Terms of Adaptive Learning

The LES bids and offers for the sealed-bid double auction mechanism are obtained by a solution of a pair of differential equations, which is clearly beyond the capability of our inexperienced subjects; yet the actual bids of such subjects (particularly the buyers), as seen in Figure 2, are in close agreement with the theory. As alluded to above, this correspondence is even closer if bids in the first few trials are discarded. Figure 3 illustrates the strong trend in the bidding behavior of the buyers in the experiment of Rapoport et al. (the one where the sellers' reservation values are uniformly distributed between 0 and 20 and the buyers' reservation values between 0 to 200). The results for the second

	Trials				
	1 to 10	11 to 20	21 to 30	31 to 40	41 to 50
Mean Buyer Bid	77	61	59	56	50
% Bids> LES max.	68%	38%	31%	20%	4%

Mean bids decline from trial to trial, and by the end of the experiment very few buyers are bidding above the LES function (see LES below).

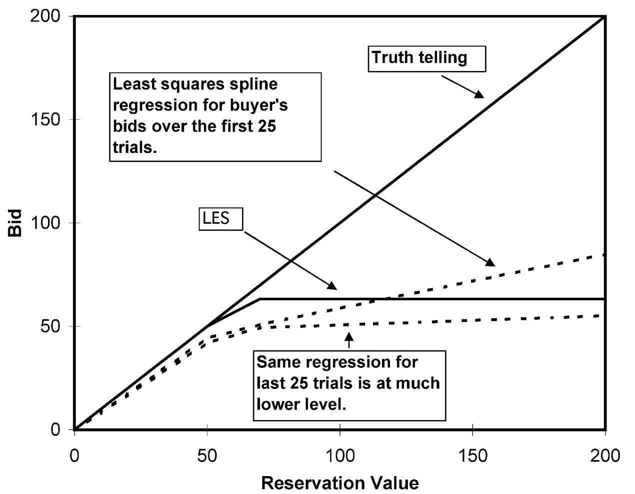

Figure 3. Learning trend exhibited by all the buyers over 50 trials.

half (trials 26–50) of the experiment are significantly different than those for the first half (trials 1–25). After the first few trials, there are very few high bids and the buyers learn to bid at or below the LES values.

Our results suggest that inexperienced subjects discover by some process of trial and error the most profitable bidding level for each reservation price. To account for changes in decisions across iterations (see Daniel, Seale, and Rapoport, 1998 for preliminary results, and Rapoport et al., 1997 for a more extensive test of the reinforcement-based learning model with a different set of data), we proposed and tested a reinforcement-based learning model based on two fundamental observations from the vast psychology literature on this topic: subjects tend to repeat what works well for them and discard that which does not, and consequences have more impact early in the learning process, with that impact diminishing with experience (see Roth and Erev, 1995 for a related approach). In the learning model that we have proposed, profitable trades on the immediately previous trial lead to more aggressive bids or offers on the next trial and missed trades lead to more conservative bids or offers, with the model being more sensitive to these profit and loss outcomes in the early phase of the experiment.

The learning model was tested with the data from the experiment of Daniel et al. in which the buyer's reservation values were randomly distributed between 0 and 200 and

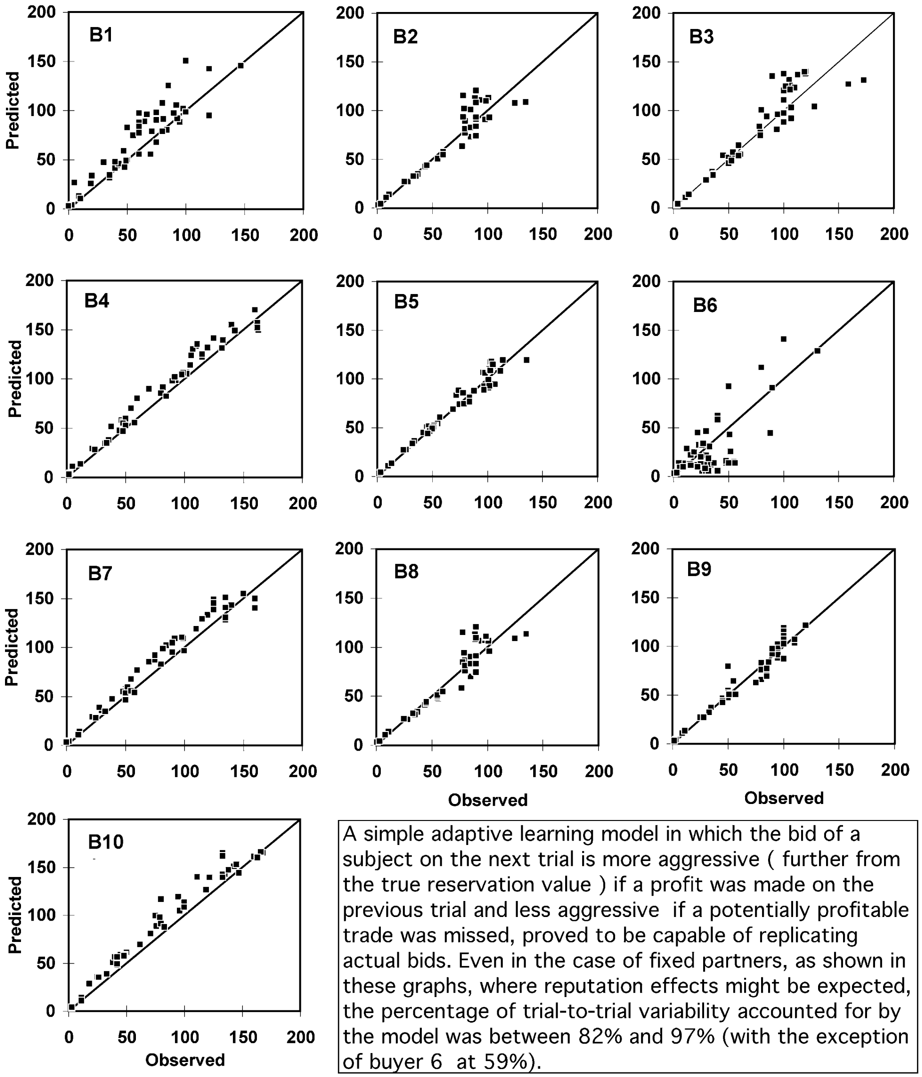

Figure 4. Model vs actual bids for all the buyers in the fixed pairs experiment. Each point represents a bid predicted by the learning model (vertical axis) corresponding to an actual bid made by the subject (horizontal axis). The diagonal lines represent perfect correspondence between model and actual bids.

the seller's values were distributed between 0 and 100. We used an extensive search procedure to estimate the best fitting parameter values for each subject separately. When the trial-to-trial decisions of each of the ten buyers and ten sellers in the fixed pairing condition were simulated by this model (using the same reservation values as were pre-

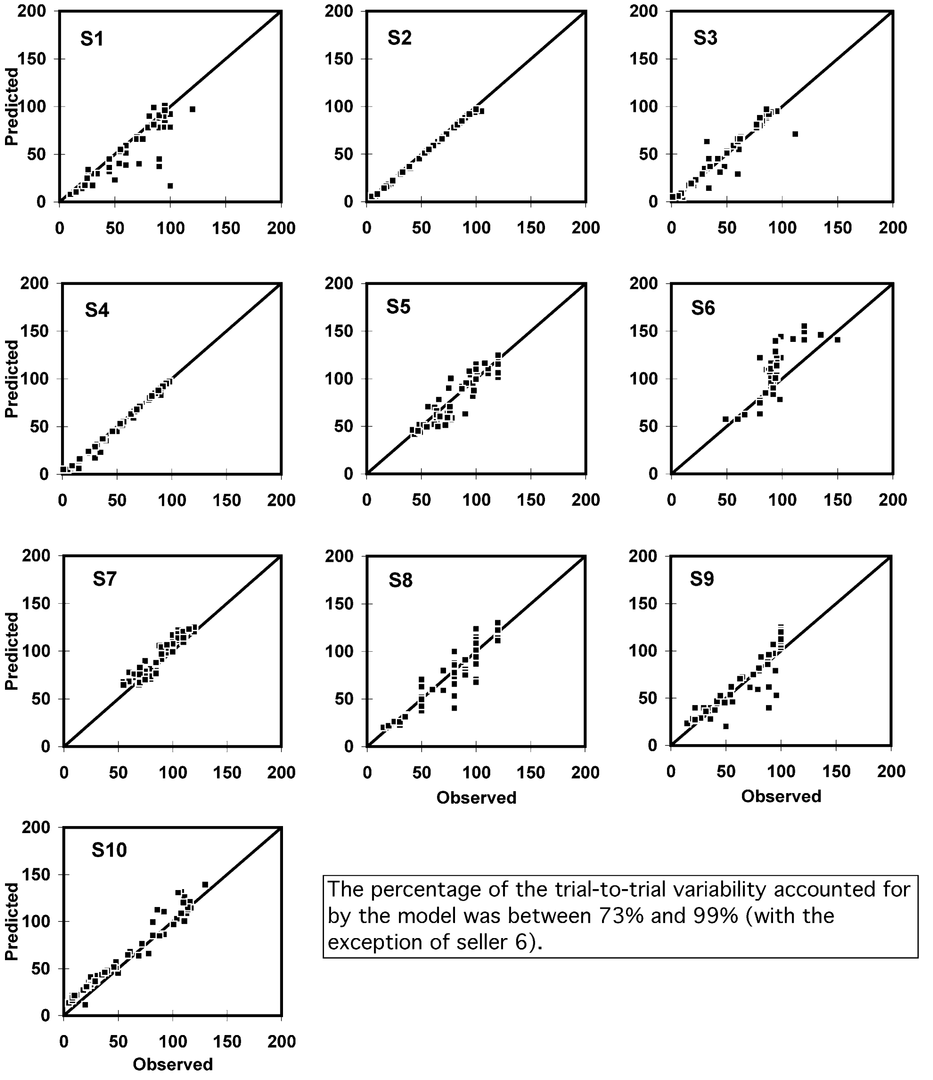

Figure 5. Model vs actual offers for all the sellers in the fixed pairs experiment.

sented in the actual experiments and only considering the outcome of the previous trial when generating a prediction for the next trial), the correspondence with the observed decisions was close. Figure 4 displays the predicted vs actual bids for each of the ten buyers in the fixed pairing condition, whereas Figure 5 compares the predicted and observed offers, again trial-by-trial, for all the ten sellers in the same condition. Each plot in both Figures 4 and 5 includes fifty points, one for each trial. The numbering of the

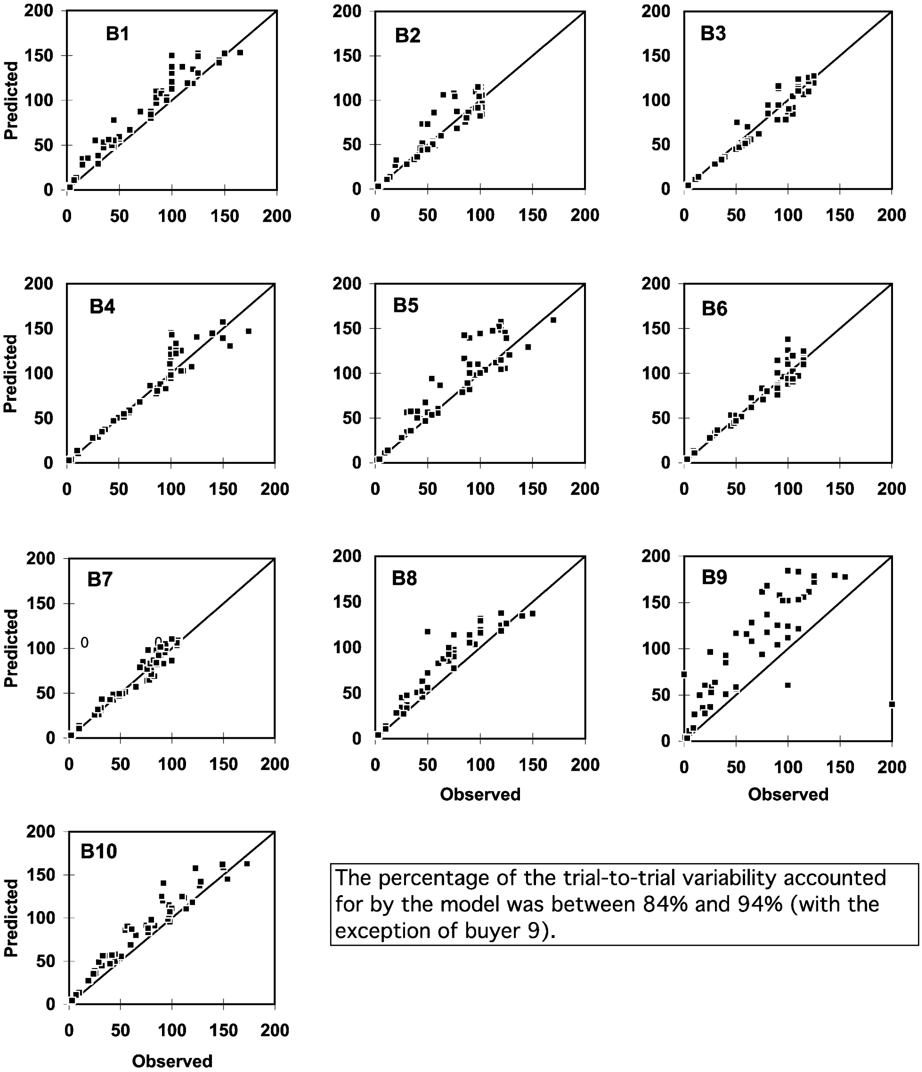

Figure 6. Model vs actual bids for all the buyers in the random pairs experiment.

buyers (1–10) corresponds to the numbering of the sellers. Perfect prediction would have resulted in all the fifty points for each subject falling on the 45 degree line. Figures 4 and 5 show that, with a few exceptions (e.g., Buyer 6, Seller 6, and Seller 9), the learning model accounts for the trial-to-trial bids and offers of our subjects remarkably well.

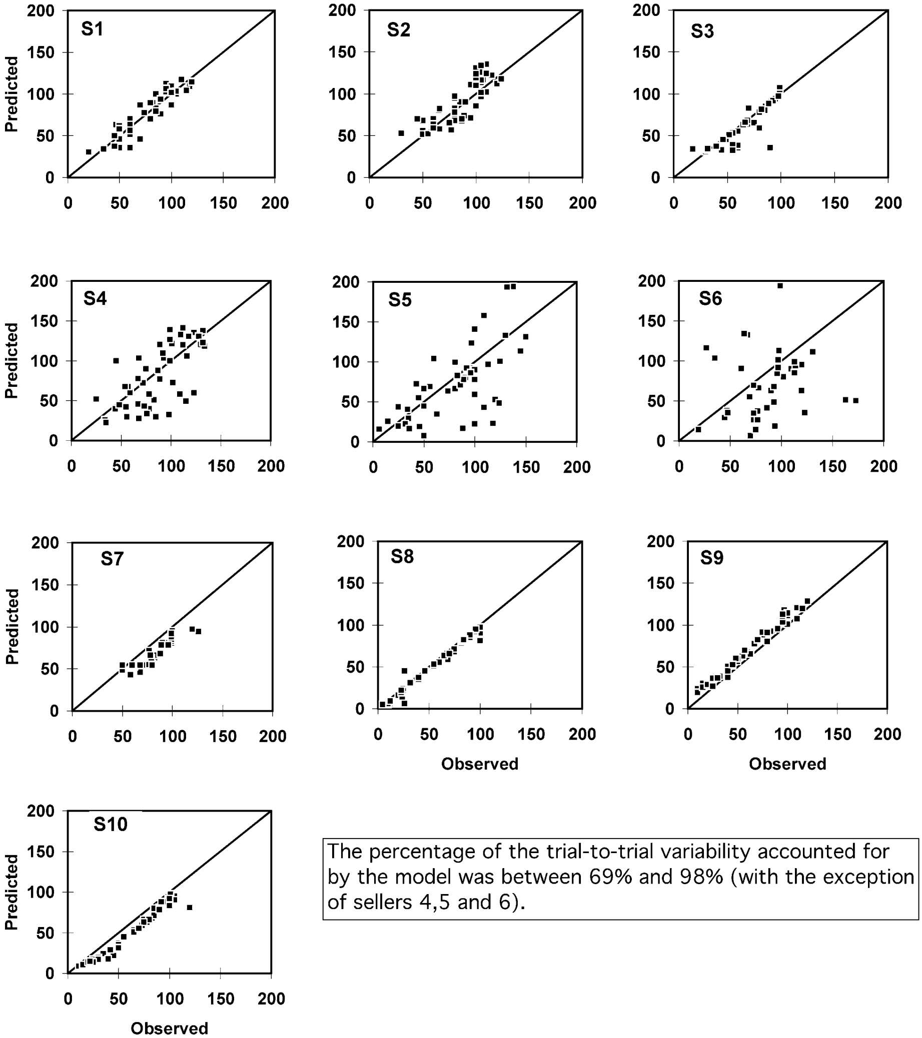

Figure 7. Model vs actual offers for all the sellers in the random pairs experiment.

Figures 6 and 7 exhibit corresponding results for a different study (Daniel, Seale, and Rapoport, 1998) with random rather than fixed pairing of buyers and sellers and same distributions of reservation values. Comparing predicted and observed bids trial by trial for buyers in the fixed pairing condition, the model accounts for (with a single exception) 82%–97% of the variability in the individual bids. Similar results hold for most of the buyers and sellers in each of the other conditions. Although we regard these results as impressive, we contend that the appropriate way of assessing the performance of our reinforcement-based learning model – and, for this matter, any other adaptive learning model – is not through hypothesis testing but rather through a competitive test against alternative models (Bush, 1963).

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