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INFLATION AND EXPECTATIONS IN EXPERIMENTAL MARKETS

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by

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Abstract: A total of nine experimental markets were studied. Seven of these involved eleven to twelve periods of inflation at a constant percentage and then two or three periods of no inflation. Two experiments involved no inflation for twelve periods and then inflation at a constant rate for three periods. In all but three markets, participants were asked to guess the mean price of the upcoming market period before they had any information about the parameters for that period. The subject with the best guess was given a financial reward in addition to any profit earned in the market.

Convergence properties are compared. Rational expectations models are tested and the structure of forecasts are studied. In general the rational expectations models capture much of what is observed but paradoxes exist in the data and in the application of the models.

The experiments reported below were designed to facilitate a study of the market adjustment process in inflating markets. For the most part experimental market studies have focused on stationary markets with perhaps one or two parameter changes in the course of the market. Seven of the markets reported here are inflating at a constant rate of 15 percent and two markets serve as stationary control experiments. In six of the markets, agents provided forecasts prior to the opening of each market period so the study permits some statistical exploration of the relationship between price expectations, actual prices, and the theoretical equilibrium process under conditions of inflation.

The study is composed of five parts plus closing remarks. The next (first) section contains the parameters and experimental design. The second section explores the equilibrating speed and the efficiency of the markets. Section three focuses on expectations. The basic questions are related to expectations formation. The fourth section explores questions about the relationship between forecasts and choices in the market.

I. MARKET PARAMETERS AND EXPERIMENTAL PROCEDURES

A. *Design*

A total of nine experimental markets were studied. Two were controls with no inflation in the underlying parameters. The remaining markets involved inflation at a constant 15 percent for a number of periods. After several periods of inflation (stationarity) the design called for a switch to stationarity (inflation). This permits the system to be observed in the presence of an unanticipated shock. The basic design is contained in Table 1.

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TABLE 1: Experimental Design

Experiment	Inflation Sequence		Subjects	Price Forecasts
1(control)	Stationary $t \in [1, 12]$ $P_t^e = 189$	Inflation $t \in [13, 15]$ $P_t^e = 189(1.15)^{t-12}$	PCC	Yes
2(control)	Stationary $t \in [1, 12]$ $P_t^e = 189$	Inflation $t \in [13, 15]$ $P_t^e = 189(1.15)^{t-12}$	PCC	Yes
3	Inflation $t \in [1, 12]$ $P_t^e = 189(1.15)^{t-1}$ $t \in [1, 11]$	Inflation $t \in [13, 14]$ $P_t^e = 880$ $t \in [12, 14]$	PCC	Yes
4	Inflation $t \in [1, 9]$ $P_t^e = 189(1.15)^{t-1}$		PCC	Yes
5	Inflation $t \in [1, 12]$ $P_t^e = 189(1.15)^{t-1}$ $t \in [1, 11]$	Stationary $t \in [13, 15]$ $P_t^e = 880$ $t \in [12, 15]$	PCC	Yes
6	Inflation $t \in [1, 10]$ $P_t^e = 189(1.15)^{t-1}$		PCC	Yes
7	Inflation $t \in [1, 11]$ $P_t^e = 189(1.15)^{t-1}$ $t \in [1, 10]$	Stationary $t \in [12, 14]$ $P_t^e = 765$ $t \in [11,14]$	CIT	No
8	Inflation $t \in [1,11]$ $P_t^e = 189(1.15)^{t-1}$ $t \in [1, 10]$	Stationary $t \in [12, 14]$ $P_t^e = 765$ $t \in [11,14]$	CIT	No
9	Inflation $t \in [1, 11]$ $P_t^e = 189(1.15)^{t-1}$ $t \in [1, 10]$	Stationary $t \in [12, 14]$ $P_t^e = 765$ $t \in [11,14]$	CIT	No

Note: P_t^e = competitive equilibrium price in period t.

B. *Parameters*

Figure 1 is a graph of the aggregate demand and supply schedules for the first period of every experiment. The basic parameters involve eight types of schedules, which are contained in Table 2.

TABLE 2: Basic Schedules and Values by Unit for Buyers and Sellers

	Basic Schedules for First Period							
	Buyers Redemption Values				Sellers Cost Values			
x	S(x) 1	S(x) 2	S(x) 3	S(x) 4	S(x) 5	S(x) 6	S(x) 7	S(x) 8
1st Unit	295	285	275	265	83	93	103	113
2nd Unit	195	245	225	255	183	133	153	123
3rd Unit	175	195	215	235	203	183	163	143
4th Unit	135	165	205	155	243	213	173	223
5th Unit	125	115	145	105	253	263	233	273

Shown there are the periodic values for each type and how they aggregate to the market equilibrium. Although Figure 1 is the actual aggregate demand and supply schedule for period one of all experiments, these aggregate schedules remain constant throughout all periods in only experiments 1 and 2, the controls. In all other experiments the equilibrium price is shifted upward at a constant rate of 15 percent for a number of periods. This is accomplished by adding .15 P_{t-1}^e to all values in all schedules in order to determine the parameters for period t. The individual redemption values and costs of each type vary accordingly as in Table 3. In addition to a displacement upward by a constant, each period the basic schedules are rotated among the participants. This rotation which is contained in Table 4 was intended to mask the formula that was behind the parameter changes.

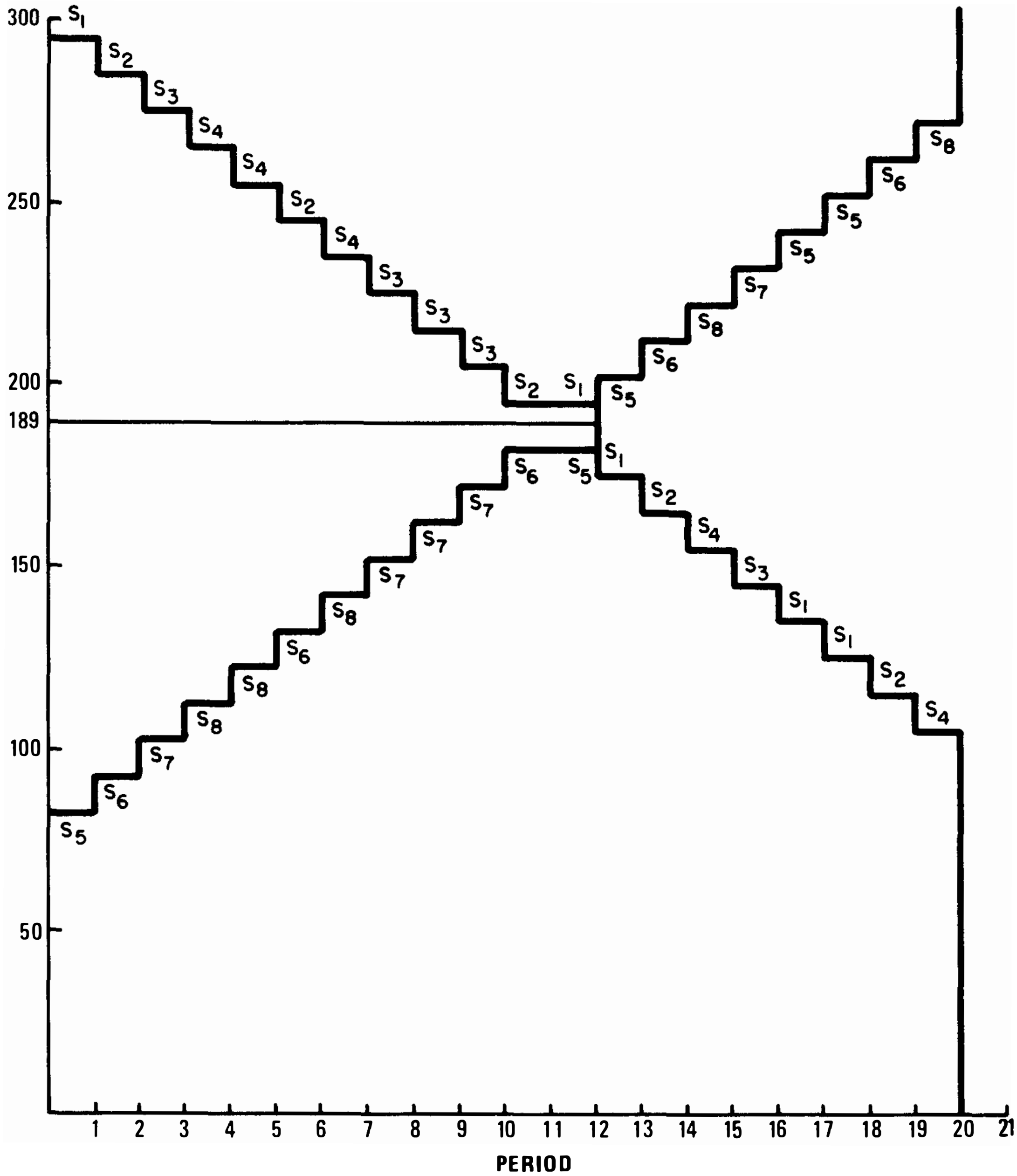

FIGURE 1

Market Demand and Supply as Aggregated
from Basic Period One Schedule

TABLE 3: Incentive Schedules All Periods, All Experiments

1, 2	$V_t^i(x) = S^i(x)$	$1 \leq t \leq 12$
	$V_t^i(x) = S^i(x)(1.15^{t-12} - 1) \cdot 189$	$t > 12$
3, 4, 5, 6	$V_t^i(x) = S^i(x) + (1.15^{t-1} - 1) \cdot 189$	$1 \leq t \leq 12$
	$V_t^i(x) = S^i(x) + (1.15^{11} - 1) \cdot 189$	$t > 12$
7, 8, 9	$V_t^i(x) = S^i(x) + (1.15^{t-1} - 1) \cdot 189$	$1 \leq t \leq 11$
	$V_t^i(x) = S^i(x) + (1.15^{10} - 1) \cdot 189$	$t > 11$

TABLE 4: Assignment of Incentive Schedules V_i to Individuals by Period

	Participant							
Period	1	2	3	4	5	6	7	8
1	1	2	3	4	5	6	7	8
2	2	3	4	1	6	7	8	5
3	3	4	1	2	7	8	5	6
4	4	1	2	3	8	5	6	7
5	1	2	3	4	5	6	7	8
6	2	3	4	1	6	7	8	5
7	3	4	1	2	7	8	5	6
8	4	1	2	3	8	5	6	7
9	1	2	3	4	5	6	7	8
10	2	3	4	1	6	7	8	5
11	3	4	1	2	7	8	5	6
12	4	1	2	3	8	5	6	7
13	1	2	3	4	5	6	7	8
14	2	3	4	1	6	7	8	5
15	3	4	1	2	7	8	5	6

We are interested in comparing behavior under inflation to that in a stable market. Experiments 3, 4, 5, 6, 7, 8, and 9 are the inflating markets. Experiments 1 and 2 are used as control experiments for the basis of our comparisons.

C. *Procedures*

The subjects were undergraduate students from the California Institute of Technology and Pasadena City College. Experiments 1, 2, 3, 4, 5, and 6 used students recruited from Pasadena City College (PCC) while the California Institute of Technology (CIT) students were used for experiments 7, 8, and 9. A pilot experiment was also conducted at CIT, but the results are not reported here.

While the PCC subjects were inexperienced, many of the CIT subjects had previous experience in the oral double auction procedure. The subjects were told that they would earn money according to decisions they made during the experiment and, in the PCC experiments, that they would receive four additional dollars simply for being present. A period zero was conducted without payment in experiments 1, 2, 5, and 6, to check the students' understanding of the trading rules and accounting. The experiments typically lasted two and one half hours, after which the subjects were paid in cash.

The markets conducted were all multiple unit oral double auctions. In each case there were four buyers (numbered 1, 2, 3, and 4) and four sellers (numbered 5, 6, 7, and 8). The markets proceeded in a sequence of trading periods, each lasting five minutes with a warning when there was one minute remaining and another when there were thirty seconds remaining in the period. The currency in these markets was francs, with each franc being worth .01 dollars in experiments 7, 8, and 9, and being worth .008 dollars in the remaining experiments. The experiments and individual incentives were explained to the subjects in terms of francs.

Bids to buy were tendered by a buyer who would orally indicate his/her number first, then the value per unit of the bid, and then the number of units desired to be purchased. For example, "two bids 250 for three." Asks to sell were announced verbally: "seven asks 400 for two." Bids and asks could also be canceled at any time, but once a bid or ask was accepted, the contract was final, denoted by a circling of the accepted bid or ask as well as the identification number of the acceptor, as shown in Figure 2. Furthermore, any integral portion of an ask or bid could be accepted, with the remaining units forming the new outstanding bid or ask (also shown). Identification numbers, values, and number of units outstanding were written from left to right for bids and right to left for asks so that identification numbers were always in the outermost columns and the number of units outstanding was always in the innermost columns.

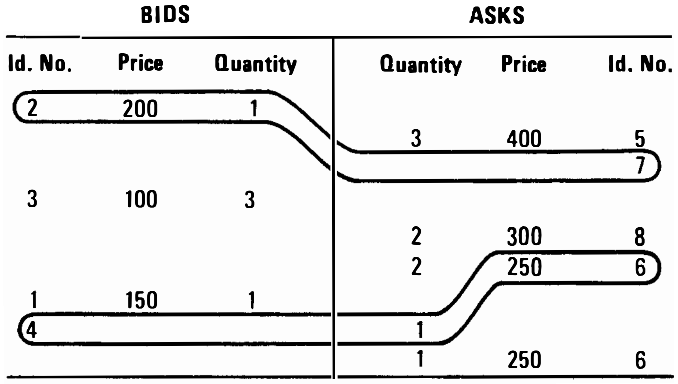

FIGURE 2

Each participant was given a folder which contained his/her private information describing to him/her the value of any decisions he/she might make during the experiment. All folders contained a set of instructions (which was read aloud) and a stack of accounting sheets, which contained one sheet for each period, including period zero where appropriate. All PCC experiments provided each subject with forms for the recording and submitting of the subject's prediction of the mean contract price for the ensuing period. The stack of accounting sheets for each of the PCC experiments was stapled together so that the chart for period t was not exposed until the chart for period $t - 1$ was removed. In experiments 1, 2, 5, 6 a cover sheet was introduced so that even the first period's chart was unseen at the time of the first prediction. (The numbering system does not reflect the order in which the experiments were conducted.)

In regard to the PCC experiments, the prediction process was conducted as follows. Before the used chart of period t was removed, the subjects were asked to submit predictions as to the mean contract price of period $t + 1$. At the end of each period, the mean contract price was calculated and posted on a side blackboard so that the complete history of this value was available to all subjects at all times. The participant with the smallest difference (absolute) between his/her predicted price and the actual mean contract price earned an additional one hundred twenty-five francs that period. If a tie occurred, each of the tying participants was awarded one hundred twenty-five francs. First period predictions for experiments 1, 2, 5, and 6 were made with absolutely no knowledge of any parameters of the experiment, giving cause at times for the omission of these first predictions from the models that will be proposed.

SECTION II. PROPERTIES OF INFLATING MARKETS

A. *Overview*

First, an overview is provided. Figure 3 contains the time series of average price (dots) for all inflating markets, and Figure 4 contains the same time series for the two stationary markets. In addition to prices, the figures contain the average forecast (triangles) of all participants in all markets. These will give the reader a visual impression of the market relative to the parameters. The solid lines indicate the competitive equilibrium based on the parameters that existed each period.

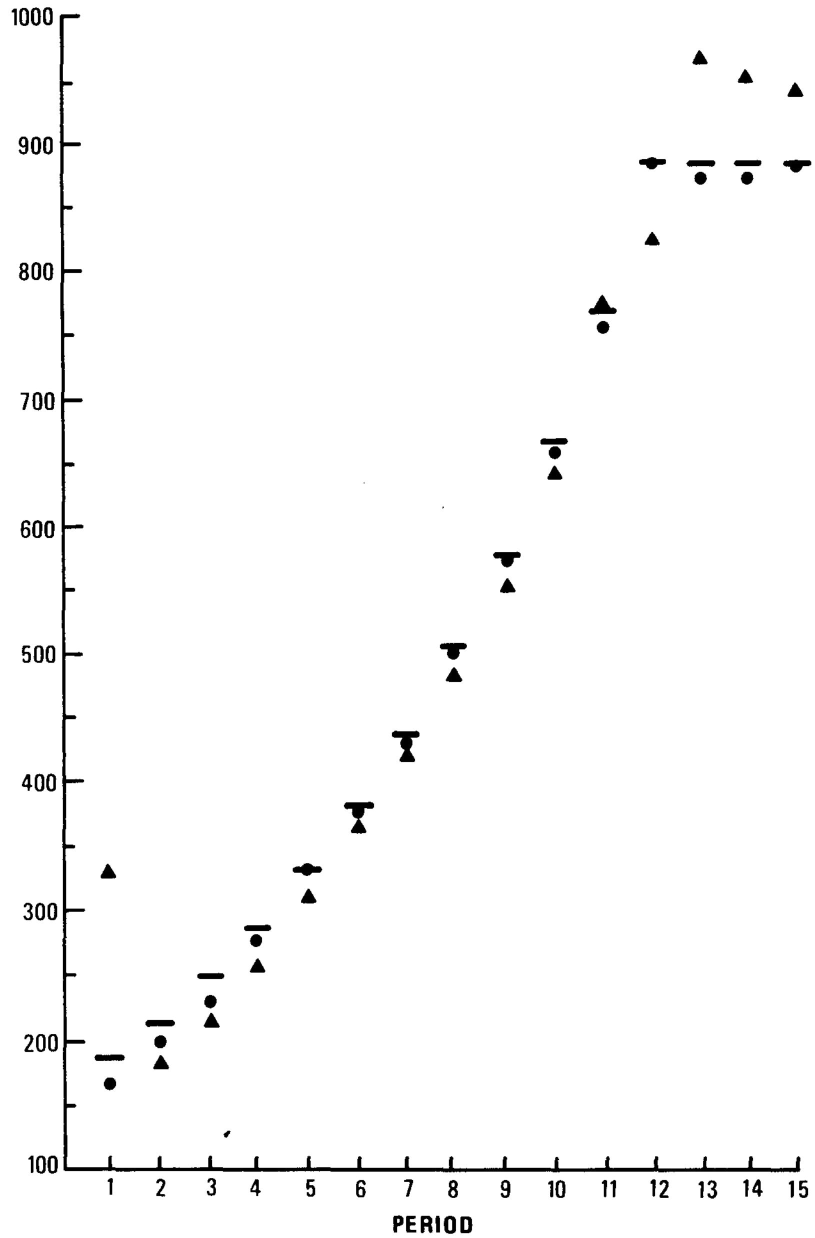

FIGURE 3

Mean Price and Mean Forecasts in All Inflating Markets for All Periods

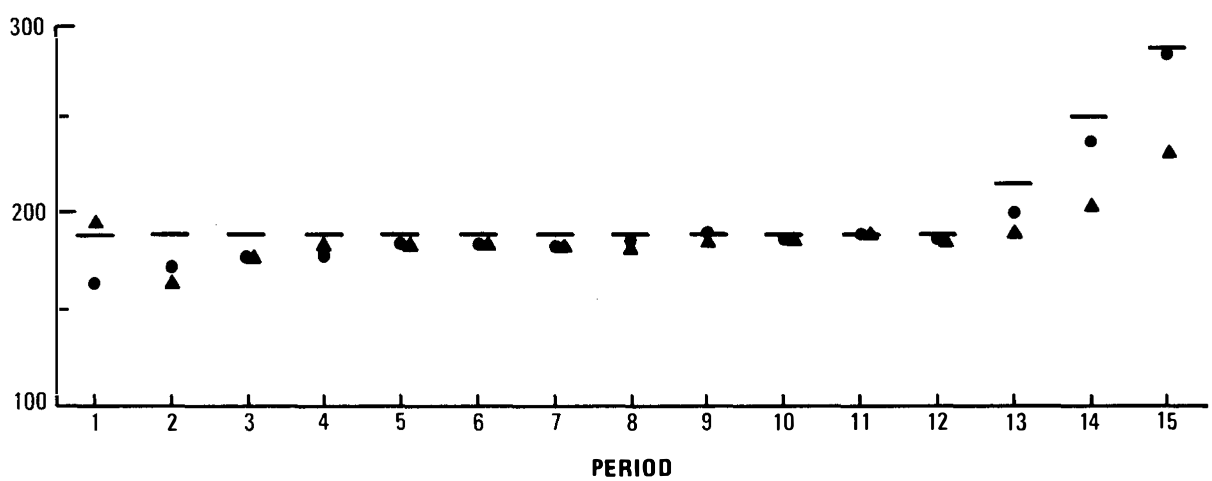

FIGURE 4

Mean Price and Mean Forecasts in Stationary Markets for All Periods

It is clear from the averages that the inflating markets approach the moving equilibrium. Similarly, the stationary markets approach the predicted equilibrium and then begin an upward adjustment as the inflationary final three periods begin.

The averages of experiments can be a little misleading about what is happening. For example, the CIT experiments behave somewhat differently from the PCC markets. Even markets within PCC have different convergence properties. Some of the markets terminated before other markets and when the short markets are deleted from the data, such as in period 12, some peculiar jumps appear.

The forecast data move at the same rate as the average price. The visual impression that the forecasts understate actual prices is true of pooled data but the proposition is difficult to establish at the individual level of analysis. The final three periods of stationary prices show forecasts overshooting actual prices. This is clearly inflationary expectations but it is difficult to see a big effect on prices.

The volume data are summarized in Table 5 and the efficiency data are summarized in Table 6.[1] Inspection reveals that efficiency levels tended to persist at the higher ranges in the stationary markets more than in the inflating markets. Volumes also tended to be higher in the stationary markets. No doubt the higher volume in the stationary markets is reflected in the higher efficiencies.

TABLE 5: Percentage of all Periods of all Markets in a Treatment at Each Level of Volume (Equilibrium Volume Equals 12 Units)

Units of Volume	Experiments 1 and 2	Experiments 3 thru 9
7	0	0
8	0	8
9	7	5
10	7	20
11	47	36
12	37	30
13	0	1
14	3	0

TABLE 6: Percentage of all Periods of all Markets in a Treatment in Each Range of Efficiency Level

Efficiency Range %	Experiments 1 and 2	Experiments 3 thru 9
70 - 74	0	1
75 - 79	0	5
80 - 84	0	2
85 - 89	4	13
90 - 94	25	11
95 - 100	71	68

Figure 5 contains a more detailed time series for all experiments. The competitive equilibrium has been subtracted from all contracts. The sequence of dots indicates the difference between the equilibrium price predicted by the competitive model and the actual price at which a contract was made. The sequence is in the order in which the contracts occurred. In addition, the figures contain the forecasts of average price made by subjects before they saw their own parameters for the upcoming period. Forecasts are plotted on the vertical lines at the start of a period. These data are included because the models presented below do not capture the complexities in the data. The equilibrating tendency of all markets is apparent in the data. It is also clear that the forecasts are near the pattern of trades. The variances, however, are complicated as will be discussed.

1) Market efficiency is the ratio of actual total earnings of subjects to the maximum possible earnings. This measure is equivalent to the percentage of maximum consumer plus producer surplus actually achieved by the market. If markets are 100 percent efficient, then no further gains from exchange exist.

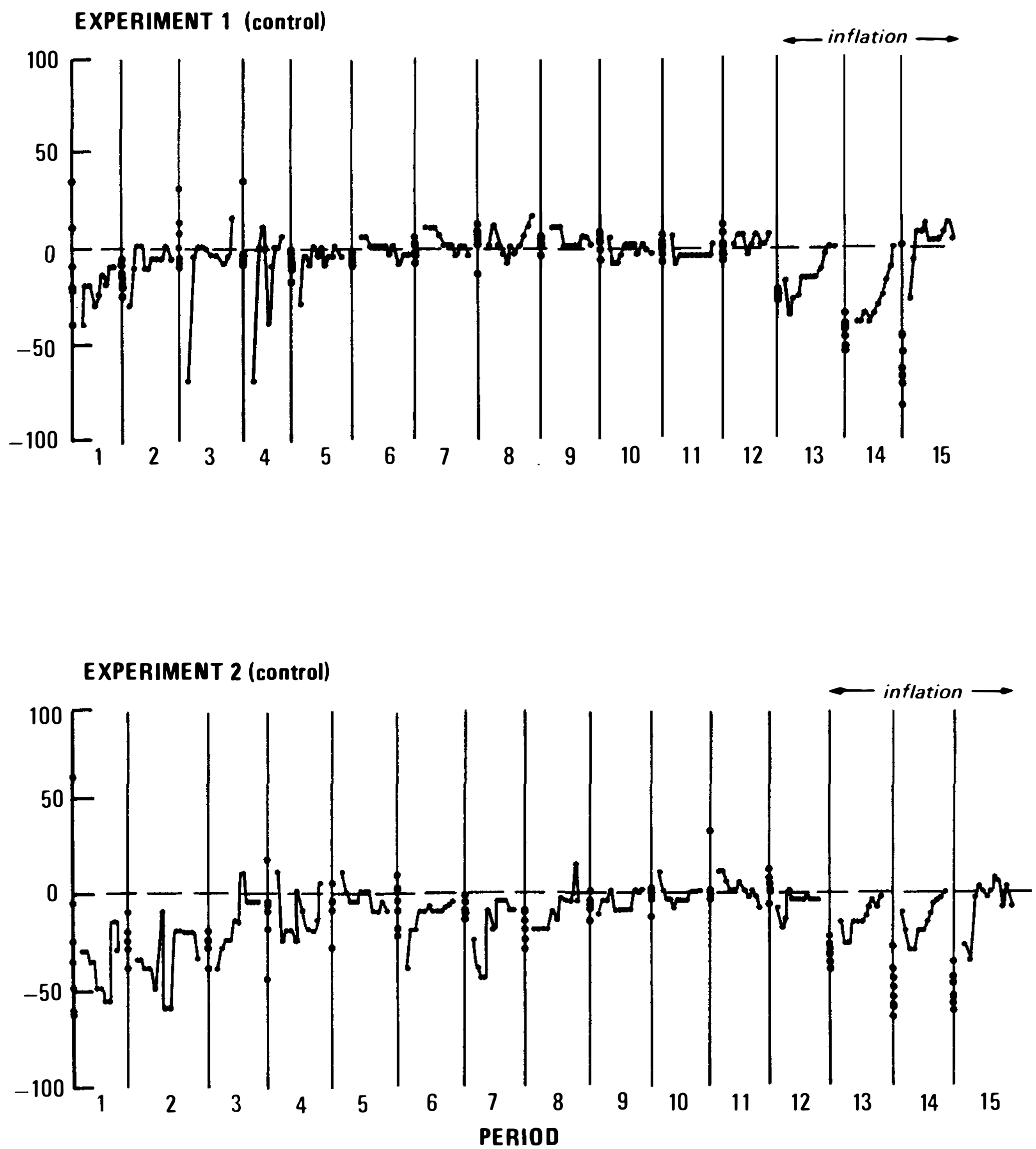

FIGURE 5
All Contract Prices and All Forecasts Expressed as Deviations from P for All Prices

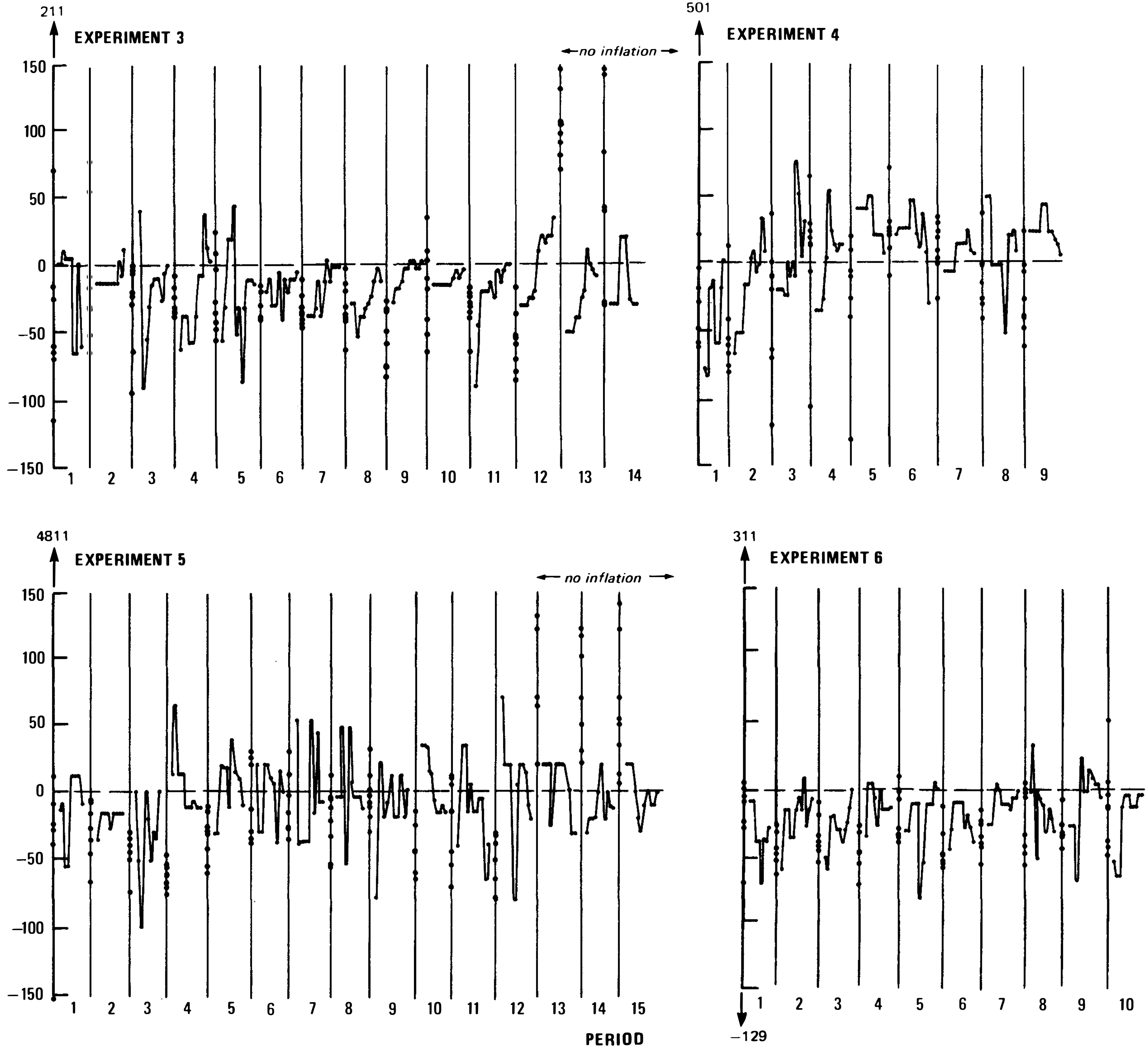

FIGURE 5 (continued)

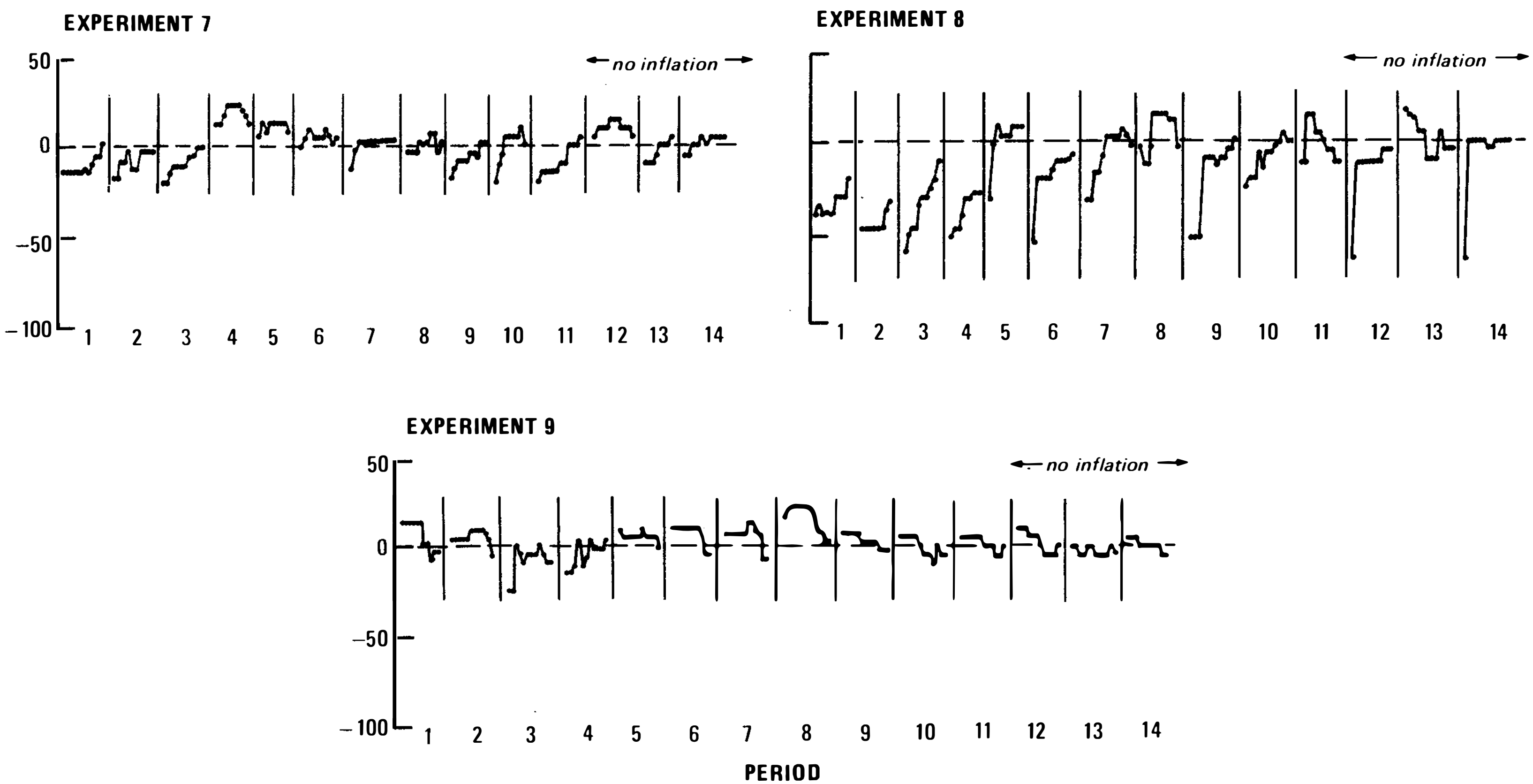

FIGURE 5 (continued)

B. *Relative Adjustment Speed*

Do constantly inflating markets adjust to equilibrium and, if they do, does it occur with the same speed as stationary markets? Three different measures suggest themselves: (1) deviation of mean price from the theoretical equilibrium price; (2) mean absolute deviation of contract price from the mean contract price; and (3) mean absolute deviation of contract price from theoretical equilibrium price. All three models were checked.

$\bar{P}_t$ = *the mean contract price in period t.*

P_t^e = *the competitive equilibrium price in period t.*

P_t^c = *the cth contract price in period t.*

V_t = *the volume of trades in period t.*

Z_t^k = *the measure of convergence according to which of the* $k \in 1, 2, 3$ *measures are used.*

$Z_t^k = ae^{\beta t}$ *is the assumed form.*

For the first measure $Z_t^{(1)} = |P_t^e - \bar{P}_t| = ae^{\beta t}$. The regression results in Table 7 show that the direction of convergence is as expected ($\beta < 0$) for all experiments except experiment four. However, close inspection indicates that β tends to be smaller and significant in the stationary (PCC) experiments than in the inflating (PCC) experiments. The R^2 are also lower in the inflating markets. Interestingly enough the inflating markets at CIT behave similarly to the stationary markets at PCC, which suggests that answers to the relative speed questions will be sensitive to the subject pool. In any case, after controlling for the influence of subject pool by comparing only experiments conducted at PCC, the behavior of an absolute difference between average price and the competitive equilibrium price suggests that inflating markets converge more slowly to the moving equilibrium than markets converge to a stationary equilibrium. The negative β in this model guarantees eventual convergence.

A second measure of convergence is the dispersion of contract prices around the mean price. We define

$$Z_t^{(2)} = \frac{1}{V_t} \sum_c \left| P_t^c - \bar{P}_t \right| = ae^{\beta t}$$

and report the regression of the log in Table 7. The two control experiments with stationary parameters show a pronounced fall in dispersion as the number of periods increase. For both $\beta < 0$ and it is significant. For the inflating experiments the slope term β is negative for only two experiments and it is significantly negative in only one. So ultimate convergence or even a decrease is not suggested. The inflating experiments at CIT begin with relatively low dispersion so the failure to shrink further is not too surprising. In any case, we can again conclude that a difference exists in adjustment speed in that inflating markets exhibit slower adjustment when we have controlled for subject pool differences.

The third measure is the mean absolute deviation of contract prices from the theoretical equilibrium price, which captures both of the above measures. Let

$$Z_t^{(3)} = \frac{1}{V_t} \sum_c \left| P_t^c - P_t^e \right| = ae^{\beta t}$$

TABLE 7: Estimates of Three Means of Price Convergence: All Experiments

	$\ln Z_t^{(1)} = \alpha + \beta t + \varepsilon_t^{(1)}$				$\ln Z_t^{(2)} = \alpha + \beta t + \varepsilon_t^{(2)}$				$\ln Z_t^{(3)} = \alpha + \beta t + \varepsilon_t^{(3)}$			
Exp.	$\hat{\alpha}$ (t-ratio)	$\hat{\beta}$ (t-ratio)	R^2 (s.e.)	n	$\hat{\alpha}$ (t-ratio)	$\hat{\beta}$ (t-ratio)	R^2 (s.e.)	n	$\hat{\alpha}$ (t-ratio)	$\hat{\beta}$ (t-ratio)	R^2 (s.e.)	n
1	2.38 (4.45)	-.16 (-2.23)	.27 (.87)	12	2.38 (9.76)	-.11 (-3.43)	.54 (.40)	12	2.63 (11.83)	-.12 (-4.12)	.62 (.36)	12
2	3.40 (7.37)	-.21 (-3.33)	.53 (.75)	12	2.52 (10.34)	-.09 (-2.65)	.41 (.40)	12	3.43 (12.08)	-.17 (-4.31)	.65 (.46)	12
3	2.95 (12.07)	-.03 (-.86)	.07 (.40)	12	3.07 (7.91)	.06 (-1.21)	.12 (.63)	12	3.21 (12.47)	-.03 (-.88)	.07 (.42)	12
4	2.24 (2.31)	.02 (.07)	.00 (1.33)	9	3.53 (15.49)	-.15 (-4.00)	.65 (.31)	9	3.50 (15.16)	-.08 (-1.86)	.33 (.32)	9
5	2.29 (3.35)	-.06 (-.68)	.04 (1.11)	12	2.61 (10.19)	.05 (1.42)	.08 (.42)	12	3.05 (20.91)	-.01 (-.36)	.01 (.24)	12
6	3.34 (12.59)	-.08 (-1.77)	.28 (.39)	10	2.34 (11.09)	.04 (1.23)	.16 (.31)	10	3.28 (14.83)	-.04 (-1.10)	.15 (.32)	10
7	2.41 (4.6)	-.08 (-1.05)	.11 (.81)	11	1.38 (7.51)	.04 (1.49)	.20 (.29)	11	2.36 (7.21)	-.05 (-1.10)	.12 (.51)	11
8	3.74 (5.98)	-.21 (-2.29)	.37 (.97)	11	1.81 (9.72)	.06 (2.23)	.36 (.29)	11	3.80 (15.05)	-.15 (-4.16)	.66 (.40)	11
9	2.21 (3.96)	-.14 (-1.75)	.25 (.86)	11	1.59 (5.42)	-.02 (-.50)	.03 (.45)	11	2.11 (7.77)	-.05 (-1.15)	.13 (.42)	11

Note: $Z_t^{(1)} = | P_t^e - \bar{P} |$; $Z_t^{(2)} = \frac{1}{V_t} \sum_c | P_t^c - \bar{P}_t |$; $Z_t^{(3)} = \frac{1}{V_t} \sum_c | P_t^c - P_t^e |$.

and study the regression results of the log transform in Table 7. Again the convergence tendency of all experiments can be seen in the $\beta < 0$ and comparable α magnitudes. The β are smaller for the stationary markets and the level of significance is greater than in all inflating markets except number eight. Again, this suggests faster convergence under stationarity.

Both measures that use the equilibrium price as a parameter tell the same story. All markets are converging. The degree of "disequilibrium" seems to be higher in the inflating markets and the rate of convergence is slower. However, this general conclusion is likely to be sensitive to the unmeasured properties of the agents because the inflating markets at CIT are comparable in some respects to the stationary markets at PCC.

C. *Bids and Asks as Part of the Convergence Process*

Vernon Smith, Gerry Suchanek, and Arlington Williams (1986) have advanced a model that claims that lagged excess bids are a good indicator of the next period contract price changes. Until now, only experiments involving asset trading have been used to test the model. Some adjustments are necessary to adapt the models to commodities that have no asset structure. Let $(B - A)_t$ be the number of bids in period t minus the number of asks. With an actual inflation (due to parametric drifts of demand) of Δ_t francs after period $t - 1$, the Smith, Suchanek, and Williams model adapted for application is $\bar{P}_t - \bar{P}_{t-1} = \alpha + \beta\Delta_t + \gamma(B - A)_{t-1}$ for the inflation experiments and is $\bar{P}_t - \bar{P}_{t-1} = \alpha + \gamma(B - A)_{t-1}$ for the control experiments since there is no inflation. Theoretically $\Delta_t = .15 P_{t-1}$ because the market parameters are inflating at a constant .15 rate.

If the model fits perfectly, then ($\alpha = 0, \beta = 1, \gamma = 0$) because the market would simply move from equilibrium to equilibrium. It is well known that such perfect adjustment is not the case but a detailed description of the departures from this model does not exist. By interpreting the Smith, Suchanek, and Williams model as above, the α term permits a constant factor to the adjustment process so the β can capture the influence of the parameter drifts and γ captures what might remain to be explained in the data after the theoretical model and the constant.

The parameter estimates are in Table 8. All the experiments but two have a positive value for γ and three of the seven have t 's greater than 1.60. It seems as though the excess bids have some slight explanatory power and might help as a predictor of the rate of inflation in relation to the underlying parameters.

TABLE 8: Estimation of Excess Bids Model of Price Adjustment for All Markets

	$\bar{P}_t - \bar{P}_{t-1} = \alpha + \beta\Delta_t + \gamma(B - A)_{t-1} + \varepsilon_t$				
Experiment	$\hat{\alpha}$	$\hat{\beta}$	$\hat{\gamma}$	R^2	n
1	1.0 (.63)		-.28 (-1.63)	.23	11
2	20.45 (3.67)		.58 (3.39)	.56	11
3	-20.77 (-2.21)	1.12 (12.89)	.58 (2.31)	.95	11
4	28.81 (1.29)	.73 (1.65)	.48 (.67)	.36	8
5	-3.4 (-.42)	1.17 (9.72)	1.12 (4.12)	.92	11
6	12.5 (.9)	.78 (2.8)	.013 (-.04)	.71	9
7	7.54 (.81)	.95 (5.28)	-.59 (-.93)	.83	10
8	3.91 (.22)	.96 (3.12)	.07 (.17)	.63	10
9	2.39 (.3)	.98 (7.97)	.44 (1.08)	.91	10

In period 13 of experiments 3, 4, 5, and 6 inflation is stopped entirely so that $\Delta_{13} = 0$. In experiments 1 and 2 inflation starts in this period so that $\Delta_{13} = 28$. In experiments 7, 8, and 9 inflation stops in period 12 so that $\Delta_{12} = 0$. Out of curiosity, we wanted to see if the excess lagged bids model would work into the regime change if the participants somehow knew that $\Delta_{13} = 0$, using the coefficients that have been derived from the previous eleven or twelve periods, as the case may be.

The results are in Table 9. The accuracy of these predictions is surprising for experiments 3 and 5, but in the remaining three instances, one can see that the results are not as striking. The model seems to work marginally well even leading into a regime change, but, of course, the subjects could not possibly have any knowledge that Δ_t was going to drop to zero as evidenced by the predictions given for period 13 in experiments 3 and 5.

TABLE 9: Predictions of Excess Bid Model at Time of Regime Changes

Experiment	Equation at First Period of Regime Changes	Predicted $(\bar{P}_t - \bar{P}_{t-1})$	Actual $(\bar{P}_t - \bar{P}_{t-1})$
3	$\bar{P}_t - \bar{P}_{t-1} = -20.77 + 1.12\,\Delta_t + 0.58(B - A)_{t-1}$	−13.23	−16.29
5	$\bar{P}_t - \bar{P}_{t-1} = 3.40 + 1.17\,\Delta_t + 1.13(B - A)_{t-1}$	−15.83	−12.50
7	$\bar{P}_t - \bar{P}_{t-1} = 7.54 + 0.95\,\Delta_t - 0.59(B - A)_{t-1}$	−14.88	19.62
8	$\bar{P}_t - \bar{P}_{t-1} = 3.91 + 0.96\,\Delta_t + 0.07(B - A)_{t-1}$	5.31	−14.09
9	$\bar{P}_t - \bar{P}_{t-1} = 2.39 + 0.98\,\Delta_t + 0.44(B - A)_{t-1}$	−5.97	.42

III. PROPERTIES OF EXPECTATIONS

A. *General Properties*

Two questions are posed for this section. (1) Are forecasts of buyers lower than forecasts of sellers, thereby exhibiting some sort of wishful thinking or possible strategic behavior? (2) Are aggregate forecasts accurate?

The first question is easy. The answer is no. In any given experiment the average forecast of buyers is just as likely to be above the average forecast of sellers as below (48/78). The probability of equal likelihood cannot be rejected at any conventional level of confidence ($Pr\,(x \geq 48 \mid \theta = 1/2) = .18$).

The second question is more complicated. The rational expectations hypothesis maintains that the difference between average price and forecasts is white noise. The difference should have a zero mean and be uncorrelated with other variables. The model is really to be applied at the individual level of analysis, but some of the properties of the average forecasts across individuals are not without interest.

Some notation is necessary.

f_t^i = *forecast of period t average price made by agent i after having observed prices in period t−1.*
$\bar{f}_t$ = *mean forecast of all agents of period t price.*

By pooling all the relevant periods ($t \geq 2$) during the inflating periods of markets, we arrive at

$$\underset{}{\bar{P}_t = \underset{(1.48)}{12.23} + \underset{(55.63)}{1.02}\,\bar{f}_t} \qquad n = 39,\quad R^2 = .99,\quad std.\ reg.\ error = 21.011,\quad DW = 2.28$$

and a regression of $\bar{P}_{t-1}$ on the error yields no explanatory results at all. In other words, on average, forecasts underestimate (with low level of significance) the inflation by a constant 12.23 francs. While the measures are not as close as one might like, the rational expectations model cannot be rejected.

A natural adjustment to explore are those that take advantage of the fact that the markets are equilibrating in the first stages. Another regression that uses only data after seven periods of inflation yields

$$\bar{P}_t = \underset{(-.33)}{-10.41} + \underset{(20.59)}{1.05}\,\bar{f}_t \qquad n = 15,\quad R^2 = .97,\quad std.\ reg.\ error = 23.48,\quad DW = 2.58$$

This yields stronger support for the rational expectations hypothesis by revealing the instability of the intercept term (-10.41 francs) which now has no significance level at all.

The possible sensitivity of the model to the time periods leads naturally to questions regarding the statistical properties of the data. In particular, the constant variances of forecasts as assumed by the regression model is suspect. A close examination of the data in Figure 5 suggests that the variance of forecasts across forecasters is sensitive to the forecast accuracy in the previous period. For example, notice the relatively big variance in forecasts after regime changes.

The following model verifies that suspicion.

$$\frac{1}{\sqrt{8}}\left[\sum_i (f_t^i - \bar{f}_t)^2\right]^{1/2} = \underset{(6.69)}{89.15} + \underset{(5.13)}{3.42} \left| \bar{P}_{t-1} - \bar{f}_{t-1} \right| \qquad \begin{array}{c} n = 55 \\ R^2 = .33 \\ std.\ reg.\ error = 25.89 \end{array}$$

The variance in forecasts the next period is systematically related to the forecast error. While these measurements are taken for the periods with no system "shock" such as period 13, the phenomenon is clearly present there. The variances in forecasts clearly go up in period 14 after the large error in forecasts in period 13.

B. *Properties of Individual Forecasts*

This section examines some of the properties of individual forecasts. Most of the attention is devoted to adaptive expectations and rational expectations. These will be covered in the two subsections.[2]

1. Adaptive Expectations

The models above suggest that forecasts might be following adaptive expectations. The data in Figure 3 suggest underestimation and the variance model suggests a sensitivity to error in forecasts. Such patterns lead to a suspicion that adaptive expectations models would summarize the data but the surprising result is that the adaptive expectation model does not seem to be appropriate.

For each individual in each experiment the equation

$$f_t^i = \lambda_1^i \bar{P}_{t-1} + \lambda_2^i (f_{t-1}^i - \bar{P}_{t-1}) + \varepsilon_t^i$$

was estimated. The adaptive expectation model holds if $\lambda_1 = 1$ and $0 < \lambda_2 \leq 1$. If $\lambda_1 = \lambda_2$ the forecasters simply ignore $\bar{P}_{t-1}$ and use some other basis such as an independent theory for developing a forecast. If $\lambda_1 = 1.15$ and $\lambda_2 = 0$ in the inflation markets and $\lambda_1 = 1$, $\lambda_2 = 0$ in stationary markets, then support is given for a rational expectations model since the forecasts increase exactly as the inflation rate increases without lag.

Estimates for all individuals for all experiments in which forecasts were made are in Table 10. The estimates give no support at all for adaptive expectations in inflating markets. The joint hypothesis that $\lambda_1 = 1, 0 < \lambda_2 < 1$ can be rejected in all inflating markets. In stationary markets the adaptive expectations model looks better than in the inflating markets in that the hypothesis cannot be rejected for five of the sixteen people. Aside from those five people all other data support the rational expectations over adaptive expectations. In inflating markets the joint hypothesis that $\lambda_1 = 1.15$ and $\lambda_2 = 0$ can be rejected

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2) The organization of this section follows the literature review provided by LOVELL (1986).

TABLE 10: Estimates of Adaptive Expectations Model of Individual Average Price Forecasts

$$f_t^i = \lambda_1^i \bar{P}_{t-1} + \lambda_2^i (f_{t-1}^i - \bar{P}_{t-1}) + \varepsilon_t^i$$

Experi-ment	Indi-vidual	λ_1 (t-ratio)	λ_2 (t-ratio)	Experi-ment	Indi-vidual	λ_1 (t-ratio)	λ_2 (t-ratio)
1	1	1.013	−0.399	4	1	1.077	−0.057
		(113.567)	(−1.853)			(39.246)	(−0.209)
	2	0.999	−0.032		2	1.132	−0.367
		(177.460)	(−0.567)			(48.079)	(−1.287)
	3	1.001	0.164		3	1.035	0.276
		(102.031)	(0.596)			(12.816)	(0.829)
	4	1.008	0.310		4	1.075	−0.088
		(63.670)	(2.105)			(24.167)	(−0.133)
	5	1.033	0.178		5	1.094	−0.136
		(33.855)	(0.623)			(37.973)	(−0.501)
	6	1.008	0.331		6	1.106	−0.293
		(247.815)	(4.590)			(49.464)	(−1.269)
	7	1.012	0.312		7	1.112	−0.139
		(148.922)	(2.062)			(27.397)	(−0.488)
	8	1.010	−0.198		8	1.159	0.013
		(167.204)	(−1.077)			(42.083)	(5.343)
2	1	1.000	−0.083	5	1	1.115	0.021
		(44.332)	(−0.249)			(45.264)	(8.095)
	2	1.019	0.091		2	1.083	0.137
		(96.608)	(0.381)			(34.576)	(0.460)
	3	1.020	0.050		3	1.090	−0.265
		(78.831)	(0.254)			(60.613)	(−1.260)
	4	0.990	0.076		4	1.127	−0.018
		(47.896)	(0.265)			(63.704)	(−0.124)
	5	1.025	−0.001		5	1.117	0.174
		(47.113)	(−3.716)			(74.071)	(0.851)
	6	1.037	0.089		6	1.107	0.016
		(45.073)	(0.385)			(55.061)	(5.086)
	7	1.009	0.503		7	1.094	0.156
		(89.740)	(1.520)			(63.257)	(0.630)
	8	0.986	0.168		8	1.119	0.091
		(17.431)	(0.540)			(104.787)	(0.461)
3	1	1.150	0.357	6	1	1.079	−0.251
		(54.120)	(1.670)			(54.713)	(−1.023)
	2	1.130	−0.065		2	1.127	−0.347
		(123.115)	(−0.499)			(79.856)	(−1.419)
	3	1.082	−0.264		3	1.155	0.321
		(55.764)	(−1.009)			(25.781)	(0.581)
	4	1.118	−0.233		4	1.094	−0.189
		(57.617)	(−0.804)			(61.354)	(−0.746)
	5	1.147	0.362		5	1.151	0.367
		(68.432)	(1.208)			(45.095)	(0.929)
	6	1.126	−0.132		6	1.091	−0.143
		(174.132)	(−1.457)			(82.760)	(−0.652)
	7	1.106	0.093		7	1.151	−0.368
		(67.944)	(0.369)			(83.974)	(−1.910)
	8	1.087	−0.067		8	1.144	0.767
		(39.796)	(−0.226)			(60.263)	(1.445)

for only four of the thirty-two individuals at .01 and it can be rejected for only eight of the thirty-two individuals at .05. So for twenty-four individuals the rational expectations model fits well. In stationary markets the joint hypothesis that $\lambda_1 = 1$ and $\lambda_2 = 0$ can be rejected at the .01 level (and for none at .05) for only one of the sixteen individuals in these markets. Thus, in the context of this model, the data support some form of rational expectations over adaptive expectations.

2. Rational Expectations Models

The pooled data for final periods and the adaptive expectations modeling both lend some support for a rational expectations formulation. The idea is that individual forecast errors should be unbiased and that all information that exists at the time of the forecast is used in the forecast.

The idea that forecast errors are unbiased takes the form of two different specifications. One was developed by Mills (1957) and the second is due to Muth (1961). They differ only in the choice of the dependent variable. We will estimate the Muth model and use a test on the coefficient to distinguish between the two.

$$f_t = \alpha_0 + \alpha_1 \bar{P}_t + \varepsilon_t \quad (Mills)$$

$$\bar{P}_t = \beta_0 + \beta_1 f_t + \varepsilon_t \quad (Muth)$$

In the Muth formulation the rational expectations hypothesis is tested by the null hypothesis $\beta_0 = 0, \beta_1 = 1$. If this hypothesis is not rejected, the Muth null model can be distinguished from Mills by the relationship between the R^2 and the coefficient. Specifically, a necessary and sufficient condition[3] that the Muth model is accepted over the Mills model is that $R < \hat{\beta}_1$. ($\hat{\beta}_1$ is the value of β_1 derived by application of the regression techniques.)

Estimates of the Muth model are in Table 11. For the control experiments 1 and 2 there is almost no variation in the independent variables plus a possibly small serial correlation. As a result the regression results for the controls are misleading. A direct examination of the errors indicates that the mean forecast error in the controls was almost zero for all individuals. The highest mean error in both experiments was eight francs. On average the mean forecast error across individuals was –.06 francs. For none of the individuals can we reject the hypothesis that the mean forecast equals the mean price. These results suggest the existence of fundamental limitations on the precision that one might expect from forecasts. When the variation of prices is very small, the relationship between price and forecast simply looks like a small "cloud" rather than a line through the origin.

The results of the inflationary markets, experiments 3 through 6, support the rational expectations hypothesis. For only nine of the thirty-two people can we come close ($t \geq 1.50$) to rejecting the hypothesis that $\beta_0 = 0$. In all thirty-two cases β_1 is close to 1 and significantly different from 0. For only one of the thirty-two cases can we reject the joint hypothesis that $\beta_0 = 0$ and $\beta_1 = 1$. Of course these results cannot prevent the nagging doubts that persist because the sample sizes are so small. One cannot avoid suspecting that, had the sample size been bigger, slight departures from the model would have become significant in the statistical tests. Nevertheless, the general approach of rational expectations over, say, adaptive expectations is certainly supported.

A check of the inequality $R < \hat{\beta}$, indicates that the Muth model is supported over the Mills model. Of the thirty-two individuals, twenty-one had $R < \hat{\beta}_1$, ten had $R > \hat{\beta}_1$ as required by the Mills model and there was one equality. Interestingly enough all the nine cases for which the rational expectations model was rejected are included in the ten cases of individuals that support the Mills version of the rational expectations model.

The conclusions above must be summarized as lending support for rational expectations in general and the Muth version of the model in particular. Certainly the results justify a more detailed look at the error to see if the data support the stronger hypothesis that, in addition to an absence of bias, the

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3) See LOVELL (1986, p. 112).

TABLE 11: Estimates of Forecast Bias for Each Individual: A Rational Expectations Measure

$$\bar{P}_t = \beta_0^i + \beta_1^i f_t^i + \varepsilon_t^i$$

Experiment	Individual	β_0 (t-ratio)	β_1 (t-ratio)	R^2	Experiment	Individual	β_0 (t-ratio)	β_1 (t-ratio)	R^2
1	1	106.722	0.424	0.451	4	1	19.824	1.022	0.959
		(3.874)	(2.865)				(0.700)	(12.828)	
	2	222.008	−0.194	0.156		2	−10.730	1.041	0.961
		(8.260)	(−1.361)				(−0.362)	(13.208)	
	3	87.722	0.529	0.279		3	128.987	0.784	0.808
		(1.765)	(1.969)				(2.338)	(5.028)	
	4	273.122	−0.457	0.691		4	−6.540	1.090	0.968
		(14.699)	(−4.724)				(−0.247)	(14.648)	
	5	167.355	0.096	0.080		5	19.459	0.999	0.935
		(8.548)	(0.933)				(0.539)	(10.048)	
	6	211.639	−0.138	0.015		6	11.685	1.006	0.945
		(3.210)	(−0.396)				(0.345)	(10.926)	
	7	104.485	0.442	0.660		7	20.867	0.969	0.890
		(5.671)	(4.408)				(0.436)	(7.536)	
	8	87.530	0.529	0.477		8	55.981	0.867	0.962
		(2.693)	(3.019)				(2.248)	(13.254)	
2	1	97.036	0.461	0.470	5	1	38.348	0.962	0.975
		(3.575)	(2.976)				(1.607)	(19.551)	
	2	53.910	0.691	0.390		2	10.969	1.054	0.965
		(1.028)	(2.396)				(0.339)	(15.787)	
	3	127.226	0.286	0.129		3	10.796	1.026	0.970
		(2.801)	(1.153)				(0.393)	(17.869)	
	4	101.526	0.439	0.281		4	60.667	0.916	0.962
		(2.638)	(1.979)				(2.169)	(15.957)	
	5	92.763	0.471	0.595		5	23.643	0.998	0.987
		(4.181)	(3.837)				(1.358)	(27.588)	
	6	171.331	0.033	0.002		6	2.869	1.037	0.981
		(3.545)	(0.128)				(0.129)	(22.428)	
	7	5.993	0.968	0.673		7	13.833	1.038	0.992
		(0.158)	(4.532)				(0.997)	(35.269)	
	8	140.483	0.221	0.585		8	−7.694	1.047	0.989
		(13.913)	(3.753)				(−0.451)	(29.813)	
3	1	54.126	0.911	0.976	6	1	1.379	1.047	0.983
		(2.494)	(20.338)				(7.575)	(21.617)	
	2	−23.284	1.056	0.977		2	21.291	0.965	0.988
		(−0.868)	(19.758)				(1.466)	(25.852)	
	3	14.157	1.031	0.985		3	41.110	0.912	0.959
		(0.760)	(25.606)				(1.577)	(13.675)	
	4	5.574	1.021	0.979		4	14.652	1.009	0.987
		(0.249)	(21.631)				(0.943)	(24.547)	
	5	−5.132	1.023	0.989		5	33.529	0.940	0.987
		(−0.312)	(30.049)				(2.301)	(25.005)	
	6	−21.390	1.058	0.981		6	−5.435	1.058	0.981
		(−0.943)	(22.441)				(−0.273)	(20.063)	
	7	7.515	1.036	0.992		7	34.666	0.920	0.983
		(0.544)	(35.014)				(2.074)	(21.723)	
	8	−8.685	1.076	0.978		8	23.785	0.955	0.978
		(−0.345)	(21.216)				(1.196)	(18.754)	

forecasters incorporate all available information into their forecasts. This hypothesis is interpreted through the regression of the error on lagged variables. In particular we check

$$e_t^i = \bar{P}_t - (\hat{\beta}_0^i + \hat{\beta}_1^i f_t) = \gamma^i \bar{P}_{t-1} + \eta_t^i$$

to see if past prices are correlated with the error and could therefore be used to improve the forecasts.

The equation was run for each individual in each of the markets in which forecasts were made. The strong rational expectations hypothesis is that $\gamma^i = 0$.

The results in Table 12 are remarkably consistent. For only three individuals in the inflating experiments is γ greater than .01 and the t-ratios are never over 1.2. The individual errors seem to be white noise, thereby suggesting that individuals use all available information in their forecasts. That is, the data support the strong version of the rational expectations hypothesis. In no case can $\gamma = 0$ be rejected.

IV. INDIVIDUAL CHOICE BEHAVIOR

To what extent do expectations and individual redemption values and costs influence individual behavior. Clearly an influence exists because the redemption values are the foundations of the demand function, which clearly predicts price behavior. But, individual buyers could be following a markdown strategy and sellers could be following a markup strategy, which suggests that individuals would ignore expectations in making choices. Alternatively, individuals could base decisions on expectations and ignore redemption values as long as a loss is not involved. Still, another possibility is that individuals get additional information from the market itself and so choices might have little to do with initial expectations.

The following notation is necessary.

$$y_{1t}^i = \begin{cases} \textit{the redemption value of the first unit for person } i \textit{ during period } t \text{ if } i \textit{ is a buyer.} \\ \textit{the cost of the first unit for person } i \textit{ during period } t \text{ if } i \textit{ is a seller.} \end{cases}$$

f_t^i = *forecast by i of average price in period t.*

P_{1t}^i = *the contract* for *the first transaction by i in period t.*

$\bar{P}_t$ = *the mean contract price in period t.*

When applied to pooled data (all periods, $t > 1$, for all individuals, with inflationary markets and stationary markets treated separately) the results are (t-ratios are below coefficient estimates):

Inflating markets 3-6

$$P_{1t}^i - \bar{P}_t = \underset{(-2.87)}{-4.80} + \underset{(2.16)}{.03}\,(y_{1t}^i - \bar{P}_t) + \underset{(-.01)}{(-.004)}(f_t^i - \bar{P}_t)$$

$n = 312$
$R^2 = .01$
std. reg. error = 25.49

Stationary markets 1-2

$$P_{1t}^i - \bar{P}_t = \underset{(-2.34)}{-2.41} + \underset{(.04)}{.0004}(y_{1t}^i - \bar{P}_t) + \underset{(-.12)}{(-.01)}\,(f_t^i - \bar{P}_t)$$

$n = 176$
$R^2 = 0$
std. reg. error = 13.067

The idea that one would get from the expected utility hypothesis is that prices should respond positively to both underlying values and expectations. As can be seen from the estimates, this property

TABLE 12: Regression of Rational Expectations Errors on Past Prices for All Individuals

$$e_t^i = \bar{P}_t - (\beta_0^i + \beta_1^i f_t^i) = \gamma^i \bar{P}_{t-1} + \eta_t^i$$

Experiment	Individual	$\hat{\gamma}^i$ (t-ratio)	Experiment	Individual	$\hat{\gamma}^i$ (t-ratio)
1	1	0.008 (1.113)	4	1	0.007 (0.202)
	2	0.002 (0.166)		2	0.010 (0.341)
	3	0.006 (0.975)		3	0.042 (0.922)
	4	0.005 (0.721)		4	0.004 (0.129)
	5	0.003 (0.350)		5	0.010 (0.253)
	6	0.010 (1.146)		6	0.006 (0.168)
	7	0.003 (0.423)		7	0.023 (0.522)
	8	0.002 (0.332)		8	0.002 (0.058)
2	1	0.005 (0.393)	5	1	0.009 (0.368)
	2	0.007 (0.675)		2	0.008 (0.264)
	3	0.007 (0.668)		3	0.003 (0.101)
	4	0.007 (0.448)		4	−0.004 (−0.146)
	5	0.009 (0.914)		5	−0.001 (−0.055)
	6	0.017 (1.111)		6	−0.000 (−0.014)
	7	0.004 (0.366)		7	−0.001 (−0.052)
	8	0.007 (0.685)		8	−0.001 (−0.085)
3	1	0.003 (0.135)	6	1	0.003 (0.190)
	2	0.007 (0.485)		2	0.009 (0.549)
	3	0.002 (0.081)		3	0.015 (0.574)
	4	0.002 (0.094)		4	0.004 (0.231)
	5	0.005 (0.303)		5	0.002 (0.087)
	6	0.007 (0.501)		6	0.005 (0.292)
	7	−0.003 (−0.174)		7	0.001 (0.042)
	8	−0.003 (−0.160)		8	0.003 (0.165)

appears to be absent from the data. Aside from the significant .03 coefficient in the first equation, nothing else exists in the data. The significant intercept reflects upward drifting prices within a period and first trades tend to be nearer the early parts of periods. This property of the adjustment path might provide a better vehicle for looking for the phenomenon but we have not pursued it.

We conclude that neither private values nor initial expectations account for variations of prices away from the mean price. Individuals seem to acquire the information used to make trading decisions within the period in which it is to be used. Evidently the attitudes formed prior to the period are not as important as information gathered on the spot. In addition, individuals appear to be willing to do as well as possible without regard to some type of sunk cost fallacy that would tie their decisions to redemption values and costs. Within the set of profitable trades, individuals do as well as possible without regard to parameters over which they have no control. That is, they do not follow markup or markdown strategies.

V. CONCLUSIONS

The most basic result is that constantly inflating markets converge to the (inflating) equilibrium but they converge more slowly than do stationary markets. The disequilibrium disappears less rapidly in the inflating markets. This phenomenon leads to paradoxes.

The price forecasts are captured reasonably well by the rational expectations hypothesis. Thus, the results differ slightly from those reported by Williams (1987). Even the strong version of the rational expectations hypothesis is supported. But, how can rational expectations exist in the presence of substantial market disequilibrium? Individuals are accurately forecasting a price that is in disequilibrium. But, disequilibrium seems to be inconsistent with the existence of rational and perfectly informed individuals.

If the number of bids exceeds the number of asks in one period, the following period will experience a slight price increase over what might have been anticipated from market fundamentals. This excess bidding is possibly a source of information for participants about the state of the market. Yet, direct tests on the relationship between individual expectations prior to the opening of the market and the subsequent prices at which individuals traded yield no relationship. Evidently information used by traders in the formation of their trading decisions is acquired close to the instance of trading. How then can excess bids have an effect?

A direct test of the adaptive expectations hypothesis leads to a clear rejection of it. The estimated model suggests that individuals put no weight on previous forecast errors in formulating their expectations. Yet an examination of aggregate forecasts demonstrates that the variance of forecasts across individuals is directly related to average forecast error in the previous period. One model says errors do not matter and the other suggests that they do. How can this be rationalized?

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