The Role of Money Illusion in Nominal Price Adjustment

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This paper experimentally investigates whether money illusion generates substantial nominal inertia. Building on the design of Fehr and Tyran (2001), we find no evidence that agents choose high nominal payoffs over high real payoffs. However, participants do select prices associated with high nominal payoffs within a set of maximum real payoffs as a heuristic to simplify their decision task. The cognitive challenge of this task explains the majority of the magnitude of nominal inertia; money illusion exerts only a second-order effect. The duration of nominal inertia depends primarily on participants' best response functions, not the prevalence of money illusion.

Fehr and Tyran (2001) (hereafter FT) investigate the role of a specific form of money illusion – taking nominal payoffs as a proxy for real payoffs – in nominal price adjustment within a price-setting game where firms' prices are strategic complements. In a laboratory setting, FT vary the payoff framing (real vs. nominal framing) and opponent types (a rational computer vs. human opponents) to study both the direct and indirect effects of money illusion. Their main finding is that a small amount of individual-level money illusion may generate significant nominal inertia following a negative monetary shock. The response to a positive monetary shock is asymmetric in that price convergence to equilibrium is considerably faster. Their results have been widely cited as evidence of money illusion, e.g. Yellen and Akerlof (2006), Cannon and Cipriani (2006), Brunnermeier and Julliard, (2008), Basak Yan (2010). While their experiments are innovative, we argue that certain features of FT's experimental design hinder a clear interpretation of their results. These features are:

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1. In the treatment they used to measure individual-level money illusion rational agents and agents with money illusion have the same optimal strategy. Consequently, money illusion cannot be measured in their experiments.
2. The treatment design does not separate the cognitive task of finding the Nash Equilibrium (NE) from the task of coordinating with one's opponents. A nominal payoff frame may slow price adjustment because it increases agents' cognitive load, not (only) because it induces money illusion.
3. A visible focal point in the participants' real payoff space is obscured in their nominal payoff space. This may have slowed coordination to the new equilibrium apart from money illusion.
4. The adjustment rates of prices following a monetary shock are well explained by agents setting their prices in period *t* so as to best respond to their opponents' prices in period *t*-1. In the payoff space of FT's positive shock environment this strategy would cause prices to adjust two to three times faster than in the payoff space of their negative shock environment, regardless of the presence of money illusion.

This paper reassesses the role of money illusion in FT's laboratory experiments. We modify the participants' payoff space to allow for (1) identification of money illusion at the individual level, (2) balance in focal points across payoff frames in treatments meant to assess the indirect effects of money illusion, and (3) symmetry in best reply functions following negative and positive monetary shocks. We also introduce a new treatment to assess the impact of cognitive load on price adjustment. We employ FT's methodology to reevaluate whether money illusion matters.

In the analysis that follows, it is important to distinguish between two categories of money illusion. The first category, which we will call "first order money illusion" includes any bounded rationality that leads agents to follow strategies that maximize their nominal payoffs. The second category, which we will call "second order money illusion," is less severe. An agent exhibits second order money illusion if his process of selecting a strategy primarily relies on the underlying real payoffs, but takes some account of nominal payoffs as well.

FT's proposed form of money illusion is that agents take nominal payoffs as a proxy for real payoffs. This is a form of first order money illusion because, although agents wish to maximize their real payoffs, they attempt to accomplish these ends by maximizing their nominal payoffs. In our experiments we find no evidence of first order money illusion, but we do find evidence of second order money illusion. Participants primarily chose from the set of prices that could result in their maximum real payoff, but within this set some participants favored prices which could also result in higher nominal payoffs. Beyond this rather small second order effect, all of the differences in price inertia across our treatments can be explained by differences in the cognitive load of finding the NE.

I. Experimental Design

In this section we briefly describe the experimental design employed by FT. We then explain how features of this design confound first order money illusion with other influences that might affect the evolution of prices after a monetary shock, and how we revise the original design to overcome these confounds in our own experiments. For the remainder of the paper we will use the terms "money illusion" and "first order money illusion" interchangeably. Second order money illusion will always be indicated by its full title.

A. *The Original Design*

FT studied money illusion in the context of a pricing experiment: participants took the role of firms choosing prices simultaneously with their opponents. No communication was allowed. Payoffs each period were determined by a profit function, the reduced form of which is:

$$\pi_i = \pi_i(P_i/\bar{P}_{-i}, M/\bar{P}_{-i})\ , i = 1, \dots, n \qquad (1)$$

where π_i is the real profit of firm i, M is the stock of money, and P_i and $\bar{P}_{-i}$ are the price set by i and the average price set by the other firms respectively. Profit function (1) implies that money is theoretically neutral, collusive pricing is a dominated strategy, and firms' prices are strategic complements (i.e., a firm's most profitable P_i is positively correlated with $\bar{P}_{-i}$).

Participants were organized into groups of four, and the membership of each group remained the same throughout the experiment. In each group, two participants took the roles of "type *x*" firms while the other two took the roles of "type *y*" firms. The firm types only differed in the functional form specified for them using profit function (1).[1] The profit functions were presented to participants as "income tables," which displayed a matrix of payoffs. The left column contained the set of P_i that a firm could choose and the top row contained all possible $\bar{P}_{-i}$ that could result from the prices chosen by its three counterparts. The income tables made it easy to look up the payoff associated with any $(P_i, \bar{P}_{-i})$ combination. All participants received the income tables for both firm types, so that the profit functions were common knowledge.

In each period, every firm in a group selected a price $P_i \in \{1,2,\dots,30\}$. Once all firms had set their prices, $\bar{P}_{-i}$ was calculated for each firm along with the corresponding real payoff, π_i. Participants were not told the individual prices chosen by each of their opponents, but they were shown $\bar{P}_{-i}$ and π_i as informational feedback at the end of each period. All negative shock experiments consisted of 2T periods. For the first T periods of the experiment the money supply was given by $M_0 = 42$, and the equilibrium prices of firms of type *x* and type *y* were 9 and 27, for an average equilibrium price, $\bar{P}_0^*$, of 18. In equilibrium, all firms earned the maximum payoff of 40. These initial T periods composed the "pre-shock" phase of the experiment

After the pre-shock phase had concluded, a monetary shock was implemented by distributing new income tables to all participants. The shock was fully anticipated in that the experimenters publicly announced that there would be a change in income tables in period T+1, as well as the fact that the experiment would continue for an additional T periods, which composed the "post-shock" phase. In this phase, the money supply was cut by two thirds to $M_1 = 14$. Consequently, in the new equilibrium type *x* firms would set a price of 3 and type *y* firms would set a price of 9, so that $\bar{P}_1^* = 6$, 12 increments below the pre-shock equilibrium. The equilibrium payoff for all firms remained 40, as in the pre-shock phase.

There were two treatment variables, the first of which was the representation of payoffs. In the Real (R) treatments, participants' income tables were populated by their real payoffs, π_i. In the Nominal (N) treatments the participants' income tables contained nominal payoffs, $\bar{P}_{-i}\pi_i$,

[1] Using unique payoff functions for each firm would have been the most realistic design, but would have made finding the equilibrium very challenging for participants. FT chose two firm types with separate payoff functions to balance realism with tractability.

which required a firm to manually deflate by the average price of its opponents to obtain real payoffs.

The second treatment variable allowed FT to separate the direct individual-level effect of first order money illusion (irrational agents setting inefficiently high prices) from its indirect strategic effects (rational agents best responding to irrational ones by also setting inefficiently high prices). In the Computerized (C) treatments, each participant was grouped with three computerized opponents who set their prices so as to maximize their real payoffs given the price that the participant had chosen in the current period. In addition to the income tables, participants in the C treatments were shown the $\bar{P}_{-i}$ that their computerized opponents would set in response to each P_i. In the Human (H) treatments, participants were grouped with one another. This introduced a coordination problem: for each participant there was an element of uncertainty regarding the prices that his opponents would set.

The 2x2 interaction of these treatment variables produced four treatments: RC, NC, RH and NH. The RC served as a baseline to test for individual-level irrationalities other than money illusion. The NC introduced the possibility for first order money illusion to directly impede adjustment to the monetary shock, but ruled out a coordination problem. Participants in the RH treatment were immune from money illusion of any kind as they saw real payoffs in their income tables, but faced a coordination problem that could slow adjustment to the new equilibrium. Finally, the NH treatment allowed for nominal framing to interact with the coordination problem and provided a measure of the combined individual-level and strategic effects of money illusion.

FT found that prices adjusted instantaneously in the RC, ruling out irrationalities other than money illusion. Adjustment was somewhat slower in the NC treatment, which they offer as evidence for a low level of individual-level money illusion. In the RH, prices adjusted to the new equilibrium by the third period. However, in the NH it took the firms 13 periods to fully adjust their prices. Consequently, FT concluded that when prices are strategic complements, even a small amount of money illusion at the individual level can lead to substantial downward price stickiness. They then conducted additional experiments in the RH and NH treatments – using different income tables – in which the average equilibrium price was higher in the post-shock phase (We refer to these as the RH^+ and NH^+, though FT do not use this notation.) They found that the prices in the NH^+ fully adjusted in just four periods. The asymmetric response of prices to negative and positive shocks is consistent with the hypothesis of first order money illusion.

B. *Confounds in the Original Design*

1. Identifying money illusion in the NC treatment

Table 1 displays the real and nominal incomes that firms of both types could expect to earn in the post-shock phase under FT's nominal mapping, as well as under our own. FT's NC treatment is incapable of separating rational participants from those with first order money illusion because their nominal frame did not sufficiently inflate the nominal payoffs that could be earned by pricing above the equilibrium. A participant suffering from first order money illusion would select the price associated with the highest nominal payoff. In FT's NC this is a price of 3 for type x and 9 for type y. But these are *also* the prices associated with the highest real payoff, which a rational participant would select. Consequently, there is no way to disentangle who actually suffered from money illusion. Moreover, the nominal inertia in their NC treatment cannot be attributed to money illusion, because participants suffering from it would have no trouble fully adjusting to the new equilibrium.

Our revised design uses $\bar{P}_{-i}(\pi_i + \bar{P}_{-i})$ to for nominal payoffs, allowing us to identify money illusion in the post-shock phase of the NC.[2] For type x firms, any price greater than or equal to 15 results in a higher nominal income than the equilibrium price of 3. For type y firms, the post shock equilibrium price is 9, but any price greater than or equal to 20 offers a higher nominal income.

2. Money Illusion vs. the Cognitive Load of Finding the Nash Equilibrium

In the computerized treatments, participants know the response of their opponents for each possible P_i. Consequently, their cognitive task essentially consists of picking their preferred payout from a list of 30 possibilities. In the human treatments, participants must coordinate to the NE with their opponents. But coordinating to the NE requires that participants first calculate what it is. In the original design the NE may be found through iterated elimination

[2] Money illusion is not identified in the pre-shock phase of our experiments, but this is not problematic because we focus our analysis on money illusion's effects on price adjustment after the monetary shock.

of dominated strategies, but it is highly unlikely that many participants are sufficiently familiar with game theory to make use of that method, especially in a game with 900 potential payoffs per firm type. The NE may be easier to find under the real frame, or with a positive shock under the nominal frame. In the RH there is no need to deflate payoffs, which may free up time and mental capacity for finding the optimal prices. Similarly, in the NH^+ the highest nominal payoffs were also the highest real payoffs, which may have made the equilibrium prices more obvious.

FT's experimental design does not separate finding the NE from coordinating to it. If there are asymmetries in the cognitive load of finding the NE across the human opponent treatments, these asymmetries may be mistaken for money illusion. We conducted a set of treatments to examine the effect of the cognitive challenge of the pricing task. Each participant was put in charge of all four firms in their group and was required to choose the prices for the firms simultaneously. In these experiments a participant had no opponent save for his or her own Self (S). We used the income tables from the human-opponent experiments to yield two negative-shock treatments (RS and NS) and one positive shock treatment (NS^+). (A positive shock treatment with the real payoff frame was not necessary for reasons explained below.)

Sessions in the RS, NS and NS^+ treatments consisted of two phases, but participants made only one set of pricing decisions per phase. In each phase the participants were given fifteen minutes to examine their income tables and choose the four prices for the firms under their control. Each participant was paid the sum of his four firms' real incomes.[3]

3. Focal Points in the Real Payoff Space

An examination of FT's RH income tables reveals a focal point that is not present in the tables for their NH treatment. Table 2 and Table 3 display the real and nominal incomes respectively in and near the equilibrium price for type *x* firms in the pre- and post-shock phases of the experiment. In the pre-shock (post-shock) table the equilibrium price rows contain seven (three) payoffs within one point of each other, making them visually striking. The equilibrium prices all possess the same payoff of 40 and offer the longest string of maximum payoffs.[4] The

[3] In the self-opponent treatments participants were paid 6.25 cents per point. Since each firm earns 40 points in equilibrium a participant could earn up to $10.00 per phase in addition to a their attendance bonus.
[4] Type *y* firms' tables (not shown here) exhibit the same basic patterns.

nominal framing not only casts the veil of money over each real payoff individually; it covers the *pattern* of real payoffs that might act as a focal point to coordinate participants' expectations.

The asymmetry in focal points between the RH and NH is a potentially serious uncontrolled variable, and may explain some or all of the difference in nominal inertia between the original RH and NH treatments. Schelling (1960) first showed that in a number of coordination games, even with very large strategy spaces, the presence of a focal point often assists players to coordinate their decisions with much greater frequency than would be predicted by game theory alone. More recent experimental work (for example, by Mehta, Starmer and Sugden., 1992 and 1994; Bacharach and Bernasconi, 1997; Bardsley et al., 2010) has confirmed the power of focal points in coordination games. We correct for the asymmetry in the original design by providing a visual focal point in both of these treatments by marking the maximum real payoffs in the appropriate cells with bold red font.[5] These markings were made in the tables for human opponent and self-opponent treatments. They were not used in the computer opponent treatments, as those treatments were meant to measure individual-level irrationalities apart from any coordination problem.

4. Asymmetric Best Reply Functions in the Negative and Positive Shock Treatments

Participants in all of FT's treatments with human opponents generally adopted a simple rule of thumb for selecting their prices after the first period of the post-shock phase. Namely, for any period t > T + 1 participant i tended to choose a price for the period, P_{it}, that was a best response to $\bar{P}_{-i,t-1}$. We will refer to this strategy as "adaptive best responding," or the "adaptive best response" (ABR).

The widespread use of ABR under both payoff treatments indicates that the best reply function of the payoff space drove price adjustment dynamics. In the negative shock treatments the best reply functions induced participants who chose their ABR to adjust toward the equilibrium at a rate of one price increment per period. In the positive shock treatments, however, FT used a different set of income tables from a different functional form of the real payoff function (1). The resulting best reply functions induced much faster convergence.

[5] For the pre-shock phase we marked every income cell that contained a real income of 40 in this manner. In the post-shock phase we marked every cell that contained a real income of 39 or 40.

Participants who chose their ABR in the positive shock treatments would adjust toward the equilibrium at a rate of two to three price increments per period. (Detailed support for our claim that FT's participants systematically followed the ABR and that this would lead to faster convergence in the positive shock treatments can be found in Section 1 of online Appendix A.)

A fair comparison of adjustment after each shock type requires symmetrical best response functions. Our solution was quite simple: we used the real income matrices from the negative shock experiments, but reversed the ordering of the rows and columns. This meant, for instance, that the payoff associated with the $(P_i, \bar{P}_{-i})$ combination (1,1) in a given negative shock table was associated with the combination (30,30) in the corresponding positive shock table. The resulting real payoff matrices could then be mapped into nominal payoffs in the manner described in Section I.B.1.[6]

Note that in our experimental design a deviation from the new equilibrium of ε after a positive shock is equivalent to a deviation of $-\varepsilon$ after a negative shock. Thus, results from the positive shock experiments can be compared directly to the negative shock experiments through a simple transformation of the data in which the deviations from equilibrium are multiplied by -1. Accordingly, a positive shock treatment using a real payoff frame was not necessary; our experiments with a positive shock all used a nominal payoff frame. The income tables for the NH^+ and NS^+ induced a pre-shock equilibrium price on type x (type y) firms of 22 (4). In the post-shock phase the type x (type y) equilibrium price was 28 (22). Thus, average equilibrium prices for the pre- and post-shock phases were 13 and 25, requiring an adjustment of 12 increments, just as in the negative shock experiments. Table 4 summarizes the parameters of our experimental design for all treatments.

C. *Participant Pool*

A total of 225 participants took part in the eight treatments described above. Each participant took part in only one experiment. For the experiments with human opponents, we conducted sessions with eight or more participants so that they would not know exactly who the other members of their group were. The experiments were conducted at Chapman University and the University of California, Santa Cruz, approximately half at each location. Participants were

[6] Notice that this means that there is, technically speaking, no money supply in the functional form of our positive shock experiments.

paid $7 for attending and in addition earned an average of approximately $25.30 based on their decisions in the experiment. The experiments typically lasted 70 – 90 minutes.[7]

II. Results

A. *Individual-Level Irrationalities and Money Illusion*

Participants facing computerized opponents displayed highly rational behavior. Table 5 contains the average deviation from the equilibrium price per period in the post-shock phase of all of our treatments with computerized or human opponents, as well as significance levels using Wilcoxon signed-rank tests with $\bar{P}_{it} - \bar{P}_t^*$ as the unit of observation, where $\bar{P}_{it}$ is the average price chosen by group i in period t.[8] Prices adjusted very quickly to the monetary shock in the RC. In the post-shock phase the average price was never more than 0.8 increments away from the equilibrium, and a substantial amount of the deviation from equilibrium was due to participants failing to submit prices before the end of the period, in which case the software submitted a random price between 1 and 30 on their behalf. If these random prices are excluded, 96 percent of participants in the RC chose the equilibrium price in period T+1, and 95 percent of all prices in the post-shock phase were exactly equal to the equilibrium. The average deviation is not statistically significant in any post-shock period at the 5 percent level, even if the random prices are included. As in FT's original experiments, we can find no evidence for individual-level irrationalities under a real payoff framing.

Unlike FT's experiments, however, there was no nominal inertia in our NC treatment. The average price in period T+1 was 0.8 increments above the equilibrium, but this is not significant at the 5 percent level. Moreover, even this slight deviation was due entirely to three participants who failed to choose a price prior to the end of the period, resulting in random price selections. *Every* firm that did submit a price in period T+1 chose their equilibrium price. In eight of the nine remaining periods of the post-shock phase the average price was exactly equal to the equilibrium, and in period T+3 it was slightly below the equilibrium. If random prices are excluded, there is only one instance in the post-shock phase of a price being selected that was not

[7] All experimental procedures, computerized interfaces, instructions and income tables can be found in online Appendices B, C and D.

[8] For statistical analysis in the RC and NC we organized the data into groups based on where each participant was seated in the experiment, because that determined group membership in the RH and NH treatments.

equal to the equilibrium prediction. That price yielded a nominal payoff *lower* than that of the equilibrium. In short, not a single decision in our NC was consistent with first order money illusion. Participants clearly distinguished between real and nominal payoffs, and based their decisions on the former.

B. *Finding the Equilibrium Under Real and Nominal Payoff Frames*

Although our participants did not take nominal income as a proxy for real income in the NC treatment, the nominal payoff frame hindered their ability to find the equilibrium. We focus our analysis on the $\bar{P}_i - \bar{P}^*$ (multiplied by negative one in the positive shock sessions) in the post-shock period of self-opponent treatments. Figure 1 shows the cumulative density functions of average price deviations in the RS, NS and NS^+. Notice that the median deviation from the equilibrium is greater under the nominal frame than under the real frame, and greater with a negative shock than with a positive one. Using Mann-Whitney tests we find that the deviation in the NS is significantly greater than in the RS ($p = 0.016$) and falls just short of a statistically significant difference from the NS^+ at the 5 percent level ($p = 0.052$). However, the RS and NS^+ have statistically identical distributions ($p = 0.821$).

What accounts for the added difficulty of finding the equilibrium under a positive versus a negative shock? Second order money illusion appears to explain the data. The pattern of prices set by individual participants (rather than averages at the group level) suggests that participants used real payoffs to find a range of suitable prices but allowed nominal payoffs to influence their selection of prices within this range.

In both the NS and NS^+ the participants showed a strong tendency to choose prices whose rows in the income table contained at least one bolded, red payoff, which indicated a maximum real income. In the post-shock period of the NS and NS^+ 88.2 percent and 94.7 percent of the prices respectively were within the bolded range. By conducting four Pearson's chi-square tests, each restricting the sample to the prices chosen for a single firm, we find that the likelihood of choosing a price in the bolded range was largely invariant across monetary shocks. Only for the second type x firm were participants significantly more likely to select such a price in the NS^+ than the NS (100 percent versus 68.4 percent, $p = 0.01$; $p > 0.5$ for all other firms).

However, within the bolded range the maximum nominal income that could be earned from a price had some effect on the frequency with which participants chose it. Figure 2 displays a histogram of all prices that were chosen within the bolded range in the post-shock period of the NS and NS^+. For ease of comparison the prices have been normalized by subtracting out the equilibrium price (and multiplying by negative one in the NS^+). The distributions are virtually identical for normalized prices of one through eight. In both treatments these corresponded with price rows in the middle of the income tables with rather moderate nominal incomes. Using Mann-Whitney tests for each of the four firms in this price range we find no significant differences between treatments ($p > 0.6$ in all cases).

There is an asymmetry between treatments for normalized prices less than one. These were the prices for which the nominal incomes were lowest in the NS and highest in the NS^+. Mann-Whitney tests for the first and second type *y* firms controlled by each participant show significant differences across treatments in this normalized price range ($p = 0.035$ and $p = 0.021$ respectively). Tests for both type *x* firms fall somewhat short of statistical significance ($p = 0.105$ and $p = 0.069$).

These results imply that second order money illusion may have a modest effect on nominal inertia. Participants primarily restricted their prices to those that could generate a maximum real payoff, but within this range they shied away from extremely low nominal payoffs and were somewhat attracted to extremely high nominal payoffs.

C. *Coordination with Human Opponents Under the Real and Nominal Frames*

Before considering the level of prices across treatments with human opponents we tested whether the adjustment dynamics in our experiments can be well described by participants following the ABR strategy. About 7 percent of participants (9 of 124) anchored on their equilibrium prices, choosing them repeatedly even when it was not the ABR to do so. Statistical analysis (described in Section 2 of online Appendix A) indicates that the remaining 93 percent of participants chose their ABR prices in the post-shock phase in all three of these treatments.[9]

[9] Note that this implies that most or all participants failed to account for the fact that their opponents would also be playing their ABR. Underestimating the sophistication of one's counterparts is commonplace in normal form games (see, e.g., Costa-Gomes and Crawford, 2006 and Crawford, Gneezy and Rottenstreich, 2008), and in our experiments the cost of naïvely adaptive expectations was low. When all firms in a group played the ABR, the

Therefore, we may conclude that neither first order nor second order money illusion affected the rate of price adjustment after period T+1 in the post-shock phase of the NH and NH^+.[10]

We have advanced the hypothesis that the pattern of maximum payoffs in the real income space gave the equilibrium prices salience, making them focal points for coordination in FT's experiments. Marking the maximum payoffs in bold red font should heighten the salience of the equilibrium prices in our experiments relative to theirs by making the pattern apparent to the participants under a nominal frame and perhaps even more obvious to those under a real frame. We find that adjustment is improved in our experiments relative to the original design.

Figure 3 shows the average deviation from the equilibrium price in the RH, NH and NH^+ treatments (multiplied by -1 in the latter case). The data indicate that there was a very small but statistically significant amount of nominal inertia in our RH treatment. 61 percent of participants chose their equilibrium price in the first post-shock period, and 89 percent chose a price within two price increments of the equilibrium. The average deviation from the post-shock equilibrium price was 1.2 increments in period T+1 (see Table 5). This is significant at the 1 percent level, but the deviation is very small. Recall that the equilibrium average price fell by 12 increments between periods T and T+1. A deviation of 1.2 increments means that participants lowered their prices by 10.8 increments on average, or 90 percent of the necessary adjustment.

The ABR pricing strategy quickly led participants to the equilibrium in the subsequent periods. By period T+2 the participants had lowered their prices by 95 percent of the necessary adjustment. The average price deviated by only 0.6 increments from the equilibrium on average ($p < 0.05$). After period T+2 the average price deviation was not significant, and after period T+4 *every* price that was submitted was equal to the equilibrium.

Heightening the salience of the focal point improved adjustment in our RH compared to FT's RH treatment, which had an average deviation of 3.1 in period T+1. In four of the first five

average price typically fell by one increment per period. Best responding to an expected average price of $\bar{P}^e_{-i}$ when the actual average price was $\bar{P}^e_{-i} - 1$ would never cost a firm more than \$0.10.

[10] In one NH session and two NH^+ sessions high random prices were chosen in period T+1 due to participants failing to set their prices before the time limit elapsed. These random prices affected adjustment in all subsequent periods through ABR dynamics. We exclude the data from these sessions because including them makes price adjustment in the NH^+ more similar to that of the NH, biasing the analysis in favor of our initial hypotheses.

post-shock periods the deviation was significantly smaller in our RH than in FT's (Mann-Whitney tests, $p < 0.02$ in periods T+1 and T+3 through T+5).

In our NH treatment the average deviation from the new equilibrium price was 5.6 ($p < 0.01$) in the first post-shock period, almost five times the deviation in the same period of the RH.[11] Because the initial price adjustment was less complete in the NH, participants took significantly longer to reach the equilibrium using the ABR strategy. The average price deviation is significant in the first seven post-shock periods (see Table 5). Moreover, Mann Whitney tests using $\bar{P}_{it} - \bar{P}_t^*$ as the unit of observation show the average deviation to be higher in the NH than the RH at the 5 percent level in the same seven periods.

These results imply a somewhat weaker effect of the focal point under a nominal frame. The average price in period T+1 of FT's NH treatment was 7.1 increments above equilibrium, which is not significantly different than period T+1 of our NH (Mann-Whitney test, $p = 0.231$). However, their prices remained out of equilibrium for 12 periods. Our focal points did not significantly reduce the magnitude of nominal inertia, but did reduce its duration by 42 percent.

The asymmetry in nominal inertia between positive and negative monetary shocks persisted in our human opponent treatments. We find only the first three post-shock average prices to be significantly below the equilibrium in the NH^+ using Wilcoxon signed rank tests ($p < 0.02$ in each case). To compare decisions across monetary shock types we normalize the price deviation data from the NH^+ to $-(\bar{P}_{it} - \bar{P}_t^*)$. Using Mann-Whitney tests we find no differences between the RH and NH^+ price deviations that are significant at the 5 percent level in any of the post-shock periods. However, we *do* find that in five of the first seven post-shock periods the price deviations are significantly different between the NH and NH^+. In the remaining two periods (T+2 and T+3) the differences are marginally significant ($p < 0.08$ in each case).

[11] There is some evidence that type *y* firms in the nominal frame adjusted faster than type *x* firms. In period T+1 of our NH, the average prices of type *x* and type *y* firms were 7.5 increments and 3.9 increments above equilibrium respectively. In period T+1 of our NH^+ type *x* and type *y* firms set prices 4 increments and 3.3 increments below equilibrium, respectively. This asymmetry may be caused by participants preferring to set their prices near the middle of the income tables. The equilibrium prices are more extreme for type *x* firms (3 in the NH, 28 in the NH^+) than for type y firms (9 in the NH, 22 in the NH^+). However, using Mann-Whitney tests we find that the differences in distributions across firm types are only marginally significant in the NH ($p = 0.085$) and insignificant in the NH+ ($p = 0.222$). We find a significant difference only if we pool the data across the two treatments ($p = 0.042$).

Notice that the pattern of nominal inertia in our RH, NH and NH^+ treatments is similar to the pattern found by FT, though smaller in magnitude and/or duration. However, this is completely explained by the cognitive load of finding the NE and second order money illusion at the individual level. We compare $\bar{P}_i - \bar{P}^*$ in the first post-shock period of our human opponent and self-opponent treatments with Mann-Whitney tests. (Notice that i indexes a group of four participants in the human opponent treatments and a single participant in the self-opponent treatments.) The comparisons of RH versus RS, NH versus NS and NH^+ versus NS^+ are all statistically insignificant at the 5 percent level ($p = 0.194$, $p = 0.129$ and $p = 0.268$ respectively). Consequently, we find no strategic effect of second order money illusion in our experiments.

III. Summary and Discussion

Our experiments refine and extend the work of FT, who suggest that money illusion can contribute significantly to nominal inertia in strategically complementary environments. By controlling for strategic uncertainty, visual focal points and cognitive load we find that participants exhibit no first order money illusion, though second order money illusion plays a minor role. The presence of a focal point in our experiments reduces the duration of price stickiness compared to FT's original experiments when participants played against one another. What stickiness remains is explained by the difficulty of finding the NE among 1800 payoffs. Second order money illusion appears to explain the persistent asymmetry between price adjustment following positive and negative monetary shocks. However, this is a modest effect manifested in an apparent preference for (aversion to) high (low) nominal payoffs within a set of maximum real payoffs. These findings indicate that FT's proposed form of money illusion is not a compelling explanation for sluggish price adjustment.

Moreover, we have demonstrated that adjustment after the first post-shock period was driven primarily by the firms adaptively best responding to one another's pricing decisions. This was true in all of our experiments with human opponents as well as FT's, regardless of whether payoffs were framed in real or nominal terms. We should note, however, that in all of our experiments (and FT's) the real best response to one's opponents was always the nominal best response as well. It may be that money illusion plays a role in price adjustment if and when the real and nominal best responses diverge. Further research on this point is warranted.

Assuming validity outside the laboratory, our strong findings of ABR has implications for both theoretical and empirical work. At the theoretical level, it suggests that incorporating adaptive expectations and best reply behavior into mathematical models is an empirically valid means of generating significant persistence from shocks and out-of-equilibrium dynamics. At the empirical level it implies that monetary shocks may have real effects due to second order money illusion and the cognitive load of finding the equilibrium. However, the duration of disequilibrium behavior following an economic shock (monetary or otherwise) will depend crucially on the best response functions of the affected agents. Consequently, the magnitude of the real effects will be primarily due to agents' best response functions, not to bounded rationality.

The price-setting behavior of firms is crucial to an economy's reaction to monetary policy. Policy rules that are optimal in forward-looking models can result in detrimental outcomes in environments with backward-looking models (Levin and Williams, 2003). For example, Blinder (1987) and Ball (1994) argue that credible disinflation policies can lead to straightforward adjustment in prices when firms are forward-looking, but lead to costly output losses when they are backward-looking. Our finding that firms set prices adaptively suggests that optimal policies designed for standard forward-looking environments may not be appropriate. Moreover, the real effects from monetary policy will persist longer in environments with adaptively responding firms.

Finally, our results serve as a reminder that subtle details of an experimental design may strongly affect participants' behavior and our perceptions of it. The nominal mapping function, best response functions and visual patterns of payoffs were all critically important in generating and assessing the sources of sticky prices. Additional features, such as the number of available strategies, may play an important role as well. The effects of nominal framing in both our paper and FT's may have been significantly reduced had participants' strategy space been condensed. Further experiments studying the effect of cognitive overload on nominal price adjustment can shed additional light on this.

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Tables

Table 1. Real and Nominal Incomes in the Post-Shock Phase of FT's NC Treatment and our revised version.

	Type *x* Firms			Type *y* Firms		
Price	Real Income (π_i)	Original Nominal Income ($\bar{P}_{-i}\pi_i$)	Revised Nominal Income ($\bar{P}_{-i}(\pi_i + \bar{P}_{-i})$)	Real Income (π_i)	Original Nominal Income ($\bar{P}_{-i}\pi_i$)	Revised Nominal Income ($\bar{P}_{-i}(\pi_i + \bar{P}_{-i})$)
1	26	181	230	5	16	25
2	35	246	295	7	21	30
3^x	**40**	**280**	329	9	28	37
4	35	246	295	13	39	48
5	26	181	230	14	56	72
6	18	125	174	20	81	97
7	12	87	136	26	129	154
8	10	80	144	35	176	201
9^y	9	84	165	**40**	**200**	225
10	9	91	191	35	176	201
11	9	99	220	26	129	154
12	9	107	251	18	89	114
13	9	114	283	12	62	87
14	9	122	318	10	60	96
15	9	130	355	9	66	115
16	9	137	393	9	73	137
17	9	145	434	9	81	162
18	8	152	476	9	89	189
19	8	159	520	9	97	218
20	8	167	567	9	105	249
21	8	174	615	9	112	281
22	8	181	665	9	120	316
23	8	188	717	9	128	353
24	8	195	771	8	135	391
25	8	202	827	8	143	432
26	8	209	885	8	150	474
27	8	216	**945**	8	157	518
28	8	223	890	8	164	564
29	6	166	853	8	171	612
30	5	128	827	8	179	**663**

x indicates the equilibrium price for type *x* firms
y indicates the equilibrium price for type *y* firms
Bold, underlined entries represent the highest income (real or nominal) for a given firm type.

Table 2. Real Payoff Tables for Pre-shock and Post-shock Phases in FT's Experiments with a Negative Monetary Shock. Left-hand column contains the firm's own price, top row contains the average price of other firms in the same group.

Pre-Shock Payoff Table								
	18	**19**	**20**	**21**[b]	**22**	**23**	**24**	**25**
7	39	38	38	38	38	37	35	33
8	40	40	39	39	39	39	38	36
9[a]	39	40	40	40	40	40	39	38
10	38	39	39	39	39	40	40	40
11	35	37	38	38	38	38	39	40
12	32	34	35	35	35	36	38	39
Post-Shock Payoff Table								
	4	**5**	**6**	**7**[b]	**8**	**9**	**10**	**11**
1	40	36	29	26	23	17	12	9
2	34	40	38	35	32	25	17	12
3[a]	25	34	39	40	39	34	25	18
4	17	25	32	35	38	40	34	25
5	12	17	23	26	29	36	40	35
6	9	12	16	18	20	27	36	40

a indicates the firm's equilibrium price
b indicates the average equilibrium price of the other three firms

Table 3. Nominal Payoff Tables for Pre-shock and Post-shock Phases in FT's Experiments with a Negative Monetary Shock. Left-hand column contains the firm's own price, top row contains the average price of other firms in the same group.

Pre-Shock Payoff Table								
	18	**19**	**20**	**21**[b]	**22**	**23**	**24**	**25**
7	1032	1092	1157	1233	1310	1374	1420	1450
8	1044	1117	1189	1268	1349	1422	1481	1523
9[a]	1033	1119	1200	1281	1364	1447	1522	1581
10	1003	1099	1186	1268	1352	1444	1536	1616
11	957	1059	1151	1233	1316	1414	1521	1623
12	903	1006	1099	1179	1262	1363	1479	1600
Post-Shock Payoff Table								
	4	**5**	**6**	**7**[b]	**8**	**9**	**10**	**11**
1	175	206	209	230	247	234	222	219
2	154	224	262	295	321	302	274	256
3[a]	116	194	272	329	379	386	351	314
4	86	148	229	295	365	439	445	400
5	65	110	173	230	295	407	498	503
6	175	206	209	230	247	234	222	219

a indicates the firm's equilibrium price
b indicates the average equilibrium price of the other three firms

Table 4. Experimental Design Parameters

Panel A: Universal Parameters

Representation of payoffs in real frame	π_i
Representation of payoffs in nominal frame	$\boldsymbol{\bar{P}_{-i}(\bar{P}_{-i}\pi_i)}$
Group size	$n = 4$
End of period informational feedback	$\bar{P}_{-i}\,,\ \pi_i$
Real equilibrium payoff	40
Choice variable	$\boldsymbol{P_i \in \{1, 2, \ldots, 30\}}$
Number of periods pre- and post-shock in computerized treatments	T = 10
Number of periods pre- and post-shock in human treatments	T = 15

Panel B: Phase-Specific Parameters

	Negative Shock		*Positive Shock*	
Phase	Pre-Shock	Post-Shock	Pre-Shock	Post-Shock
Money Supply	42	14	--	--
Average equilibrium price, $\bar{P}^*$, for the entire group	18	6	13	25
Equilibrium price, P_i^*, for type *x*	9	3	22	28
Equilibrium price, P_i^*, for type *y*	27	9	4	22

Panel C: Data Summary for Revised Experiments by Treatment

Monetary Shock	*Payoff Framing*	*Opponents*	*Treatment Name*	*Participants*
Negative	Real	Computer	RC	24
Negative	Real	Human	RH	36
Negative	Real	Self	RS	15
Negative	Nominal	Computer	NC	24
Negative	Nominal	Human	NH	44
Negative	Nominal	Self	NS	19
Positive	Nominal	Human	NH^+	44
Positive	Nominal	Self	NS^+	19
			Total	**225**

Table 5. Average Deviation of Prices from the Equilibrium in the Post-Shock Phase. Reported Significance Levels are from Wilcoxon Signed-Rank Tests Using Group-Level Deviation as the Unit of Analysis.

	Negative Shock				**Positive Shock**
	Computerized Opponents		Human Opponents		Human Opponents
Period	Real (RC_R)	Nominal (NC_R)	Real (RH_R)	Nominal (NH_R)	Nominal (NH_R^+)
T+1	-0.4	0.8	1.2**	5.6**	-2.6**
T+2	0.7	0.0	0.6*	3.8**	-1.2*
T+3	-0.2	-0.2	0.3	4.2**	-0.6*
T+4	0.7	0.0	0.1	3.4**	-0.2
T+5	0.4	0.0	0.0	2.6*	-0.1
T+6	0.0	0.0	0.0	2.0*	0.0
T+7	0.7	0.0	0.0	1.4*	0.0
T+8	0.0	0.0	0.0	1.1	0.0
T+9	0.8	0.0	0.0	0.8	0.0
T+10	0.5	0.0	0.0	0.6	0.0
T+11			0.0	0.4	0.0
T+12			0.0	0.2	0.0
T+13			0.0	0.2	0.0
T+14			0.0	0.2	0.0
T+15			0.0	0.1	-0.8

* indicates significance at the 5 percent level
** indicates significance at the 1 percent level

Figures

Figure 1. Cumulative Density Functions of the Deviations of Average Prices from the Equilibrium in Sessions in Which Each Participant Chose All Four Firms' Prices. The Deviations Have Been Multiplied by -1 in the NS^{+} to allow direct comparison.

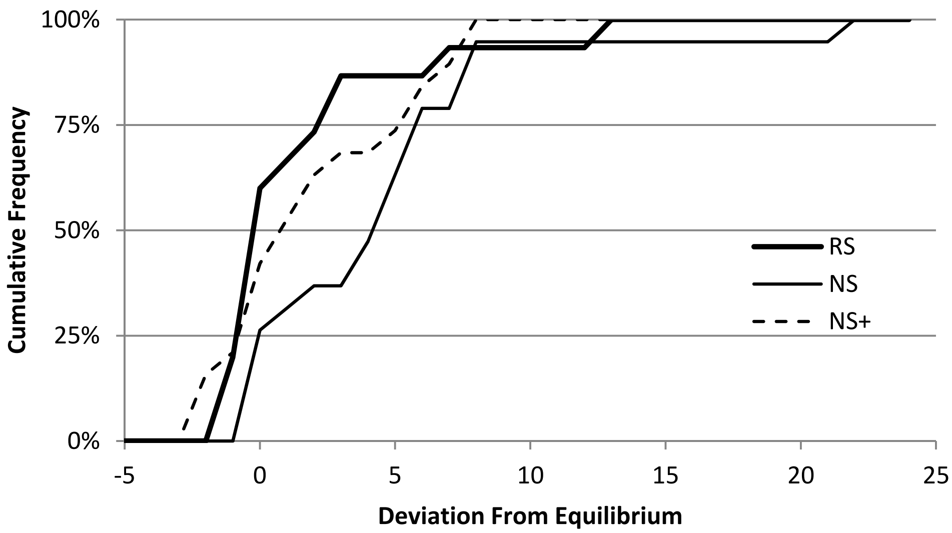

Figure 2. Histogram of the deviations from the equilibrium prices in the post-shock phase of the NS and NS+ treatments within the range of prices that contained a bolded payoff. The deviations have been multiplied by negative one in the NS+ to allow direct comparison.

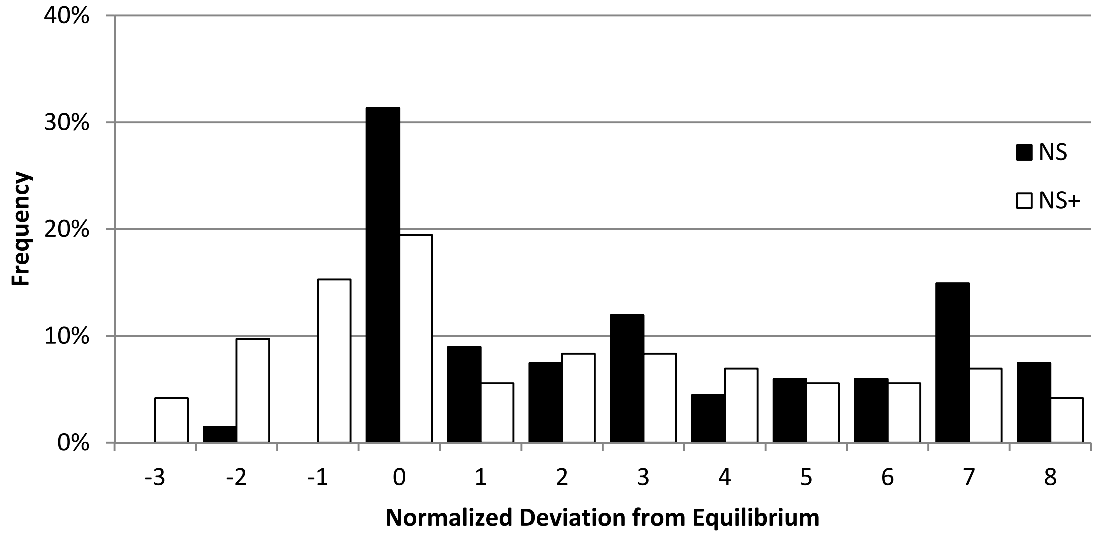

Figure 3. Evolution of Average Price Deviations from Equilibrium in Experiments with Human Opponents. Deviations in the NH+ have been multiplied by -1 to allow direct comparison.