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LIMITED RATIONALITY AND STRATEGIC INTERACTION: THE IMPACT OF THE STRATEGIC ENVIRONMENT ON NOMINAL INERTIA

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LIMITED RATIONALITY AND STRATEGIC INTERACTION: THE IMPACT OF THE STRATEGIC ENVIRONMENT ON NOMINAL INERTIA

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Much evidence suggests that people are heterogeneous with regard to their abilities to make rational, forward-looking decisions. This raises the question as to when the rational types are decisive for aggregate outcomes and when the boundedly rational types shape aggregate results. We examine this question in the context of a long-standing and important economic problem: the adjustment of nominal prices after an anticipated monetary shock. Our experiments suggest that two types of bounded rationality—money illusion and anchoring—are important behavioral forces behind nominal inertia. However, depending on the strategic environment, bounded rationality has vastly different effects on aggregate price adjustment. If agents' actions are strategic substitutes, adjustment to the new equilibrium is extremely quick, whereas under strategic complementarity, adjustment is both very slow and associated with relatively large real effects. This adjustment difference is driven by price expectations, which are very flexible and forward-looking under substitutability but adaptive and sticky under complementarity. Moreover, subjects' expectations are also considerably more rational under substitutability.

KEYWORDS: Bounded rationality, strategic substitutes, strategic complements, money illusion, anchoring, nominal rigidity, sticky prices.

1. INTRODUCTION

A LARGE BODY OF EVIDENCE now suggests that, at the level of individual decision-making, a substantial number of people violate the rationality assumptions routinely made in most economic models (Kahneman, Slovic, and Tversky (1982), Camerer (1995, 2003), Crawford (1997), Kahneman and Tversky (2000), Costa-Gomes, Crawford, and Broseta (2001)). However, this evidence does not imply that individual deviations from rationality necessarily falsify the aggregate predictions of rational choice models. In competitive experimental markets with agents trading standardized, nonrisky goods, for example, prices and quantities typically converge quickly and reliably to the competitive equilibrium derived from individual rationality assumptions (Smith (1962, 1982)). Gode and Sunder (1993) have shown that even programmed players

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with "zero intelligence" quickly converge to the competitive equilibrium. Thus, there are conditions in which deviations from individual rationality have little effect on aggregate outcomes.

It would, however, also be a mistake to assume that interactions in competitive markets always eradicate the impact of bounded rationality. Theoretical work by Akerlof and Yellen (1985), Haltiwanger and Waldman (1985, 1989), and Russell and Thaler (1985) shows that there are plausible conditions under which even a small fraction of boundedly rational agents may have important effects on aggregate results. Moreover, empirical work by Camerer (1987) and Gneezy, Kapteyn, and Potters (2003) suggests that individual deviations from full rationality can have a significant impact on competitive market outcomes. In view of these results, the key question, therefore, is to identify the conditions under which limited rationality occurs *and* when it affects aggregate outcomes in economic interactions.

In this paper, we tackle this question experimentally in the context of an important economic problem—the sluggish adjustment of nominal prices after a fully anticipated and exogenous monetary shock. For decades, macroeconomists have examined the microfoundations of nominal price stickiness, because it is widely believed that nominal inertia is a main reason for the short-run nonneutrality of money. Much of the literature has emphasized informational (Lucas (1972), Mankiw and Reis (2002)), contractual (Fischer (1977), Taylor (1979)), and other (Mankiw (1985), Ball and Romer (1991)) frictions as causes of nominal inertia. There is, however, still considerable disagreement about the extent and the sources of nominal price inertia (see, e.g., Blinder, Canetti, Lebow, and Rudd (1998), Romer (2001)). Since we explicitly examine determinants of nominal price stickiness, our experiments not only shed light on when limits to rationality prevail and matter at the aggregate level, but they also contribute to a deeper understanding of the sources of nominal inertia. We show, in particular, that—in the absence of any exogenous frictions or costs of price adjustment—the strategic environment is a decisive factor, shaping price expectations and the extent of nominal price stickiness.

The theoretical work of Haltiwanger and Waldman (1989) inspired our experimental design. They showed that a given share of agents with nonrational, adaptive expectations influences the speed of adjustment toward equilibrium in varying degrees, depending on the extent to which agents' actions are strategic complements. Their model suggests that boundedly rational players have a smaller impact on the adjustment of prices after an anticipated monetary shock when strategic substitutability prevails than when complementarity prevails.[2]

[2]Price competition in oligopolistic goods markets is often characterized by strategic complementarity because if other firms cut prices, individual firms often have an incentive to cut their prices as well. Cournot duopoly is a good example of strategic substitutability. The more firm j produces, the less will firm i produce. In a macroeconomic context, strategic complementarity plays a role if search frictions (Diamond (1982)), informational frictions (Bryant (1983)), or

As a consequence, one would expect less nominal inertia under substitutability. The intuition behind this prediction is that the rational individuals have an incentive to partly mimic the behavior of the boundedly rational players under complementarity while they have an incentive to do the opposite of what the boundedly rational players do under substitutability. Therefore, the rational players amplify the effects of players with adaptive expectations under complementarity while they weaken the effects of adaptive players under substitutability.

However, there is little empirical work which examines how strategic substitutes and complements affect aggregate behavior differentially. In particular there seems to be no empirical evidence regarding how the strategic environment affects the nature and the speed of price adjustment after a nominal shock.[3] Therefore, we implemented a price setting game with a complements and a substitutes condition in which subjects simultaneously choose nominal prices in every period. We implemented a fully anticipated monetary shock in both conditions and ensured that any exogenous frictions for nominal price adjustment were absent. This means that if all subjects have rational expectations about the other players' actions and play a best reply to their expectations, the monetary shock leads to complete and instantaneous adjustment in both the complements and the substitutes treatment. However, the results of our experiments suggest that two psychological forces—money illusion and anchoring—inhibit nominal price adjustment after a fully anticipated negative monetary shock. In our context, money illusion means that subjects take nominal incomes as a proxy for real incomes, implying that they prefer price vectors that yield high nominal incomes. Subjects with money illusion thus tend to resist a general reduction in prices because it is associated with lower nominal incomes. Anchoring means that subjects start adjusting their behavior toward

increasing returns (Weitzman (1982)) are important. For a general account of the role of strategic complementarity in macroeconomic models, see Cooper (1999). Oh and Waldman (1990), Cooper and Haltiwanger (1993, 1996), and Blinder, Canetti, Lebow, and Rudd (1998) provided evidence for the relevance of strategic complementarity in various contexts. Evans and Ramey (1992) demonstrated the role of calculation costs in the context of a macromodel with strategic complementarity.

[3]There is interesting literature (Nagel (1995), Ho, Camerer, and Weigelt (1998), Costa-Gomes and Crawford (2006), Weizsäcker (2003)) on the depth of reasoning in games. However, the focus of this literature is not on how strategic substitutes and complements differentially affect behavior, but how many steps of iterated reasoning underlie subjects' behavior in games that can be solved by iterated elimination of strictly dominated strategies. This literature also does not deal with how monetary shocks affect nominal inertia. Woodford (2002) investigated how limited information operating through higher-order expectations can imply powerful effects of monetary policy. While his paper assumes fully rational agents, the implications of limited information and limited rationality can be rather similar. More recently, Potters and Suetens (2005) and Heemeijer, Hommes, Sonnemans, and Tuinstra (2006) examined the role of complements and substitutes for equilibrium play empirically, and Fehr and Tyran (2005) provided a discussion of the role of the strategic environment for the relevance of bounded rationality at the aggregate level.

an optimal or correct solution from a salient reference point, or anchor. If subjects are uncertain about the optimal or correct solution, they often tend to make insufficient adjustments (Tversky and Kahneman (1974), Epley and Gilovich (2001, 2004)) toward the correct solution.[4] In our context, the pre-shock equilibrium price represents a natural anchor because subjects played the pre-shock equilibrium for many periods. Thus, if subjects are uncertain about the correct response to the monetary shock, they may adjust prices insufficiently toward the new equilibrium. Money illusion and anchoring are the two forms of bounded rationality that constitute the psychological raw material for our study. They enable us to examine how the strategic environment transforms bounded rationality into aggregate outcomes that deviate or are close to the predictions of models with only rational agents.

Our results show that the strategic environment indeed plays a decisive role. Under strategic complementarity, long-lasting nominal inertia prevails after the monetary shock. This result contrasts sharply with behavior under strategic substitutability where adjustment is extremely rapid. In fact, we cannot reject the hypothesis in the substitutes treatment that nominal prices are instantaneously in equilibrium after the shock, while the hypothesis of equilibrium play can be rejected for 8 periods in the complements treatment. We can also show that these treatment differences are driven by the fact that price expectations are very flexible in the substitutes treatment and very sticky in the complements treatment. These results suggest that the distinction between complementarity and substitutability is critical for understanding the nature and the extent of nominal inertia.

In principle, the strategic environment may affect the impact of bounded rationality on aggregate outcomes in two ways. First, it may amplify or weaken the effects of a *given* amount of individual irrationality. We demonstrate this effect in our context by means of a simulation. The simulation shows that a fixed percentage of adaptive players generally causes a much slower adjustment toward equilibrium in the complements condition. The fact that adjustment in the complements condition is indeed much slower in our experiments may be interpreted as support for this effect. However, our data also suggest that the first effect cannot be the whole story. The strong differences in price expectations across treatments indicate, in particular, that additional forces must be at work because if the percentage of adaptive players is the same across treatments, we should also observe the same percentage of adaptive expectations.

Second, the strategic environment may change the amount of individual-level irrationality. We find evidence for this effect, that is, money illusion and anchoring have a much smaller impact on adjustment behavior in the substitutes treatment. Under substitutability the players appear to be considerably

[4]Insufficient behavioral adjustment toward the correct solution is an inherent feature of the anchoring heuristic. Therefore, it might be better to use the term "anchoring and insufficient adjustment heuristic," but for convenience we use the term "anchoring" in this paper.

more rational and also seem to attribute more rationality to the other players. 49 percent of the subjects in the substitutes condition have rational expectations following the implementation of the monetary shock, while only 26 percent exhibit rational expectations in the complements condition. Moreover, roughly twice as many subjects in the substitutes condition already exhibit equilibrium expectations in the first post-shock period, suggesting that the players attribute more rationality to the other players in this condition. This pattern contrasts sharply with the complements condition, where many subjects believe that the other players choose prices close to the pre-shock equilibrium.

Why do more players have rational expectations in the substitutes treatment? We hypothesize that this is due to the fact that adaptive expectations imply a much larger expectations error in the substitutes treatment compared to the complements treatment; therefore, the error is (i) more salient and (ii) involves higher economic costs under substitutability. The higher saliency of the error means that detecting the error is less cognitively costly; the higher economic cost associated with the error implies that the gains from avoiding the error are higher. Intuitively, the higher saliency and economic cost of the error associated with adaptive expectations under strategic substitutability are the consequence of the fact that a rational player has an incentive to choose an action that is very different ("far away") from that of an adaptive player. This big difference means that the mistake associated with adaptive expectations is very salient and the payoff gain from playing rationally is relatively large. In contrast, under strategic complementarity, a rational player has an incentive to follow an irrational crowd, meaning that the rational players choose actions similar to those of the adaptive players. This small difference means that the mistake associated with adaptive expectations is less salient and the payoff gains from playing rationally are relatively small compared to those from playing adaptively. In fact, we observe that significantly fewer subjects exhibit rational expectations under strategic complementarity. This suggests that the degree of rationality should not be taken as exogenously given. Instead, rationality should be viewed as a variable that responds to the cognitive costs of detecting an error (i.e., to how salient an error is) and to the economic cost of committing it. Our evidence may, therefore, be interpreted as support for theories that endogenize the rationality with which people form expectations (Evans and Ramey (1992, 1998), Brock and Hommes (1997), Reis (2006)).

The rest of the paper is organized as follows. In the next section, we discuss our experimental design. In Section 3, we present our results. Section 4 discusses the extent to which various theories of nominal inertia are consistent with our data, and Section 5 summarizes and concludes the paper. Instructions and data are provided online in Appendixes B–D in the Supplemental material (Fehr and Tyran (2008)).

2. EXPERIMENTAL DESIGN

A main purpose of our experiments was to examine how bounded rationality affects the adjustment of nominal prices in different strategic environments. We conjectured, in particular, that money illusion[5] and anchoring may cause a slow adjustment of nominal prices after an anticipated monetary shock. Several studies (Shafir, Diamond, and Tversky (1997), Kooreman, Faber, and Hofmans (2004), Basu, Markov, and Shivakumar (2006), Cohen, Polk, and Vuolteenaho (2005), Brunnermeier and Julliard (2008)) now indicate that a nonnegligible share of the people exhibit money illusion. The evidence in Cohen, Polk, and Vuolteenaho (2005) suggests, for example, that money illusion even affects aggregate stock market behavior. Experimental work by Fehr and Tyran (2001, 2007) also shows that a nonnegligible share of the subjects exhibits money illusion in price-setting games where payoff information is given to the subjects in nominal terms.[6] Conjecturing that subjects in our price-setting experiments may also be prone to money illusion if they are confronted with a nominal payoff representation therefore seems natural.

A relatively large psychological literature (e.g., Tversky and Kahneman (1974), Strack and Mussweiler (1997), Epley and Gilovich (2001, 2004)), as well as some economic applications (e.g., Ariely, Loewenstein, and Prelec (2003)), suggest that anchoring may affect people's behavior quite strongly. For example, arbitrary anchors affect subjects' reservation prices for various goods in the experiments of Ariely, Loewenstein, and Prelec. Before these authors elicited reservation prices in an incentive compatible way, the subjects had to state the last two digits of their social security numbers. Then they were asked whether they were willing to pay a larger or smaller amount of dollars than this number for the good in question. After this initial question, subjects stated their explicit reservation prices. The results show that the anchoring question—whether subjects are willing to pay more or less than the last two digits of their social security numbers for the good—had a strong impact on reservation prices: the higher the social security number, the higher the stated reservation price. This effect was also present if subjects participated in a competitive auction for the good in question.

There is no unambiguously correct answer in the case of the elicitation of reservation prices because these are inherently subjective. However, much

[5]On the concept of money illusion, see Howitt (1989). For effects of money illusion on individual behavior, see Shafir, Diamond, and Tversky (1997), and for potential effects on markets, see Howitt (2002) or Tyran (2007).

[6]In Fehr and Tyran (2007), for example, money illusion causes striking differences in equilibrium selection. All subjects quickly converge to the Pareto-efficient equilibrium in the real payoff condition, where the real payoff of each player is highest. In contrast, a large number of subjects play close to the inefficient equilibrium in the nominal payoff condition because this equilibrium corresponds to high prices and, consequently, to high *nominal* payoffs. Thus, although these subjects suffer in real terms from playing the bad equilibrium, they coordinate on the high nominal payoffs in the inefficient equilibrium, indicating the existence of money illusion.

research on anchoring in tasks with objectively correct solutions (Epley and Gilovich (2001, 2004)) indicates that many subjects insufficiently adjust their answers toward the correct solution if they are uncertain about what the correct solution is. Anchoring and insufficient adjustment may also affect subjects' behavior after an anticipated monetary shock. Subjects may be anchored on the previous equilibrium price, and this anchoring is particularly plausible if the previous equilibrium price prevailed for a considerable time. In addition, if subjects are uncertain about what the rational expectation or the rational action after the shock is (perhaps because they are uncertain about what the other players do), the adjustment may be insufficient in much the same way as adjustment is insufficient in many psychological anchoring experiments.

2.1. *General Description of the Experimental Design—Main Treatments*

To study how bounded rationality affects behavior in different strategic environments, we implemented a price-setting game in which both money illusion and anchoring could play a role. Money illusion could play a role because subjects in our main treatments received payoff information in nominal terms. Anchoring could play a role because we implemented a pre-shock phase in which subjects had sufficient time to converge to the equilibrium of this phase and to play this equilibrium for several periods. We implemented a negative monetary shock after subjects had played the equilibrium for several periods. In the following we describe the two main treatments.

Our price-setting game was implemented in two versions: a complements treatment (CT) and a substitutes treatment (ST). Since we were interested in adjustment dynamics, the price-setting game was repeated for a finite number of periods. The same unique equilibrium at the stage-game level existed in both treatments. The only difference between the two treatments was that the slope of each subject's best-reply function was positive in the stage game of the CT while the slope was negative but had the same absolute value in the ST. In each period, the subjects simultaneously chose a nominal price. In addition, they indicated their expectations of the average nominal price of the other subjects. At the end of the period, each subject was informed about the average nominal price of the others and about the payoff in that period. The subjects moved to the next period after the information feedback. The experiment was divided into a pre- and a post-shock phase of equal length, and we implemented an exogenous and fully anticipated nominal shock at the beginning of the post-shock phase. The shock was anticipated by the players because it was announced at the beginning of the first post-shock period, before they had made their decision in that period. We study the impact of the strategic environment on adjustment dynamics by comparing price adjustment after the shock across the CT and the ST.

At the beginning of this project, the stage game was a price-setting game with monopolistic competition. It turned out, however, that—for our purposes—this design had two major drawbacks. First, and most importantly, it is not possible to move from strategic complementarity to strategic substitutability within the context of monopolistic competition, while keeping everything else constant. If one changes the slope of the reaction functions, one in general also changes equilibrium prices, the real payoffs in equilibrium, the number of dominated strategies, and the real payoffs in the neighborhood of best replies. Thus, it is not possible to conduct a clean comparison between the impact of strategic complements and strategic substitutes in the context of monopolistic competition. Second, the equilibrium under monopolistic competition is not efficient and this hinders the adjustment toward equilibrium. The existence of an inefficient equilibrium means that subjects can earn more money if they try to collude and thus prevent adjustment toward equilibrium. These efforts to collude in turn introduce some nominal inertia after the announcement of the shock which is then confounded with the amount of nominal inertia that stems from the strategic complementarity or substitutability that we implemented via the monetary payoff functions.

This problem can also be viewed as one of *unobservable* strategic complementarity. It is well known that many subjects exhibit preferences for conditional cooperation in the presence of cooperation opportunities (see, e.g., Fischbacher, Gächter, and Fehr (2001) or Fehr and Fischbacher (2002)). They are willing to cooperate if others cooperate as well. Since we cannot directly observe subjects' preferences for conditional cooperation, this introduces *unobservable* strategic complementarity, that is, we lose control over the precise amount of complementarity. We conducted pilot experiments with monopolistic competition, which confirmed these problems. After the nominal shock, subjects tried hard to reap the gains from collusion, which strongly retarded adjustment toward equilibrium. Note that this means that strategic complementarity is not necessarily a feature of the objectively given technology of interaction. Subjective preferences may also be an important source of strategic complementarity that adds to nominal inertia. Yet since we wanted to have full control over the extent of strategic complementarity or substitutability, we ruled out that preferences for conditional cooperation can play a role in our experiments by implementing the following design features.[7]

First, we implemented a unique, money-neutral and efficient Nash equilibrium in both treatments. In fact, the Nash equilibrium was the only efficient

[7] A clean isolation of the impact of strategic complements versus substitutes forces us to set up a price-setting game that cannot be derived from usual market structures such as oligopoly or monopolistic competition. We believe, however, that this does not question the potential importance of our results for behavior outside the laboratory. To the extent to which firms' profit functions under monopolistic or oligopolistic competition exhibit similar degrees of strategic complementarity as the payoff functions in our experiment, we even have reason to believe that nominal inertia is stronger in reality because of the possibility that preferences for conditional cooperation may increase the overall degree of strategic complementarity. In addition, a negative monetary shock may constitute a coordination device for conditionally cooperative firms to collude at least temporarily to keep nominal prices high after the shock because this enables them to extract more rents from the consumers.

point in payoff space. This feature rules out collusion and conditional cooperation as a decelerator in adjustment toward equilibrium. Since the equilibrium is neutral with regard to the nominal shock variable (money supply), any real effects of the nominal shock must be associated with out-of-equilibrium behavior. Second, equilibrium prices and real equilibrium payoffs do not change across the CT and the ST. Third, real payoffs along the reaction functions are also the same across CT and ST. Fourth, if a player deviated from best-reply behavior, the real income loss for a given deviation from the best reply is also identical across treatments. Fifth, the number of strictly dominated strategies within the range of feasible price choices is identical across CT and ST after the shock. Thus, the players faced exactly the same incentives to play best replies in both treatments. Finally, if the subjects play a best reply to the expected price choices of the other players, a *given* expectations error causes exactly the same monetary loss for a subject in the CT and the ST. Taken together, these design features mean that the only difference between the treatments concerned the slope of the reaction function. If, at a given price vector in the CT, the slope was $z > 0$, then the slope in the ST was given by $-z < 0$ at that price vector.

In each experimental session, we formed several groups of n players who played the pricing game for T periods. The group composition remained unchanged throughout the session. The money supply was given by M_0 during the first $T/2$ periods of a session. Then we implemented a fully anticipated monetary shock by reducing the money supply to M_1 (see Table I for a complete list of parameters). All subjects were informed about the shock at the beginning of the post-shock phase, before making their decision in the first post-shock period. This shock and the fact that the post-shock phase lasted another 15 periods was common information. We were only interested in comparing subjects' pricing behavior across treatments in the post-shock phase. The pre-shock phase served the purpose of familiarizing subjects with the computer terminal and the decision environment. In addition, the pre-shock phase allowed subjects to reach an equilibrium in that phase and to play that equilibrium for several periods. This is important, as we wanted to study how the strategic environment affects adjustment to a purely nominal shock *after* subjects had already reached the money-neutral equilibrium. This ensures that the adjustment requirements are the same across treatments.

The real payoff of subject i was given by

$$v_i = v_i(P_i, \bar{P}_{-i}, M) = v_i(P_i/M, \bar{P}_{-i}/M, 1), \tag{1}$$

where P_i denotes i's nominal price, $\bar{P}_{-i}$ represents the nominal average price of the other $n-1$ group members, and M denotes a common nominal shift variable (money supply). The real payoff function $v_i(\cdot)$ is homogeneous of degree 0 in P_i, $\bar{P}_{-i}$, and M so that real payoffs can be written as a function of P_i/M and $\bar{P}_{-i}/M$. Since we implemented a unique equilibrium, homogeneity of degree 0 ensured that the equilibrium was neutral in money.[8] Note also that, for a given money supply, the optimal choice of P_i only depends on the average price of the other players and not on the other players' individual prices. This means that subjects need not form expectations about other players' individual prices, but only about the average price $\bar{P}_{-i}$. In addition, this payoff function has the advantage that, for a given money supply, we can represent the subjects' payoffs in a matrix that informs subjects about their payoffs at any feasible $(P_i, \bar{P}_{-i})$ combination.

2.2. *Experimental Procedures, Parameters, and Subject Pool*

All major experimental parameters and design features of the two main treatments are summarized in Appendix A and Table I. The experimental instructions for the subjects are presented in Appendix B (see the Supplemental material).[9] The experiment was conducted with the software *z*-tree (Fischbacher (2007)) in a computerized laboratory. We implemented groups of size $n = 4$ and the experiment lasted $T = 30$ periods. There were two types of subjects in each group: subjects of type x and subjects of type y. The two types have slightly different payoff functions, where the best reply of the x types involved slightly lower prices than the best reply of the y types. Since heterogeneity is a fact of life, a case with four different payoff functions would be most realistic, but also most complicated. Therefore, we chose an intermediate solution with only two types of players. A total of 76 students from the University of Zurich participated in the main treatments. Each subject participated either in the CT or in the ST. In the pre-shock phase of each treatment, the money supply was given by $M_0 = 42$, while in the post-shock phase, it was given by $M_1 = M_0/2 = 21$. In the pre-shock equilibrium, the average price over all n group members was given by $\bar{P}_0^* = 25$, while the post-shock equilibrium price was $\bar{P}_1^* = 12.5$.

The subjects had to choose a nominal price $P_i \in \{1, 2, 3, \dots, 30\}$ in each period. In addition, they had to provide an expectation about $\bar{P}_{-i}$, which we denote by $\bar{P}_{-i}^e$. At the end of each period, each subject was informed about the actual value of $\bar{P}_{-i}$ and the actual real payoff v_i on an outcome screen (see Appendix B in Supplemental material). In addition, the outcome screen provided information about the subject's past choices of P_i, past values of $\bar{P}_{-i}$, and past real payoffs v_i.

[8]To see that homogeneity of degree 0 implies neutrality, note that a change in M from M_0 to $\lambda M_0 = M_1$ leaves real payoffs unaffected if prices change to λP_i and $\lambda \bar{P}_{-i}$. Moreover, if P_i, $i = 1, 2, \dots, n$, is a best reply to $\bar{P}_{-i}$ at M_0, then λP_i also is a best reply to $\lambda \bar{P}_{-i}$ at λM_0. Thus, if P_i^* for all i is a pre-shock equilibrium, then λP_i^* for all i is the post-shock equilibrium.

[9]Instructions and payoff tables can also be found in the working paper version of this paper (Fehr and Tyran (2002)).

TABLE I

OVERVIEW OF PARAMETERS

	Strategic Complements (CT)	Strategic Substitutes (ST)
All periods		
Group size	$n = 4$	$n = 4$
Information feedback in period t	$\bar{P}_{-i}, v_i$	$\bar{P}_{-i}, v_i$
Representation of payoffs	Nominal ($\bar{P}_{-i}v_i$)	Nominal ($\bar{P}_{-i}v_i$)
Real equilibrium payoff	39	39
Choice variables	$P_i = \{1, 2, \dots, 30\}$	$P_i = \{1, 2, \dots, 30\}$
Pre-shock periods		
Money supply M_0	42	42
Average equilibrium price $\bar{P}^*$ and average equilibrium expectation for the *whole* group	25	25
Equilibrium price for type x	22	22
Equilibrium expectation for type x	26	26
Equilibrium price for type y	28	28
Equilibrium expectation for type y	24	24
Post-shock periods		
Money supply $M_1 = M_0/2$	21	21
Average equilibrium price $\bar{P}^*$ and average equilibrium expectation for the *whole* group	12.5	12.5
Equilibrium price for type x	11	11
Equilibrium expectation for type x	13	13
Equilibrium price for type y	14	14
Equilibrium expectation for type y	12	12
Number of dominated strategies for type x	9	9
Number of dominated strategies for type y	6	6
Slope of reaction function	+1 or 0	−1 or 0

Subjects received the payoff information in the form of a matrix, which has the advantage that the payoffs from different $(P_i, \bar{P}_{-i})$ combinations are easy to figure out. In Appendixes C and D (in the Supplemental material), we provide the post-shock payoff matrices for the x and y types for both treatment conditions. Appendix C shows the *real* payoffs for any feasible $(P_i, \bar{P}_{-i})$ combination, whereas Appendix D shows the *nominal* payoffs. Because we wanted to allow for the possibility of money illusion affecting subjects' behavior, we gave them only nominal payoff tables in our main treatments. The real payoff tables in Appendix C were only used in the control treatments described in the next subsection. The real payoff tables make it immediately transparent that, except for the slope of the best-reply functions, the real payoff structure was kept constant across the substitutes and the complements treatment. To render the difference across treatments transparent, we have also shaded the best-reply functions in Appendix C. Subjects, of course, never received payoff tables with shaded best replies.[10] In subjects' nominal payoff tables, the matrix showed the nominal payoff $V_i = \bar{P}_{-i}v_i$ for each feasible $(P_i, \bar{P}_{-i})$ combination. To compute the real payoff for a particular $(P_i, \bar{P}_{-i})$ combination, a subject had to divide $V_i = \bar{P}_{-i}v_i$ by $\bar{P}_{-i}$. This was described at some length in the instructions (see Appendix B in the Supplemental material). To inform subjects about the payoffs of the other type, each subject also received the payoff matrix of the other type. This information was common knowledge.

At the end of period 15, the nominal shock was implemented in the following way: subjects were publicly informed that x and y types would receive new payoff tables. These tables were based on $M_1 = M_0/2$. Again, each subject received his or her own payoff table and the table of the other type. Subjects were told that, except for payoff tables, everything else, including group composition, would remain unchanged. They were given enough time to study the new payoff tables and to choose P_i for period 16.[11] This procedure ensures that, in period 16, subjects face an *exogenous*, *fully anticipated*, and *negative* nominal shock: it is exogenous because subjects' behavior does not affect the timing or the content of the new payoff tables. It is fully anticipated because the new tables were distributed before subjects had to decide and because the distribution of new tables was common knowledge. At the beginning of period 16, it was common knowledge that the experiment would last for a further 15 periods.

Note that there are *no exogenous frictions* present in this design: there are no nominal frictions, since nominal prices can be changed from period to period at no cost. There are no informational frictions, since subjects are given full information about the shock.

In total, we had 10 groups in the CT and 9 groups in the ST in our main treatments. The experiments took place at the University of Zurich and the subjects were undergraduate students from different disciplines. They were paid a show-up fee of roughly \$8 (CHF 10) and their earnings from the experiment were on average \$28 (CHF 34). An experimental session lasted approximately 80 minutes.

[10] Appendix C shows that the slope of the best-reply function is 0 around the equilibrium. Otherwise, the absolute value of the slope is 1 (except for very high levels of others' average prices). The zero slope around the equilibrium may speed up adjustment toward equilibrium because it may make it easier for the subjects to find the equilibrium. However, because this feature of the best-reply function is identical across treatments, it cannot affect differences in adjustment speed between the ST and the CT. We avoided absolute slopes larger than 1 because—if implemented globally—this would have implied unstable equilibria; in addition, we also wanted to avoid varying slopes that give rise to multiple equilibria.

[11] Subjects were given a total of 10 minutes between distribution of the new tables and their decision. During the first 7 minutes, subjects could not enter any decision into the computer. Within the remaining 3 minutes, the average subject decided after 38 seconds in the CT and after 39 seconds in the ST. Very few subjects used up the available time entirely (two subjects in the CT and none in the ST made their decision less than 10 seconds before the available time had elapsed). Thus, if we observe disequilibrium play, this cannot be due to binding time constraints.

2.3. *Identifying Money Illusion and Anchoring*

The main treatments described in the previous two subsections ensure that both money illusion and anchoring can affect subjects' behavior. However, we need to further control treatments to be able to show that these psychological forces contribute to nominal inertia and disequilibrium play in our price setting experiment. For this purpose, we implemented four additional treatment conditions, where we added a third phase—the restart phase—after the post-shock phase (see Table II). The restart phase constitutes a simple restart of the experiment with the same money supply as in the post-shock phase. The fact that merely restarting an identical experiment sometimes causes substantial disequilibrium behavior at the beginning of the restart is the motivation for implementation of the restart phase. Andreoni (1988) and Croson (1995), for example, have shown that the mere restart of a finitely repeated public goods experiment causes a strong increase in cooperation levels despite the fact that most subjects played the equilibrium strategy of complete free-riding at the end of the previous (identical) experiment. Because the implementation of the monetary shock inevitably involves a restart of the experiment, albeit with a different money supply, we cannot be sure whether the change in the money supply or the restart feature of the monetary shock causes disequilibrium play after the shock. Therefore, the comparison between price adjustment in the post-shock phase and the restart phase can answer the question whether

TABLE II

OVERVIEW OF TREATMENTS[a]

	Treatment Label		Representation of Payoffs: Pre-Shock Phase ($M = M_0$, 15 periods)	Post-Shock Phase ($M = M_1$, 15 periods)	Restart Phase ($M = M_1$, 10 periods)
Main treatments	CT (10 groups)		Nominal	Nominal	—
	ST (9 groups)		Nominal	Nominal	—
Control treatments	CT-real (8 groups)	CT-restart-real (4 groups)	Real	Real	Real
		CT-restart-nominal (4 groups)	Real	Real	Nominal
	ST-real (6 groups)	ST-restart-real (3 groups)	Real	Real	Real
		ST-restart-nominal (3 groups)	Real	Real	Nominal

[a]CT indicates a complements treatment; ST indicates a substitutes treatment. "Real" indicates that subjects received payoff tables in real terms while "Nominal" indicates that they received nominal payoff tables.

a mere restart causes disequilibrium prices and to what extent a disequilibrium observed in the post-shock phase is likely to represent a restart effect.

In our first control treatment (denoted “CT-restart-real”), we implemented the complements treatment with *real* payoff tables in all three phases—the pre-shock, the post-shock, and the restart phase—for four groups (see Table II). We implemented the substitutes treatment with *real* payoff tables in all three phases for three groups in the second control treatment (denoted “ST-restart-real”). In our third control treatment (CT-restart-nominal), four groups received real payoff tables in the first two phases (pre- and post-shock), but at the beginning of the restart phase, subjects received nominal payoff tables. Finally, three groups received real payoff tables in the pre- and the post-shock phases, and nominal payoff tables in the restart phase in our fourth control treatment (ST-restart-nominal). Because CT-restart-real and CT-restart-nominal are identical in the pre- and post-shock phases, we label the corresponding eight groups CT-real, and label the six groups with substitutes ST-real in these two phases (see Table II).

These four control conditions enable us to isolate the impact of money illusion, anchoring, and the restart feature of the monetary shock on price adjustment. In all four control conditions we implemented real payoff tables in the pre-shock and the post-shock phases; hence money illusion could play no role after the shock in these treatments. Thus, if nominal inertia during the post-shock phase is larger in the presence of nominal payoff tables, we can conclude that money illusion slows down price adjustment after the shock. However, anchoring can still play a role when subjects receive real payoff tables, because the new equilibrium requires lower *nominal* prices after the monetary shock, but subjects may be anchored on the pre-shock equilibrium that they played for several periods. Therefore, if we observe that subjects choose nominal prices close to the pre-shock equilibrium in the post-shock phase of the control treatments, we can conclude that anchoring contributes to disequilibrium play after the shock.

Our control treatments also enable us to see what happens if neither money illusion nor anchoring can affect subjects’ behavior. This is the case in the restart phase with real payoffs, that is, in the restart phase of CT-real and ST-real. Anchoring (i.e., insufficient adjustment) effects cannot occur in the restart phase, because—from the viewpoint of equilibrium play—there is no need to adjust nominal prices, and money illusion cannot occur in these treatments because payoffs are provided in real terms. Therefore, if anchoring and money illusion are the only sources of disequilibrium play in the post-shock phase, we should not observe any disequilibrium play in the restart phase of CT-real and ST-real. However, if the restart feature of the post-shock phase is also a source of disequilibrium play after the monetary shock, then we should also observe disequilibrium play in the restart phase. Disequilibrium play in the restart phase of CT-real and ST-real is, therefore, an unambiguous indicator of a restart effect.

Finally, the treatments where we implement nominal payoff tables in the restart phase (CT-restart-nominal, ST-restart-nominal) provide a further independent measure of the existence of money illusion in our price-setting game. We rule out any anchoring effects in the restart phase of these treatments because there is no need for nominal price adjustment after the restart. However, as subjects now receive nominal instead of real payoff tables, money illusion may now constitute an independent source of disequilibrium play in the restart phase, causing a larger disequilibrium than the mere restart effect that might occur with real payoff tables. If some subjects take nominal incomes as a proxy for real incomes, they may choose prices above the equilibrium regardless of whether they are in the substitutes or the complements condition. If instead, subjects only believe that others behave in this way, while they themselves are not prone to money illusion, we should see that subjects in the CT choose prices that are too high relative to equilibrium, while subjects in the ST choose prices that are too low. Thus, the pattern of actual and expected price choices across the substitutes and complements treatment also gives us a hint whether money illusion, or the expectation about others' money illusion, is a source of disequilibrium play.

3. RESULTS

3.1. *Adjustment of Prices*

To what extent do different strategic environments affect the adjustment of prices toward the post-shock equilibrium? A first impression is provided by Figure 1, which plots the evolution of pre- and post-shock average prices across main treatments. The figure indicates that nominal prices quickly approach the average equilibrium price in the pre-shock phase, which is given by $\bar{P}_0^* = 25$. Except for periods 1 and 2, the hypothesis that pre-shock prices in the ST and the CT are in equilibrium can never be rejected.[12] The situation changes dramatically, however, after the nominal shock. In the first post-shock period, average prices in the CT are far above the equilibrium, whereas in the ST prices slightly overshoot relative to the equilibrium. Moreover, according to Figure 1, it takes a large number of periods until nominal prices in the CT have fully adjusted. Not until period 27, twelve periods after the shock, do CT prices seem to be fully back to equilibrium. This contrasts sharply with the price dynamics in the ST, where full adjustment already seems to be achieved in the second period after the shock.

[12]The deviation from equilibrium is somewhat larger in the complements treatment in periods 1 and 2 of the pre-shock phase. This is likely to be due to the fact that—in the pre-shock phase—there are more strictly dominated strategies in the feasible price range (i.e., for prices between 1 and 30) in the ST than in the CT, which makes it easier to reach equilibrium in the ST. However, subjects played the equilibrium in the ST and the CT from period 2 onward. Note that *after* the shock, the number of strictly dominated strategies within the feasible price range is the same across treatments.

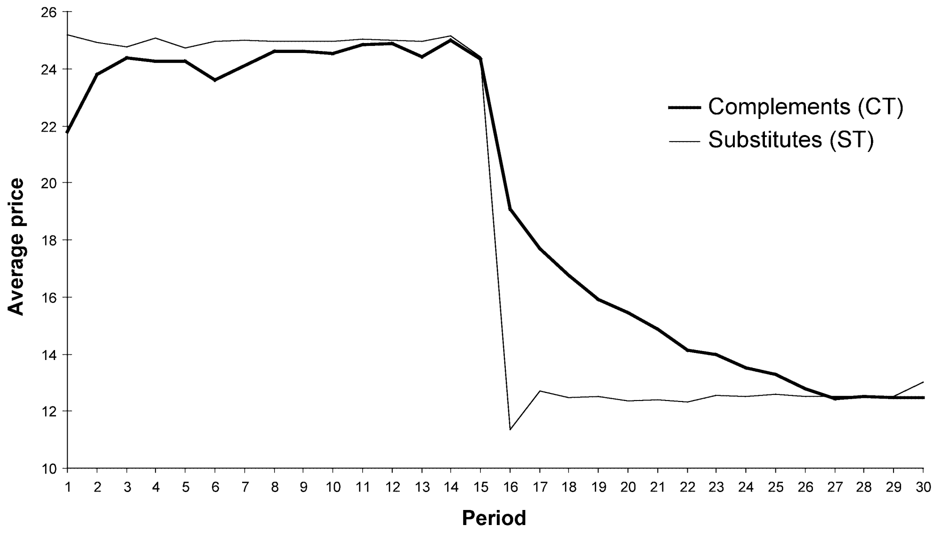

FIGURE 1.—Nominal average prices over time in the main treatments.

To examine the deviations from equilibrium more rigorously, we conducted the regression for the post-shock phase,

$$\bar{P}_{jt} - \bar{P}_1^* = \sum_{t=1}^{14} \alpha_t d_t + \sum_{t=1}^{15} \beta_t (1 - d_t), \tag{2}$$

where $\bar{P}_{jt}$ denotes the average price of group j in period t, $\bar{P}_1^*$ represents the average equilibrium price after the shock, and $d_t = 1$ if the price observation in period t comes from the CT.[13] The coefficients α_t measure the deviation from equilibrium in the CT, whereas the coefficients β_t measure the deviation in the ST. We have summarized the results of regression (2) in Table III. The absolute size of the coefficients in Table III informs us how much average group prices deviate from equilibrium. This indicates that in period 16, the average price in the CT is 6.6 above equilibrium, while in the ST it is 1.17 below equilibrium. In fact, as the significance tests indicated in Table III show, we can never reject the hypothesis that group average prices in the ST are in equilibrium. For the CT, however, the hypothesis of equilibrium play can be rejected for the first eight post-shock periods at the 1 percent level. Thus, Figure 1 and Table III leave little doubt that the strategic environment has decisive effects on adjustment dynamics.

[13]To prevent linear dependence among the regressors, we included no dummy variable for period 15 of the CT.

TABLE III

DEVIATION OF PRICES FROM POST-SHOCK EQUILIBRIUM[a]

Post-Shock Period	Strategic Complements Treatment (CT) Coefficient α_t	Strategic Substitutes Treatment (ST) Coefficient β_t
1	6.600***	−1.167
2	5.175***	0.194
3	4.275***	−0.028
4	3.425***	0.000
5	2.950***	−0.139
6	2.375***	−0.111
7	1.625**	−0.167
8	1.475**	0.056
9	1.000	0.000
10	0.800	0.083
11	0.275	0.000
12	−0.050	0.000
13	0.000	0.000
14	−0.025	0.000
15	—	0.528

[a] $\bar{P}_{jt} - \bar{P}_1^* = \sum_{t=1}^{14} \alpha_t d_t + \sum_{t=1}^{15} \beta_t (1 - d_t)$; $d_t = 1$ if price observation in period t is from CT.
*Significant at $p = 0.05$.
**Significant at $p = 0.01$.
***Significant at $p = 0.001$.

So far, we have only looked at average prices. However, equilibrium also requires that individual actions coincide with equilibrium prices. With this in mind, we constructed Table IV and Figures 2A and 2B. The figures graph the

TABLE IV

PERCENTAGES OF NOMINAL PRICE CHOICES ABOVE, IN AND BELOW EQUILIBRIUM (SUBJECTS AS UNITS OF OBSERVATION)

	Strategic Complements			Strategic Substitutes		
Period	Above Equilibrium	In Equilibrium	Below Equilibrium	Above Equilibrium	In Equilibrium	Below Equilibrium
13–15	3	93	5	1	96	3
16	75	23	3	14	67	19
17	75	23	3	19	67	14
18	68	28	5	3	92	6
19–21	48	51	1	1	97	2
22–24	34	65	1	3	96	1
25–27	18	77	6	3	96	1
28–30	2	94	4	1	99	0

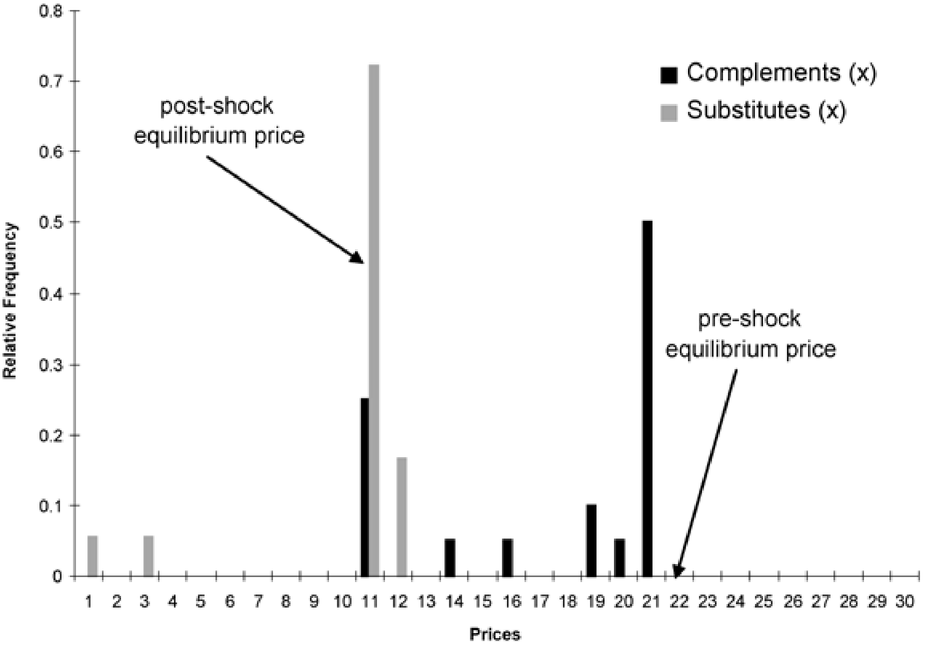

FIGURE 2A.—Distribution of individual price choices in period 16 (x types).

distribution of prices in the first post-shock period across treatments for the x types (Figure 2A) and the y types (Figure 2B). A remarkably high percentage of the x types (72 percent) in the ST jump directly to the new equilibrium and 17 percent are just 1 unit above the equilibrium. In contrast, the majority of the x subjects (50 percent) in the CT choose a price far above the equilibrium (i.e., $P_i = 21$) and only 25 percent jump directly to the new equilibrium. For the y types, the picture is qualitatively similar: 61 percent of the subjects in the ST jump directly to the new equilibrium and 28 percent are only 1 unit above or below the equilibrium, whereas only 20 percent of the y types play the equilibrium in the CT and the rest choose prices far above the equilibrium.

Table IV indicates that 23 percent of the subjects play the equilibrium in the CT in the first two post-shock periods, while 75 percent of the subjects choose prices *above* the equilibrium. This result contrasts sharply with the ST, where 67 percent play exactly the equilibrium and the percentage of prices above the equilibrium equals roughly the percentage below the equilibrium. Table IV also shows that these differences in individual play across treatments persist a long time. These differences can be illustrated by comparing period 18 in the ST with periods 28–30 in the CT. In $t = 18$, 92 percent of the subjects in the ST already choose exactly the equilibrium price. A similar incidence of exact equilibrium play only occurs in the final three periods of the CT. Taken together, these results indicate that equilibrium adjustment is breathtakingly

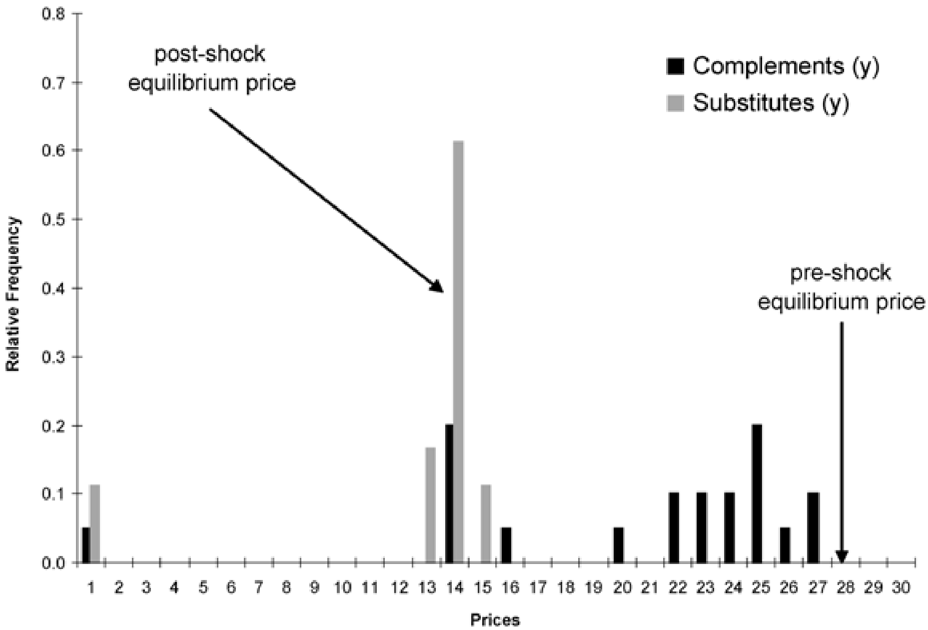

FIGURE 2B.—Distribution of individual price choices in period 16 (y types).

quick in the ST, whereas it is extremely slow in the CT. This suggests that the strategic environment is a decisive determinant of nominal inertia and shapes the impact of bounded rationality in important ways.

3.2. *Best-Reply Behavior and Price Expectations*

One reason for the different adjustment patterns could be that there are differences in best-reply behavior across treatments. Since we asked subjects for their expectations regarding the average price of the other players, we are able to compute the best reply for each subject in each period and compare it with the actual price choice.[14] We did this for the different price intervals depicted in Figures 3A and 3B. These figures compare the average best reply in each interval for which we observe price expectations with the average price actually chosen in response to these expectations. The numbers above the bars indicate the relative frequency of price expectations in the different price intervals.

Figure 3A shows that the average best reply in the CT for each expectation interval coincides almost exactly with the average price that was chosen in the

[14]If a subject does not exactly know the true value of $\bar{P}_{-i}$, the computation of the best reply requires that the whole subjective distribution over $\bar{P}_{-i}$ be taken into account. However, for simplicity, in the following discussion we use the term "best reply" in the sense of a best reply to the expectation of $\bar{P}_{-i}$.

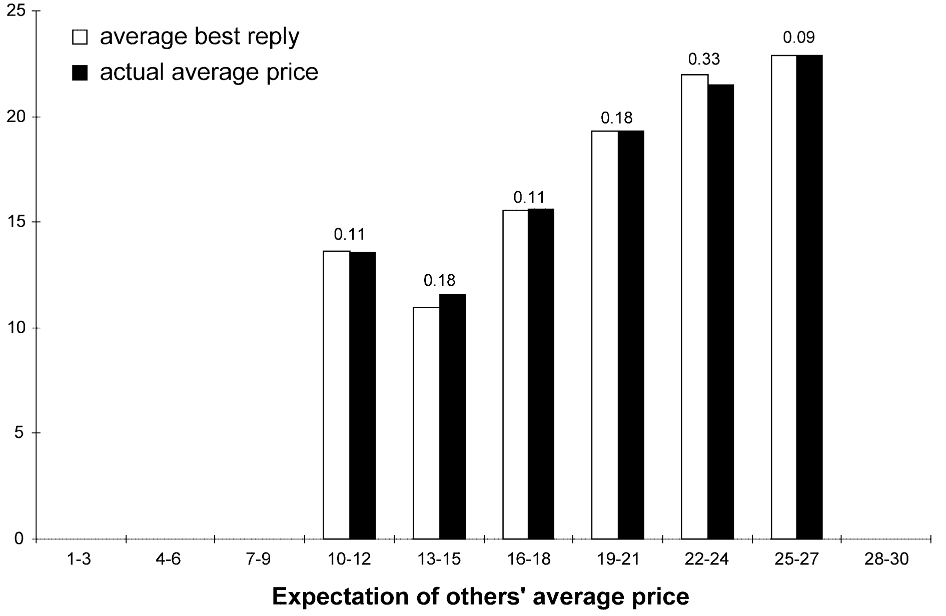

FIGURE 3A.—Actual average prices and average best reply for given expectations complements treatment (periods 16–18).

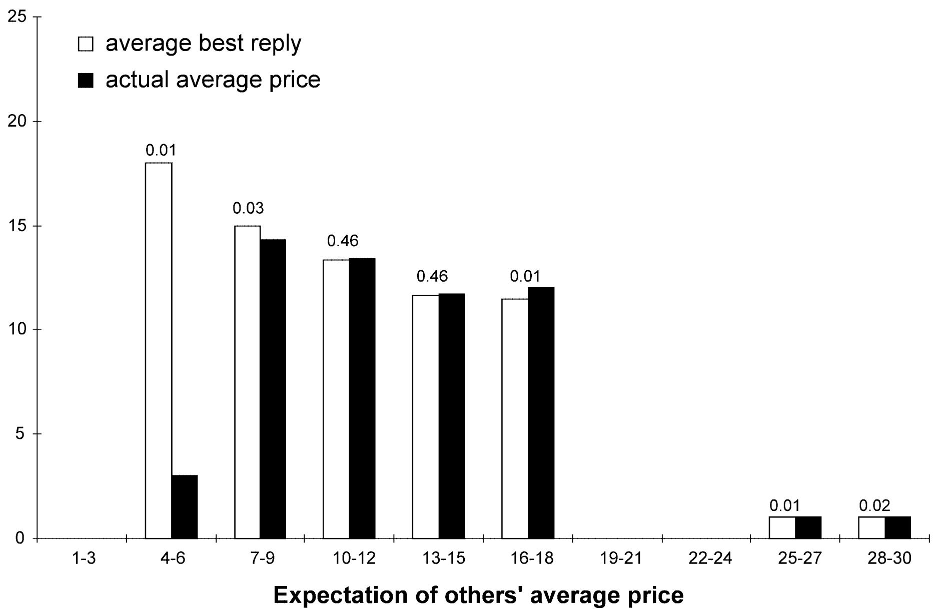

FIGURE 3B.—Actual average prices and average best reply for given expectations substitutes treatment (periods 16–18).

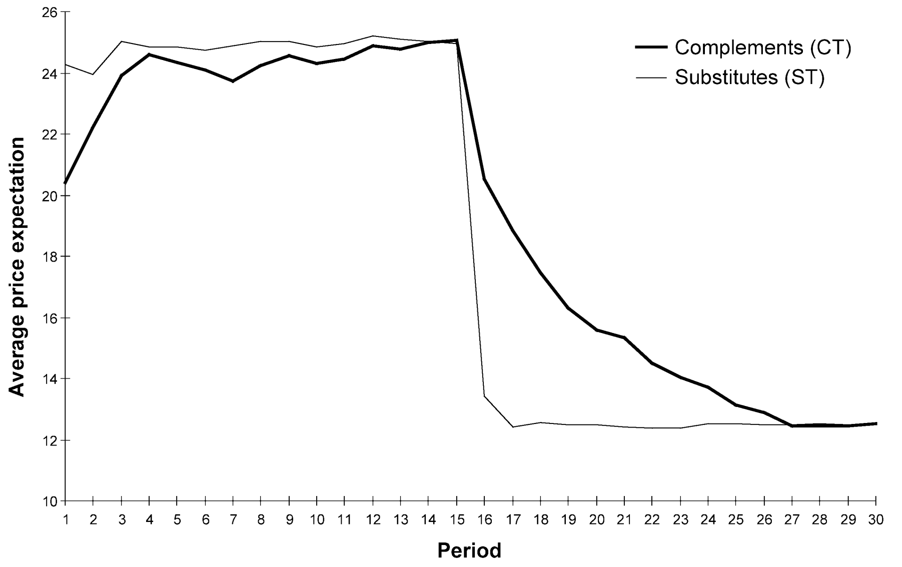

FIGURE 4.—Average price expectations over time in the main treatments.

respective interval. Thus, the slow adjustment in the CT cannot be attributed to deviations from best-reply behavior. Likewise, the average best replies in the ST are very close to the actual average prices in the different intervals.[15] From this, we conclude that the differences in adjustment dynamics across treatments cannot be due to differences in best-reply behavior.

If subjects play a best reply most of the time to the expected average price of others, then the differences in actual price choices across treatments are likely to be generated by differences in expectations. The relative frequencies in Figure 3 (see numbers above the bars) provide a first indication of strong treatment differences in price expectations. 60 percent of the price expectations in the CT are at or above 19 in periods 16–18, while in the ST, 96 percent of the expectations are at or below 15 during these periods. To further examine the role of price expectations, we plotted the average expectations in both treatments in Figure 4. The figure indicates that average expectations are in equilibrium in the ST and the CT before the shock. After the shock, average expectations remain very sticky in the CT, but jump almost completely to the new equilibrium expectations in the ST. From period 17 onward, average expectations are in equilibrium in the ST, whereas out-of-equilibrium expectations prevail in

[15]The only exception is the interval between 4 and 6. Note, however, that only 1 percent of the price expectations are in this interval, so that the deviation between actual price and best reply is probably due to the small number of observations. Note also that, in both treatments, more than 80 percent of the post-shock choices represent exact best replies and the rest of the choices are typically close to the exact best reply.

TABLE V

DEVIATION OF EXPECTATIONS FROM POST-SHOCK EQUILIBRIUM[a]

Post-Shock Period	Strategic Complements Treatment (CT) Coefficient α_t	Strategic Substitutes Treatment (ST) Coefficient β_t
1	8.025***	0.917
2	6.325***	−0.083
3	4.950***	0.056
4	3.800***	0.000
5	3.100***	0.000
6	2.825***	−0.083
7	2.000**	−0.139
8	1.525*	−0.111
9	1.225	0.028
10	0.625	0.028
11	0.400	0.000
12	−0.050	0.000
13	−0.050	0.028
14	−0.050	−0.028
15	—	0.028

[a] $\bar{E}_{jt} - \bar{E}_1^* = \sum_{t=1}^{14} \alpha_t d_t + \sum_{t=1}^{15} \beta_t (1 - d_t)$, where $\bar{E}_{jt}$ is group j's average expectation of others' average price in period t, and $\bar{E}_1^*$ is the average equilibrium expectation. $d_t = 1$ if a price observation in period t is from the CT.

*Significant at $p = 0.05$.

**Significant at $p = 0.01$.

***Significant at $p = 0.001$.

the CT until period 27. To examine this issue more rigorously, we conducted regressions analogous to equation (2). The only difference is that instead of using the actual deviation of group prices from the equilibrium, we take the deviation of the groups' price expectations from the equilibrium expectation as the dependent variable. The results of this regression are displayed in Table V. The table shows that the average expectation in the CT in period 16 is 8.0 units above the equilibrium, while it is only 0.9 units above equilibrium in the ST. Moreover, we can reject the hypothesis that subjects in the CT have equilibrium expectations (at the 5 percent level) for eight periods and at the 10 percent level ($p = 0.056$) for the ninth post-shock period, too. In the ST, the hypothesis that expectations are in equilibrium can never be rejected at the 10 percent level.

These results suggest that the key mechanism that generates the different adjustment behaviors is the differential stickiness of price expectations. Whereas strategic substitutability causes very flexible expectations that instantaneously approach the equilibrium, strategic complementarity is associated with very sticky expectations. The players then play best replies to their expectations, so that the flexible expectations translate into flexible prices in the ST, while sticky expectations translate into sticky prices in the CT.

3.3. *Real Effects During Adjustment Toward Equilibrium*

One important question in macroeconomics is whether anticipated monetary shocks are associated with real effects. To the extent to which adjustment toward equilibrium is slow, anticipated monetary shocks will cause real effects. Therefore, one can expect that the negative monetary shock causes larger reductions in the players' joint payoffs under complementarity than under substitutability. To check, we computed for each group j and each period t how much the real average payoff of the group, v_j, falls short of the real average payoff in equilibrium, v^*. Based on this computation, we measure the efficiency loss of group j in period t by $\varepsilon_{jt} = (v_{jt} - v^*)/v^*$, that is, as a percentage of the equilibrium payoff. In Figure 5, we present the evolution of the average value of ε_{jt} across treatments during the post-shock phase.

One has to remember when interpreting this figure that we deliberately implemented payoff functions that imply relatively large payoff reductions in case a subject does not play a best reply to the *actual* average price of the other players. This means that subjects have strong incentives to predict the average price of the others correctly, because otherwise they cannot play a best reply. An inevitable consequence of this payoff structure is that large payoff reductions are associated with out-of-equilibrium play. When interpreting Figure 5,

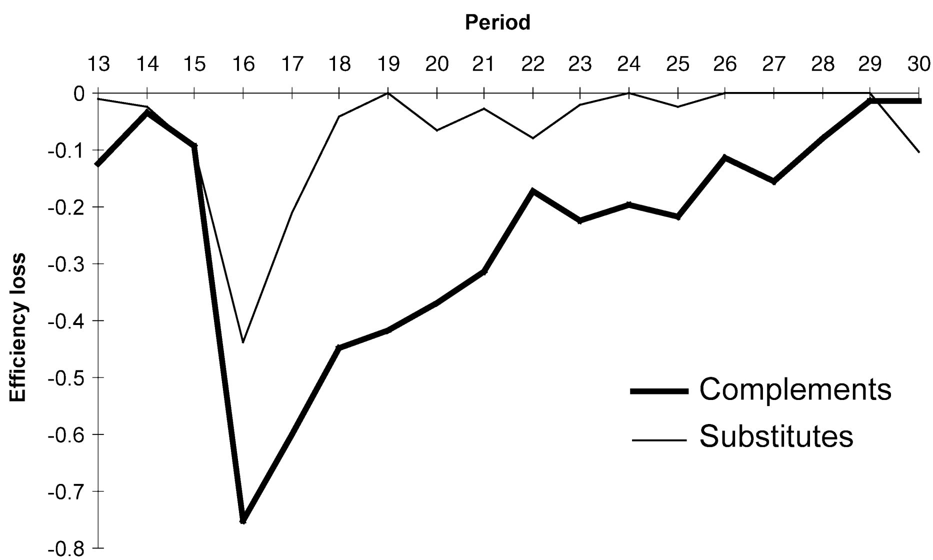

FIGURE 5.—Efficiency losses during the post-shock phase of the main treatments.

therefore, we do not wish to emphasize the absolute value of ε_{jt}. The difference in the average value of ε_{jt} across treatments is more important.

The figure reveals that the payoff losses due to nonequilibrium play throughout the whole post-shock phase are much larger in the CT than in the ST. While sizeable payoff losses only occur in the first two post-shock periods in the ST, large losses occur until period 27 in the CT. This indicates that the different adjustment dynamics associated with strategic complements and substitutes give rise to considerably larger real effects in the complements condition.

3.4. *Money Illusion and Anchoring as Forces Behind Disequilibrium Play*

What are the psychological forces behind disequilibrium play in the post-shock phase of the main treatment? To answer this question, we turn to our control treatments. Recall that the subjects face real payoff tables in all three phases of CT-restart-real and ST-restart-real. Therefore, money illusion can play no role in these treatments. In addition, anchoring effects cannot play a role in the restart phase of CT-restart-real and ST-restart-real because there is no need to adjust nominal prices when subjects play the equilibrium in the final periods of the post-shock phase and then enter the restart phase. We can thus examine whether there are disequilibrating forces other than money illusion and anchoring by examining disequilibrium play in the restart phase of CT-restart-real and ST-restart-real. If a restart causes a disequilibrium in these treatments, we would have to conclude that money illusion and anchoring are not the only forces that cause disequilibration in our setting.

Figures 6A and 6B depict the path of actual prices (Figure 6A) and expected prices (Figure 6B) in the post-shock and restart phases of the control treatments. The figures show that subjects play the equilibrium in the final 10 periods of the post-shock phase of both CT-real and ST-real. Moreover, both actual and expected prices are instantaneously in equilibrium in the restart phase of the treatments with real payoff information. Thus, if money illusion and anchoring are ruled out, instantaneous equilibrium play occurs in the restart phase.

In the next step, we examine the disequilibrium forces associated with money illusion by looking at the CT-restart-nominal and the ST-restart-nominal treatments. Recall that the subjects in the restart phase of these treatments experienced real payoff tables in the pre-shock and the post-shock phases, but they were faced with nominal payoff tables in the restart phase, implying that money illusion can affect their behavior in the restart phase.[16] Figure 6B shows that

[16]We had four groups in CT-restart-real and four groups in CT-restart-nominal. All eight groups received real payoff tables in the post-shock phase. We therefore pool all eight groups under the label CT-real in the post-shock phase of Figures 6A and 6B. We then have four groups in the restart phase with real payoff tables (labeled CT-restart-real) and four groups with nominal payoff tables (labeled CT-restart-nominal). The same convention applies to the graphs of ST-real

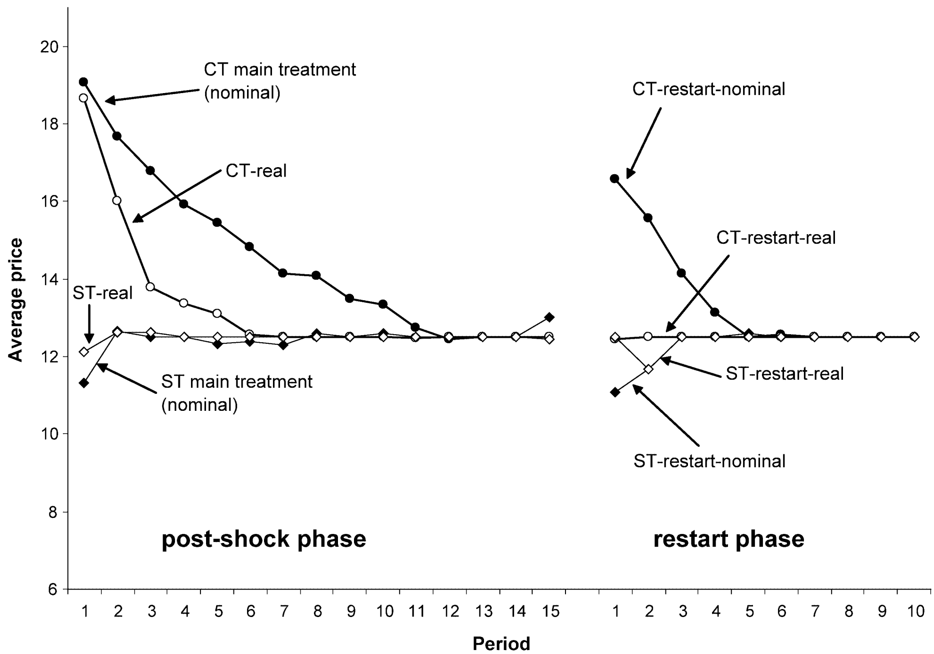

FIGURE 6A.—Average prices in the post-shock and the restart phases across treatments.

the subjects now expect prices that are *above* the equilibrium in both the substitutes and the complements treatments, despite the fact that the same unique equilibrium exists in the post-shock and the restart phases. Moreover, although these subjects expected and played the equilibrium in the preceding post-shock phase for 10 or more periods, they suddenly expect above-equilibrium prices at the beginning of the restart phase when they are given nominal payoff tables. This phenomenon can be taken as a strong indication that money illusion or expectations about others' money illusion affect behavior in our setting. It is also interesting to see that nominal payoff tables have a much stronger impact on expectations in the complements treatment. Price expectations in CT-restart-nominal jump 4.6 units above the equilibrium in the first restart period and a statistical test similar to equation (2) shows significant deviations ($p < 0.05$) for the first three restart periods. Price expectations in ST-nominal restart increase by only 2.2 units above the equilibrium and significant disequilibrium ($p < 0.05$) only occurs for the first restart period. The existence of disequilibrium expectations also translates into disequilibrium play (Figure 6A). Actual prices in CT-restart-nominal also rise quite far above the equilibrium, whereas

and ST-restart-nominal. This pooling of observations is justified because there are no behavioral differences across the pooled treatments during the post-shock phase.

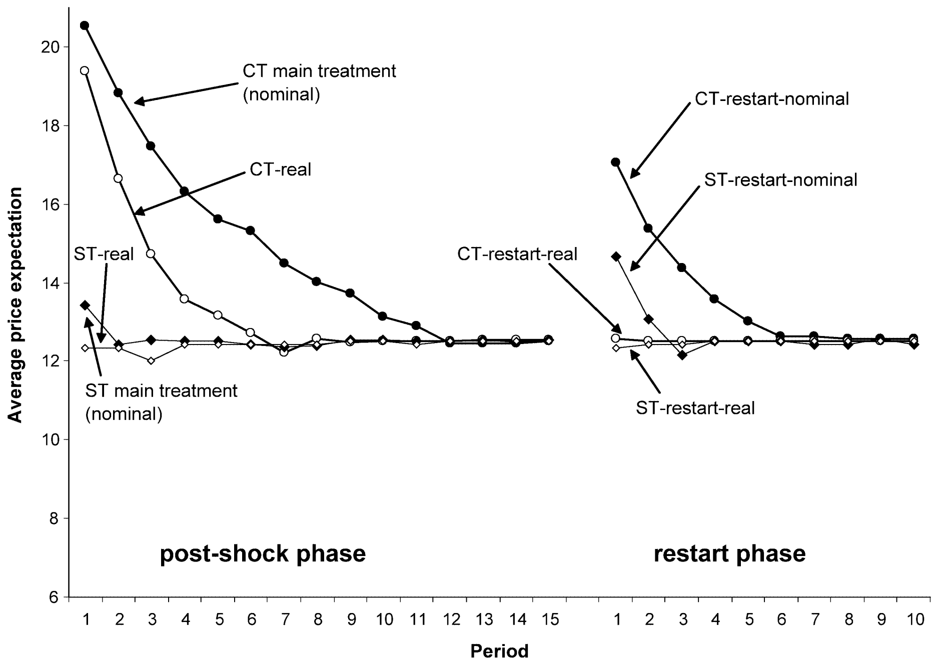

FIGURE 6B.—Average price expectations in the post-shock and the restart phases across treatments.

subjects in ST-restart-nominal best reply by choosing on average prices below the equilibrium. In fact, significant deviations ($p < 0.01$) from equilibrium play occur in CT-restart-nominal for three periods, whereas prices never deviate significantly from equilibrium in ST-nominal restart.

Next, we examine the impact of pure anchoring on post-shock price adjustment. The post-shock graphs of CT-real in Figures 6A and 6B rule out any impact of money illusion on prices and expectations. These graphs indicate that anchoring plays an important role in the complements but not in the substitutes treatment. Anchoring occurs, in particular, during the first four periods of the complements treatment, where we find deviations from equilibrium play (by running regression (2)) at the 5 percent significance level. In contrast, we never observe a significant deviation from equilibrium in ST-real. Both actual prices and price expectations are instantaneously in equilibrium in the post-shock phase of ST-real.

In addition to CT-real and ST-real, we also depicted the post-shock paths of prices and expectations for the main complements and substitutes treatments. We labeled these treatments CT-nominal and ST-nominal in Figures 6A and 6B. Comparing the nominal and the real treatments allows us to identify the extent to which money illusion increases nominal inertia after the shock. Figure 6B shows that price expectations are much more sticky in the nominal complements treatment than in the real complements treatment. Price expectations in CT-nominal deviate significantly (at $p < 0.05$) from equilibrium for the first nine post-shock periods, whereas significant deviations occur only for four periods in CT-real. A similar result holds for actual average prices: they are significantly ($p < 0.05$) above the equilibrium for eight periods in CT-nominal, while significant deviations occur for only four periods in CT-real. Thus, money illusion clearly has a strong impact on post-shock nominal inertia in the complements treatment.

The situation differs radically in the substitutes treatment. Here, neither money illusion nor anchoring has much impact on expectations and prices. Figures 6A and 6B as well as regressions analogous to equation (2) support this result. Actual prices in both ST-nominal and ST-real never deviate significantly (at $p = 0.05$) from the equilibrium in the post-shock phase. The same holds true for price expectations in both ST-nominal and ST-real, suggesting that the impact of bounded rationality on behavior and expectations is greatly diminished in the substitutes treatment.

3.5. *How Does the Strategic Environment Affect Disequilibrium Play?*

In our view, the outstanding feature of the post-shock adjustment of prices and expectations is how quickly equilibrium is reached in the ST relative to the CT. According to the approach taken by Haltiwanger and Waldman (1989), the interaction between a *given* distribution of rational and adaptive players and the strategic environment can explain these large adjustment differences. What is important here is that the rational players in this approach are also assumed to anticipate the share and the behavior of the adaptive players correctly.

To illustrate how a given mix of rational and adaptive players affects the adjustment toward equilibrium in different strategic environments, we constructed Figures 7A and 7B. Both figures show simulations of price adjustment in the context of the two main treatments of our price-setting game. The simulations are based on the parameters of the post-shock phase and the assumption that equilibrium has been reached in the pre-shock phase. We simulated post-shock price adjustment for different assumptions about the shares of rational and adaptive players. For simplicity, the simulations assume that the adaptive players have fully adaptive expectations, that is, they expect the last period's average price to prevail in this period as well. Either money illusion or anchoring could easily cause adaptive expectations because money illusion tends to inhibit the adjustment of expectations after a negative monetary shock and anchoring is naturally associated with sticky, backward-looking expectations. In the simulations, the rational players are also assumed to know the share of adaptive players and they also correctly anticipate the adaptive players' price choices.

In Figure 7A, for instance, the graph associated with $(2x, 2y)$ is based on the assumption that both x types and both y types in the group exhibit fully

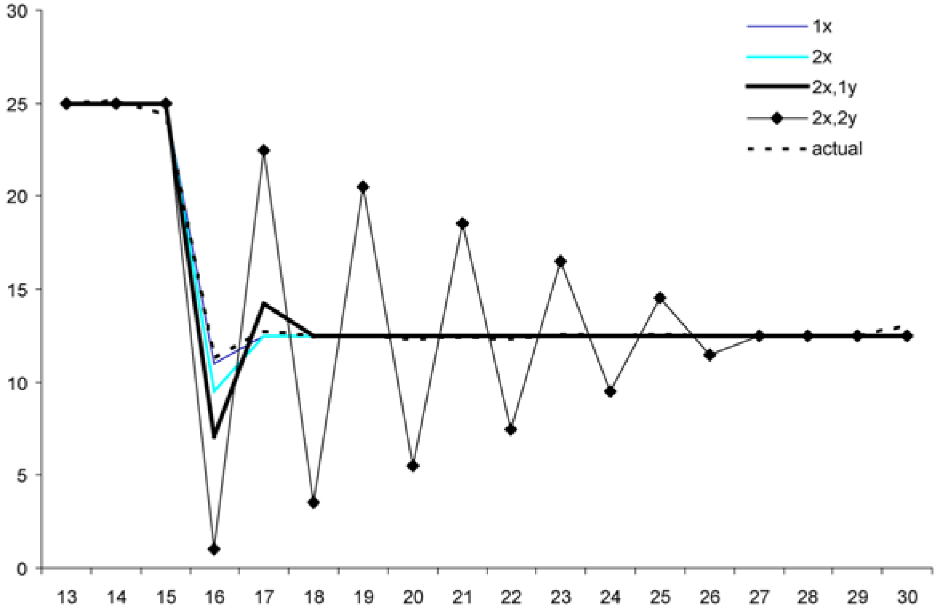

FIGURE 7A.—Simulations of price adjustment with varying numbers of adaptive players in the substitutes treatment (ST).

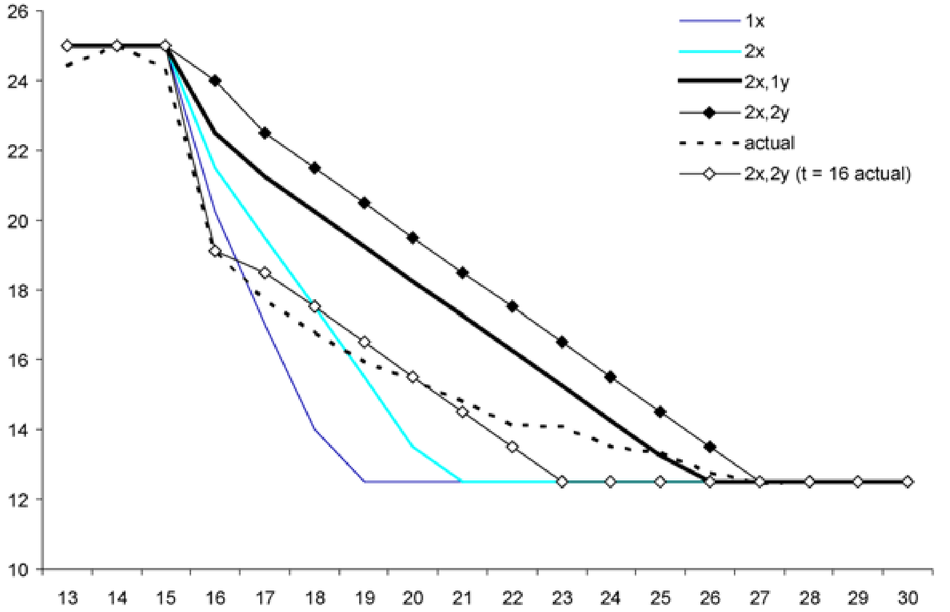

FIGURE 7B.—Simulations of price adjustment with varying numbers of adaptive players in the complements treatment (CT).

adaptive expectations in the ST. The graph shows that we should observe a cyclical adjustment pattern with large amplitudes, and full adjustment would only be reached in period 27. The graph associated with $(2x, 1y)$ assumes that both x players but only one of the y players have fully adaptive expectations, whereas the other y player correctly anticipates the behavior of the three adaptive players. If this is the case, adjustment is also cyclical, but with much smaller amplitudes, and full adjustment is already reached in period 18. If only one of the x players has adaptive expectations and the others in the group are rational, then equilibrium in the ST is reached already in period 17 (see the $1x$ graph in Figure 7A). Figure 7B is constructed analogously for the CT.

A comparison of the two figures shows that if all players are fully adaptive, complete adjustment is only achieved in period 27 in both treatments. However, whereas adjustment is cyclical in the ST, the players in the CT gradually converge to the equilibrium from above. The big differences in adjustment speed across treatments occur when there are some rational players in the population, because they partly mimic the actions of the adaptive players in the CT, whereas they counteract the actions of the adaptive players in the ST. For instance, if one of the y types is a rational player (see the $(2x, 1y)$ graphs), equilibrium in the ST is reached in period 18, whereas adjustment is completed only in period 26 in the CT. Thus, if one or more (but not all) players is rational, the strategic environment has a large impact on adjustment speed.[17]

Figures 7A and 7B also provide a first indication that the strategic environment does not just amplify or weaken the effects of a given amount of bounded rationality. A very good fit with the actual average price path is achieved in the ST if one assumes that only one player is adaptive (see the $1x$ graph in Figure 7A). In the CT, this assumption implies that complete adjustment is already achieved in period 19, whereas in fact this occurs only in period 27. The best fit with the actual average price path is achieved in the CT if we take the prices actually observed in period 16 as our initial values and assume thereafter that all players in the group have fully adaptive expectations. This simulation is shown in the graph $(2x, 2y, t = 16$ actual$)$ of Figure 7B. None of the other simulations in Figure 7B captures the features of the actual average price path in the CT. This is due to the fact that 23 percent of the players in the CT jump directly to the equilibrium in period 16. However, this jump was based on wrong expectations about the behavior of the other players, so that thereafter the players' expectations became very sticky. This explains why the best simulation after $t = 16$ is based on the assumption that all players have fully adaptive expectations. Thus, it seems difficult to explain the actual average price path on the basis of the assumption that there is the same mix of

[17]Our results regarding adjustment speed vary slightly depending on whether we assume that x or y players are rational. The quantitative differences are, however, very small. In Figure 7A, for instance, the graph for the case where only the x player is fully adaptive is almost identical to the case where only the y player is fully adaptive (this case is not shown in the graph).

rational and adaptive players across treatments, because we have to assume a much smaller percentage of adaptive players in the ST to match the observed price changes in the post-shock phase.[18] This suggests that the strategic environment does more than just translate a given mix of expectation formation rules into different aggregate behaviors. Perhaps it also changes the players' expectation formation rules by affecting the impact of bounded rationality on expectation formation.

A first indication for strong treatment differences in expectation formation is provided by the pattern of individual price expectations in the first post-shock period of the two main treatments. There are many more players in the CT who have price expectations in the vicinity of fully adaptive expectations: 45 percent of the x players and 60 percent of the y players have price expectations that are within 2 units of fully adaptive expectations. In contrast, only 6 percent of the x players and 0 percent of the y players have such sticky price expectations in the ST. Thus, in the first post-shock period, the frequency of sticky expectations is much larger in the CT.

Figure 6B provides more direct evidence for the hypothesis that bounded rationality affects expectation formation. The figure shows that subjects suddenly expect very high out-of-equilibrium-prices at the beginning of the restart phase of CT-restart-nominal although they had equilibrium expectations for the preceding 10 periods of the post-shock phase. This pattern indicates that money illusion or beliefs about other players' money illusion have a strong effect on expectation formation in the complements treatment. In contrast, money illusion does not affect price expectations in ST-restart-nominal nearly as much, because the upward jump at the beginning of the restart phase is much smaller (see Figure 6B).

The expectation pattern in the *post-shock* phase illustrated in Figure 6B further supports the view that the strategic environment also affects the extent of bounded rationality. The figure indicates that money illusion strongly affects expectations in the complements treatment because expectations are much

[18] A similar conclusion emerges if cognitive hierarchy theory (Camerer, Ho, and Chong (2004)) is applied to explain subjects' behavior in period 16. The key assumption of this theory is that players exhibit different degrees of rationality and are unaware that there are players like themselves or of higher rationality: players of type 0 choose randomly, players of type 1 choose the best reply to the actions of type 0 players, players of type 2 best reply to the actions of type 0 and type 1 players, and so forth. The nice feature of this theory is that it provides precise quantitative predictions once a single parameter is fixed. This parameter then also determines the distribution of player types. Conversely, it is possible to estimate the parameter and, hence, the distribution of player types for a given distribution of behavior. If the distribution of player types is estimated with the data of the first post-shock period, the best-fitting estimates for our two treatments show that the percentage of players with higher degrees of rationality is considerably larger in the ST. For example, the percentage of players of type 0, 1, 2, 3, and ≥ 4 in the CT is given by 60.7%, 30%, 7.6%, 1.3%, and 0.4%, respectively. In contrast, the estimated percentages in the ST are given by 8.3%, 21%, 26%, 22%, and 22.7%.

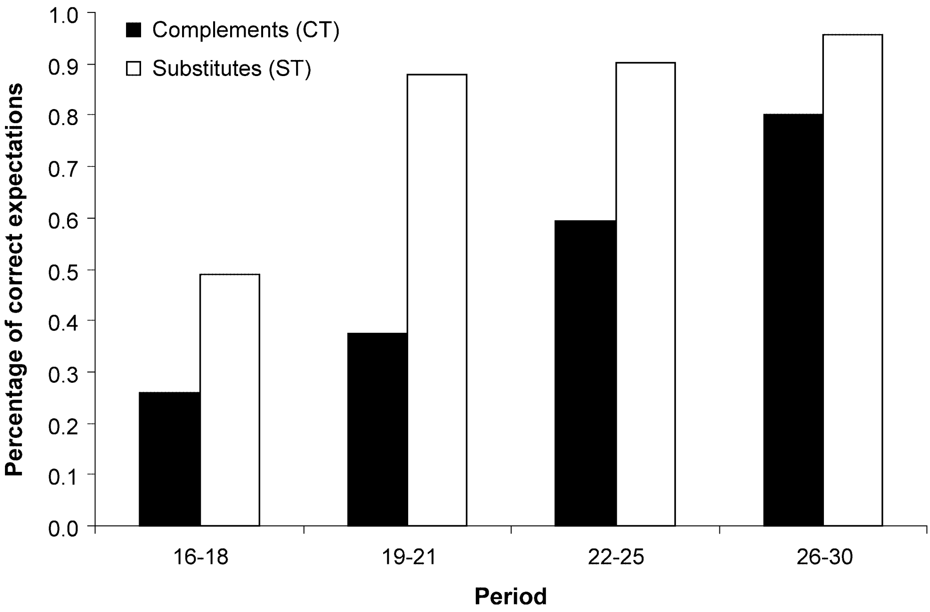

FIGURE 8.—Percentage of correct expectations during the post-shock phase of the main treatments (CT and ST with nominal payoff tables).

more sticky in CT-nominal than in CT-real. Again, this pattern in the complements treatment contrasts sharply with the results in the substitutes treatment. In the latter, money illusion has no impact at all because the expectations in ST-nominal and ST-real are virtually indistinguishable from each other. These observations indicate that bounded rationality has less impact on expectation formation in the substitutes treatment.

An examination of the correctness of players' expectations across treatments further supports this view. Figure 8 shows the percentage of subjects with correct expectations during the post-shock phase in the two main treatments. The percentage of subjects with exactly correct expectations in periods 16–18 and 19–21 is roughly twice as high in the ST as in the CT. Moreover, more subjects in the ST exhibit correct expectations throughout the entire post-shock phase.[19] Taken together, the evidence thus suggests that the strategic environment has a strong effect on expectation formation. It seems that bounded rationality is more pervasive under strategic complementarity, rendering the players' expectations much more sticky and less rational.

This result initially appears to be rather puzzling, because we kept everything constant that can be kept constant across the ST and the CT. In partic-

[19] Chi-squared tests indicate that the treatment differences displayed in Figure 8 are significant at the 1 percent level in each interval.

ular, the cost of deviations from best-reply behavior is exactly identical across treatments and if subjects play a best reply, they earn exactly the same amount of money. Likewise, the cost of a *given* expectation error is identical across treatments. For example, if a subject mispredicts the others' average price by x units, the individual payoff is reduced by the same amount regardless of whether the subject is in the ST or the CT. Therefore, the cost of an expectation error in both treatments increases with the expectation error. The only difference between the ST and the CT is the slope of the best-reply function in $(P_i, \bar{P}_{-i})$ space.

This difference has important consequences, however. It means that adaptive and sticky expectations cause a much larger expectation error in the ST than in the CT. As a result, the payoff loss associated with adaptive expectations is considerably larger, rendering the error more salient in the ST. In addition, it means that subjects in the ST can gain much more if they move from adaptive (sticky) to rational expectations. We illustrate this difference between strategic complementarity and substitutability with the help of Figure 9. This figure shows the pre-shock and the post-shock best-reply functions under complementarity and substitutability. For simplicity, and to ease the graphical exposition, we assumed a symmetric game in Figure 9 so that the equilibrium is given at the intersection between the best-reply function and the 45-degree line. The pre-shock equilibrium is given by point A and the post-shock equilibrium is given by point A'. It is important to keep in mind that the shock in Figure 9 is purely nominal and the required price adjustments (from A to A') are also purely nominal. Figure 9 thus constitutes a nominal representation of the monetary shock. This shock could not be represented in the space of real prices, that is, in $(P_i/M, \bar{P}_{-i}/M)$ space, because a monetary shock does not change the best-reply functions in this space.

For our purposes, the key feature of Figure 9 is that adaptive expectations imply a much larger nominal price adjustment after the shock in the ST compared to the CT. If an individual subject expects that others' average price $\bar{P}_{-i}$ in the first period after the shock is given by the average price in the pre-shock equilibrium A, $\bar{P}_A$, the subject will choose the price P_B in the CT and $P_{B'}$ in the ST (see Figure 9; P_B and $P_{B'}$ are the individual prices that correspond to points B and B', respectively). If, however, all subjects behave in this way, that is, if all choose P_B in the CT and $P_{B'}$ in the ST, the average price will be at $\bar{P}_C = P_B$ in the CT and $\bar{P}_{C'} = P_{B'}$ in the ST. As a consequence, the expectation error in the CT, which is given by $(\bar{P}_A - \bar{P}_C)$ on the horizontal axis, is much smaller than the expectation error in the ST, which is given by $(\bar{P}_A - \bar{P}_{C'})$. Thus, adaptive expectations after a nominal shock imply a much larger expectation error in the ST than in the CT, implying that the error is much more salient and associated with larger costs in the ST.

The previous argument assumes that all players have adaptive expectations. However, the argument holds regardless of the number of adaptive players in the group. To demonstrate this property in more detail, Table VI shows the

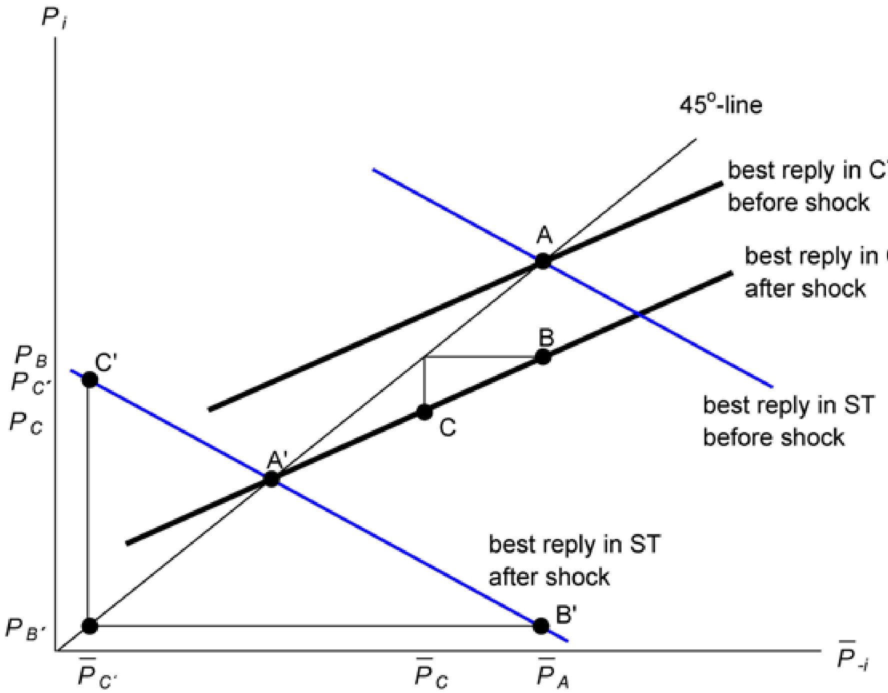

FIGURE 9.—Adaptive expectations under complementarity and substitutability.

expectation error of adaptive players in both treatments conditional on the number of adaptive and rational players in a group. The table shows that, irrespective of the prevailing mix of adaptive and rational players in a group, the expectation error implied by adaptive expectations is always larger in the

TABLE VI

EXPECTATION ERROR IMPLIED BY ADAPTIVE EXPECTATIONS IN THE FIRST POST-SHOCK PERIOD[a]

	Set of Adaptive Players in a Group											
Treatment	$1y$ (y)	$2y$ (y)	$1x, 1y$ (y)	$2x, 1y$ (y)	$1x, 2y$ (y)	$2x, 2y$ (y)	$1x$ (x)	$2x$ (x)	$1x, 1y$ (x)	$2x, 1y$ (x)	$1x, 2y$ (x)	$2x, 2y$ (x)
Complements	3	2	3	2	2	2	6	4	3	3	2	2
Substitutes	11	12	14	16	16	22	12	14	18	17	17	24

[a] If all players in a group have adaptive expectations, the $2x$, $2y$ column is relevant. The numbers in this column then indicate the expectation error of a player with adaptive expectations. The symbols in parentheses, (x) or (y), indicate whether the displayed error is committed by an x or a y player. The other columns have to be interpreted according to the same rules, that is, if one x player and two y players have adaptive expectations, the two columns indicated by $1x$, $2y$ are relevant.

ST. For example, if one of the x players and both y players have adaptive expectations, the expectation error of the x player is 2 in the CT and 17 in the ST. If subjects play a best reply to their expectation, larger expectation errors are associated with lower payoffs. In other words, the benefits from avoiding the error are larger in the ST. The higher benefits from rational expectations can also be illustrated from a different perspective. If, in the symmetric case of Figure 9, a subject expects the other players in the group to have adaptive expectations (and expects them to choose a best reply to this expectation), the expected average price will be at $\bar{P}_C = P_B$ in the CT and $\bar{P}_{C'} = P_{B'}$ in the ST. If the player chooses a best reply to this expectation, he chooses price P_C in the CT and $P_{C'}$ in the ST (P_C and $P_{C'}$ are the *individual* prices that correspond to points C and C', respectively). Thus, the rational subject's price is relatively close to the price P_B of the adaptive subjects in the CT, whereas the rational subject's price is very different from $P_{B'}$ in the ST. However, this is just another way of saying that, in the ST, the rational action is saliently different from the action implied by adaptive expectations and, therefore, the subject's payoff gain from rational expectations is relatively high in the ST compared to the CT. It seems plausible that at least some subjects responded to these differences in the saliency of the error implied by adaptive expectations and the associated payoff gains from rational expectations. This then gives us a natural explanation for the fact that more players in the CT had backward-looking, sticky, and incorrect expectations.

In view of our interpretation that the differences in the stickiness and rationality of expectations across the CT and ST were caused by differences in the saliency and the costliness of the error associated with sticky expectations across these two treatments, one might speculate how an increase in the stake size would affect post-shock adjustment in our experiment. The answer to this question depends on whether the higher saliency or the higher economic cost of an expectation error is primarily responsible for the reduction of bounded rationality in the ST. If the higher saliency of the error is the primary cause of a reduction in bounded rationality, an increase in stake size will not cause fewer mistakes. However, even if the economic costliness of the error is also important, an increase in stakes may not completely remove the error. So far there is little evidence for the claim that bounded rationality will vanish if the stake size in the laboratory is increased. The meta-analysis by Camerer and Hogarth (1999), which includes experiments in which subjects could earn the income of 3 months in less than 2 hours, reports that higher stakes often do not affect mean behavior, but they do reduce the variance in individual behaviors. In tasks where performance is responsive to effort and skills are relatively unimportant, higher stakes tend to improve mean performance. However, Camerer and Hogarth (1999, p. 7) also reported that "no replicated study has made rationality violations disappear purely by raising incentives." Therefore, the behavioral differences between CT and ST may well survive higher stake levels.

In this context it is also worthwhile to point out that our design basically removed all sources of bounded rationality related to the computation of a best reply. It may be that such additional sources of error and uncertainty make subjects more conservative and thus more prone to anchoring and money illusion effects.

Another question is whether money illusion and anchoring lose force if monetary shocks occur repeatedly. Here, we believe, one has to distinguish between repeated identical shocks and repeated nonidentical shocks. If the same subjects play the same experiment several times, there is a high chance that the impact of bounded rationality on post-shock adjustment gradually decreases. However, if subjects are exposed to different monetary shocks, as is typically the case in reality, we have much less confidence that the impact of bounded rationality decreases with experience.[20]

4. IMPLICATIONS FOR THEORIES OF NOMINAL INERTIA AND EXPECTATION FORMATION

In this section we discuss the extent to which different theories of nominal inertia are compatible with the facts in our experiment. We hope that the following short discussion induces macroeconomic theorists to take the characteristic features of our data into account in their future work. It is obvious that models based on best-reply behavior and fully rational expectations cannot explain our results, because such models imply instantaneous adjustment to the new equilibrium independently of the treatment condition. It is equally obvious that theories that are based on contractual (Fischer (1977)) or informational (Lucas (1972)) frictions cannot explain the sticky adjustment in the CT; neither can they explain the rapid adjustment in the ST. This follows simply from the fact that neither such informational nor contractual frictions existed in our experiments. The theories by Sargent (1993) or Evans and Honkapohja (2001) are based on the assumption that agents are backward looking in the sense that they run least squares regressions on past data which are used to form expectations about future prices. These theories cannot explain the differences between the CT and the ST at the beginning of the post-shock phase because the players in both treatments experienced very similar prices before the shock. Figure 1 shows that the players played very close to the pre-shock equilibrium for a large number of periods both in the CT and the ST. This implies that least square regressions on past data lead to very similar expectations

[20]Note also that in an environment with multiple equilibria, money illusion may cause coordination on Pareto-inefficient equilibria. Fehr and Tyran (2007) showed explicitly that even if most or all individual subjects may eventually learn to pierce the veil of money, *individual* learning does not suffice to avoid miscoordination. As long as rational subjects believe that other subjects prefer the bad equilibrium because of money illusion, rational subjects best reply by also playing the bad equilibrium.

in both treatments at the beginning of the post-shock phase. Figure 4 shows, however, that subjects' expectations were very different in the first post-shock period.[21]

The previous section has shown that the theory of Haltiwanger and Waldman (1989) could, in principle, explain why adjustment is rapid in the ST and slow in the CT. In fact, this approach inspired the current study and thus contributed to the insights of this paper. However, this theory has difficulties in explaining the much higher frequency of sticky expectations in the CT and the fact that subjects' expectations in the CT are less rational than in the ST (as shown in Figure 8). If the degree of subjects' rationality is constant across treatments, then the percentage of correct expectations should be the same. The theory of near-rational behavior by Akerlof and Yellen (1985) also does not seem to be able to capture the differences between the CT and the ST. This theory rests on the idea that the deviation from the optimal price choice causes only second-order losses for the individual in an interior equilibrium in a price-setting game where agents face smooth and concave payoff functions. Therefore, the gains from fully optimal price setting are small so that a percentage of the agents do not play a best reply to their expectations. The theory assumes, however, rational expectations. We observe exactly the opposite result in our experiments: subjects do play their best reply, but many of them have incorrect expectations in the CT. In this context one should, however, keep in mind that we deliberately implemented a design in which deviations from best-reply behavior are associated with first-order losses so that subjects had a strong incentive to play best replies. This design feature allows us to isolate the impact of the strategic environment on expectation formation. Therefore, in environments with payoff functions that are relatively flat in the vicinity of the best reply, the theory by Akerlof and Yellen may well be relevant.

Mankiw and Reis (2002) recently proposed the concept of sticky information. Their model is consistent with one aspect of our data: players play best replies to their expectations so that the stickiness of expectations is the driving force behind nominal inertia. Thus, the model is broadly consistent with the stickiness of price expectations in the post-shock phase of the CT. However, it cannot account for the differences between the CT and the ST. Reis (2006) provided a microfoundation for the assumption of sticky information by assuming that agents face costs of acquiring, absorbing, and processing information. This view is consistent with the idea that the differences in the gains from rational expectations between the CT and the ST are a driving force behind

[21]Note that although least squares (LS) learning models cannot account for behavior and expectations in the first post-shock period, they may be capable of capturing part of the differential adjustment across ST and CT in subsequent periods because LS models incorporate a (quadratic) loss function. Therefore, an LS learner would react to the larger forecast errors in the ST compared to the CT, shown in Figure 9, by adapting estimates in the ST more rapidly toward the equilibrium. We are grateful to one of the referees for pointing this out to us.

our treatment differences, because if agents have no costs of forming rational expectations, any gain, however small, from rational expectations should induce them to form their expectations rationally. If, however, the agents have cognitive or other costs of forming their expectations rationally, an increase in the gains will make it worthwhile for some additional agents to form rational expectations.

The papers by Evans and Ramey (1992, 1998) and Brock and Hommes (1997) introduced the idea that forming rational expectations is cognitively costly. In these papers, the agents take the cognitive costs and the benefits of different expectation formation rules into account when they decide which rule to use. Evans and Ramey (1992) were able to show that this principle of expectation formation may lead to an equilibrium where nobody has rational expectations or one where everybody incurs the calculation cost and, hence, everybody exhibits rational expectations. Therefore, depending on the costs and benefits of calculating rational expectations, the model is consistent both with slow and gradual adjustment as well as with instantaneous adjustment toward equilibrium. We believe that the strong behavioral differences between the CT and the ST provide support for these approaches because they are associated with strong differences in the cognitive costs and economic benefits of forming rational expectations.[22]

5. SUMMARY

There is now considerable evidence indicating that a share of the people are not fully rational, but in strategic interactions, aggregate outcomes are more than just the summation of individual behavior. Therefore, it is, in principle, possible that a large fraction of boundedly rational agents nevertheless will end up in a situation that is predicted by rational choice models. Yet it is also possible that a small share of boundedly rational agents have a large effect on the behavior of the rational agents, so that aggregate behavior is driven away from the rational prediction. In view of these different possibilities, it is important to know when bounded rationality matters and when it does not affect aggregate outcomes. We examined this question in the context of an important economic problem—the adjustment of nominal prices after a fully anticipated negative monetary shock.

In our experiments, the adjustment of nominal prices is instantaneous, and real effects of the monetary shock are absent if all players have rational expectations and play a best reply to their expectation. This holds regardless of

[22]The more extreme stickiness results in Evans and Ramey (1992) occur when the slope of the best-reply function is relatively close to 1, that is, for a relatively high degree of strategic complementarity. This is interesting insofar as the slope of the best reply function in the complements treatment is 1, lending further support to the idea that costly cognition is the driving force behind our treatment differences.

whether subjects' actions are strategic complements or strategic substitutes. In fact, however, the strategic environment has a decisive impact on the nature and the speed of the adjustment process. When strategic complementarity prevails, adjustment to the new equilibrium is very slow and associated with large effects on subjects' real income. Under strategic substitutability, adjustment is extremely rapid. The evidence indicates that differences in the stickiness of price expectations are the key to understanding these results. If actions are complements, expectations are very sticky, while if actions are substitutes, expectations are very flexible. Since the players almost always choose a best reply to their expectations, the differences in the inertia of price expectations translate into differences in actual price adjustment.

The data suggest that the complements condition not only provides incentives for the rational types to (partly) mimic the behavior of the adaptive players, but it also renders the subjects' expectations less forward-looking and less rational relative to the substitutes treatment. The key difference between strategic substitutes and strategic complements—the slope of the best-reply function—provides a plausible explanation for the pattern of expectations described above by implying that adaptive expectations are associated with a much larger expectation error in the substitutes treatment than in the complements treatment. Therefore, the error that adaptive expectations imply is more salient and more costly in the substitutes treatment. As a consequence, the cognitive costs of forming rational expectations are likely to be lower under substitutability, whereas the economic gains from forming rational expectations are higher. Thus, our results provide support for theories which assume that the degree of rationality with which the players form expectations is not exogenously given but responds to the cognitive costs and the economic gains associated with rationality. Such theories have been proposed by Evans and Ramey (1992, 1998), Brock and Hommes (1997), and, more recently, by Reis (2006).

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APPENDIX A: FUNCTIONAL SPECIFICATION OF PAYOFFS

Subjects received the information about the payoff function in the form of a matrix (see Appendix D in the Supplemental material). For completeness, we also describe players' payoff functions here in analytical terms. Since we kept everything constant across treatment conditions with the exception of the

TABLE A.1

BEST-REPLY FUNCTION IN THE COMPLEMENTS AND THE SUBSTITUTES TREATMENT

If the Average Price of the Other Firms, $\bar{P}_{-i}$, Is in the Range	Player i's Best Reply in the *Strategic Complements* Treatment Is Given by[a]	Player i's Best Reply in the *Strategic Substitutes* Treatment Is Given by[b]
$\frac{\bar{P}_{-i}}{M} \le \frac{\bar{P}^*_{-i}}{M} - \frac{P^*_i}{M}$	Δ	$\frac{2P^*_i}{M} - \Delta$
$\frac{\bar{P}^*_{-i}}{M} - \frac{P^*_i}{M} \le \frac{\bar{P}_{-i}}{M} \le \frac{\bar{P}^*_{-i}}{M} - \Delta$	$A + \frac{\bar{P}_{-i}}{M}$	$A - \frac{\bar{P}_{-i}}{M}$
$\frac{\bar{P}^*_{-i}}{M} - \Delta \le \frac{\bar{P}_{-i}}{M} \le \frac{\bar{P}^*_{-i}}{M} + \Delta$	$\frac{P^*_i}{M}$	$\frac{P^*_i}{M}$
$\frac{\bar{P}^*_{-i}}{M} + \Delta \le \frac{\bar{P}_{-i}}{M} \le \frac{\bar{P}^*_{-i}}{M} + \frac{P^*_i}{M}$	$A + \frac{\bar{P}_{-i}}{M} - 2\Delta$	$A - \frac{\bar{P}_{-i}}{M} + 2\Delta$
$\frac{\bar{P}^*_{-i}}{M} + \frac{P^*_i}{M} \le \frac{\bar{P}_{-i}}{M}$	$\frac{2P^*_i}{M} - \Delta$	Δ

[a]Here $A = -1/21$ if type x, $A = 3/21$ if type y, and $\Delta = 1/21$ for both types.
[b]Here $A = 23/21$ if type x, $A = 25/21$ if type y, and $\Delta = 1/21$ for both types.

slope of the best-reply function, the analytical representation of the payoffs is a bit complicated. The real payoff function for all i is

$$v_i = 1 + \frac{38}{1 + \Delta^{-2}(P_i/M - \text{best-reply function})^2}.$$

Table A.1 shows the best reply for player i for every feasible average price of the other players $\bar{P}_{-i}$. P^*_i is the equilibrium price for player i, $\bar{P}^*_{-i}$ is the average price of the other players in equilibrium, and M is the nominal shift variable. For the numerical values of these parameters, please refer to Table I.

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