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Experimental Macroeconomics: Essays on Partial and General Equilibrium Dynamics in Laboratory Economies

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EXPERIMENTAL MACROECONOMICS:

ESSAYS ON PARTIAL AND GENERAL EQUILIBRIUM DYNAMICS IN LABORATORY ECONOMIES

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in

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by

Luba Petersen

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The Dissertation of Luba Petersen
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Abstract

Experimental Macroeconomics: Essays on Partial and General Equilibrium Dynamics in Laboratory Economies

By Luba Petersen

This study explores how macroeconomic questions can be studied in laboratory settings. A novel experimental methodology is proposed and implemented to study how partial and general equilibrium economies respond to stochastic productivity and monetary shocks under various conditions. Following the DSGE approach, subjects interact over numerous periods to converge to a steady state, then are shocked with temporary or permanent shocks. Their responses to the shocks are compared with theoretical impulse responses. Findings indicate that subjects experience considerable difficulty converging to the efficient competitive equilibrium in economies where money is present. There is a high degree of heterogeneity in how individuals react to monetary shocks and form expectations. Elicited expectations are highly adaptive but are converging in the direction of rationality over extensive stationary repetition. We fail to find evidence in both partial and general equilibrium settings that subjects exhibit money illusion.

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Abel Winn coauthored Chapter 4 of this dissertation. He has been a fantastic collaborater and I have immensely enjoyed working with him on our money illusion research.

The University of California Santa Cruz provided me with a stellar academic environment and the financial support necessary to complete my graduate studies. I have had the opportunity to learn from brilliant researchers in macroeconomics, international economics, and experimental economics.

To that end, Ryan Oprea, Carl Walsh, and my advisor Dan Friedman deserve my utmost gratitude. They were a dream committee! They allowed me the freedom to adventurously pursue research in experimental macroeconomics. Ryan kept me on the right track. I learned from him the importance of good experimental design and presentation. His guidance and support through the job market season was incomparable, and I am so fortunate to have Ryan as an academic role model.

Carl was always positive and receptive to my experimental ideas, not once making me feel like I was off my rocker! He provided essential theoretical guidance while I was devising the New Keynesian framework for my experimental economies. I greatly appreciate how welcoming his macroeconomics workshop was to my experimental interests. In short, his advice and open-mindedness made this research experience a delight!

Dan gave me the time and resources to focus on my research. He identified the risks and challenges associated with my research but encouraged me to see it through. I am deeply indebted to him for all his feedback, careful reading on countless manuscripts, and his overall enthusiasm throughout my dissertation years. All his wisdom, direction, and guidance have been instrumental in refining my skills as an experimental economist.

Finally, I appreciate the generous financial support from the University of California Santa Cruz, Chapman University, and the Sury Intiative for Global Finance and International Risk Management that funded parts of the research in this dissertation.

Chapter 1

Introduction

Modern macroeconomic models extensively used today are equilibrium-centric: their focus is on identifying and characterizing equilibria rather than on how individuals and markets arrive at equilibrium. The rational expectations revolution played a significant role in the discipline's move to equilibrium modeling and the rejection of adaptive expectation models. While this enabled theory to satisfy the Lucas Critique, it forced theorists to assume nearly perfect information and usage of that information on the part of agents. Such an assumption may be valid in some contexts and less so in others. This assumption has been predominantly applied for at least two reasons. First, the structure of adaptive expectations is often ad-hoc, without solid micro-foundations for why systematic errors are formed in the ways modeled. And second, it is not clear under which markets and scenarios adaptive expectations would better describe agent behavior.

This is where laboratory experiments can play an essential role. In the real world, central banks and governments cannot engage in policy experiments for the sake of academic inquiry. It is nearly impossible to create a controlled macro-environment. Partial equilibrium and DSGE modeling provides theorists and policy makers with the ability to 'experiment' under rather strict behavioral and market assumptions. Laboratory experiments provide a synthesis of theoretical and real world experimentation. As the experimenter, I am able to specify the market structures, timing and nature of economic shocks. Four additional degrees of freedom are available in laboratory experiments: individual decision-making, heterogeneity, multiple agents, and disequilibrium dynamics. Subjects are free to make potentially suboptimal decisions subject to a binding budget constraint. Subjects, though induced with a set of preference, bring their own indigenous preferences into the lab. The aggregation assumptions needed to generate a representative agent become unnecessary and multiple agents can interact together. Finally, the lab provides an ideal environment to study the adjustment processes that are critical in market and economy-wide responses to exogeneous innovations.

Laboratory findings provide micro-founded guidance on how to implement these features in theoretical models. It also allows us to run a battery test of competing models to see which best describe agent behavior and market dynamics. Moreover, the findings aid theorists in equilibrium selection, an issue that has recently arisen in macroeconomics with the presence of the zero lower bound.

My research has been funded by the Sury Initiative for Global Finance and International Risk Management (SIGFIRM), Chapman University, and the University of California Santa Cruz. To date, I have been working with discrete time environments programmed in zTree, a free and widely used experimental economics software.

This dissertation begins with a study of the role of money within a general equilibrium economy. In "Does Money Matter? Experimental General Equilibrium Dynamics in Cash and Cashless Economies", I construct a general equilibrium environment to evaluate whether dynamics differ in the presence of money. The design of markets and preference inducements are such that the presence of money should be irrelevant. Following the dynamic stochastic general equilibrium approach employed in the RBC and New Keynesian macroeconomic literature, I then apply a stochastic productivity shock to the economy and observe how the decisions of interdependent agents and the dynamic paths of aggregate variables are affected. Experimental findings match the theoretical predictions of cashless economies rather well. When money and sequential markets are introduced into the experimental environment, real wages, consumption, and efficiency are substantially less than their equilibrium values. The presence of money adds a significant adjustment friction and its own set of dynamics.

Chapter 2, "Nonneutrality of Money, Preferences and Expectations in Laboratory New Keynesian Economies", studies the impact of an unanticipated expansionary monetary shock on agents' behavior and expectations within an expanded general equilibrium setting. Employing a 2x2 design, I automate individual sides of the market as well as study behavior in a fully human economy. Expansionary policy occurs through a decrease in the nominal interest rate that immediately adjusts the nominal wage rate according to equilibrium predictions. Experimental findings indicate significant heterogeneity in output reactions and preferences. While subjects do respond significantly to the nominal interest rate shock, it is often not in the direction predicted. Output responses most closely match theoretical predictions in the human firm (automated household) treatment. Individual household behavior and realized preferences significantly differ from predicted values. Households' persistent oversupply of labor and under-consumption is attributed to debt aversion. Labor supply and consumption are significantly inelastic to the real wage and real interest rate respectively. Subjects form expectations adaptively, relying heavily on past variables and forecasts in forming two-steps-ahead forecasts, but despite numerous repetitions, exhibit significant difficulty forming expectations on impact of the shock and thereafter.

In more behaviorally driven work, I study the effect money illusion has on nominal price adjustment. Money illusion, the mistaking of nominal values of real values, is one of many explanations for asymmetries in price stickiness. Fehr and Tyran (2001) have advanced the hypothesis that even a small amount of money illusion among a minority of agents can lead to significant price inertia in the face of a fully anticipated negative shock. Their experimental results have been widely cited as evidence of money illusion and served as the motivation of theoretical and empirical work incorporating such irrational behavior. (eg. Yellen and Akerloff, 2006; Brunnermeier and Julliard, 2010; Basak and Yan, 2010) Through a series of partial equilibrium experiments discussed in Chapter 4, Abel Winn and I investigate whether money illusion on the part of price-setting firms does indeed generates substantial nominal inertia. Building on the design of Fehr and Tyran, we find no evidence that agents choose high nominal payoffs over high real payoffs. Rather, 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 while money illusion exerts only a second-order effect. Moreover, the duration of nominal inertia depends not on the presence of money illusion but on participants' best response functions.

Chapter 2

Money Matters: Experimental General Equilibrium Dynamics in Cash and Cashless Economies

2.1 Introduction

How does an economy react to a stochastic shock? Modern macroeconomics, namely the dynamic stochastic general equilibrium literature, has attempted to answer this question under countless environments for decades. Answering such questions accurately is crucial for determining optimal monetary and fiscal policies. These models typically rely on strong microfounded behavioral assumptions - rational expectations, consumption smoothing, and exponential discounting - within a representative-agent framework. How can an economy populated with potentially-boundedly rational, heterogeneous individuals ever match the theoretical predictions proposed by these models?

I compare and contrast the behavior of simplified cashless and cash-in-advance general equilibrium laboratory environments in response to permanent and temporary productivity shocks. The cashless economy most resembles an RBC economy with labor as the sole factor of production. The cash-in-advance economy adds sequential markets where the labor market operates before the goods market. Cash is used as a medium of exchange. In short, I demonstrate the ability of experimental production economies to match the theoretical predictions of three dynamic stochastic general equilibrium (DSGE) models. After having time to equilibrate, the cashless economy is subjected to either a permanent increase or a temporary decrease in labor productivity. In the cash-in-advance economy, the shock is a temporary decrease in productivity.

Do markets converge to the theoretical predictions of each model? Yes, but it takes more time than predicted. Convergence and economic efficiency are significantly worse when cash is used as a medium of exchange.

This paper is the first to explore an experimental DSGE environment. Production GE experiments, such as those conducted by Bosch-Domenech and Silvestre (1997), Lian and Plott (1998), and Noussair et al. (2007), demonstrate the ability of such laboratory environments to converge to their equilibrium predictions. These environments typically involve different types of agents (primarily consumer-workers and firms, but sometimes governments) and multiple markets (goods and labor) in both closed and open economy settings. Simultaneous, cash-in-advance markets are implemented using computerized double auctions and induced values and costs. [1] In a standard DSGE simulation, changes in policy variables or parameters occur within a single treatment, capturing the individual reaction to changes in policy or eco-

[1]Though markets can operate simultaneously, the authors find that the labor market operates first so that wages can be earned and output can be produced before entering the goods market.

nomic disturbances after the economy has reached a steady state. Existing laboratory experiments have failed to explore these behavioral reactions. Rather, changes in experimental variables occur between treatments.[2]This paper addresses this gap in the literature by redesigning the way in which GE experiments are conducted. By allowing subjects to reach a steady state before shocking the economy, the impact of the shock on the time paths of relevant economic variables can be measured in a way that is comparable to the macroeconomic techniques currently used.

It bears emphasizing that the DSGE methodology was developed to serve as a laboratory in which theories could be tested. As exciting and informative as it would be, economists cannot induce real-world recession or fiddle with policy for the sake of academic inquiry. Not only would it lead to sure disaster, but it would also be confounded by past experience and policy. Computing capabilities, on the other hand, enable theorists to investigate the effects of a variety of policies or shocks on a macroeconomy without the aforementioned consequences. I build in two additional degrees of freedom through laboratory experimentation: individual decision-making and heterogeneity. Subjects are free to make potentially suboptimal decisions subject to a binding budget constraint. Subjects, though induced with a set of preference, bring their own indigenous preferences into the lab. These are elements that are particularly desirable in a model but challenging and adhoc to implement.

Like the representative agent framework in macroeconomics, I design a workhorse experimental methodology that can easily be implemented in most laboratories. The computerized experiment is programmed in zTree, a free and widely used experimental software. Markets are run using double auctions - a market mechanism well

[2]In Bosch-Domench and Silvestre (1997), credit levels change between rounds. In series 1 and 2 of Lian and Plott (1998), the constant money supply level changed between sessions. In series 3, money supply growth begain the first period and not from a point of equilibrium.

known to experimental economists. The experiments discussed in this paper can easily be replicated and extended to consider a variety of environments and shocks.

2.2 Experimental Design

Two environments are considered. The first is a cashless, one market economy where inputs are traded for a share of the output that they produce. The second is a money-facilitated, sequential market economy where inputs are traded in a labor market before its resulting output is traded in a goods markets. Neither environment allows subjects to hold inventories of inputs or outputs. Money, however, may be stored over time in bank accounts. Given the market design, the competitive equilibrium is identical across environments. A detailed derivation of each competitive equilibrium can be found in Section 2.7.

Each market is organized through a computerized multi-unit double auction, a standard mechanism in market experiments and in the experimental macroeconomic literature.[3] Laboratory double auctions provide the quickest convergence to the competitive equilibrium. Table 1 details the actual functional forms and experimental parameters used in the RBC and money treatments.

Environment I: RBC

The RBC environment is reminiscent of the classic RBC framework with labor as the sole input. There are two types of agents: worker-consumer (henceforth workers) and firms. Workers are endowed with units of labor for which they receive no utility

[3]Other market structures such as posted offer, call, and bargaining markets may be interesting alternatives to explore. In particular, posted offer markets are realistic yet, to this author's knowledge, seldomly explored in the macroeconomic literature.

Table 2.1: Experimental Parameters

Parameter	Type	Environment I: RBC	Environment II: Money
Preferences:			
	Households	U_t=$9ln(c_t) - 0.5N_t^2$	U_t=$4ln(c_t) - 0.5N_t^2$
	Firms	Π_t=0.5($Y_{produced}$-Y_{paid})+$I_{N>0}$	Π_t=$P_tY_t^D$-W_tN_t+$I_{Y>0}$
Endowments:			
	Households	L=5, Y=0, M= 0	L=5, Y=0, M=50
	Firms	L=0, Y=0, M=0	L=0, Y=0, M=50
Market Size:			
	Households	4	4
	Firms	4	4
Production:			
		Y=3L	Y=3L
		Y=5L	Y=5L

from. They face positive but diminishing marginal utility from acquiring units of the output good and increasing marginal disutility from working. Firms face a constant returns to scale technology.

There is a single market in which households trade their endowment of labor to firms in exchange for a share of output that they themselves produced. Preferences are induced for both subjects. Household subjects receive lab points for their net utility. Firm subjects receive lab points for profits earned. In a competitive equilibrium, firms earn zero profits. As this may discourage firms from playing competitively, each earns points for hiring at least one worker in a given period. Firms are further incentivized to pay as little output as possible to workers in exchange for their labor. Firms earn points for each unit of output that is kept for their own consumption. Neither type of subject has a value for labor other than as an input.

Environment I differs from the traditional RBC framework in that households do not have a mechanism in which to smooth consumption. Unlike the traditional RBC model, households do not maintain a stock of capital that can be carried forward between periods.

Environment II: Money

Environment II introduces two modifications. First, households and firms interact in sequential markets. At the beginning of each period, households sell their labor to firms in exchange for a nominal wage. After the labor market closes, the goods market opens. Firms sell their produced output to households in exchange for a nominal price. The sequential markets, by construction, require the introduction of money to act as a medium of exchange. Households may now hold money balances between periods, as in the traditional cash-in-advance and New Keynesian models.

The structure of inducements changes for the firm. Firms still seek to maximize profits but they do so by paying a lesser wage for labor and charging a higher price for their output. Again, to encourage competitive behavior, firms earn lab points for selling at least one unit of output. Workers still seek to maximize their net utility.

At the very beginning of each game, firms are endowed with money balances that they can use to purchase labor. Households must sell their labor in order to have money to make purchases. If a household does not spend all of its earnings, it can carry the money forward for future purchases. No interest is paid on money balances.

2.3 Experimental Procedures

5 sessions were conducted at the University of California Santa Cruz LEEPS lab. For each session 8 inexperienced subjects and up to 6 extras were recruited from a pool of undergraduate students using an online recruitment software. The subject pool included students from a variety of majors and participation was purely voluntary. Each subject participated in only one treatment.

Sessions lasted between 1.5 and 2 hours, including time spent on instructions.

In all but Sessions 1 and 2, subjects began the session by completing a Holt and Laury (2002) low-stakes risk assessment test. The safe lottery A paid either $2 or 1.60, while the risky lottery B paid either $3.85 or $0.10 The purpose was to determine whether risk aversion influenced subjects' behavior. Subjects were informed that a random decision from the test would be selected at the end of the session and would be played out. Earnings would be paid to them in cash (ie. the earnings were not converted according to a lab exchange rate). This test can be found in the supplementary materials provided in Chapter 5. After completing the risk assessment, subjects began the second phase of the experiment. Subjects were randomly assigned the role of either worker or firm for the duration of the session. They were trained to make decisions according to their inducements and to use the auction software. The software was designed using zTree (Fischbacher, 2007). They were walked through instructions and a video tutorial of how the software worked. In addition to a paper worksheet of worker values and costs, subjects also had access to a computerized spreadsheet that would calculate earnings in the RBC treatments. In the money treatments, the computer interface was modified so that workers could see how many points they would lose from selling the next 1 and 2 hours of labor and would gain from buying the next 1 and 2 units of output. This was introduced to make earnings more salient. Following the instructions and video tutorial, subjects completed quizzes to ensure that they understood how the experiment worked. Subjects in the money treatments also participated in a 1-period practice period that lasted for double the length. Instructions, spreadsheets, and screenshots can be found in Chapter 5 - Supplementary Materials.

Rather than using the traditionally neutral frame of "X" and "Y", markets are framed realistically: "labor market" and "goods market". Workers work a number of hours collecting fruit. In the RBC environment, households are paid a fraction of fruit that they themselves collected. In the money environment, households work hours in exchange for a wage. They use these wages to purchase fruit in the goods market. Workers lose points by working more hours and gain points by consuming more fruit. Natural framing was used to further motivate subjects' inducements and to make the environment feel more realistic. Sessions consisted of repeated trading periods. To induce a quasi-infinite horizon environment, subjects were told that the experiment would last at least 30 periods (and 15 periods in Sessions 4 and 5), and would end after some specified time after that. A defined horizon was not used as there was the potential for subjects, especially in the money treatments, to backward induct and not hold excess money balances. An infinite horizon with a random stopping rule was not employed as it was undesirable to have sessions with differing lengths.

Subjects played the same environment repeatedly for numerous periods. The intention was to have them converge on some equilibrium. Each period, all subjects were informed on the screen the productivity levels of the households for the upcoming period. After an unannounced number of periods, a permanent or temporary productivity shock was imposed. Not only was this information displayed for subjects on their computer screen but it was also announced to all subjects before the next period began. Two levels of productivity were used, $Z = 3$ and $Z = 5$. Sessions 1-2 involved permanent productivity increases while Sessions 3-5 involved temporary productivity decreases. The number of periods, type of shock, and duration of shock for each session are given in Table 2.2.

In money treatments, each firm was endowed with 50 lab dollars to make purchases of labor in advance of sales. They were encouraged to take note of their money balances as they would not receive extra money should they run out. After hitting zero lab dollars, a firm would no longer be able to participate in the game. Fortunately, no firms ran out of money.

Market lengths in Sessions 4 and 5 (money treatments) were extended to allow for more transactions (60 and 170 seconds for labor and goods markets, respectively, rather than 30 and 60 seconds in the RBC treatments). It is possible that too many units of output had to be traded, and that this would be exhausting for subjects. The utility function of workers was modified so as to reduce the equilibrium labor supply, and subsequently, output in all phases of the experiment. Given laboratory time constraints, the extended market lengths implied fewer periods could be run. In the money sessions, the number of periods was reduced to 18. Increased learning within-period arguably compensates for fewer periods.

Subjects were paid for randomly selected periods. The purpose was to induce subjects (particularly workers) to maximize their per-period profits rather than strategize temporally. Workers, for example, would otherwise have the incentive to work for many periods without consuming only to consumption binge in a later period. This behavior is not in line with the theoretical design considered in the RBC and money treatments. In Session 1-3, earnings from two randomly selected periods were converted into U.S. Dollars and paid to subjects in cash. In Sessions 4 and 5 workers were paid based on two randomly selected periods while firms were paid based on five randomly selected periods. Subjects that participated in the risk assessment test were paid their earnings directly without a conversion rate.

2.4 Equilibrium Behavior and Predictions

The following section briefly describes the equilibrium behavior in each environment. Detailed derivations of the competitive equilibria are given in Section 2.7.

RBC Environment

Workers derive positive but diminishing marginal utility from acquiring units of the output good. They face increasing marginal disutility from working more hours. In the absence of money to inter-temporally smooth consumption, the worker's problem reduces to an intra-temporal tradeoff between the utility gained from consumption and the disutility incurred from work. The representative worker's optimal choice for labor and consumption are such that

$$N = \sqrt{\psi} \tag{2.1}$$

$$C = \sqrt{\psi}\frac{W}{P} = \sqrt{\psi}W \tag{2.2}$$

where P_t is normalized to 1.

Given this, the representative firm that hires this worker to work will be able to produce

$$Y^S = ZN = Z\sqrt{\psi} \tag{2.3}$$

In a competitive equilibrium, firms pay labor its marginal product, $W = Z$, in units of the output good and earn zero profits

$$\Pi = 0.5(ZN - ZN) = 0 \tag{2.4}$$

Table 2.2: Summary of Sessions

Session Number	Environment	Shock	Number of Periods	Period of Shock	Duration of Shock	Period Length
1	RBC	perm. increase	32	16	16	60
2	RBC	perm. increase	32	16	16	60
3	RBC	temp. decrease	40	16	5	60
4	Money	temp. decrease	18	6	3	60/170
5	Money	temp. decrease	18	6	3	60/170

All workers and all firms, respectively, face the same preference schedule. For four workers and four firms, the equilibrium economy-wide values are $N^* = 4\sqrt{\psi}$, $W^* = Z$, $Y^* = C^* = 4Z\sqrt{\psi}$, and $\Pi^* = 0$.

Money Environment

Worker and firm preferences are identical to those in the RBC environment. Workers and firms each possess bank accounts in which they can store money balances. Each firm is endowed with money in order to make advance purchases of labor. Money balances do not enter into either subject's utility functions. Firms seek to maximize profits while the objective of workers is to maximize net utility from consumption and labor. Money only serves as a required medium of exchange.

The worker's utility is increasing in the consumption of output, and so the worker is better off by purchasing an additional unit with remaining cash balances. In equilibrium, workers hold zero money balances at the end of the period. As such, the economy-wide equilibrium values remain the same when money is introduced into the environment.

Some workers may prefer to smooth their consumption over time in the face of a potentially risky environment. Such precautionary savers will hold positive money balances and not spend their entire wage earnings on output. This will result in losses for firms that are pricing competitively and unable to sell their output. This cannot be an equilibrium outcome. Firms may (1) hire fewer workers to depress the supply, (2) pay a lower wage for each hour worked, (3) charge a higher price for each unit sold, or (4) a combination of these three outcomes.

Table 2.3: Equilibrium Predictions

					PRESHOCK			SHOCK			POSTSHOCK[a]		
Session	Type	ψ	N^*	M^*	Z^b	C^*	Y^*	Z	C^*	Y^*	Z	C^*	Y^*
1	RBC	9	12		3	36	36				5	60	60
2	RBC	9	12		3	36	36				5	60	60
3	RBC	9	12		5	60	60	3	36	36	5	60	60
4	Money	4	6	0	5	40	40	3	24	24	5	40	40
5	Money	4	6	0	5	40	40	3	24	24	5	40	40

[a] Sessions 1 and 2 involved a permanent productivity increase. The initial shock is included.
[b] The marginal productivity of labor is also the real wage, $Z=\frac{W}{P}$

Testable Hypotheses

The following three hypotheses test the theoretical predictions discussed above.

Hypotheses 1. Market variables (labor supply, real wages, and efficiency) in the RBC permanent and temporary treatments match theoretical predictions.

Hypothesis 2. Market variables (labor supply, consumption, real wages, and efficiency) in the temporary money treatments match theoretical predictions.

Hypothesis 3. RBC and money environments behave identically in response to a temporary productivity shock.

2.5 Findings

The following section presents findings from the three treatments described earlier. Data is depicted both as time series plots and as per-period statistical deviations from predicted values. To determine whether a variable is significantly different from its equilibrium value, an OLS estimation strategy is used:

$$x_t - x_t^* = \sum_{t=1}^{T-1} \alpha_t d_t \tag{2.5}$$

where x_t denotes measure of the average real wage, aggregate labor supply, percentage of aggregate output sold, average household end-of-period bank balances, or efficiency, x_t^* is the respective equilibrium value, d_t denotes a dummy that takes the value of 1 in period t and 0 otherwise, and finally, $\hat{\alpha}_t$ is the estimated mean deviation from the steady state. The estimation results include robust standard errors.

RBC Environment

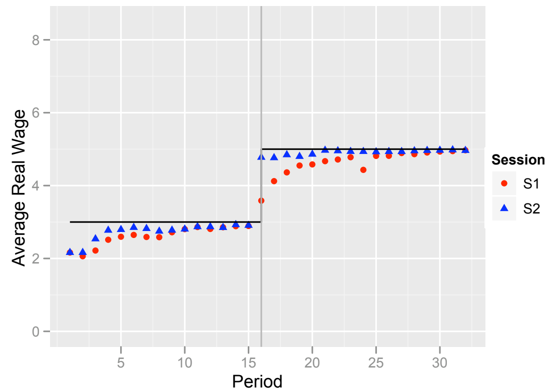
Permanent Productivity Increase

This section summarizes the results of the RBC economy with permanent productivity shocks.

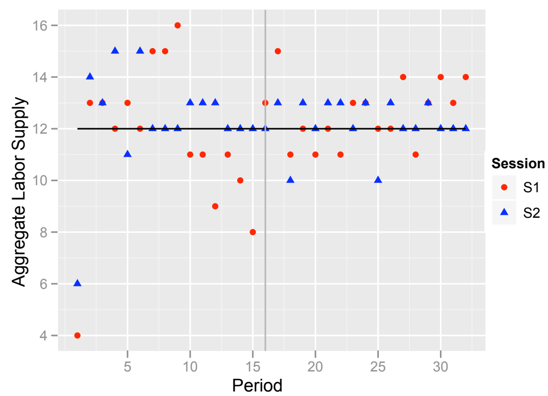
Figure 2.1 shows the evolution of real wages in Sessions 1 and 2. Fifteen periods of repetitive play where the worker productivity level is $Z = 3$ are followed by a permanent increase in productivity to $Z = 5$. Grey vertical lines indicate changes to productivity. Solid black lines indicate the competitive equilibrium values for real wages and aggregate labor supply. By the 15th period in both sessions, the average real wage has converged to the competitive equilibrium. Speeds of adjustment in response to the shock differ across sessions. In Session 1, there is greater sluggishness in real wage adjustment. It takes an additional 14 periods to converge to the new competitive equilibrium. Real wages in Session 2 reach the competitive equilibrium within 5 periods.

Finding 1. Laboratory markets reasonably match the theoretical predictions of the RBC environment with a permanent increase in productivity. The only significant difference is in real wage adjustment. In response to a permanent productivity shock,

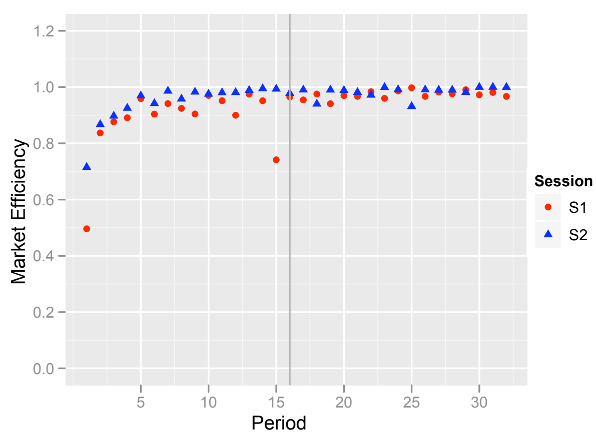
Figure 2.1: RBC with a Permanent Productivity Shock



(a) Average Real Wages



(b) Aggregate Labor Supply



(c) Market Efficiency

real wages do not adjust instantaneously but take a number of periods to reach the new equilibrium value.

Table 2.5 estimates for each period the deviations from equilibrium for variables of interest. Average real wages, aggregate labor supply, and efficiency converge to the preshock competitive equilibrium. They are not statistically different from their theoretical predictions by period 15. For most of the preshock phase, aggregate labor supply varies between 10 and 14 workers (+/- 2 hours of work for the entire market). This deviation is not significant. Average efficiency reaches as high as 98.2%.

Real wages do not immediately adjust to the new competitive equilibrium, $\frac{w}{p} = 5$, following the permanent increase in productivity. Average real wages are statistically different from their equilibrium values for 4 periods following the permanent productivity shock that occurs at period 16. Real wages are sluggish to adjust. This finding is driven mostly by Session 1 data. There, the percent-deviation of real wages from the equilibrium prediction increases from 3.6% in period 15 (preshock) to 28.2% in period 16 (postshock). Real wages do not reach their preshock percent-deviations until period 26. On the other hand, adjustment is much quicker in Session 2. The percent-deviation of real wages increases from 3.1% in period 15 to 4.5% in period 16, and returns to its preshock percent-deviations by period 18. Aggregate labor supply remains relatively constant around its equilibrium prediction and efficiency improves slightly following the shock.

Subjects converge to the post-shock competitive equilibrium. Average real wages, aggregate labor supply, and market efficiency are all insignificantly different from their equilibrium values. By period 32 of the permanent RBC sessions, the average real wage reaches a value of 4.96 while the aggregate labor supply is 12.5 (implying about half the workers are working one additional hour). Market efficiency is at 99%.

Finding 1 is not particularly surprising. The competitive and efficient nature of single-market double auctions is well established. One might expect a more equitable split of the surplus given the framing of the tasks. Workers collect fruit for the firms, and firms must pay a fraction of the fruit to the workers. Subjects with equity aversion might be reluctant to take a majority share of the surplus. Given that households face diminishing marginal utility from work and firms face a constant returns to scale technology in labor, excess demand for labor inevitably arises. This drives the real wage to the competitive equilibrium and leaves firms with no profits (other than the bonus 1 point that they receive for hiring a worker) and workers sharing the entire surplus.

Temporary Productivity Decrease

Given a permanent productivity increase in the RBC economy, the adjustment to the new competitive equilibrium is relatively simple. Subjects only have to adjust their real wages. It is highly plausible that the productivity announcement at the beginning of each period acts as a simplifying focal point for the equilibrium real wage. Moreover, all market participants welcome a positive productivity shock as the potential surplus has grown; there would be little resistance adjusting to it.

In the third session, a temporary decrease in productivity is imposed on the RBC economy. Productivity falls from a level of $Z = 5$ to $Z = 3$ during periods 6-8, and then returns to its original level. A decrease in productivity implies a decrease in the market surplus. The challenge will be how to split the remaining surplus between workers and firms. Of particular interest is how markets revert back to the original productivity level. Results from the temporary productivity shock can be found in

Figure 2.2 and Table 2.6. The evidence suggests that the additional complication does not have a significant effect on subjects' ability to converge to the competitive equilibria.

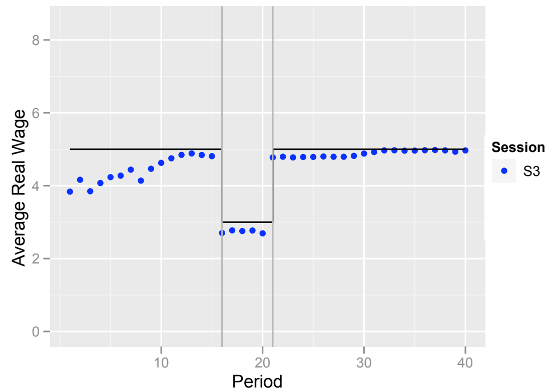
It is important to reiterate that only one session is explored in this treatment. As such, little can be said about the statistical significance of this section's results.

Finding 2. Laboratory markets reasonably match the theoretical predictions of the RBC environment with a temporary decrease in productivity. The only significant difference is in real wage adjustment. In response to a temporary productivity shock, real wages do not fully adjust to the temporary equilibrium, and upon returning to the preshock productivity level, real wages are very slow to adjust back to the original equilibrium. Aggregate labor supply remains mostly constant. The market reaches 100% efficiency.

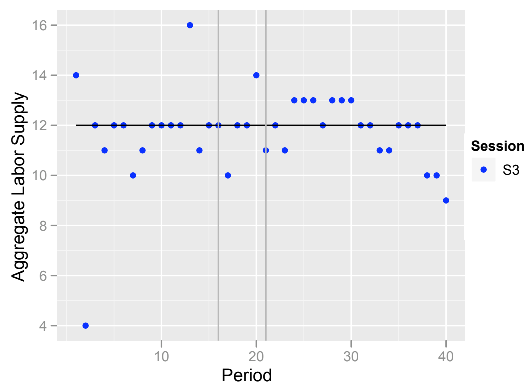
Preshock, market variables converge to their predicted values. This serves as a robustness check on Finding 1. As subjects did not know the type of shock that they were facing (permanent or temporary) until it occurred, the pre-shock phase in the temporary treatment is similar to that in the permanent treatment. Subjects were informed the shock was temporary or permanent when it hit the economy. The only difference is that, preshock, the productivity starts at a level of $Z = 5$ rather than $Z = 3$. Percent-deviation of real wages from equilibrium fall to under 10% by period 10 when $Z = 5$, and by period 9 when $Z = 3$., ie. there is little difference in real-wage evolution due to productivity levels. Aggregate labor converges to a value of $N^* = 8$ while efficiency is above 90% for 10 of the 16 preshock periods.

In response to a temporary decrease in productivity, real wages fall short of equilibrium values. Aggregate labor supply remains constant and market efficiency im-

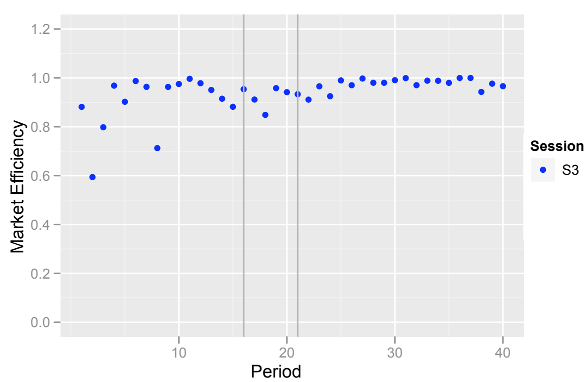
Figure 2.2: RBC with a Temporary Productivity Shock



(a) Real Wages



(b) Aggregate Labor Supply



(c) Market Efficiency

proves. Real wages fall below the new equilibrium of $\frac{w}{p} = 3$, to 2.70 in period 16. Wages remain depressed for the 5 periods of lowered productivity and reach a high (low) of 2.77 (2.69) in the 19th (20th) period. The OLS estimates in Table 2.5 interpret these results to not be statistically different from equilibrium. With such a small sample and an approximate 10 percent deviation from equilibrium real wages, it is difficult to accept these results. As predicted, aggregate labor supply does not change significantly in response to the productivity shock. Market efficiency also continues to increase throughout this temporary shock.

When productivity levels return to a level of $Z = 5$, average real wages are lower than before the negative shock. Postshock, real wages in period 21 (4.77) are lower than in the preshock periods 13 (4.88) and 15 (4.81) . Real wages fail to reach the 15th period preshock values until period 29. The temporary decline in productivity appears to lead to sluggish adjustment in real wages even after worker productivity levels return to normal. By period 31, real wage deviations are below 1%. Market efficiency reaches 100% by period 36.

Money Environment

Temporary Productivity Decrease

The final treatment explored is a temporary productivity decrease in the money environment. Each period is divided into two subperiods: a 60 second labor market followed by a 170 second goods market. As in the previous treatments, the equilibrium real wage is equal to the marginal product of labor. Parameters are modified such that the optimal level of aggregate labor throughout the treatment is $N^* = 8$. Money is introduced to facilitate the trade of labor and goods in sequential markets. In equilibrium, end-of-period money balances are zero.

Results from Sessions 4 and 5 are discussed below. Figure 2.3 shows the time paths of relevant market variables and Table 2.6 provides estimates of the deviations of these variables from their predicted values.

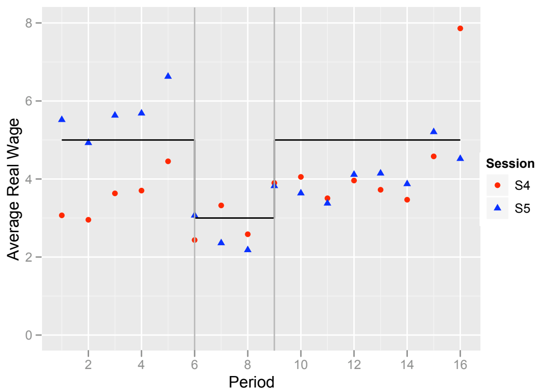
Finding 3. Laboratory experiments do not match many of the theoretical predictions of the money environment with a temporary productivity shock. Real wages are significantly below the equilibrium predictions throughout most phases of the treatment. Though too minimal to make additional purchases, worker cash balances are positive and significant. Upon returning to the preshock productivity level, average real wages are extremely slow to adjust and remain below the level of the shock phase. Efficiency is lower than in other treatments and highly volatile.

Preshock, average real wages are less than 10% above the predicted real wage and are not considered statistically different from equilibrium. At the session level, however, real wages are 11% below equilibrium in Session 4 and 32% above equilibrium in Session 5. It is unclear from the data how real wages behave, pre-shock, in the money environment.

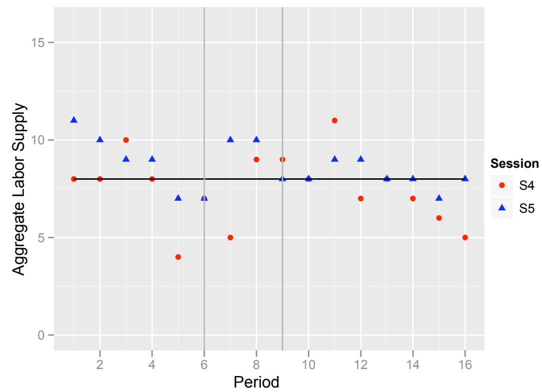
Aggregate labor supply remains above the equilibrium for all but the 5th period of the preshock phase. In Period 5, the aggregate labor supply is statistically different from equilibrium. This is driven by data in Session 4, where the aggregate labor supply is 50% below equilibrium. Each worker in this session sold one unit of labor. While two workers submitted unsuccessful bids to work in the last 10 seconds of the period, firms did not make further asks to hire workers.

Market efficiency is low in the preshock phase. Average efficiency is 61% in the 5th period before the shock. This stems from a very low labor supply and either

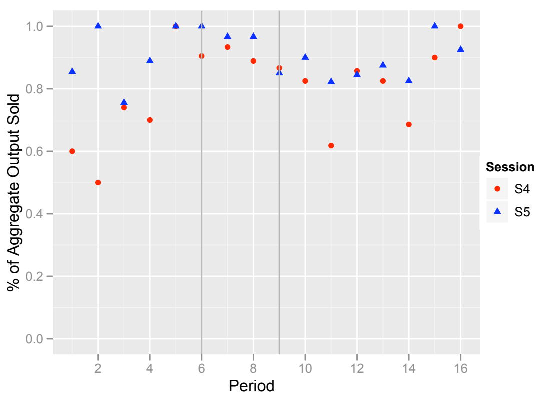
Figure 2.3: Money with a Temporary Productivity Shock



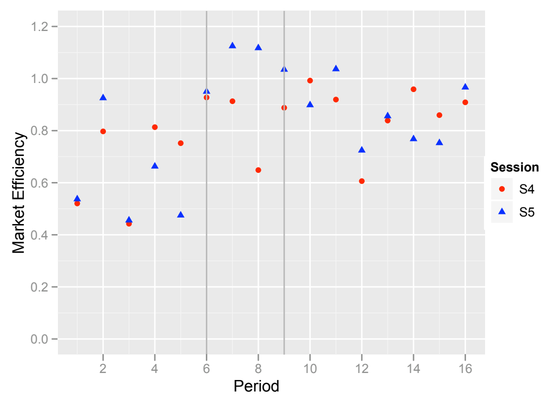
(a) Real Wages



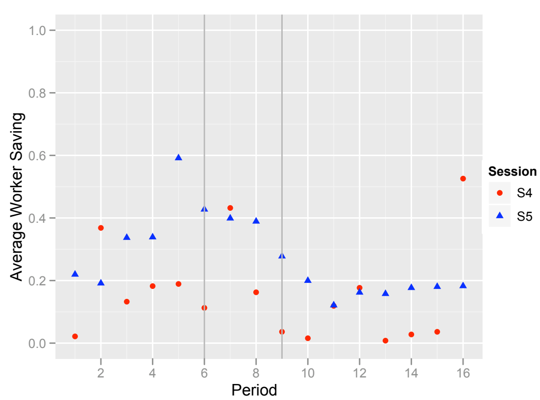
(b) Aggregate Labor Supply



(c) Percentage of Aggregate Output Sold



(d) Market Efficiency



(e) Market Average Household End-of-Period Bank Balances significantly low or high real wages in Sessions 4 and 5, respectively. Despite output being depressed, workers purchase 100% of the output produced by firms. Average worker cash balances, at 0.39 lab dollars, are too little to make additional purchases. Interestingly, workers do not submit bids to purchase units for prices equal to their remaining cash balances.

Postshock, real wages are significantly below equilibrium. While labor and output are not significantly reduced, significantly less output is sold in every period. Efficiency is significantly lower than in the temporary RBC treatment. Real wages do not return to their preshock levels following the increase in productivity. Real wages are on average 23% below equilibrium, after having been 10% *above* equilibrium preshock. This trend is persistent and real wages do not reach their pre-shock levels over the next 7 periods.

Finding 4. Worker and firm surplus levels are negatively correlated in the RBC economies while weakly positively correlated in the money economy.

Figure 2.4 provides time series plots of the percentage of maximum surplus acquired by subject type across treatments. Panels on the left depict total firm surplus while panels on the right depict total worker surplus. Separate scales are used for the subjects so that the data are clearer.[4] The correlation between average firm and worker surplus in the permanent and temporary RBC environments is -0.42 and -0.49, respectively. That is, 17.64% and 24.01% of the variances are in common. In the temporary money environment, the correlation is low at 0.17 (2% variance is in common).

[4] A value of 1 means that the sum of all workers (firms) points earned equals the equilibrium aggregate earnings for workers (firms). This often implies that some subjects within a type are earning more than predicted while others are earning less.

Figure 2.4: Surplus by Subject Type Across Treatments

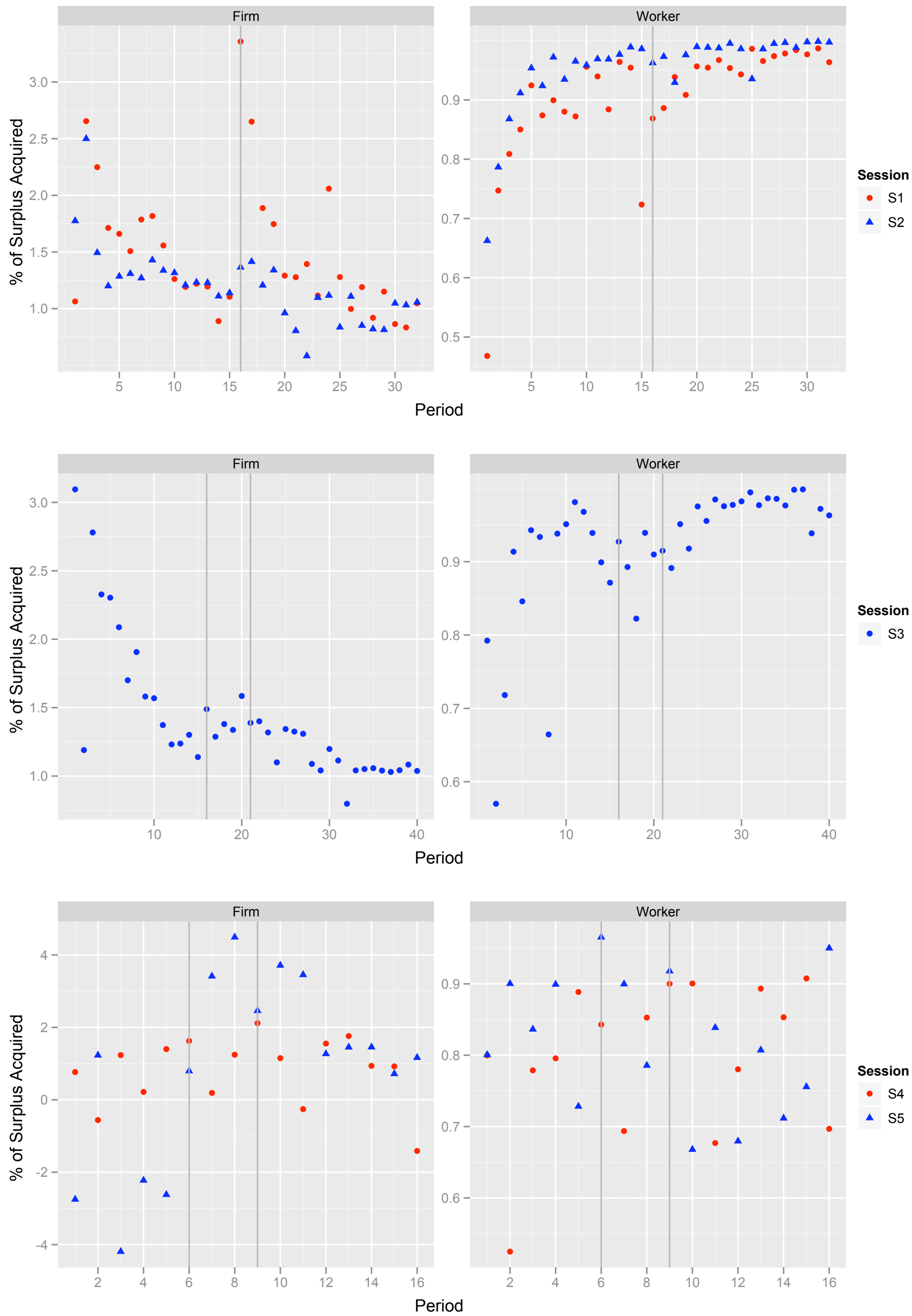
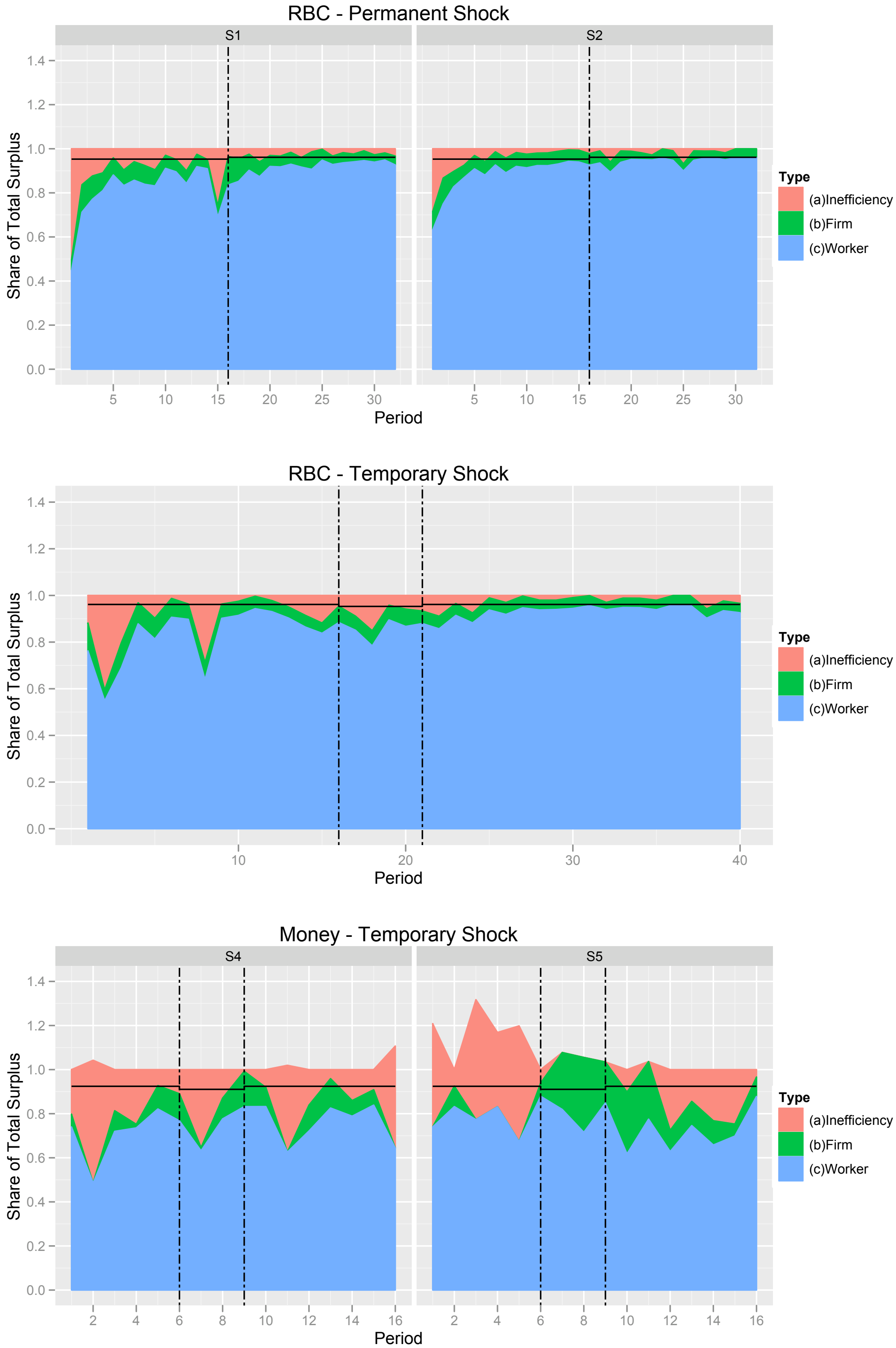


Figure 2.5: Share of Surplus by Subject Type Across Treatments



Interestingly, the negative correlation is not present in the money treatment. This seems counterintuitive in a market environment where the goals of workers and firms conflict. The positive (though insignificant) relationship may occur because of the mutual gain from worker savings. Workers that are unable to spend their entire cash balances can use savings (in addition to future earnings) to purchase additional units in the next period. The correlation between average worker beginning-of-period nominal balances and average worker efficiency is 0.38. Worker savings also benefit firms by increasing demand (as demonstrated by Finding 5). The correlation between average worker nominal balances and average firm surplus is 0.22 (4.84% of the variance is in common).

Finding 5. Worker surplus is significantly lower in the money treatment. Firm surplus is significantly higher in the money treatment.

Table 2.4 provides the average surplus for workers and firms in each phase of each treatment. The differences within-subject across the RBC treatments are small. Worker surplus is nearly identical in the preshock and postshock phases. Since preshock RBC treatments are identical by construction, an average of efficiencies weighted by number of sessions can also be taken. The measures for workers and firms, respectively, are 0.87 and 1.57 and are very similar to those given in Table 2.4. Firms earn higher average profits in the permanent RBC environment, postshock.

Efficiencies are noticeably different in the temporary money treatment. Relative to the temporary RBC treatment, workers appear to retain a smaller share of the surplus in all phases. Counting the number of periods in each treatment where the surplus is greater than 0.90 confirms this. In the RBC treatment, the worker surplus exceeds 0.90 for 75% of the session. In the money treatments, the worker surplus

Table 2.4: Average Worker and Firm Surpluses by Treatment

	Worker Surplus			Firm Surplus		
	Preshock	Shock	Postshock	Preshock	Shock	Postshock
Permanent RBC	0.88	—	0.97	1.46	—	1.25
Temporary RBC	0.86	0.90	0.96	1.79	1.41	1.14
Temporary Money	0.79	0.84	0.80	-0.75	1.96	1.40

exceeds 0.90 for 6.25% (S4) and 18.75% (S5) of the sessions. This is occurring because workers are under-consuming. As pointed out earlier, in every period of the money treatment units of output sold is too low, ranging from 15-46% below the optimal amount. Workers simply do not have the cash balances to purchase more fruit.

Except for in the preshock phase, firms earn significantly higher profits. Ideally, a Mann Whitney U test would be conducted to determine whether the efficiency levels in the two treatments are statistically different. Unfortunately, with such prohibitively small samples, the test cannot be accurately conducted.

Firms earn significantly more postshock in the money treatment than in the RBC treatment when there is a temporary productivity shock. The middle- and bottom-left panels of Figure 2.4 present time series of firm surpluses across treatments. This result can be misleading. When firms earn positive profits in the money treatment, they earn much larger amounts on average. There are, however, periods pre- and post-shock where the total firm surplus is negative. (Periods 2, 11, and 16 in Session 4; Periods 1, 3, 4 and 5 in Session 5). Such negative firm surpluses cannot occur in the RBC treatments.

Figure 2.5 gives the percentage-share of the total surplus acquired by each subject type across treatments in stacked area plots. It also provides a measure for the market inefficiency, interpreted as the share of the surplus not obtained by firms or workers. For readers who are reading in black-and-white or are color-blind, the share of surplus that is lost (inefficiency) is the top area, followed by firms' share of the surplus, and finally workers' share on the bottom. Vertical two-dashed lines indicate when productivity shock took place. The horizontal solid line indicates the workers' equilibrium share of the surplus. In equilibrium, workers' share of the surplus is the area below the line while firms' share is above the line. Note that when productivity shifts occur, the equilibrium shares change slightly. The horizontal line shifts up (down) when there is a productivity increase (decrease).

The total shares acquired by firms, workers, and by no one sums to one in the RBC treatments. Given the parameterization, neither subject type could earn negative points. As such, the area plots reach a maximum height of one. In the money treatment, however, both workers and firms can easily earn negative points. This results in the area plots exceeding a maximum height of one.

Immediately apparent is the large inefficiency that occurs in the money treatment. Inefficiency in the preshock phase is justifiable; subjects are still learning to play the game. Many units of output also need to be sold and it takes time for workers and firms to determine their optimal labor and consumption decisions. When the market experiences a temporary decrease in productivity (which would presumably make selling relatively fewer units of output easier), both worker and firm surpluses still fall in Session 4. Postshock, inefficiency is high in both sessions.

Even more visually striking is how large the firm surplus can become in the shock and post-shock phases of the money treatment. This far surpasses the firm surplus in the RBC treatments. In these phases, the firms' markups are significantly greater than 1. More than 90% of aggregate output is sold during the shock phase. When the firm markups increase in the postshock phase, still more than 80% of the output is sold. Finding 2.4 and Figure 2.5 suggest that large firm surpluses do not result in lower worker surpluses. Rather, larger inefficiencies are correlated with lower firm and worker surpluses. The correlation between the share of total surplus earned by workers (firms) and the share not received by anyone is -0.63 (-0.87) for the entire sample. (39.69% and 75.69% of the variance is in common.)

Finding 6. RBC and money environments do not behave identically in response to a temporary productivity shock.

The empirical work discussed above corroborates this finding. While the RBC environment conforms to the equilibrium predictions after some learning, the money environment is significantly different after 16 periods of play.

Finding 7. Subjects' degree of small-stakes risk aversion has no statistical significance on labor, output pricing, or markup decisions in the money treatment. Less risk averse firms adjust quicker in response to a productivity shock.

All subjects completed a Holt and Laury (2002) low stakes risk assessment at the beginning of each session. Selecting the risky lottery, B, six times implies risk neutrality. In the money treatments, 8.75% of subjects selected the risky lottery 6+ times. 12.5% of workers and 25% of firms selected B. That is, the majority of subjects can be labeled as risk averse. The HL score used in this section refers to the number of times a subject selected the risky lottery.

Does the degree of subject risk aversion affect subjects' decisions? A risk averse firm would prefer to avoid the risk associated with uncertain demand (and thus, revenue) for their output. Such firms would either hire fewer workers or pay a lower real wage. Similarly, risk averse workers may demand a higher wage or may choose to work less to avoid the risk associated with an uncertain supply of output.

There is little association between firms' average markup, prices, or hiring and their HL scores. 14% (15%) {9.7%} of the variance in average markups (prices) {hiring} and risky B choices are in common. Less risk-averse individuals tend to set lower nominal wages. The correlation coefficient is -0.55, implying 31% of the variance in nominal wages and risky choices are in common.

Comparing the HL scores with firms' percentage change in nominal wages in period 6 and period 9, respectively, we find a somewhat stronger correlation. Less risk averse firms tend to adjust their wages downward by more when a negative temporary productivity shock hits in period 6. These same firms tend to increase their wages upward by more when productivity returns to its original level in period 9. The correlation coefficients are 0.51 and -0.50, respectively, implying that 26% and 25% of the variances in wage adjustment and HL scores are in common.

Workers' behavior does not appear to covary with their HL scores either. The variance in their accepted average wages, the number of hours worked, end-of-period bank balances, and wage adjustment has little in common with their HL scores. The correlation coefficient between workers' accepted average wages and their HL score (0.43) suggests that 19% of the variances in these variables is in common. All other variables exhibited less correlation with the HL scores.

2.6 Discussion

The rational expectations representative agent workhorse model of macroeconomists may, on first thought, seem implausible. Experimental work suggests that ordinary people do not exhibit rational expectations in the lab. Consumption smoothing has proved challenging for subjects. Juggling labor and consumption decisions in a stochastic environment leaves much room for error.

Despite these challenges, laboratory market behavior matches the competitive equilibrium predictions of the cashless economy rather well. Real wages are sluggish to adjust (as we observe in the real world), but this is due not to the usual explanations of contracts or menu costs. In their questionnaires, firms indicate that they wanted to retain as much profit for as long as possible (until competition drives the real wage to its predicted value). Adjustment to the competitive equilibrium takes a relatively short amount of time when the productivity shock is positive and permanent. When the shock is downward and temporary, adjustment is slower but does reach the competitive equilibrium.

Given that the theoretical predictions of the cash-in-advance environment are identical to that of the cashless, it is reasonable to believe the two economies would behave in a similar manner. This expectation would be naive. The introduction of money and sequential markets generates significant inefficiencies. The high inefficiency shares concur with the findings of Hey and Di Cagno (1998) and Noussair et al. (2005). Sequential markets, designed either explicitly or implicitly, have a tendency to be more inefficient than single markets. Inefficiencies in the first market spillover into the second. Aggregate labor supply is usually above equilibrium in the money treatment; overworking decreases workers' utility, and consequently their surplus. Moreover, workers are under-consuming because they lack sufficient money balances due to low real wages. With excess output, why do output prices not fall? Firms undersell to prevent output prices from falling. Without costly disposal of unsold output, firms have an incentive to restrict supply. Inefficiencies also stem from the wasted cash each period. Workers end up carrying forward nontrivial cash balances that are often insufficient to purchase an extra unit of output.

Why are workers willing to accept relatively lower real wages in the cash-in-advance economy? One explanation is that workers do not know the optimal levels of labor and consumption. They know that they ought to work less and consume more, but what is the optimal combination? In contrast, workers in the cashless economies know that they will earn more points by acquiring a greater share of the fruit that they collect. It is far simpler to determine the optimal combination of labor and consumption in the barter economy.

Particularly intriguing are the large firm surpluses in the shock and post-shock phases of the money treatment. Both types are in precarious situations while in the labor market. Firms risk overhiring and overpaying workers; workers risk overworking and having insufficient cash balances. Both have reasonable bargaining power in the goods market. Given that workers are unsure about the optimal level of consumption and risk under-purchasing, firms best-respond by charging a higher price on their initial units. Even if a firm undersells, it still has the possibility of making a considerable profit. This story still fails to explain why workers agree to pay the higher prices - and subsequently underconsume.

The findings discussed in this paper have implications for macroeconomic modeling. There is clear evidence of sticky real wages even without the usually imposed rigidities. It appears that the inclusion of money makes real wage adjustment slower. It may be worth exploring how money affects price adjustments. Moreover, money increases the level of market inefficiency in experimental economies. Few, if any, macro models account for such efficiency losses.

Two types of productivity shocks are explored here, but the design can easily be modified to consider alternative environments. It would be both interesting and relevant to observe the effects of supply, demand, and money shocks within the money environments. One challenge when dealing with money experiments is having the periods be both long and numerous in quantity. Two hours would be the bare minimum needed to run such sessions. At that point, however, subjects are prone to becoming tired or bored. Finally, for these findings to be informative to macroeconomists, it is essential that an appropriate conversion rate between laboratory periods and real-time quarters be determined.

2.7 Appendix

Consumer-Worker Problem

The representative worker seeks to maximize its utility

$$\psi \frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\eta}}{1+\eta} \tag{2.6}$$

subject to the following budget constraint

$$W_t N_t = P_t C_t \tag{2.7}$$

where C_t is their consumption of a homogeneous good, N_t is the number of hours worked, W_t is the hourly wage earned and P_t is the price paid for the unit(s) of consumption. The Lagrangian and first order conditions for the worker's optimization problem are given by

$$\Lambda = E_t \sum_{t=0}^{\infty} \beta^t \left(\psi \frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\eta}}{1+\eta} + \lambda_t \left\{ W_t N_t - P_t C_t \right\} \right) \tag{2.8}$$

$$[C_t] : \psi C_t^{-\sigma} = P_t \lambda_t$$

$$[N_t] : \chi N_t^{\eta} = W_t \lambda_t$$

Without capital or money, the worker's intertemporal problem reduces to a one-period optimization exercise. Solving, the worker face a lesiure labor tradeoff according to

$$\frac{W_t}{P_t} = \frac{\chi}{\psi} N_t^{\eta} C_t^{\sigma} \tag{2.9}$$

Firm Problem

The representative firm posseses a constant returns to scale production technology

$$Y_t = Z_t N_t \tag{2.10}$$

and seeks to maximize profits

$$\Pi_t = P_t Z_t N - W_t N_t \tag{2.11}$$

where Z_t is the marginal productivity of a single unit of labor. Thus, the firm chooses to hire such that the real wage is equal to the marginal productivity of labor

$$\frac{W_t}{P_t} = Z_t \tag{2.12}$$

Equilibrium

In equilibrium, labor supply equals labor demand. Setting equations (#) and (#) equal,

$$Z_t = \frac{\chi}{\psi} N_t^{\eta} C_t^{\sigma} \tag{2.13}$$

Environment II: Money

Model II introduces two modifications. First, households and firms interact in sequential markets. At the begining of a period, households sell their labour to firms in exchange for a nominal wage. After the labour market closes, the goods market opens. Firms sell their produced output to households in exchange for a nominal price. The sequential markets, by construction, require the introduction of money to act as a medium of exchange. Households may now hold cash balances between periods.

These modifications only impact the household's optimization problem. Now, households seek to maximize their period utility (#) subject to a modified budget constraint:

$$W_t N_t + M_t = P_t C_t + M_{t+1} \tag{2.14}$$

where M_t are money balances carried forward from the previous period that are available to be spent in period t. Equation (#) states that the household uses current earnings from the sale of its labor, $W_t N_t$, plus money balances carried forward, M_t, to purchase output for consumption use, $P_t C_t$, and to carry forward into period $t+1$.

Households face a cash-in-advance constraint

$$P_tC_t \leq W_tN_t + M_t \tag{2.15}$$

The Lagrangian and first order conditions for the household's problem is given by

$$\Lambda = E_t \sum_{t=0}^{\infty} \beta^t \left(\psi \frac{c_t^{1-\sigma}}{1-\sigma} - \chi \frac{N_t^{1+\eta}}{1+\eta} + \lambda_t \left\{ W_tN_t + M_t - P_tC - M_{t+1} \right\} \right) \tag{2.16}$$

$$\begin{aligned}
[c_t] :& \psi C_t^{-\sigma} = P_t\lambda_t \\
[N_t] :& \chi N_t^{\eta} = W_t\lambda_t \\
[M_{t+1}] :& \lambda_t = \beta E_t \lambda_{t+1}
\end{aligned}$$

Solving we have a solution to the household's intratemporal problem. The household face a lesiure labour tradeoff according to

$$\frac{W_t}{P_t} = \chi N_t^{\eta} C_t^{\sigma} \tag{2.17}$$

We also obtain a solution to the households' intertemporal problem. Households trade off consumption today for future consumption according to

$$C_t^{-\sigma} = \beta E_t C_{t+1}^{-\sigma} \frac{P_t}{P_{t+1}} \tag{2.18}$$

It is suboptimal to hold any end-of-period money balances. If $M_{t+1} > 0$, it must be that $W_tN_t + M_t > P_tC_t$. But in equilibrium, $W_tN_t + M_t = P_tC_t$. The representative worker is underconsuming if its money balances are positive.

Calibration

The models are calibrated for the experimental environment as follows:

σ : The elasticity of intertemporal substitution. This is set equal to 1 in all treatments, yielding log utility over consumption.

η : The elasticity of labor supply. In micro studies, labor supply is calibrated to be highly inelastic (eg. 0.1) while in macro studies, it is calibrated to be highly elastic (eg. >1). This is set to 1 in all treatments.

β : The discount factor. In macroeconomic studies, this is usually calibrated to be 0.98 or 0.99. To avoid the additional complication of explaining discounting to subjects, this is set to 1 in all treatments.

ψ : This coefficient is set equal to 9 in the RBC treatments and 4 in the money treatment. It dictates the size of equilibrium labor and output. In the money treatment, it is convenient to reduce the size of the coefficient so that fewer units required transaction.

χ : This coefficient is set equal to 0.5 in all treatments.

Z_t: This is the marginal product of labor. It takes a value of $Z = 3$ or $Z = 5$ in all treatments.

Table 2.5: Deviations from Equilibrium - RBC Permanent Shock

Period	Avg. Real Wage	Agg. Labor Supply	Efficiency
1	-0.837***	-7.000***	-0.395***
	(0.000)	(0.985)	(0.108)
2	-0.888***	1.500**	-0.148***
	(0.050)	(0.492)	(0.015)
3	-0.623***	1.000***	-0.113***
	(0.157)	(0.000)	(0.010)
4	-0.357**	1.500	-0.092***
	(0.128)	(1.477)	(0.017)
5	-0.306**	0.000	-0.036***
	(0.097)	(0.985)	(0.005)
6	-0.252*	1.500	-0.077***
	(0.100)	(1.477)	(0.019)
7	-0.295*	1.500	-0.036
	(0.114)	(1.477)	(0.022)
8	-0.334***	1.500	-0.059**
	(0.081)	(1.477)	(0.017)
9	-0.253***	2.000	-0.056
	(0.028)	(1.969)	(0.039)
10	-0.195***	0.000	-0.027***
	(0.000)	(0.985)	(0.003)
11	-0.134***	0.000	-0.034*
	(0.003)	(0.985)	(0.014)
12	-0.161***	-1.000	-0.060
	(0.029)	(1.969)	(0.040)
13	-0.148***	-0.500	-0.018*
	(0.005)	(0.492)	(0.007)
14	-0.094***	-1.000	-0.027
	(0.020)	(0.985)	(0.021)
15	-0.100***	-2.000	-0.133
	(0.008)	(1.969)	(0.124)
16	-0.820	0.500	-0.029***
	(0.585)	(0.492)	(0.006)
17	-0.557	2.000	-0.028
	(0.315)	(0.985)	(0.018)
18	-0.397	-1.500**	-0.042*
	(0.237)	(0.492)	(0.017)
19	-0.326*	0.500	-0.035
	(0.122)	(0.492)	(0.024)
20	-0.280*	-0.500	-0.021*
	(0.137)	(0.492)	(0.009)
21	-0.181	0.500	-0.026***
	(0.147)	(0.492)	(0.007)
22	-0.166	0.000	-0.022***
	(0.117)	(0.985)	(0.006)
23	-0.143	0.500	-0.020
	(0.077)	(0.492)	(0.019)
24	-0.317	1.000***	-0.011***
	(0.248)	(0.000)	(0.002)
25	-0.130*	-1.000	-0.035
	(0.055)	(0.985)	(0.032)
26	-0.126*	0.500	-0.021
	(0.057)	(0.492)	(0.012)
27	-0.087***	1.000	-0.014***
	(0.019)	(0.985)	(0.004)
28	-0.092*	-0.500	-0.017*
	(0.045)	(0.492)	(0.007)
29	-0.065*	1.000***	-0.014**
	(0.027)	(0.000)	(0.004)
30	-0.049**	1.000	-0.014
	(0.017)	(0.985)	(0.013)
31	-0.037*	0.500	-0.010
	(0.016)	(0.492)	(0.009)
32	—	—	—

***, **, * denotes significance at the 1-percent, 5-percent, and 10-percent level, respectively.

Table 2.6: Deviations from Equilibrium - RBC Temporary Shock

Period	Avg. Real Wage	Agg. Labor Supply	Efficiency
1	-1.163	2.000	-0.119
2	-0.837	-8.000	-0.406
3	-1.152	0.000	-0.202
4	-0.927	-1.000	-0.032
5	-0.766	0.000	-0.098
6	-0.725	0.000	-0.013
7	-0.560	-2.000	-0.037
8	-0.861	-1.000	-0.288
9	-0.535	0.000	-0.037
10	-0.373	0.000	-0.025
11	-0.248	0.000	-0.004
12	-0.154	0.000	-0.022
13	-0.114	4.000	-0.049
14	-0.157	-1.000	-0.085
15	-0.189	0.000	-0.118
16	-0.297	0.000	-0.046
17	-0.225	-2.000	-0.089
18	-0.244	0.000	-0.151
19	-0.229	0.000	-0.042
20	-0.307	2.000	-0.058
21	-0.224	-1.000	-0.067
22	-0.205	0.000	-0.089
23	-0.223	-1.000	-0.035
24	-0.213	1.000	-0.075
25	-0.210	1.000	-0.010
26	-0.198	1.000	-0.030
27	-0.206	0.000	-0.003
28	-0.206	1.000	-0.020
29	-0.181	1.000	-0.020
30	-0.117	1.000	-0.009
31	-0.076	0.000	-0.001
32	-0.031	0.000	-0.030
33	-0.028	-1.000	-0.011
34	-0.039	-1.000	-0.012
35	-0.037	0.000	-0.020
36	-0.027	0.000	-0.000
37	-0.020	0.000	-0.000
38	-0.030	-2.000	-0.057
39	-0.068	-2.000	-0.024
40	—	—	—

***, **, * denotes significance at the 1-percent, 5-percent, and 10-percent level, respectively.

Table 2.7: Deviations from Equilibrium - Money Temporary Shock

Period	Avg. Real Wage	Agg. Labor Supply	Output Sold	Avg. HH Saving	Efficiency
1	-0.707	1.500	6.500***	0.120	-0.471***
	(1.188)	(1.455)	(1.455)	(0.096)	(0.008)
2	-1.059	1.000	7.000***	0.280**	-0.139*
	(0.957)	(0.970)	(0.970)	(0.086)	(0.062)
3	-0.369	1.500**	6.500***	0.235*	-0.551***
	(0.969)	(0.485)	(0.485)	(0.099)	(0.006)
4	-0.307	0.500	7.500***	0.260**	-0.262**
	(0.961)	(0.485)	(0.485)	(0.076)	(0.073)
5	0.540	-2.500	10.500***	0.390	-0.387*
	(1.054)	(1.455)	(1.455)	(0.195)	(0.134)
6	-0.248	-1.000***	9.000***	0.270	-0.061***
	(0.307)	(0.000)	(0.000)	(0.153)	(0.011)
7	-0.159	-0.500	8.500**	0.415***	0.019
	(0.468)	(2.425)	(2.425)	(0.016)	(0.103)
8	-0.618**	1.500**	6.500***	0.276*	-0.117
	(0.195)	(0.485)	(0.485)	(0.110)	(0.227)
9	-1.140***	0.500	7.500***	0.157	-0.039
	(0.037)	(0.485)	(0.485)	(0.117)	(0.071)
10	-1.155***	0.000	8.000***	0.108	-0.055
	(0.203)	(0.000)	(0.000)	(0.089)	(0.046)
11	-1.559***	2.000	6.000***	0.120***	-0.022
	(0.064)	(0.970)	(0.970)	(0.001)	(0.057)
12	-0.963***	0.000	8.000***	0.169***	-0.335***
	(0.074)	(0.970)	(0.970)	(0.007)	(0.057)
13	-1.065***	0.000	8.000***	0.083	-0.153***
	(0.204)	(0.000)	(0.000)	(0.073)	(0.008)
14	-1.329***	-0.500	8.500***	0.102	-0.137
	(0.196)	(0.485)	(0.485)	(0.072)	(0.093)
15	-0.107	-1.500**	9.500***	0.108	-0.194**
	(0.304)	(0.485)	(0.485)	(0.070)	(0.052)
16	—	—	—	—	—

***, **, * denotes significance at the 1-percent, 5-percent, and 10-percent level, respectively.

Chapter 3

Nonneutrality of Money, Preferences and Expectations in Laboratory New Keynesian Economies

3.1 Introduction and Motivation

Laboratory experiments are a new and important alternative test bed for studying macroeconomic dynamics. Like the dynamic stochastic general equilibrium framework, the lab provides an environment to study the effects of policy on individual behavior and expectations within controlled and micro-founded economies. Especially appealing is the allowance for heterogeneous preferences and behavior to emerge and affect market dynamics, a key step in moving beyond the rational representative agent analysis. While heterogeneous-agent macroeconomic models are growing in popularity, they have been arguably simple and ad-hoc in their modeling assumptions. Laboratory findings provide the necessary microfoundational insight for modeling behavior. Consistent behavioral deviations from theoretical predictions provide reason and direction to modify existing theory.

This paper demonstrates how general equilibrium experiments can be used to test the validity of the theoretical predictions of a canonical dynamic stochastic general equilibrium (DSGE) model. We introduce stationary repetition to facilitate learning and study how subjects converge to a steady state. We then analyze subjects' responses to a positive monetary policy shock modeled as an exogenous fall in the nominal interest rate. New Keynesian dynamic stochastic general equilibrium models are extensively used to study the economy-wide effects of innovations and provide central bankers with policy guidance. If a set of models is to take such prominence in policy makers' toolboxes, it is imperative that the models' predicted mechanisms and behavior are well tested and understood.

Our experimental findings suggest that market reactions to monetary policy depend on the composition of households in each economy. Though identically induced to be highly responsive to changes in real interest and wage rates, the median subject exhibits significantly inelastic behavior. There is considerable heterogeneity in subjects' revealed elasticity of intertemporal substitution and elasticity of labor supply with respect to the real wage. Nominal wage and price expectations are elicited to generate implied output gap and inflation expectations. Preshock expectations become increasingly rational after numerous stationary repetitions. However, on impact of the shock, subjects under forecast the output gap and their expectations do not appear to improve with stationary repetition. Though median expectations are nearly rational post-shock, there is significant inaccuracy in expectations at the individual level. The reduced variance and greater accuracy in inflation forecasts is attributed to the imposed nominal rigidities.

Experimental macroeconomics is an emerging literature studying intertemporal dynamics, expectations and coordination problems in partial and general equilibrium economies. Theories of Ricardian equivalence, time consistency, and fiscal and monetary policies have been analyzed in the lab. Duffy (2008) provides a vast review of the literature that encompasses labor, monetary, closed and open economy macroeconomics. Related work has shown the power of experimental macroeconomics to provide insights into how people respond to macroeconomic policies, for example, how subjects form expectations when a central bank changes from inflation targeting to price-level targeting (Amano et al. 2011).

This paper is among the first to explore the role of discretionary expansionary monetary policy in a production economy following the DSGE methodology. Production-focused GE experiments, such as those conducted by Bosch-Domenesch and Silvestre (1997), Lian and Plott (1998), Noussair et al. (2007), and Noussair et al. (2011), have demonstrated the ability of such laboratory environments to converge in the direction of their equilibrium predictions. These environments typically involve different types of agents (primarily consumer-workers and firms, but sometimes governments) and multiple markets (goods and labor) in both closed and open economy settings. Simultaneous, cash-in-advance markets are implemented using computerized double auctions and induced values and costs. Paid subjects interact over multiple trading days with the objective to maximize their utility or profit. The experiments conducted by Lian and Plott (1998) and Noussair et al. (2011) do not find significant effects associated with expansionary monetary policy. Bosch-Domenesch and Silvestre modify the credit levels and find that this results in real effects when credit constraints are binding, but only leads to inflation when credit is already abundantly available.

In a standard DSGE simulation, changes in policy variables or parameters occur within a single treatment, capturing the individual reaction to changes in policy or economic disturbances after the economy has reached a steady state. Existing laboratory experiments have yet to explore such behavioral reactions; rather, changes in experimental variables have typically occurred between treatments.[1] To deal with this gap between theory and experimentation, we modify the way in which the GE experiments are conducted. By allowing subjects to reach a steady state before shocking the economy, the impact of the shock on the time paths of relevant economic variables can be measured in a way that is comparable to the macroeconomic techniques currently used.

Much of the anecdotal criticism of the experimental GE literature pertains to identification. In complex interdependent systems it is difficult to identify causal factors. Effective experimental design involves being able to clearly identify cause and effect. In the existing studies, it is not obvious where suboptimal behavior is coming from. For example, a firm underproducing may be the result of workers underbuying or may simply be due to risk aversion on the part of the firm. It is for this reason that many experimentalists veer away from general equilibrium environments, and for the most part, have abandoned study in this area. To circumvent this issue, we first focus on individual types of agents first and then study both households and firms interacting together in an economy. In one treatment, human consumers interact with rational automated firms. In a second treatment, human firms interact with rational automated consumers. Finally in a third treatment, human consumers and firms interact together. The results are compared with our fourth "treatment", the

[1]In Bosch-Domensch and Silvestre (1997), credit levels change between rounds. In series 1 and 2 of Lian and Plott (1998), the constant money supply level changed between sessions. In series 3, money supply growth begain the first period and not from a point of equilibrium.

theoretical benchmark.

We design a workhorse experimental methodology that can easily be implemented in most laboratories. The computerized experiment is programmed in zTree (Fischbacher (2007)), a free and widely used experimental software. Markets are run using posted price environments - a market mechanism well known to experimental economists. The experiments discussed in this paper can easily be replicated and extended to consider a variety of environments and shocks.

Innovations that we introduce to the experimental design relative to the existing experimental literature are discussed in Section 2. The theoretical environment and experimental implementation are described in Sections 3 and 4. Results are presented in Section 5 and a discussion in Section 6 concludes.

3.2 Methodological Contribution to the Experimental General Equilibrium Literature

The design deviates from the existing experimental general equilibrium literature in four ways. First, it incorporates posted price (PP) markets rather than continuous double auctions (CDA) as a mechanism to trade output. The conventional method in production economy experiments is to use the continuous double auction to represent a highly competitive market (Smith, 1962). These experiments have been unable to generate real effects from exogenous increases in the money supply. The New Keynesian macroeconomic literature has identified price and/or wage rigidities as an essential element in generating real effects from monetary policy. The stickiness allows agents in the economy enough time to adjust their demand and supply functions before nominal values have an opportunity to respond. In a CDA, prices adjust extremely rapidly for at least two reasons. Firms see increased money balances as a signal of households' ability to pay more and households' willingness to pay for each unit is non-decreasing in money balances. Without a sufficient nominal friction, prices increase without any change in output. PP markets combined with Calvo pricing result in sufficient nominal rigidity to match the theoretical assumptions of the benchmark New Keynesian model. Noussair et al. (2011) also use a PP market to generate persistence in output prices but do not study its effects in the context of a monetary policy shock.

Second, nominal wages are determined differently. Rather than interacting in a labor market where the market clearing wage is determined through trades in a double auction, all subjects are presented with a nominal wage determined through New Keynesian equilibrium conditions, the current nominal interest rate and expectations on the output gap and inflation. The decision to use this method is three-fold. There is a desire to have as many elements of the experimental design "pinned down" so that we can identify what causes changes in the nominal wage. Methodologically, it reduces the amount of time necessary for markets to converge. A typical GE experiments with multiple markets operated by CDAs lasts 4-5 hours with instructions and can become very expensive. Elimination of the CDA for the labor market effectively shortens each period by 1.5-2 minutes. This amounts to over 2 hours over 90 periods! Finally, this approach is closer to the theoretical benchmark that assumes labor markets are competitive in that agents take nominal wages as given. Section 4 discusses the wage determination and importance of stationary repetition in greater detail.

We also modify the monetary instrument. Nearly all laboratory experiments studying expansionary monetary policy do so through the injection of money balances into bank accounts on either one or both sides of a market. This combined with CDA markets results in rapid inflation. Instead, a monetary shock in the proposed economy occurs through a decrease in the nominal interest rate on saving and borrowing. Noussair et al. (2011) construct a GE experimental economy in which interest rates adjust according to a Taylor rule due to changes in the inflation rate. They find no evidence of real effects from changes in the interest rate, mostly because real wages fail to respond despite the presence of nominal rigidities. By the New Keynesian paradigm, a decrease in the nominal interest rate theoretically implies - all else equal - an increase in the output gap and inflation, and necessarily an increase in the real wage rate.

A key assumption in New Keynesian models is that firms operate in a monopolistically competitive environment, which is typically introduced through household preferences for variety. We retain monopolistic competition but eliminate the actual task of having the household purchase different varieties directly. Determining the optimal combination of each variety is difficult when prices for different varieties are changing. This would serve only as an additional complication without telling us much about reactions to nominal interest rates. Instead, consumers automatically consume their desired bundle as a feature of our design.

Finally, we ask subjects to form wage and price forecasts at the beginning of each period for the current and following period. These forecasts are used to calculate implied output gap and inflation expectations necessary to generate the nominal wage. Other laboratory experiments, including Pfajfar and Žakelj (2011) and Assenza, Heemeijer, Hommes and Massaro (2011), and have studied expectations, but only in "partial-general equilibrium" frameworks. We are the first to analyze expectations formations in a general equilibrium environment where subjects interact in multiple markets.

3.3 Theoretical Environment

The theoretical framework follows the benchmark New Keynesian model described in Walsh (2003) and based on earlier models including Clarida, Gali, and Gertler (2000). The economy consists of households, firms, and a monetary authority. The objective of households is to maximize their expected present discounted value of utility from consumption and leisure. Each period they decide how much to work and consume. The objective of firms is to maximize their real profits by producing and selling a particular variety of output. Firms are monopolistically competitive and set prices à la Calvo (1983). Firms face a constant probability of being able to update their price each period, allowing for a dispersion of prices outside of a steady state. Pricing decisions of all firms affect consumer demand for each variety and, subsequently, firms' demand for its sole input, labor. Labor markets are competitive in that all agents take nominal wages as given. Borrowing and saving is done through one-period bonds that pay a nominal rate of return. The central bank sets the nominal interest rate on lending and borrowing each period. It follows a Taylor rule that targets inflation. The only stochastic economic disturbance that occurs in this economy is an expansionary monetary shock conducted through the nominal interest rate. The shock is persistent and follows an AR(1) process. Agents are assumed to form rational expectations. The equilibrium of the economy can be described by a system of four log-linearized equations:

$$\begin{aligned} x_t &= E_t x_{t+1} - \frac{1}{\sigma}(i_t - E_t \pi_{t+1} - \rho) &(3.1)\\ \pi_t &= \beta E_t \pi_{t+1} + \kappa x_t &(3.2)\\ i_t &= \rho + \delta \pi_{t-1} + v_t &(3.3)\\ v_t &= \rho_v v_{t-1} + \varepsilon_t &(3.4) \end{aligned}$$

The derivations of this system are discussed in the next sections. The output gap x_t is defined as deviations of output from its flexible price level. The inflation rate is given by π_t while i_t is the nominal interest rate and depends on ρ, the long run nominal interest rate and past inflation. Finally, v_t is an AR(1) process with persistence ρ_v governing the nominal interest rate and ε_t is a stochastic shock.

Equation 3.1 is the expectational investment-saving (IS) curve and models the demand side of the economy. It says that the output gap will increase if there are expectations that it will increase in the future, if nominal interest rates fall today, and if inflation is expected to increase in the future. Equation 3.2 is the New Keynesian Phillips Curve that describes the evolution of the aggregate price level. Inflation will increase if inflation is expected to increase in the future and if the output gap increases today. Equation 3.3 is the central bank's nominal interest rate setting equation that follows a Taylor rule. The central bank aggressively targets lagged inflation. The nominal interest rate may also be affected by random economic disturbances described by Equation 3.4. A shock to the nominal interest rate is autoregressive and takes many periods to dissipate.

An unanticipated expansionary monetary policy shock occurs through a stochastic decrease in ε_t. This causes v_t, and thus i_t, to fall by the same amounts on impact.

A decrease in the nominal interest affects the households directly. On impact, households prefer to increase their consumption. This is because lower nominal interest rates imply lower borrowing costs and return on saving. For both reasons, households are better off consuming more today than tomorrow. An increase in overall consumption requires more output production and more labor participation. Real wages must adjust upward to entice workers to supply more labor. In a sticky-price world, this requires that firms' markups decrease.

3.4 Experimental Implementation

The experiment consists of two types of agents: households and firms. There are $F = 4$ monopolistically competitive firms and $H = 4$ households interacting in each economy. The experiment consists of three separate treatments across sessions:

1. **Human Firms (HF):** Four subjects play the role of firms and interact with four automated consumers

2. **Human Households (HH):** Four subjects play the role of households and interact with four automated firms

3. **Human Firms and Households (HFH):** Four subjects play the role of firms while another four subjects play the role of consumers

Automated agents make decisions according to the first order conditions defined in the canonical model and are elaborated on in the following subsections. First order conditions that involve expectations of future variables use the median elicited expectations of the human subjects.

In a given session, subjects play the same role over five repetitions of the same environment with the same group of subjects. Each repetition has an expected length of 21 periods and resets the economy back to the initial steady state. An expansionary monetary shock occurs midway through the repetition.

3.4.1 Induced Preferences

The experimental implementation involves transitioning from a representative agent framework to an environment where multiple agents of different types interact. We must first induce agents with preferences. According to induced value theory (Smith, 1976), an experimenter can control subjects' preferences if three conditions are met. First, subjects' induced preferences must be strictly *monotonic* in monetary payments. Second, changes in the subjects' earnings must be *salient* in that they are a result of specific actions taken by agents or Nature that is consistent with the environment being induced. Third, changes in subjects' utility must depend pre-*dominantly* on the reward scheme and not on other factors. Monotonicity is ensured by paying subjects based on the objective function they maximize. Saliency is encouraged as subjects are reminded that the actions of themselves and others in the experiment will affect their earnings. We also ensure dominance is maintained by not displaying the payoffs of others and by keeping subjects actively participating to prevent boredom.

Households

Each household is induced with identical preferences to maximize their expected present discounted value of utility:

$$E_t \sum_{t=0}^{T} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\eta}}{1+\eta} \right]$$

where C_t is their consumption of a composite good consisting of differentiated products produced by monopolistically competitive firms, N_t is the amount of hours a household works and $1/\eta$ is the Frisch elasticity of labor supply. Subjects face an indefinite horizon T rather than an infinite horizon.[2] The composite good is made up of numerous varieties:

$$C_t = 4^{\frac{1}{1-\theta}} \left[\sum_{i=1}^{4} C_{it}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

where C_{it} is the household's consumption of variety i and

θ is a preference parameter describing the household's love for variety.

Households are asked each period their maximum willingness to work (N_t^S) and their maximum level of consumption (C_t^D). They make their decisions according to their utility function and a nominal budget constraint:

$$P_t C_t + B_t = W_t N_t + (1 + i_{t-1}) B_{t-1} + \Pi_t$$

The left hand side of the budget constraint describes the household's nominal expenditures ($P_t C_t$) and current saving (B_t). The right hand side describes the household's current flow of income, made up of wage income ($W_t N_t$), last period interest on saving ($(1 + i_{t-1}) B_{t-1}$), , and dividend payments from the firm (Π_t).

Household subjects receive payments based solely on their accumulation of the composite commodity good and their labor decisions over their experimental lifetime. They do not receive payments based on their lab money holdings. The first order conditions of the optimizing household yield an Euler equation describing the intertemporal tradeoff between current and future consumption

[2]The infeasibility of implementing an infinite horizon is discussed in Section 4.6. An indefinite horizon allows for comparable discounting and avoids the issue of backward inductions.

$$C_t^{-\sigma} = \beta(1+i_t)E_t C_{t+1}^{-\sigma}\frac{P_t}{P_{t+1}}$$

and an equation of the intratemporal tradeoff between consumption and leisure

$$N_t^{\eta} C_t^{\sigma} = \frac{W_t}{P_t}$$

Firms

Firms are induced to maximize real profits:

$$\Pi_t = \frac{P_t^i Y_t^i - W_t N_t^i}{P_t}$$

where $P_t^i Y_t^i$ are revenues earned by firm i, $W_t N_t^i$ is its wage bill, and P_t is the aggregate price level in the economy. Each firm possesses identical, constant returns to scale technology described by

$$Y_t^i = Z N_t^i$$

where Z is a productivity parameter that remains constant throughout the experiment.

Firms must decide what price to set for their output. Each period, the probability that a firm can update its price is $1-\omega = 0.25$. It must factor in expected nominal wages and demand over its expected lifetime when making its decision.[3]

[3]Calvo pricing has its experimental shortcomings. While on average a firm will update its price every 4 periods, it may also never update its price. This can make subject learning highly limited and data analysis difficult. An alternative approach is to use staggered pricing contracts a la Taylor (1980), in which firms update exactly every *m* periods, potentially in revolving order. While experimentally appealing, the theoretical outcome implies inflationary dynamics that are inconsistent with empirical data for reasonable parameter values.

The prices set by all firms will determine the level of demand for each variety:

$$Y_{it} = \frac{1}{I} P_{it}^{-\theta} P_t^{\theta} C_t$$

where P_t is the aggregate price level defined as $P_t = I^{\frac{1}{\theta-1}} \left[\sum_{i=1}^{I} \left[(P_{it})^{1-\theta}\right]\right]^{\frac{1}{1-\theta}}$ and I is the number of firms in the economy. A challenge that arises here is how to induce a small number of subjects to behave as monopolistically competitive firms, ie. to take the aggregate price level as given and ignore the impact its price has on others when setting its own price. Our approach is to present a firm about to update its price with a calculator that takes as inputs their own price and the aggregate price level, and outputs a level of demand and profits. Using this approach, we are leaving it up to the individual firms to realize that their own price does in fact impact the aggregate price index.[4] When it comes to calculating actual demand, the updating firm's price will be included in the aggregate price level calculation.

Firms are expected to supply to all households who demand their output, and will thus demand the required amount of labor taking nominal wages as given. The sum of nominal firm profits is split equally among all households in the form of a dividend payment at the end of each period. Accumulated real profits are recorded and paid out to firms at the end of the experiment.

[4]Davis and Korenok (2011) implement monopolistic competition through a linear demand curve that is increasing in the average price of firms. To deal with this issue, they increase their number of firms to 6 where this should decrease the impact of a single firm's price on the average price.

3.4.2 Markets

Firms and households interact simultaneously in input and output markets. Households submit their labor supply and output demand at the same time as firms make pricing decisions. In the case of automated firms, the pricing decision of the updating firm is known a priori. This differs from Noussair et al. (2011) where the labor market precedes the output markets.

Labor Market

Households trade their labor hours to firms in exchange for money wages, specified at the start of the market. Firms' demand for labor is determined by the demand for their output, and thus by the prices set by all firms in the economy and the consumption levels of households. The nominal wage process is discussed below. Households have a maximum 10 hours in which they may work, and may work fractions of an hour. Households lose an exponentially increasing number of points as they work additional hours.

Output Market

Each firm produces a different color variety of a good (Red, Blue, Green, and Orange). One firm is randomly selected to reset its price each period. An aggregate price index is calculated; this will be the price that households pay for each unit of the composite good. Firms are required to fully supply household demand given its own price and the aggregate price level. Households must then decide how many units of the composite good they would like to purchase while making their labor decisions. They may borrow up to 150% of their expected wealth in the form of a one-period bond. That bond must be repaid, with interest, in the next period through a deduction in wage income. Alternatively, a household may choose to not consume their entire budget. In that case, their unspent income is saved and earns interest. Their desired consumption levels along with the firms' prices determines the demand for each firm's variety.

Note that households do not directly purchase individual varieties. This differs from Noussair et al. (2011) where households purchased units from three different firms. While both are equally valid approaches to modeling and implementing monopolistic competition in the New Keynesian world, it is experimentally and cognitively simpler for households to purchase a single good. Our interest is not whether households can consume an optimal combination of varieties, but rather how they trade off consumption inter- and intra-temporally. We eliminate the potential confound by imposing that households consume optimal combinations.

Procedures

1. Given a wage, one firm has the opportunity to update its price. An aggregate price index is then generated.

2. Households have the opportunity to select how much they would like to work and consume. The demand for each variety is calculated.

3. Total labor demand by firm i given total variety demand by each of the h households is given by:

$$N_{it}^{D} = \frac{\sum_{h=1}^{4} Y_{ht}^{i}}{Z}$$

   Total labor demand is the sum of demands across all four firms:

$$N^{D} = \sum_{i=1}^{4} N_{it}^{D}$$

while total labor supply is given by the sum of supplies across all four households:

(a) If $N_t^D = N_t^S$, labor is distributed across firms according to need. Each household works and consumes the amount they submitted.

(b) If $N_t^D < N_t^S$, there is excess labor supply. Firms will hire up to their desired demand. Each household will consume the amount that they requested, and receive a rationed amount of labor hours. Households that submitted $N_h^S \leq \frac{C_h^D}{Z}$, ie. are not contributing to the relative excess labor supply, will work their desired number of hours. Otherwise, a household is allocated $N^S = \frac{C^D}{Z}$. If there is any remaining labor hours available (due to some households under-working), those hours will be distributed among the over-working households according to relative demand.

(c) If $N_t^D > N_t^S$, there is excess labor demand. All households will work the maximum amount they desired. Labor will be split across firms according to relative demand. Households that submitted $N_h^S \geq \frac{C_h^D}{Z}$, ie. are not contributing to the relative excess consumption demand, will consume their desired number of units. Otherwise, a household is allocated $C^D = ZN^S$. Remaining units of output are distributed among the over-consuming households according to relative demand.

Nominal Wages and Expectations

A key feature of this experiment is that nominal wages are not determined through negotiations or market interactions. Rather, subjects are presented with the nominal wage and asked to make labor supply or pricing decisions. This is consistent with the notion that agents take the nominal wage as given. This has the desirable feature that inventories and the risks of advance production are absent. Output is "made-to-order", and consistent with the New Keynesian framework all output produced is consumed. It also allows us to reduce the amount of time required to complete a period. Eliminating the 1.5 minutes needed for the labor market to clear saves us over 2 hours. Given that the nominal wage is not our focus of interest, it is reasonable to let it be automated.

Our approach is to use a reformulated expectational IS equation to generate a nominal wage. In short, we note that the output gap can be rewritten as a function of deviations of the real marginal cost, $\hat{\phi}_t$, from its flexible price level[5]:

$$\begin{aligned} x_t &= \frac{1}{\eta+\sigma}\hat{\phi}_t \\ &= \frac{1}{\eta+\sigma}\left(\hat{W}_t - \hat{P}_t\right) \end{aligned}$$

The expectational IS curve is given by

$$x_t = E_t x_{t+1} - \frac{1}{\sigma}\left(i_t - E_t \pi_{t+1} - \rho\right)$$

Substituting in for x_t, $E_t x_{t+1}$ and noting that $\pi_t = \hat{P}_t - \hat{P}_{t-1}$, we can express the log wage deviations from the steady state as a function of known variables

$$\hat{W}_t = E_t \hat{W}_{t+1} + \frac{\eta}{\sigma} E_t\left(\hat{P}_{t+1} - \hat{P}_t\right) - \frac{\eta+\sigma}{\sigma}\left(i_t - \rho\right)$$

[5] $\hat{Z}_t$ is dropped from the real marginal cost formulation as productivity measures are fixed at their steady state level for the duration of the experiment. The symbol ˆ denotes log deviations from the steady state flexible price level.

The nominal wage, in levels, is given by

$$W_t = \overline{W}\left(1+\hat{W}_t\right)$$

where $\overline{W}$ is the steady state nominal wage.

The nominal wage can be determined through agents expectations about nominal wages and prices. This is obtained by asking all subjects to make forecasts about period t and $t+1$ nominal wages and prices at the beginning of period t. The median forecasts, which are less easily manipulated by subjects than the mean, and the current nominal interest rate are used in the calculation of the nominal wage. To further avoid manipulation, the human firm that has an opportunity to reset its price is excluded from the calculation.[6]

It is important that subjects take the task of forecasting seriously. Each subject is paid a small bonus for relatively accurate forecasts, that is, forecasts that are within 0.01 lab dollars of the correct answer. The bonus is small relative to payments for making labor, consumption, and pricing decisions to ensure that dominance is not compromised. The scoring rule has the virtue of simplicity and, assuming negligible marginal effort costs to improving the forecast, is incentive compatible.

3.4.3 Central Bank and Shock Process

An automated central bank operates in the background. It follows a Taylor rule which sets nominal interest rates to target deviations of last period's inflation from its target

[6]Agents in the New Keynesian world are assumed to form rational expectations about the output gap and inflation. These are in percentage terms, a concept that can be cognitively challenging for many people. Forecasting nominal wages and prices provides an equivalent expectation in percent deviation forms and is a simpler task for the subject.

$\pi^* = 0$:

$$i_t = \rho + \delta\pi_{t-1} + v_t$$

and

$$v_t = \rho_v v_{t-1} + \varepsilon_t$$

is the monetary shock that follows an AR(1) process.

In theory, the central bank can affect the real interest rate, and subsequently output, through manipulation of its nominal interest rate. The experiment presented here tests whether discretionary monetary policy in the form of an exogeneous and unanticipated decrease in the nominal interest rate leads households to increase their consumption on impact relative to future consumption. After subjects have been given time to equilibrate (approximately 12 periods in the first session, and fewer throughout), the policy shock $\varepsilon = -0.025$ occurs, lowering the nominal interest from 5% to 2.5%.

Impulse responses resulting from the shock are assumed to start from a steady state. To replicate this feature of the model, we have subjects play under a stable (i.e. disturbance-free) environment repeatedly for approximately 15 periods.[7] This approach of stabilization has also been employed by Fehr and Tyran (2001), Davis and Korenok (2010), and Petersen and Winn (2011) to explore the effects of money supply shocks on price adjustment in partial equilibrium frameworks. This feature is absent in the experimental general equilibrium literature, where shocks occur either between treatments (Lian and Plott, 1998) or continuously within a treatment without any opportunity for stabilization (Bosch-Domenech and Silvestre, 1997; Noussair et al., 2011).

[7]We experimented with other stabilization lengths, including as long as 55 periods before shocking the economy. There is not much improved convergence beyond 15 periods. Subjects became very restless during the 55 period stabilization and dominance was potentially compromised.

3.4.4 Stationary Repetition

An important experimental design issue is learnability. It takes time for subjects to familiarize themselves with an environment and to understand the consequences of their decisions. Stationary repetition is a critically necessary requirement for testing theory. Under stationary repetition subjects are presented with the same laboratory task multiple times. This allows them to adapt to the relatively unfamiliar task. It is the outcomes observed after behavior settles down that are compared to theoretical predictions. If a subject fails to behave as theory would predict in their first encounter with the software, it is unjust to claim the theory faulty. If, however, the subject repeatedly behaves contrary to the theoretical predictions of the model, presumably having learned from their past actions, we may then have reason to question the theory. Stationary repetition is not easily implemented in the existing production GE experiments where a single treatment lasts for 4-5 hours. Inviting subjects back for further sessions can be challenging for such lengthy experiments. Each period cannot be thought of as a stationary repetition as previous decisions affect current cash balances and economic variables. We get around this issue by implementing automation of the market wage and, in some treatments, agents in the economy. Automation not only reduces the length of each period but also increases the speed of convergence to the steady state due to equilibrium play by one side of the market.

Subjects interact in five stationary repetitions with the same groups. Each economy lasts for a random number of periods, with the shock occurring near the middle of the sequence. Table 3.1 provides detailed repetition lengths and periods of shocks. Subjects start "fresh" in each repetition in that earnings are reset to zero. Stationary repetition typically involves running subjects through identical processes multiple times. In this experiment, however, subjects are subjected to an unanticipated

Table 3.1: Calibrations

Parameter	Parameter Description	Value
Z	Productivity level	10
$1-\omega$	Fraction of firms updating	0.25
ρ_v	Persistence of shock	0.5
δ	Inflation targeting of CB	1.005
ε	Shock	-0.025
κ	Slope of NKPC	0.07904
θ	Measure of substituability	7.666
β	Rate of discounting	0.9523
χ	Disutility coefficient	1
$1/\sigma$	Elasticity of intertemporal substitution	2
$1/\eta$	Frisch labor supply elasticity	3.03
ρ	Steady state nominal rate of return	0.05
μ^*	Steady state markup $(\theta/(1-\theta))$	1.15
C^*	Steady state consumption	33.8
N^*	Steady state labor supply	3.38
W^*	Steady state nominal wage	10
P^*	Steady state price	1.15
FirmsN	Number of firms	4
HouseholdN	Number of households	4
Sessions	Number of sessions per treatment	6
Repetition	**No. Periods**	**Period of Shock**
1	22	12
2	13	8
3	15	11
4	10	5
5	21	12

stochastic shock. To maintain the unexpectedness of the shock, but to not deviate far from the notion of stationary repetition, we slightly vary the period of the shock. The size and the direction of the shock remained constant across repetitions.

3.4.5 Automation

Making sense of agents' behavior by studying aggregate data can be complicated. It is often unclear from which side of the market suboptimal behavior is coming from.

To better understand where the theory may not be lining up with the experimental findings, we devise two treatments where a single side of the economy's decisions are rationally automated. We then observe the choices of human subjects playing either the role of firms in the HF treatment or the role of households in the HH treatment. The automated agents follow the rational expectations behavior outlined by the model. Under both treatments, the nominal wage process is determined solely by the expectations formed by human subjects. Below is a discussion of the different types of automation.

Human Firm Treatment

In the HF treatment, human firms interact with automated households. This environment allows us to detect suboptimal pricing behavior in the presence of optimally behaving households.

Firms submit their daily forecasts at the beginning of each period. Only the forecasts made by the non-price setters are used in the median forecast calculations. A nominal wage is determined and firms are informed of the current wage rate and the anticipated demand of households. Using the first order conditions from their optimization problem and noting that $E_tC_{t+1} = E_tY_{t+1} = E_tx_{t+1}$, each household will consume such that

$$\hat{C}_t = E_t\hat{C}_{t+1} - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) \quad (3.5)$$

$$= \frac{1}{\eta+\sigma}\left(E_t\hat{W}_{t+1} - E_t\hat{P}_{t+1}\right) - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho) \quad (3.6)$$

In levels, we have that $C_t = \overline{C}\left(1+\hat{C}_t\right)$. Given this level of consumption, each household's labor supply decision will be given by

$$N_t^S = \left[C_t^{-\sigma} \frac{W_t}{P_t} \right]^{\frac{1}{\eta}} \tag{3.7}$$

Any income that is unspent on output is saved and earns a nominal rate of return.

The updating firm is able to reset its price after learning the nominal wage and aggregate level of consumption. Demand for each variety is determined and profits are calculated.

Human Household Treatment

In the HH treatment, human households interact with automated firms. Here we are able to observe how subjects playing the role of households trade off current and future consumption, as well as trade off consumption for leisure.

Each period begins with households submitting their daily forecasts. A nominal wage and aggregate price level are determined. The automated firms that can update their prices do so optimally given the economy-wide expectations. All firms start off at the steady state price level. Conveniently, we do not need to obtain the optimal price of the updating firm to calculate the price index. Rather, we can make use of the New Keynesian Phillips Curve, substitute in the New Keynesian IS curve and simplify to obtain

$$\pi_t = \beta E_t \pi_{t+1} + \kappa \left\{ \frac{1}{\eta + \sigma} \left(E_t \hat{W}_{t+1} - E_t \hat{P}_{t+1} \right) - \frac{1}{\sigma} \left(i_t - E_t \left(\hat{P}_{t+1} - \hat{P}_t \right) - \rho \right) \right\}$$

The price of the composite good is then given by

$$P_t = P_{t-1}(1 + \pi_t) \tag{3.8}$$

3.4.6 Calibrations

Table 3.1 outlines the parameter set used throughout the experiment. Calibrations are constant across treatments and are selected to ensure a sufficiently large predicted behavioral effect of the shock. In most cases, we are able to use empirically consistent parameters. To implement exponential discounting of future payoffs and the stationarity associated with an infinite horizon, we follow the advice of Duffy (2008) and have a constant probability β of continuation onto a next period. If a sequence does not continue onto a next period, a new sequence is begun. Because we cannot feasibly keep subjects for very long stretches of time, we do not use the standard $\beta = 0.99$, but reduce it slightly to $\beta = 0.9523$, implying an expected duration of 21 rounds from the start of each pre-drawn sequence.

3.4.7 Experimental Predictions

The economy-wide resource constraint and the production function imply that $C = Y = ZN$. Substituting this constraint into the household's intratemporal first order condition yields a steady state level of individual labor

$$N = \left[\frac{W}{P} Z^{-\sigma}\right]^{\frac{1}{\eta+\sigma}}$$

which is calibrated to $N = 3.38$. This results in a steady state level of individual consumption of $C = 33.8$. Changes in the nominal interest rate that affect the real interest rate should induce households to adjust their intertemporal tradeoff of consumption. Decreases in the nominal interest rate are expected to lead to a positive increase in current consumption and labor supply. Assuming households form rational expectations about future variables, a 2.5% decrease in the nominal interest rate induces consumers to increase their labor supply and consumption by 7.74% to $N = 3.63$ and $C = 36.3$.

Monopolistically competitive firms are expected to maintain a markup of 15% in the steady state. When the shock occurs, the theoretical predictions of the model suggest that the markup should fall. Inflation should equal 1.1% resulting in a small change in the nominal price from 1.15 to 1.1626.

3.4.8 Experimental Procedures

The experiments took place at the University of California Santa Cruz LEEPS lab. A total of six sessions were conducted for each of the three treatments. Sessions lasted for approximately 2-2.5 hours and involved undergraduate students from a variety of disciplines at the university. Sessions began with instructions, a quiz, and three rounds of practice with the software. All this was done to familiarize subjects with the experimental environment and their payoff structure. Subjects were informed that the nominal interest rate could adjust every period, but that in the long run, the experimental central bank would aim to keep the rate at 5%. They were also informed that wages and prices will be affected by the nominal interest rate, and to pay attention to the nominal interest rate when setting forecasts. A set of instructions is provided in Chapter 6. After three repetitions, subjects' points were converted according to a provided exchange rate and paid to subjects in cash. Average earnings were $28.45, including a $5 showup fee and prediction bonuses.

3.5 Results

3.5.1 Real Effects of Monetary Policy

In this subsection, we explore whether a nominal interest rate-induced wage increase leads to a change in the labor supply.

Finding 1: *A decrease in the nominal interest rate consistently leads to a significant increase in the labor supply and desired consumption in the presence of automated households. When human households are introduced in the HH and HFH treatments, there is significantly greater output variability than predicted but often occurs in the opposite direction. Inflation seldom adjusts as significantly as predicted.*

A vector autoregression (VAR) analysis on each treatment is conducted to detect whether changes in the nominal interest rate have an effect on the level of output. None of the variables require detrending. A Dickey-Fuller unit root test is applied, rejecting the presence of a unit root in all cases at $p < 0.001$. The number of lags to be chosen in the HF, HH, and HFH treatments is 1 based on the optimal information criteria test. For a thorough treatment of vector autoregression methods, see Stock and Watson (2001).

More specifically, we are interested in studying the impulse responses of the nominal interest rate, inflation, and the output gap to a 2.5% exogeneous decrease in the nominal interest rate while holding the errors associated with inflation and the output gap constant. This can be achieved by imposing that the errors of all three variables are uncorrelated across equations. We estimate a recursive VAR ordered as (i) nominal interest rates, (ii) output, (iii) inflation. The interest rate is the dependent variable and is regressed on lagged values of all three variables. In the second equation, output is the dependent variable and the regressors are lagged values of all three variables plus the value of the current interest rate. Finally, the third equation describes inflation as a function of the lagged values of all three variables plus the current values of the nominal interest rate and the level of output. The recursive VAR essentially constructs the error terms. Thus, the exactly identified system appears as follows:

$$i_t = \alpha_{10} + \alpha_{11} i_{t-1} + \alpha_{12} x_{t-1} + \alpha_{13} \pi_{t-1} + \varepsilon_t^i \tag{3.9}$$

$$x_t = \alpha_{20} + \alpha_{21} i_{t-1} + \alpha_{22} x_{t-1} + \alpha_{23} \pi_{t-1} + \alpha_{24} i_t + \varepsilon_t^x \tag{3.10}$$

$$\pi_t = \alpha_{30} + \alpha_{31} i_{t-1} + \alpha_{32} x_{t-1} + \alpha_{33} \pi_{t-1} + \alpha_{34} i_t + \alpha_{35} x_t + \varepsilon_t^\pi \tag{3.11}$$

The recursive VAR structure imposes that the error terms in each regression are uncorrelated with the error term in the preceding equation. The ordering is easily justified in this experimental environment. The interest-rate rule has been set to be completely backward looking. Output depends on workers' labor supply decisions. When making their decision, they know the current nominal interest rate, wage rate and past prices. Contemporaneous values of inflation do not play a direct role in their labor decisions. Finally, firms update their price with an estimate of current household demand and knowledge of the current nominal interest rate. We assume the covariances between the variables are unrelated and estimate only their own variance.

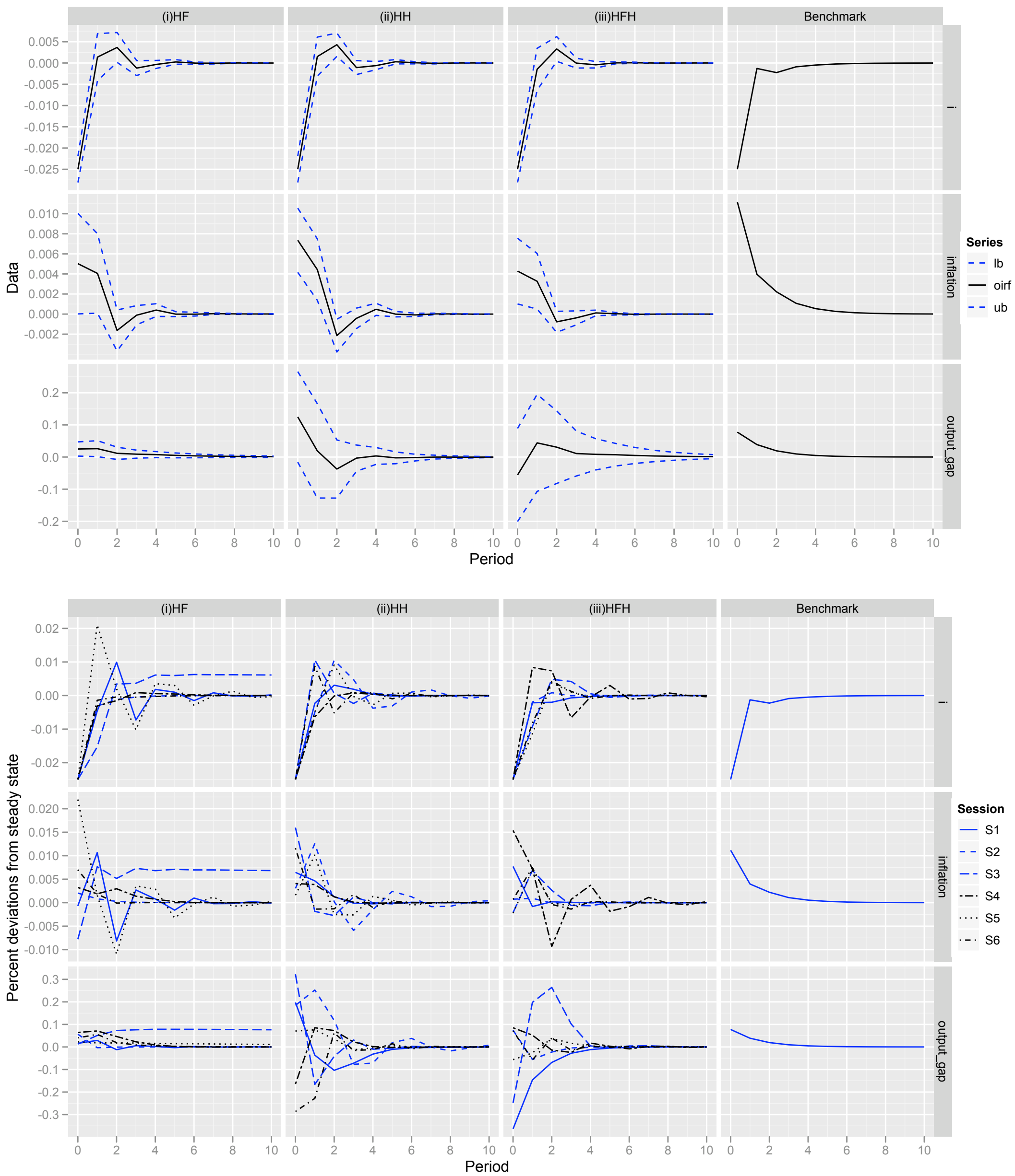
The VARs are estimated in all instances with the full sample of repetition-5 data using two methods. First we consider a data set of 84 periods, consisting of each of the 21-period repetition-5 data from the six sessions of each treatment. We also estimate VARs for individual sessions to highlight any heterogeneity and outliers that may be present. The policy shock and the resulting responses are normalized to be expansionary. Impulse response functions are presented in Figure 3.1. The top panel presents average orthogonalized impulse responses (solid line) from the aggregate data, upper and lower bounds (ub and lb) associated with a 95% confidence interval (dashed lines), and the theoretical benchmark predictions. The bottom panel presents impulse responses from individual sessions. On impact, a 2.5% decrease in the nominal interest rate generates predicted inflation of 1.1% and a predicted output gap of 7.74%. The effects of the shock last for four to five periods.

The realized nominal interest rate has a tendency to overshoot its predicted value after the first or second post shock period. This is due to the fact that inflation tends to adjust slower than predicted. In many instances it peaks a period after the shock occurs rather than on impact (eg. S1 and S3 in HF, S1 and S2 in HH, and S3 in HFH). By that point though, the shock to the nominal interest rate has begun to dissipate. The backward looking nominal interest rate increases when previous period inflation increases. With large inflation and a significantly lower residual shock, the nominal interest rate rises above its steady state value.

Human Firms

In response to an expansionary monetary shock, human firms raise their prices on average by 0.5%, less than half of the predicted adjustment. This increase in average prices is largely driven by behavior in S5, where inflation increased by 2.2%. Most sessions under price, and in S3, firms appear to respond to decreases in the nominal interest rate by decreasing prices on impact. This was followed by significant inflation) Interestingly, S2 appears to maintain steady positive inflation.

Figure 3.1: Orthogonalized impulse responses to a nominal interest rate shock



The output gap is positive and on average 2.5%, indicating that automated households increased their desired consumption and labor supply in response to an increase in the real wage. The impact on output is significantly dampened for most of the sessions because subjects did not form sufficiently large output gap expectations.

Human Households

In the human household treatment inflation rises on impact in response to the nominal interest rate shock. At the individual session level, the automated firms respond by increasing prices to generate inflation but the degree of inflation varies significantly from just below 0.1% to 1.6% and is dependent on the inflationary and output gap expectations formed by human households in the economy. The output gap increases an average 10.5% on impact while inflation increases by 0.7%. The shock leads to a significant adjustment in the output gap for all sessions, but in one-third of the cases the shock results in an initial contraction followed by an expansion of smaller magnitude.

Human Firms and Households

In the combined human firm and household treatment, the impact of the shock generates an average increase in inflation of 0.4%, with a treatment minimum of -0.2% and maximum of 1.5%. The reaction of consumers is mixed. On average, the output gap decreases by 5.6%. As in the HH treatment, there is significant variance in this estimate. Output falls by 36% in S1 but increases by 8.5% in S4. These impulse responses are all significantly different from zero on impact of the shock.

3.5.2 Subject Behavior

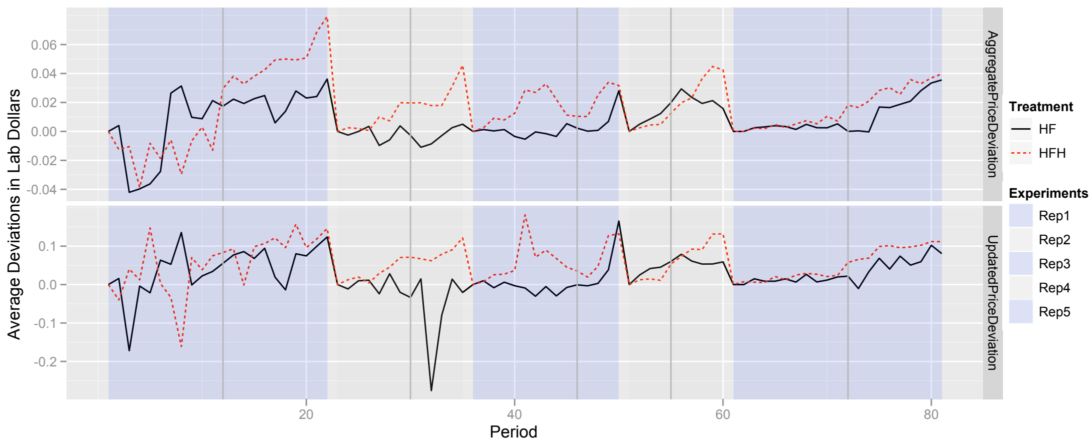
This subsection explores subjects' behavior by role. How are human firms setting prices? Do they set optimal markups and do they react to the change in interest rates? Do human households work the optimal number of hours, and do they respond to the interest rate-induced nominal wage rate change?

Finding 2: *While converging to the optimal price pre-shock after numerous repetitions, firms in both the HF and HFH consistently and significantly over-markup their output post-shock relative to theoretical predictions. Price deviations by updating firms are significantly greater in the HFH treatment.*

The top panel of Figure 3.2 displays the time series of price index deviations and the bottom panel shows the updater's price deviations in the HF and HFH treatments, averaged over the four sessions in each treatment. The start of a new repetition is denoted by a change in background color. Grey vertical lines indicate the period in which the nominal interest rate shock occurred. The solid black and dashed red indicate deviations in the HF and HFH treatments, respectively. Deviations of the price index are calculated as the difference between the realized price index and the price implied by the New Keynesian Phillips Curve given by Equation 3.8 where we interpret each quarter to correspond to one period.

Table 3.2 presents mean price deviations and standard errors in Repetition 5. The deviations are converging toward zero for both the HF and HFH treatments in the preshock phase. In the final repetition, the mean price deviation in both treatments is negligible at the 95% level (0.002 ± 0.002 for HF, 0.004 ± 0.003 for HFH). Given that the software rounds the aggregate price to two decimal places, we cannot conclude

Figure 3.2: Average price index and updater price deviations in human firm treatments(HF and HFH)



that this is a significant difference. The treatments begin to differ once the shock occurs. On impact, the mean deviation from the shock in the HF is 0.01 ± 0.012, and a Wilcoxon sign-rank test fails to reject the null hypothesis that the mean deviation is zero ($p < 0.05$). The deviation is positive and significant in the HFH. Post-shock, the mean price deviation in the HFH treatment is 1.5 times larger than in the HF, and this difference is significant.

A similar pattern arises in the updater's price deviation series. The treatments

Table 3.2: Mean price deviations in repetition 5

	Preshock	Shock	Postshock
Price Index			
HF	0.002 ± 0.001	0.01 ± 0.006	0.019 ± 0.004
HFH	0.004 ± 0.001	0.018 ± 0.009	0.030 ± 0.004
Updater's Price			
HF	0.011 ± 0.004	0.022 ± 0.020	0.055 ± 0.012
HFH	0.016 ± 0.005	0.058 ± 0.031	0.095 ± 0.009
Observations	66	6	54

Values following $\pm$ symbols are standard errors.

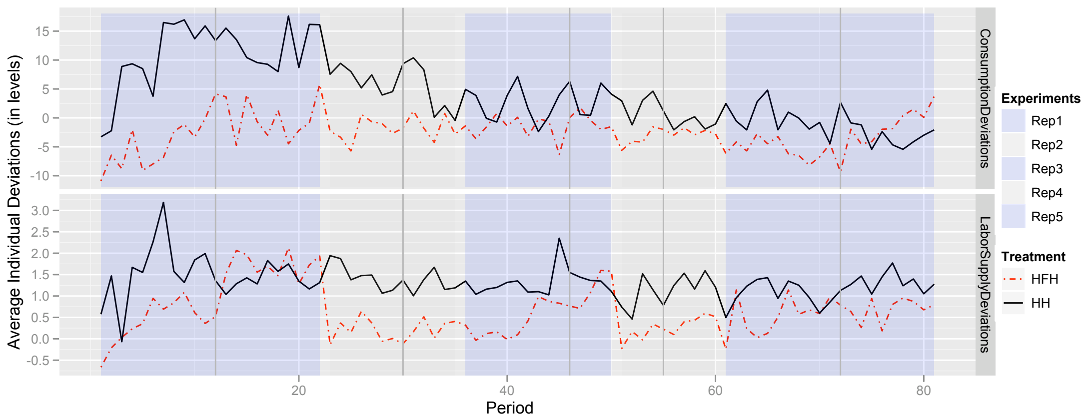
are not significantly different from each other in the pre-shock and shock periods of repetition 5. Once the shock hits, the updater's price deviation is significantly greater in the HFH treatment. Updating firms set prices that are on average 5.5 cents and 9.5 cents greater than predicted in the HF and HFH treatments, respectively.

Finding 3: *By the final repetition, consumers in both HH and HFH are still prone to underconsuming and overworking. The deviations from optimality are more pronounced in the HH treatment.*

Figure 3.3 displays the time series of average individual consumption and labor supply deviations from their predicted values across sessions in the HH and HFH treatments. Varying shaded phases indicate a new repetition. The dashed red and solid black lines represent deviations in the HF and HFH treatments, respectively. Vertical grey lines indicate the period when the exogenous interest rate shock occurred. The individual optimal supply is given by Equation 3.7. The general downward trend in consumption deviations in the HH and HFH treatment is indicative of learning. The excess labor supply in both treatments does not appear to decrease much over time.

Mean subject-level deviations from optimal behavior are presented in Table 3.3. HH households' demand for output converged to the optimal level from above over the course of the sessions. Preshock in repetition 5, mean demand is insignificantly different from its predicted level. While demand increases on impact following the exogenous decrease in the nominal interest rate, postshock demand falls significantly below its predicted value. In contrast, HH households significantly overwork for the entire experiment. In the final repetition, households overwork an average of 1.04 hours pre-shock and 1.33 hours post-shock.

Figure 3.3: Average individual consumption and labor deviations in human household treatments (HH and HFH)



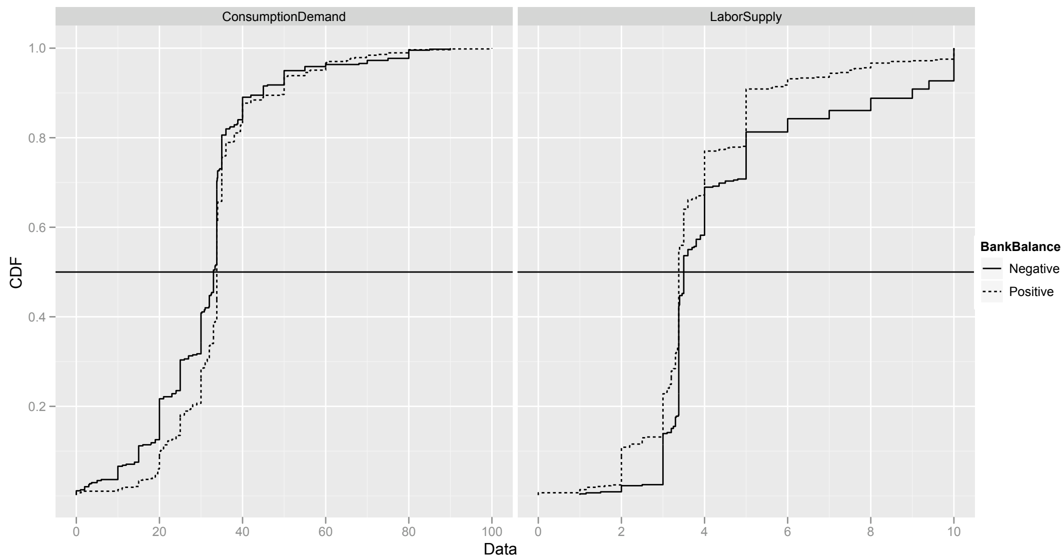
Demand deviations in the HFH treatment significantly exceed demand deviations in the HH treatment for the majority of the session. Only in the post-shock phase of the final repetition are HH demand deviations greater (and this is not significant at the 5% level). HFH households also consistently overwork throughout the session, but by significantly less than those in the HH treatment. Households only work an extra 0.52 hours preshock and 0.68 hours postshock.

Table 3.3: Mean household deviations in repetition 5

	Preshock	Shock	Postshock
Desired Consumption			
HH	-0.074 ± 0.994	2.679 ± 3.279	-3.238 ± 1.208
HFH	-5.318 ± 1.062	-9.3325 ± 2.297	-0.962 ± 1.853
Labor Supply			
HH	1.043 ± 0.144	1.129 ± 0.445	1.329 ± 0.167
HFH	0.523 ± 0.150	0.784 ± 0.966	0.680 ± 0.203
Hypothetical Labor Supply			
HH	0.741 ± 0.269	1.358 ± 0.240	0.328 ± 0.292
HFH	-0.858 ± 0.341	-1.330 ± 1.125	-0.069 ± 0.517
Observations	66	6	54

Values following $\pm$ symbols are robust standard errors, clustered at the session level.

Figure 3.4: Empirical CDFs of observed output demand and labor supply decisions - pooled across HH and HFH in repetition 5



Given a subject's desired consumption level, does he or she supply the appropriate amount of labor? The results in the final repetition suggest no. Compared to the first order conditions specified for the household, subjects significantly over (under) work in the HH (HFH) preshock phase. While the trend continues post-shock, the deviations from optimality are not statistically significant.

Indebted subjects behave differently than those who enter a period with positive bank balances. Figure 3.4 displays the empirical cumulative distribution functions of repetition 5 consumption and labor supply decisions across treatments. The horizontal line indicates the behavior of the median subject. The solid and dashed lines indicate decisions for negative and positive bank account subjects, respectively. 56% of observations come from households with positive bank balances. Households with negative bank balances consume relatively less and work relatively more. Households with positive bank balances supply an average 3.88 hours and demand 36.02

units, creating an excess labor supply of 7%. Households with negative bank balances supply an average 4.49 hours and demand 34.84 units, with an excess labor supply of 22%. Table 3.4 presents random effects panel regressions evaluating the effect of being indebted on output demand and labor supply.[8] Indebtedness is significantly associated with lower demand and increased labor supply.

We also consider the effect the size of bank balances have on demand and labor supply by indebtedness. Table 3.5 presents the random effect panel regression

[8]The estimating equations are given by $C_{it} = \alpha + \beta_1 Indebted_{it} + \beta_2 E_t C_{t+1} + \beta_3 r_t + \mu_i + \varepsilon_{it}$ and $N_t = \alpha + \beta_1 Indebted_{it} + \beta_2 RW_t + \beta_3 C_{it} + \mu_i + \varepsilon_{it}$. The panel data is estimated using random effects regressions, where we assume that there are time-constant attributes of unique individuals that are the result of random variation and uncorrelated with the individual regressors. where we allow each individual to have a different β_1. Assuming the distribution of μ_is is normal, we can find the most likely μ_i for each individual given their behavior. This approach is commonly used in analyzing experimental data to characterize individual heterogeneity and avoid aggregation bias, (e.g. Wilcox 2006).

Table 3.4: Aggregate Demand and Labor Supply - Random Effects Models

	Output Demand		Labor Supply	
	(1)	(2)	(3)	(4)
indebted	-3.283*	-4.086**	0.578***	0.385**
	(1.282)	(1.274)	(0.125)	(0.148)
$E_t C_{t+1}$	0.014	-0.030		
	(0.096)	(0.028)		
r_t	-24.613*	-61.783		
	(12.431)	(62.544)		
RW_t			0.078	0.382
			(0.239)	(0.252)
C_t			0.033***	0.020
			(0.006)	(0.014)
α	36.247***	35.695***	2.092	-0.049
	(2.456)	(1.239)	(1.983)	(1.784)
Sample	Full	Rep 5	Full	Rep 5
Observations	3582	979	3887	1007

indebted is a dummy variable that takes the value of 1 if a subject enters the period with debt and 0 otherwise.
Robust standard errors in parentheses, clustering at the session level.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.5: Effect of Entering Bank Balance on Demand and Labor Supply - Random Effects

	Output Demand				Labor Supply			
	$Bank \geq 0$		Bank<0		$Bank \geq 0$		Bank<0	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Bank_t$	0.136*	0.167	-0.107***	-0.065	-0.005	0.009	-0.076***	-0.044***
	(0.060)	(0.102)	(0.026)	(0.087)	(0.003)	(0.007)	(0.007)	(0.005)
$E_t C_{t+1}$	0.010	-0.034*	-0.041	-0.322***				
	(0.116)	(0.017)	(0.104)	(0.082)				
r_t	-33.402*	-75.512	-3.535	-39.356				
	(15.468)	(64.840)	(11.692)	(73.597)				
RW_t					-0.128	-0.141	0.060	0.357
					(0.140)	(0.192)	(0.232)	(0.534)
C_t					0.038***	0.049***	0.010	-0.004
					(0.005)	(0.012)	(0.019)	(0.016)
α	34.691***	34.279***	34.505***	41.547***	3.674**	3.328	2.914	1.012
	(3.226)	(1.171)	(3.234)	(3.073)	(1.313)	(1.784)	(1.809)	(4.317)
Sample	Full	Rep 5	Full	Rep 5	Full	Rep 5	Full	Rep 5
Observations	1810	511	1545	419	1953	520	1692	438

Robust standard errors in parentheses, clustering at the session level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

results. For every extra lab dollar an indebted subject owes, he works an additional 0.044 hours ($p < 0.001$). Higher debt is not associated with a stastistically significant change in demand. Subjects with positive bank balances do not adjust their demand and labor supply decisions significantly with increased balances.

We attribute this overall excess labor supply to debt aversion. In most sessions, at least one student asked the experimenter how to get themselves out of debt as the experiment progressed. Many subjects expressed frustration after the experiment that they had difficulty getting out of debt. Moreover, in follow up discussions with subjects with large bank balances, we were told that debt was "bad". One subject commented that "I would never want to be in debt! I always tried to accumulate money." This is intriguing as subjects were not induced with a demand for money balances. Because of this aversion to debt, the overall welfare in the economy was lower.

Finding 4: *There is significant variability in household reactions to the nominal interest rate shock in the final repetition. While the largest share of subjects increase both consumption and leisure, many subjects exhibit no response or adjust in ways that are inconsistent with predicted behavior.*

Behavior among households in HH and HFH are similar. Using a Wilcoxon rank-sum test, the null hypothesis that average desired consumption decisions by HH and HFH households are identical cannot be rejected (p=0.4232). We obtain the same result for average labor supply decisions. Table 3.6 presents the percentage of subjects adjusting their consumption and labor behavior in one of nine combinations post-shock. Data is pooled across HH and HFH households for repetition 5. The average

Table 3.6: Distribution of HH and HFH behavior during the shock in Repetition 5

<table>
<tr><td colspan="3"></td><td colspan="3">Labor Supply</td></tr>
<tr><td colspan="3"></td><td>+</td><td>0</td><td>-</td></tr>
<tr><td rowspan="6">Consumption</td><td rowspan="3">HH</td><td>+</td><td>0.46
(0.59, 0.49)</td><td>0.08
(1.14, 0)</td><td>0.08
(0.05, -0.05)</td></tr>
<tr><td>0</td><td></td><td>0.21
(0, 0)</td><td></td></tr>
<tr><td>-</td><td></td><td>0.08
(-0.10, 0)</td><td>0.08
(-0.17, -0.30)</td></tr>
<tr><td rowspan="3">HFH</td><td>+</td><td>0.25
(0.26, 0.22)</td><td>0.08
(0.10, 0)</td><td>0.17
(0.66, -0.29)</td></tr>
<tr><td>0</td><td></td><td>0.29
(0, 0)</td><td></td></tr>
<tr><td>-</td><td>0.04
(-0.05, 0.03)</td><td>0.04
(-0.64, 0)</td><td>0.13
(-0.24, -0.38)</td></tr>
</table>

percentage change in desired consumption and labor supply are provided in brackets below. Table 3.7 provides a breakdown of behavior for each treatment.

We can classify households into four different categories: “Positive”, “Inelastic”, “Negative”, and “Mixed”. Positive households increase both consumption and labor in response to the shock. They make up the largest shares of HH and HFH subjects. 36% of households increased both their consumption and labor supply as predicted by our theoretical benchmark. An additional 25% of subjects can be classified as in-

Table 3.7: Distribution of pooled household behavior during the shock in Repetition 5

<table>
<tr><td colspan="2"></td><td colspan="3">Labor Supply</td></tr>
<tr><td colspan="2"></td><td>+</td><td>0</td><td>-</td></tr>
<tr><td rowspan="3">Consumption</td><td>+</td><td>0.36
(0.47, 0.40)</td><td>0.08
(0.62, 0)</td><td>0.13
(0.45, -0.21)</td></tr>
<tr><td>0</td><td></td><td>0.25
(0, 0)</td><td></td></tr>
<tr><td>-</td><td>0.02
(-0.05, 0.03)</td><td>0.06
(-0.27, 0)</td><td>0.10
(-0.21, -0.35)</td></tr>
</table>

Values in brackets refer to the percentage change in consumption and labor on impact of shock.

elastic. These individuals make no changes to their consumption and labor decisions on impact of the shock. 10% of the subjects respond negatively to the nominal interest rate shock by decreasing both their desired consumption and labor supply. Finally, the mixed subjects, collectively making up 29% react by not adjusting consumption and labor in the same direction.

Subjects that do adjust their consumption and labor decisions overreact when the shock occurs. The size of adjustment should be 7.74% to both consumption and labor, yet average adjustments are more than double that in the majority of the outcomes. Subjects who increase their consumption and labor do so by an average 47% and 40%, respectively. This can provide some insight into our VAR responses in Figure 3.1. In the HH treatment, S1-S3's output gap was more than twice the theoretical benchmark on impact of the shock. For example, in S3 the 32% output gap is attributed to three of four subjects responding to the shock by increasing both consumption and labor by (150%, 25%), (13%, 13%), (50%, 50%), (0%, 0%), respectively. With plenty of extra consumption demand being met with an increase in the labor supply, output can actually increase. Similarly, the 36% decrease in the output gap in S1 of HFH is due three of four subjects responding by decreasing both consumption and labor ((-1%,-1%), (-40%, -55%), (-23%, -50%), (0%,0%)). Because of the significantly larger decrease in labor supply, output produced fell more than output demand and resulted in excess demand. Not all orders were satisfied.

Another interesting case is S5 in HFH that experienced a moderate 5.6% drop in the output gap on impact of the shock. While all subjects significantly increased their consumption demand, three-fourths of them also decreased their labor supply ((33%, 12%), (71%, -40%), (133%, -29%), (50%, -40%)). The demanded output could not be produced with insufficient labor and the economy dipped in response to the expansionary shock. The composition of households in each economy is key in anticipating economic dynamics; those with a relatively larger share of positive households will see large increases.

Finding 5: *In the HH treatment, increases in the real and nominal interest rates lead to quantitatively large and significant decreases in demand. Households react more to changes in the nominal interest rate than to expected inflation. The effect of monetary policy is unclear in the HFH treatment where only expectations of higher future consumption lead to small but significant increases in demand.*

Movement in the nominal interest rate theoretically induces households to adjust their tradeoff of current for future consumption. This behavior is governed by the elasticity of intertemporal substitution, $\frac{1}{\sigma}$. While we have induced subjects with identical, highly elastic preferences, subjects may bring their own intertemporal preferences into the lab. We can estimate the average and individual household preference parameter using the theoretical first order conditions from the household's problem:

$$
\begin{aligned}
C_t^{-\sigma} &= P_t \lambda_t \\
N_t^{\eta} &= W_t \lambda_t \\
\lambda_t &= \beta(1+i_t) E_t \lambda_{t+1}
\end{aligned}
$$

Taking natural logs of this system yields

Table 3.8: Aggregate Demand Elasticities - Random Effects

$\Delta \ln C_{t+1}$	HH				HFH			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\Delta \ln E_{t+1} C_{t+2}$	-0.046	-0.124	-0.069	-0.137	-0.051	0.214^{***}	-0.063	0.218^{***}
	(0.138)	(0.865)	(0.135)	(0.866)	(0.109)	(0.023)	(0.099)	(0.026)
$\Delta \ln r_{t+1}$	-0.173	-5.232^{***}			-0.784^{*}	1.507		
	(0.408)	(1.395)			(0.361)	(2.108)		
$\Delta \ln i_{t+1}$			-0.523	-7.275^{**}			-2.114	1.936
			(0.748)	(2.685)			(1.516)	(2.558)
$\Delta \ln E_{t+1} \pi_{t+2}$			0.044	2.350			0.331	-0.375
			(0.339)	(3.257)			(0.209)	(0.539)
α	-0.004	-0.009	-0.004	-0.009	-0.002	-0.003	-0.001	-0.003
	(0.007)	(0.010)	(0.007)	(0.010)	(0.007)	(0.007)	(0.007)	(0.007)
Sample	Full	Rep 5	Full	Rep 5	Full	Rep 5	Full	Rep 5
Observations	1571	449	1571	449	1561	451	1561	451

Robust standard errors in parentheses, clustering at the session level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.9: Aggregate Labor Supply Elasticities - Random Effects Models

$\Delta \ln N_{t+1}$	HH				HFH			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\Delta \ln C_{t+1}$	0.141**	0.110	0.141**	0.109	0.157	0.133	0.157	0.133
	(0.054)	(0.107)	(0.054)	(0.106)	(0.088)	(0.078)	(0.088)	(0.079)
$\Delta \ln RW_{t+1}$	-0.130	0.938			-0.654	-0.739		
	(0.522)	(0.530)			(0.854)	(1.153)		
$\Delta \ln W_{t+1}$			-0.123	0.617			-0.617	-0.672
			(0.521)	(0.522)			(0.871)	(1.153)
$\Delta \ln P_{t+1}$			0.697*	2.798			1.274*	-1.472
			(0.306)	(1.541)			(0.607)	(1.582)
α	0.002	0.003	0.001	-0.001	0.009	0.013***	0.007	0.017***
	(0.004)	(0.003)	(0.004)	(0.003)	(0.005)	(0.004)	(0.007)	(0.005)
Sample	Full	Rep 5	Full	Rep 5	Full	Rep 5	Full	Rep 5
Observations	1571	449	1571	449	1561	451	1561	451

Robust standard errors in parentheses, clustering at the session level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

$$lnC_t = -\frac{1}{\sigma} lnP_t - \frac{1}{\sigma} ln\lambda_t \tag{3.12}$$

$$lnN_t = \frac{1}{\eta} lnW_t + \frac{1}{\eta} ln\lambda_t \tag{3.13}$$

$$ln\lambda_t = ln\beta(1+i_t) + lnE_t\lambda_{t+1} \tag{3.14}$$

Rewriting the Euler equation in log form as:

$$lnC_t = -\frac{1}{\sigma} ln\beta(1+i_t) + \frac{1}{\sigma}(lnP_{t+1} - lnP_t) + lnEC_{t+1}$$

Defining $\Delta x_{t+1} = x_{t+1} - x_t$, we have that

$$\begin{aligned} \Delta lnC_{t+1} &= lnC_{t+1} - lnC_t \\ &\approx \Delta lnE_{t+1}C_{t+2} - \frac{1}{\sigma}(\Delta lnr_{t+1}) \end{aligned}$$

where $lnr_t = lni_t - lnE_t\pi_{t+1}$ is the Fisher equation and defines the real interest rate in logs. We estimate the following model under random effects with our panel data for both the full sample and final repetition:[9]

$$\Delta lnC_{it+1} = \alpha + \beta_1 \Delta lnE_{t+1}C_{i,t+2} + \beta_2 \Delta lnr_{t+1} + \mu_i + \varepsilon_{it} \tag{3.15}$$

where β_2 is the estimated real interest rate elasticity of demand. We expect $\beta_1 > 0$ and $\beta_2 < 0$, and if subjects behave according to their inducements, $\beta_2 = -2$.

We also consider a modified estimating equation

[9] A Hausman test of the null hypothesis that the coefficients estimated by the efficient random effects estimator are the same as the one estimated by the consistent fixed effects estimator cannot be rejected ($p > 0.99$ in all cases). We only report the random effects results.

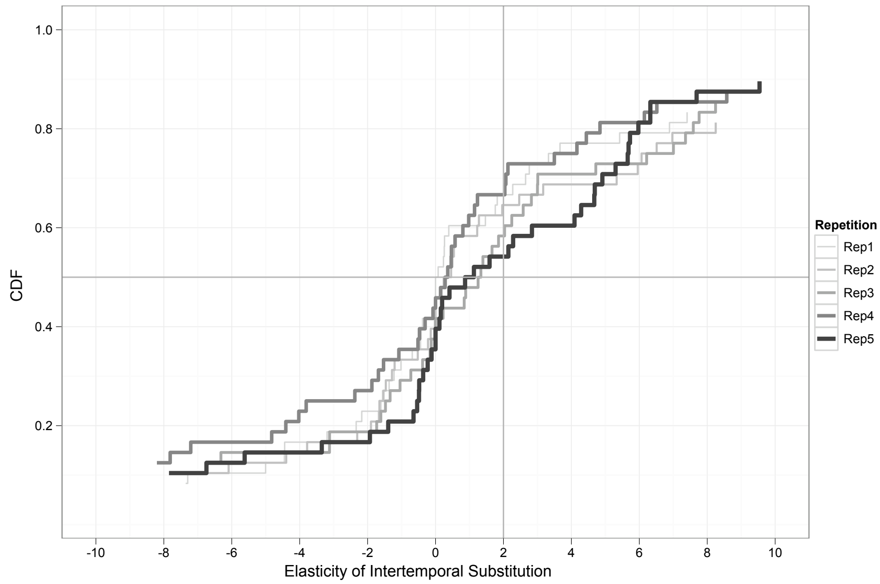
$$\Delta lnC_{it+1} = \alpha + \beta_1 \Delta lnE_{t+1}C_{i,t+2} + \beta_2 \Delta ln i_{t+1} + \beta_3 \Delta lnE_{t+1}\pi_{i,t+2} + \mu_i + \varepsilon_{it} \quad (3.16)$$

that evaluates the responsiveness of demand to changes in the nominal interest rate. A subject exhibiting "interest rate illusion" would respond to changes in the nominal interest rate without considering its purchasing power, ie. β_2 would be significantly different from zero and β_3 would be close to zero.

Table 3.8 presents the regression results from the HH and HFH treatment. Specifications (1), (2), (5) and (6) consider real interest rate elasticities of demand while specifications (2), (3), (7) and (8) consider nominal interest rate elasticities of demand. Robust standard errors are reported. First, the nominal and real interest rates variables have the correct sign in most of our specifications. The exception is in the HFH repetition 5 results, where increases in the nominal and real interest rates lead to increases in consumption. This is not a statistically significant result.

An increase of the real interest has a significant and negative effect on current consumption in the final repetition of the HH sessions. Overall consumption tends to over-react; a 1% increase in the real interest rate (eg. from 2% to 3%) results in a 5% increase in output. While subjects react significantly to nominal interest rate changes, they are not as quantitatively or significantly responsive to changes in expected inflation. A 95% confidence interval of $\hat{\beta}_3$ includes 0. The effect of an increase in the real interest rate in the final repetition of the HFH treatment is unclear. A 1% increase in the real rate leads households to increase consumption by 1.5%, though this result is not statistically significant. Interestingly, in specifications (6) and (8) where only the final repetition is considered, expected future consumption has a small but significant effect. In all other cases, future consumption is statistically

Figure 3.5: Empirical CDFs of observed intertemporal elasticities of substitution (HH and HFH pooled)



irrelevant for for current consumption.

Elasticities of intertemporal substitution are estimated for each household in each repetition and plotted as an empirical cumulative distribution functions in Figure 3.5. The heavier and darker lines denote later repetitions. The vertical grey line indicates the induced elasticity of intertemporal substitution, $\frac{1}{\sigma} = 2$. The horizontal grey line at 0.5 denotes the elasticity of the median subject. Plotted are the $-\beta_2$ from each individual subject's regression Equation 3.15. The distribution of elasticities appears to be converging toward the induced value after numerous repetitions.

The median subject in the final repetition has an estimated elasticity of $\hat{\frac{1}{\sigma}} = 0.87$, implying that a decrease in the real interest rate of 1% increases output by 0.87%. More than 35% of repetition 5 households respond to a decrease in the interest rate by contracting their current consumption, counter to what the theory predicts. Approximately 60% of subjects over-react in either direction, where $\left|\hat{\frac{1}{\sigma}}\right| > 2$. This coincides with the dramatic changes in the output gap displayed in Figure 3.1.

Finding 6: *There is significant variance in labor supply responses to changes in real and nominal wages. The average household responds to increases in the real wage by decreasing their labor supply, though this is neither quantitatively large or statistically significant.*

While experimental subjects are induced with certain behavioral parameters and are incentivized to optimize their problems under specific behavioral assumptions, it is not uncommon for them to deviate from the imposed inducements. Significant and persistent deviations from inducements provide reason to question the experimental model's calibration.

The Frisch elasticity of labor supply is estimated for consumers in the HH and HFH treatments following Altonji (1986). Taking logs of the intratemporal consumption-leisure tradeoff, we have

$$\begin{aligned} lnN_t &= \frac{1}{\eta} lnW + \frac{1}{\eta}\left(-\sigma lnC - lnP\right) \\ &= \frac{1}{\eta}\left(lnW_t - lnP_t\right) - \frac{\sigma}{\eta} lnC_t \end{aligned}$$

Taking log differences and carrying forward yields

$$\Delta lnN_{t+1} = \frac{1}{\eta}\left(\Delta lnRW_{t+1}\right) - \frac{\eta}{\sigma}\left(\Delta lnC_{t+1}\right)$$

where $lnRW_t = lnW_t - lnP_t$ is the real wage in logs.

We again use random effects models to estimate the effect of changes in the real wage on individual labor supply:

$$\Delta lnN_{i,t+1} = \alpha + \gamma \Delta lnRW_{t+1} + \phi \Delta lnC_{i,t+1} + \mu_i + \varepsilon_{i,t+1} \tag{3.17}$$

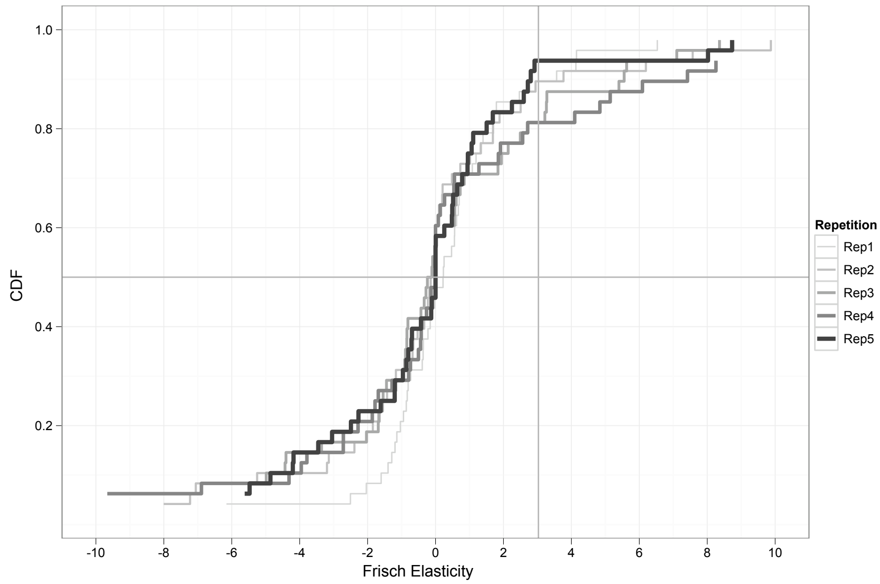
where α is a constant, $\phi = -\frac{\sigma}{\eta}$ and ε_{it} is a normally distributed error. $\gamma = \frac{1}{\eta}$ is the Frisch elasticity of labor supply and is the parameter of interest. We also consider the possibility for money illusion, whereby subjects focus on nominal wages rather than real wages when making labor decisions:

$$\Delta lnN_{i,t+1} = \alpha + \gamma_1 \Delta lnW_{t+1} + \gamma_2 \Delta lnP_{t+1} + \phi \Delta lnC_{i,t+1} + \mu_i + \varepsilon_{i,t+1} \tag{3.18}$$

A positive and significant coefficient for γ_1 while γ_2 is insignificant suggests that subjects fail to consider the real value of their income. In the experiments, households are induced to behave such that $\gamma = 3.03$ and $\phi = -1.515$. Table 3.9 presents aggregate elasticities for the HH and HFH treatments. Specifications (1), (2), (5), and (6) are based on regression Equation 3.17. Specifications (3), (4), (7) and (8) are based on regression Equation 3.18. We consider both the full sample and repetition 5. Robust standard errors are clustered by session.

Increases in output demand are associated with small but significant increases in labor supply in the HH treatment. A 10% increase in demand coincides with a 1.4% increase in output. This is an order of magnitude smaller than predicted. This is consistent with our earlier findings that labor supply tends to adjust less than 1-for-1 with consumption on impact of the shock. While we find that output demand and labor demand are positively correlated in both HH and HFH, the relationship is only statistically significant in the former treatment.

Figure 3.6: Empirical CDFs of observed Frisch elasticities (HH and HFH pooled)



There is significant variability in households' reactions to changes in the real wage, nominal wage, and price index. We obtain negative estimates for γ and γ_1 and relatively large standard errors, making it difficult to make inference on the direction of behavior at the 95% confidence level. For many subjects, however, increases in the real and nominal wage lead to decreases in their labor supply. There is no evidence of sustained money illusion.

Such low average elasticities of labor supply to changes in the real wage do not line up with our findings that aggregate output was highly responsive to changes in the nominal interest rate. We instead estimate labor supply elasticities at the individual level using the full sample of data for each repetition. The empirical cumulative distribution function of pooled observed Frisch elasticities are given in Figure 3.6. The vertical grey line indicates the induced Frisch elasticity of $\frac{1}{\eta} = 3.03$. Pairwise Mann-Whitney test fail to reject the null hypothesis that the HH and HFH distributions are identical in the final repetition ($p = 0.521$), so we report the pooled distribution. The horizontal grey line at 0.5 denotes the elasticity of the median subject. With stationary repetition, the distribution of elasticities appears to be converging in toward zero, and by the final repetition, the median subject is completely unresponsive to changes in the real wage ($\frac{\hat{1}}{\eta} \approx 0$). 23% of subjects are highly elastic to real wage changes, with $\left|\frac{\hat{1}}{\eta}\right| > 3.03$.

3.5.3 Expectations

Finding 7: *Expectations formed on impact of the shock and in the postshock phase are biased downward. Post-shock, subjects exhibit considerable difficulty forming expectations on the output gap, though they appear to be improving over time. Previous wages are an important factor in wage forecasts, but past prices do not significantly affect expectations. Subjects simplify the forecasting task by relying on their expectation for current wages and prices to form their future expectations.*

Rational expectations play an important role in the standard New Keynesian model. If agents do not exhibit rational expectations, dynamic paths of key economic variables such as output and inflation will differ from theoretical predictions. To test whether subjects' bias their expectations away from the realized value in the final experiment, we consider the following models:

$$\begin{aligned} E_t x_{t+1} - x_{t+1} &= \alpha_x \\ E_t \pi_{t+1} - \pi_{t+1} &= \alpha_\pi \end{aligned}$$

where α_π and α_x are constants that equal zero under rationality. Estimated α_x and α_π

Table 3.10: Estimated expectation bias in repetition 5

	Preshock	Shock	Postshock
	Estimated expectation bias		
Output Gap			
HF	-0.003 ± 0.002	-0.070 ± 0.008	0.012 ± 0.004
HH	-0.006 ± 0.002	-0.023 ± 0.006	0.006 ± 0.003
HFH	0.021 ± 0.010	0.040 ± 0.075	0.042 ± 0.018
Inflation			
HF	0 ± 0	-0.009 ± 0.002	-0.001 ± 0.001
HH	0 ± 0	-0.005 ± 0.003	0 ± 0.001
HFH	0 ± 0	0.001 ± 0.001	0 ± 0
	Share of subjects with accurate expectations		
Output Gap			
HF	0.90	0.00	0.14
HH	0.90	0.06	0.42
HFH	0.71	0.07	0.37
Inflation			
HF	0.96	0.06	0.85
HH	0.98	0.08	0.86
HFH	0.95	1.00	0.92
	Observations		
HF	195	16	110
HH	200	15	107
HFH	425	38	285

Note that the median expectations used to calculate realized inflation and output gap are dropped from the estimation.
Values following ± symbols are standard errors.

for each treatment and phase are presented in Table 3.10. The output gap estimates are mostly significant at the 5% level. Pre-shock, biases in the output gap are negligible with the exception of the HFH treatment where there is a significant upward bias. On impact of the shock and the periods thereafter, subjects in the HFH continue to expect overly high output gaps. In the HF and HH treatments, subjects under forecast the output gap when the shock occurs. Following the shock, HF expectations are slightly biased upward.

The majority of the inflation expectation bias estimates are not statistically significant at the 5% level. Quantitatively, by the final repetition, subjects are forming unbiased inflation expectations. This is not particularly surprising; the price index did not fluctuate nearly as much as the output gap and forecasts were more easily made.

Empirical CDFs in Figures 3.7 and 3.8 describe the distribution of the observed deviations in output gap and inflation expectations from the realized value and Table 3.10 presents the percentage of subjects with accurate expectations in each phase of repetition 5. We define accurate to being within less than 0.01 absolute units from the realized value. The vast majority of subjects form accurate expectations in the preshock phase. When the shock occurs, subjects in the HF and HH treatments have significant difficulty forecasting the next period's output gap and inflation. Their accuracy improves in the post-shock phase, though significantly more for inflation forecasts.

To test whether subjects are forming expectations adaptively post-shock, we run the following random effects model

$$E_t Y_{it} = \alpha + \beta_1 Y_{t-1} + \beta_2 Type + \beta_3 Type \times Y_{t-1} + \mu_i + \varepsilon_{it}$$

Figure 3.7: Empirical CDFs of observed inflation expectation deviations in each phase

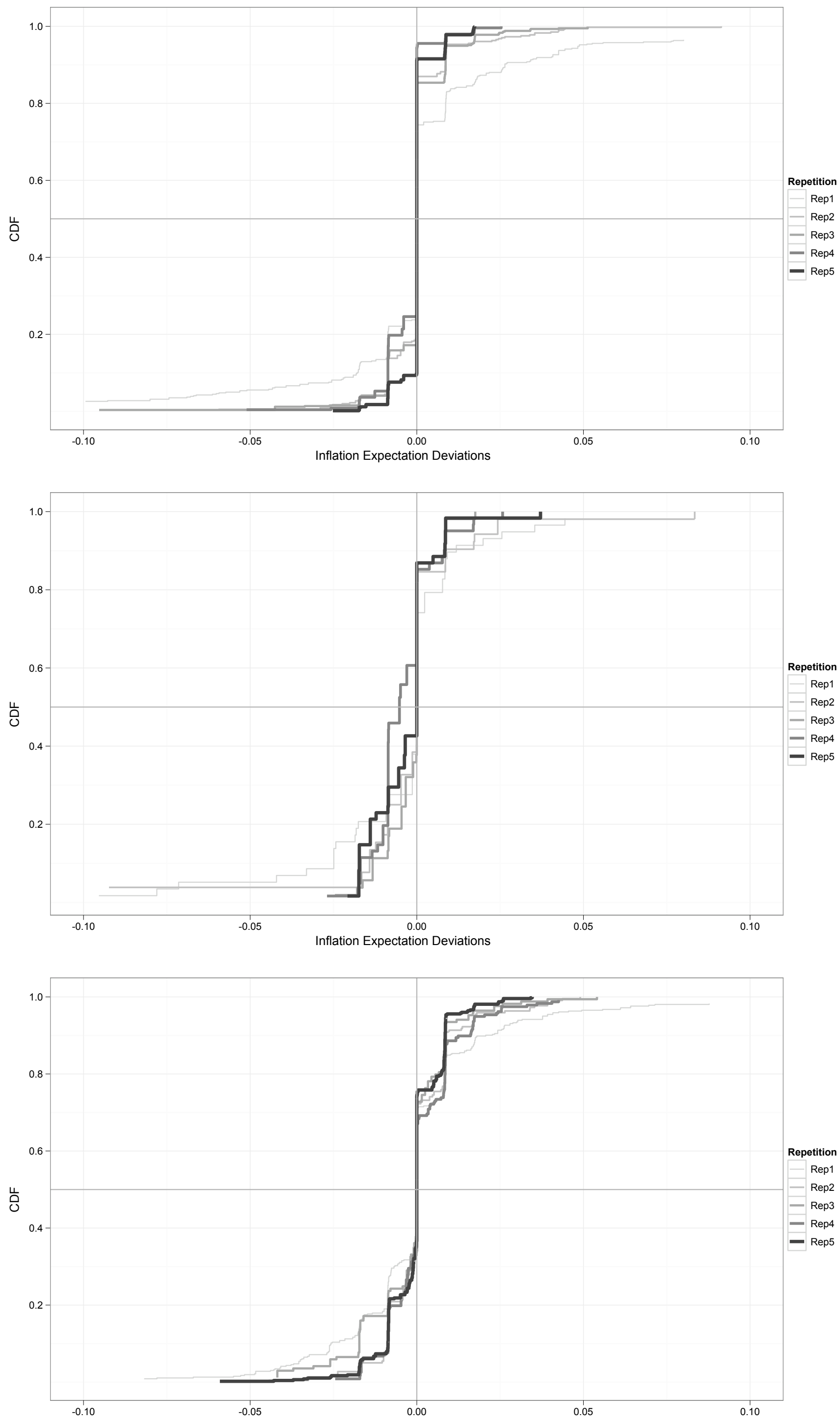
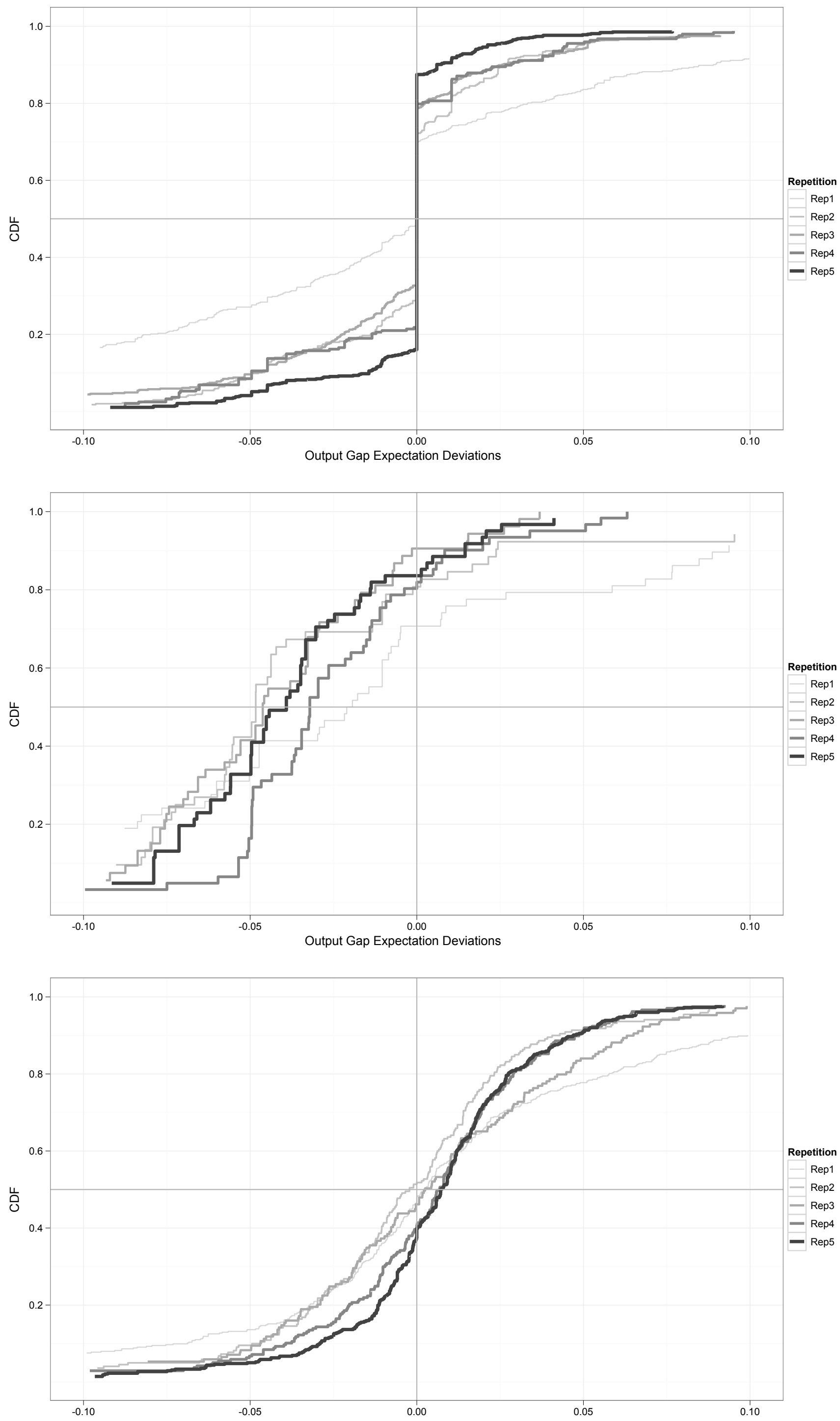


Figure 3.8: Empirical CDFs of observed output gap expectation deviations in each phase



where E_tY_{it} is either E_tW_t or E_tP_t , Y_{t-1} is either realized wages W_{t-1} or prices P_{t-1} from the previous period, *Type* is a dummy variable that takes the value of 1 if a subject plays the role of a firm and 0 otherwise, and μ_i is assumed to be distributed normally with zero mean and constant variance. If subjects consistently formed backward looking expectations, we would expect to find $\beta_1 = 1$ and $\alpha = \beta_2 = \beta_3 = 0$. The regression is run on period 13-21 data after the shock occurs in $t = 12$. Results are presented in Table 3.11.

We find that subjects do form expectations adaptively and previous nominal wages are an important determinant of current wage expectations. The estimate on last period wages is $\beta_1^W = 0.671$ ($p < 0.001$) with a 95% confidence interval of ± 0.324. Note that 1 is just barely inside this interval and we cannot reject the null hypothesis that $\beta_1^W = 1$. The estimate on the constant $\alpha = 3.496$ is large and statistically significant at the 5% level. Last period prices do not have a significant effect on expectations. The estimate on last period's price level is $\beta_1^P = -0.815$ ($p = 0.475$) and does not include 1 in its 95% confidence interval. The coefficients α, β_2, and β_3 are all statistically insignificant and include zero in their 95% confidence interval. Overall, wage and price expectations appear to be identical across households and firms in the post-shock phase. Our findings suggest that subjects form adaptive expectations on wages but not on prices.

Expectations on wages and prices for the current period significantly determine expectations for the following period. We run an alternative random effects model:

$$E_tY_{it+1} = \alpha + \beta_1 E_tY_t + \beta_2 Type + \beta_3 Type \times E_tY_t + \mu_i + \varepsilon_{it}$$

where the dependent variable is either E_tW_{t+1} or E_tP_{t+1} and the regressor E_tY_t is the expectations E_tW_t or E_tP_t. The estimates from this regression find $\beta_1^W = \beta_1^P = 0.998$

Table 3.11: Estimated adaptive expectations in post-shock phase of repetition 5

Regressor	EW	EP	EW1	EP1
lwage	0.671***			
	(0.165)			
type	-0.280	-1.821	-0.0984	0.00658
	(1.930)	(1.334)	(0.209)	(0.0231)
lwagetype	0.0145			
	(0.191)			
lprice		-0.815		
		(1.142)		
lpricetype		1.565		
		(1.146)		
EW			0.998***	
			(0.00274)	
wagetype			0.00982	
			(0.0203)	
EP				0.998***
				(0.00209)
pricetype				-0.00494
				(0.0198)
α	3.496*	2.118	0.00268	0.00218
	(1.655)	(1.330)	(0.0291)	(0.00208)
Observations	556	556	556	556
Wald χ^2	70.21	68.82	135356.77	318088.54
R^2	0.2409	0.100	0.9959	0.9973

Robust standard errors in parentheses, clustering at the session level

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

($p < 0.001$). We cannot reject the null hypothesis that $\beta_1^W = \beta_1^P = 1$. All other coefficients are small and statistically insignificant. Due to insufficient observations, we cannot run the model on our period 12 data. We do find that the expected percentage change in nominal wages and prices on impact is 0.001% for both. Moreover, 63% of expected wage inflations and 81% of expected price inflation predictions are equal to zero on impact of the shock, and 58% of subjects expect no change in the output gap when the nominal interest rate changes.

3.6 Discussion

The findings from this experiment suggest that the New Keynesian framework predicts many aspects of behavior in an experimental economy reasonable well. Output does increase in the majority of our sessions and prices move in the correct direction and the median subject's expectations are not significantly biased in most instances. In sessions where the output decreases on impact of the expansionary shock, the economies generally rebound later to experience a positive output gap. The median experiences of subjects well matches the predictions of the model. Moreover, there is considerable stability in this environment under a simple Taylor rule after considerable learning. In only one final repetition session did the economy not converge back to its original steady state. This makes us confident that the lab can serve as a promising tool to study further general equilibrium environments.

At the same time, considerable subject level heterogeneity leads to vastly different responses in each session. An important finding of this experiment is that households' revealed preferences differ substantially despite our inducements of identical preferences. The majority of subjects do not respond to expansionary policy with significant increases in labor supply and output demand. Those that do respond, however, do so far more than predicted, and this results in large changes in the output gap. Many subjects respond to increases in the real wage by cutting back consumption and labor. In many instances, heterogeneity in behavior leads to clashes. Subjects who want to consume substantially larger amounts are often limited by the lack of labor supply and output in the economy. In other instances, subjects that wish to work more were often left underemployed due to a lack of consumer demand in the market.

Subjects exhibit a high degree of rationality in the preshock phases after numerous repetitions. This is not particularly surprising, since they had familiarized themselves with the steady state values. Subjects still have considerable difficulty forming accurate forecasts on impact of the shock, and thereafter when forecasting the output gap. This challenge in forecasting is consistent with much experimental and empirical work suggesting that individuals do not generally form rational expectations. Heuristics such as assuming zero wage and price adjustment were used to simplify their one-period ahead forecasts post-shock. While subjects are capable of forming rational expectations, they do not adapt quickly post-shock.

It is imperative that research in general equilibrium laboratory experiments continues to develop. Understanding adaptive agent behavior as it relates to the macroeconomy is critical in moving beyond the equilibrium analysis that is the focus of our benchmark models. As this experiment demonstrates, learning plays an important role in macroeconomic dynamics. Even with multiple repetitions subjects had considerable difficulty forming rational expectations and optimal consumption-leisure decisions. In developing this tool further, we must acknowledge the need for greater stationary repetition and a resetting of the environment to facilitate an effective test of theory. Given that the observed dynamics are driven primarily by heterogeneous households, our recommendation for future extensions is to automate behavior of the firm and focus on consumer behavior within a general equilibrium environment. We also suggest introducing alternative labor markets that allow for negotiation of the nominal wage, as this has the potential for considerably different outcomes. Current work includes incorporating an asset market where the opportunity for asset price bubbles exists. Such an environment allows for testing of different policy schemes to deflate bubbles. We are also extending this interface to study central bank policies aimed at influencing agents' expectations as a means of reversing dynamics toward the zero lower bound. These are two aspects of policy that lend themselves to laboratory experimentation.

Chapter 4

The Role of Money Illusion in Nominal Price Adjustment

Ernst Fehr and Jean-Robert 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. Janet Yellen and George Akerlof (2006), Edmund Cannon and Giam Cipriani (2006), Markus Brunnermeier and Christian Julliard, (2008), Suleyman Basak and Hongjun 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:

1. The treatment intended to measure individual-level money illusion cannot differentiate between rational agents and agents with money illusion.

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 chapter 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. We find no evidence of individual-level money illusion beyond a rather small second order effect. Beyond this effect, all of the differences in price inertia across treatments can be explained by differences in the cognitive load.

4.1 Experimental Design

In this section we briefly describe the experimental design employed by FT. We then explain how features of this design confound 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.

4.1.1 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:

$$\pi_i = \pi_i \left(P_i / \bar{P}_{-i}, M / \bar{P}_{-i} \right), i = 1, ..., n \tag{4.1}$$

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). 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 $P_i \in \{1, 2, ..., 30\}$. 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. 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, $\bar{P}_{-i}\pi_i$, 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 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 distinct 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 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 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 money illusion.

4.1.2 Confounds in the Original Design

Identifying money illusion in the NC treatment

Table 4.1 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 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 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 money illusion would have no trouble fully adjusting to the new equilibrium.

Table 4.1: Real and Nominal Incomes Resulting from All Price Decisions 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	**<u>40</u>**	**<u>280</u>**	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	**<u>40</u>**	**<u>200</u>**	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	**<u>945</u>**	8	157	518
28	8	223	890	8	164	564
29	6	166	853	8	171	612
30	5	128	827	8	179	**<u>663</u>**

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.

Our revised design operationalizes the nominal payoff mapping as $\bar{P}_{-i}(\pi_i + \bar{P}_{-i})$, allowing us to identify money illusion in the post-shock phase of the NC.[1] 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.

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 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

[1] 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.

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. [2]

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 4.2 displays the real and nominal incomes 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.[3] The 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.

[2]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 their attendance bonus.

[3]Type y firms' table (not shown here) exhibit the same basic patterns.

Table 4.2: Real and Nominal Payoff Tables for Pre-Shock and Post-Shock Phases in FT's Experiments with a Negative Monetary Shock

Real Frame

Pre-shock Payoff Tables

Own Price	Average Price of Other Firms: 17	18	19	20	21[b]	22	23	24	25
7	40	39	38	38	38	38	37	35	33
8	40	40	40	39	39	39	39	38	36
9[a]	38	39	40	40	40	40	40	39	38
10	36	38	39	39	39	39	40	40	40
11	33	35	37	38	38	38	38	39	40
12	30	32	34	35	35	35	36	38	39

Post-shock Payoff Tables

Own Price	3	4	5	6	7[b]	8	9	10	11
1	35	40	36	29	26	23	17	12	9
2	25	34	40	38	35	32	25	17	12
3[a]	18	25	34	39	40	39	34	25	18
4	12	17	25	32	35	38	40	34	25
5	9	12	17	23	26	29	36	40	35
6	7	9	12	16	18	20	27	36	40

Nominal Frame

Pre-shock Payoff Tables

Own Price	Average Price of Other Firms: 17	18	19	20	21[b]	22	23	24	25
7	968	1032	1092	1157	1233	1310	1374	1420	1450
8	963	1044	1117	1189	1268	1349	1422	1481	1523
9[a]	939	1033	1119	1200	1281	1364	1447	1522	1581
10	899	1003	1099	1186	1268	1352	1444	1536	1616
11	850	957	1059	1151	1233	1316	1414	1521	1623
12	796	903	1006	1099	1179	1262	1363	1479	1600

Post-shock Payoff Tables

Own Price	3	4	5	6	7[b]	8	9	10	11
1	113	175	206	209	230	247	234	222	219
2	85	154	224	262	295	321	302	274	256
3[a]	62	116	194	272	329	379	386	351	314
4	46	86	148	229	295	365	439	445	400
5	36	65	110	173	230	295	407	498	503
6	113	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

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. Thomas 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 Judith Mehta et al., 1992 and 1994; Michael Bacharach and Michele Bernasconi, 1997; Nicholas 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.[4] 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.

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

[4] 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.

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. 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 7.1.

Table 4.3: 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**

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.[5]

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 4.3 summarizes the parameters of our experimental design for all treatments.

4.1.3 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 paid $7 for attending and in

[5]This implies that there is no money supply in the functional form of our positive shock experiments.

addition earned an average of approximately $25.30 based on their decisions in the experiment. The experiments typically lasted 70 – 90 minutes. All experimental procedures, computerized interfaces, instructions and income tables can be found in Sections 7.2 and 7.3.

4.2 Results

4.2.1 Individual-Level Irrationalities and Money Illusion

Participants facing computerized opponents displayed highly rational behavior. Table 4.4 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.[6] 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

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

framing.

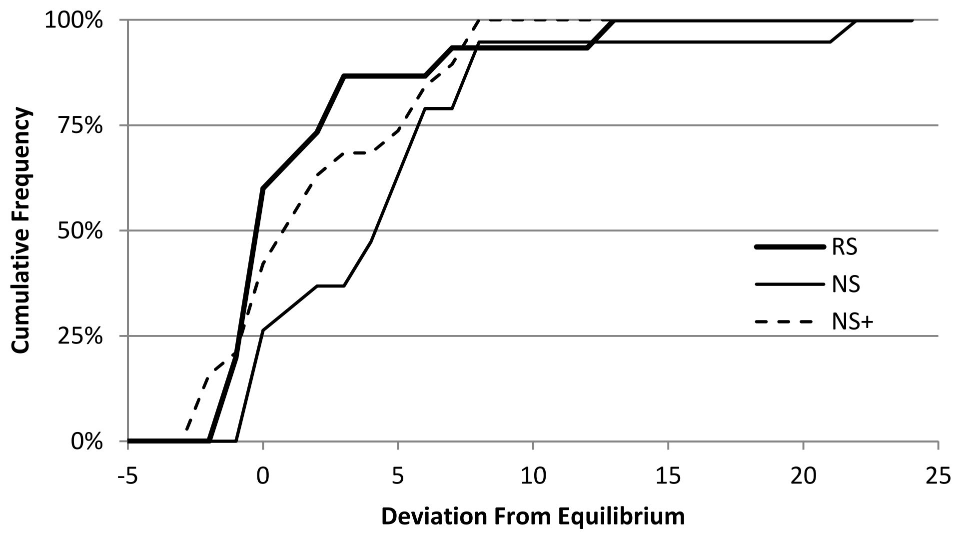
Table 4.4: Average Deviation of Prices from the Equilibrium in the Post-Shock Phase

	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

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 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 money illusion. Participants clearly distinguished between real and nominal payoffs, and based their decisions on the former.

Figure 4.1: Cumulative Distribution Functions of the Deviations of Average Prices from the Equilibrium in Sessions in Self Treatments.



Deviations have been multiplied by -1 in the NS+ to allow direct comparison.

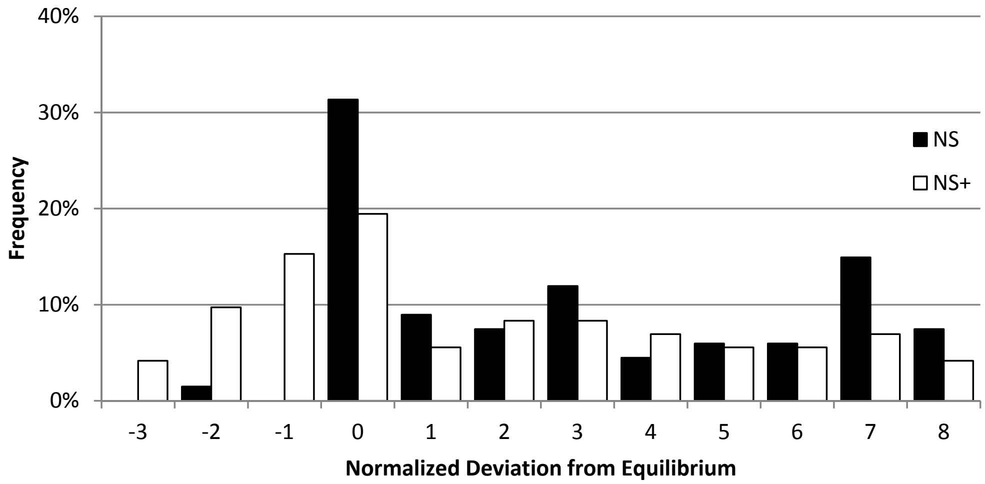
4.2.2 Finding the Equilibrium Under Real and Nominal Payoff Frames

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 4.1 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? This is our one finding in which money illusion may play a role, albeit in a different form than that proposed by FT. 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).

Figure 4.2: Histogram of the Deviations from Equilibrium Prices in Post-Shock Phase of the NS and NS+ Treatments Within the Range of Prices that Contain a Bolded Payoff.



Deviations have been multiplied by -1 in the NS+ to allow direct comparison.

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 4.2 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).

An asymmetry between treatments does arise 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 money illusion may have a moderate second-order 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. This is congruent with our finding that money illusion had no direct effect in our NC treatment. In those experiments there was only one price for each firm type that was consistent with the maximum payoff of 40.

4.2.3 Coordination with Human Opponents Under the Real and Nominal Frames

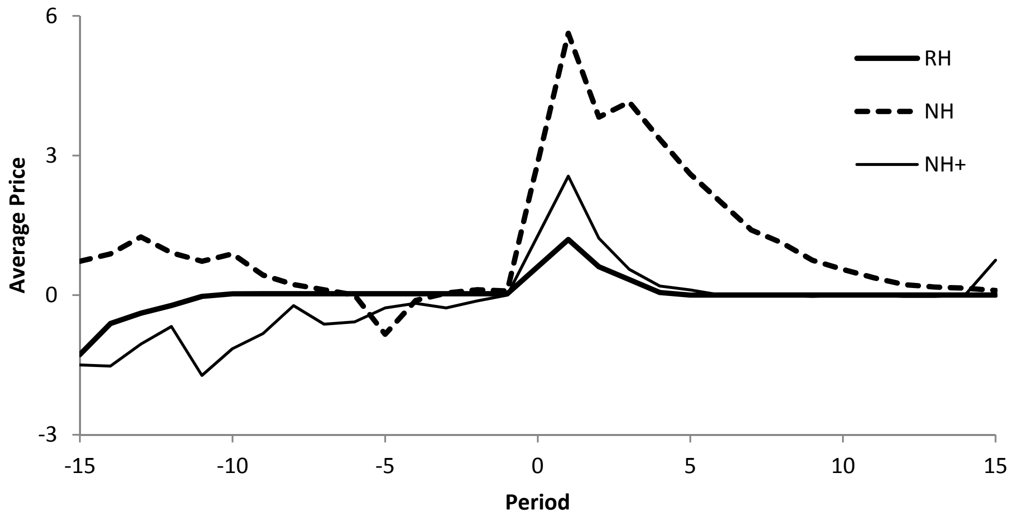
Before considering the level of prices across treatments with human opponents we tested whether the adjustment dynamics in our experiments can be well described by participants following the ABR strategy. Statistical analysis (described in detail in Section 7.2) indicates that subjects chose their ABR prices in the post-shock phase in all three of these treatments. Therefore, we may conclude that money illusion did not affect the rate of price adjustment after period T+1 in the post-shock phase of the NH and NH+.[7]

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

[7]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 our initial hypotheses.

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 4.3: Evolution of Average Price Deviations from Equilibrium in Experiments with Human Opponents



Deviations have been multiplied by -1 in the NS+ to allow direct comparison.

Figure 4.3 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 4.4). 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 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. 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 4.4). 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).

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. 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 money illusion in our experiments.

4.3 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 money illusion plays only a small role. Participants exhibit no money illusion when playing against perfectly predictable computerized opponents. 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. Money illusion may explain the persistent asymmetry between price adjustment following positive and negative monetary shocks. However, this is a second-order effect manifested in an apparent preference for (aversion to) high (low) nominal payoffs within a set of maximum real payoffs. These findings suggest that 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 the duration of disequilibrium behavior following an economic shock (monetary or otherwise) will depend crucially on the best response functions of the affected agents. As different markets and industries are undoubtedly characterized by different best response functions, the effects of a shock will not be uniform across the economy. 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 perceived money illusion in both our research 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.

Chapter 5

Supplementary Materials for "Money Matters"

Experimental Materials

1. Holt and Laury (2002) small stakes risk aversion assessment, Sessions 3-5.

RBC Treatments (Sessions 1-3) Materials

2. Instructions

3. Excel Workers' Spreadsheet

4. Values and Costs Table

5. Screen Shots for Workers and Firms

Money Treatments (Sessions 4-5) Materials

6. Instructions

7. Values and Costs Table

8. Screen Shots for Workers and Firms

Subject # ______________________________

For each decision below, please specify which gamble you prefer more: Option A or Option B. At the end of the session, one decision will be selected at random. The option you chose will be played out using ten playing cards numbered 1-10 and will be paid accordingly.

Example: Consider the following hypothetical table.

	Option A	YOUR CHOICE	Option B
Decision 0	$5.00 if Card is 1 $3.90 if Card is 2-10		$10.85 if Card is 1 $0.50 if Card is 2-10

If you selected Option A, you will be paid $5.00 if the card randomly selected is a "1" and $3.90 if the card is "2"-"10". If you selected Option B, you will be paid $10.85 if the card randomly selected is "1" and $0.50 if the card is "2"-"10".

	Option A	**YOUR CHOICE**	**Option B**
Decision 1	$2.00 if Card is 1 $1.60 if Card is 2-10		$3.85 if Card is 1 $0.10 if Card is 2-10
Decision 2	$2.00 if Card is 1-2 $1.60 if Card is 3-10		$3.85 if Card is 1-2 $0.10 if Card is 3-10
Decision 3	$2.00 if Card is 1-3 $1.60 if Card is 4-10		$3.85 if Card is 1-3 $0.10 if Card is 4-10
Decision 4	$2.00 if Card is 1-4 $1.60 if Card is 5-10		$3.85 if Card is 1-4 $0.10 if Card is 5-10
Decision 5	$2.00 if Card is 1-5 $1.60 if Card is 6-10		$3.85 if Card is 1-5 $0.10 if Card is 6-10
Decision 6	$2.00 if Card is 1-6 $1.60 if Card is 7-10		$3.85 if Card is 1-6 $0.10 if Card is 7-10
Decision 7	$2.00 if Card is 1-7 $1.60 if Card is 8-10		$3.85 if Card is 1-7 $0.10 if Card is 8-10
Decision 8	$2.00 if Card is 1-8 $1.60 if Card is 9-10		$3.85 if Card is 1-8 $0.10 if Card is 9-10
Decision 9	$2.00 if Card is 1-9 $1.60 if Card is 10		$3.85 if Card is 1-9 $0.10 if Card is 10
Decision 10	$2.00 if Card is 1-10		$3.85 if Card is 1-10

INTRODUCTION

You will play one of two roles for the duration of this experiment:

Workers **Firms (Store Owners)**

in a sequence of several **PERIODS (days).**

The sheet by your terminal indicates which role you will play. Please keep this information private.

In this experiment, **FIRMS** will hire **WORKERS** to collect fruits and vegetables to sell in their stores.

Each period, **FIRMS** and **WORKERS** form new work contracts that last for only one period.

FIRMS will repay their **WORKERS** in fruits that the **WORKER** collected earlier in the day.

All quotes and profits during the experiment will be in lab points. At the end of the experiment, two randomly selected periods will be chosen. Your earnings from these periods will be converted into US Dollars at a conversion rate written on the board and paid to you in cash along with your earnings from the gamble. You will also receive $5 for participating in this experiment.

LABOR-GOODS MARKET

FIRMS require **WORKERS** to collect fruit that can be traded to the **EXPERIMENTER** for a profit. However, **FIRMS** can only pay **WORKERS** in fruit.

WORKERS receive points for every piece of fruit that they acquire. They prefer more fruit to less fruit. At the same time, **WORKERS** dislike working and lose points for every hour worked.

In this market, **WORKERS** may agree to trade some or all of their available labor hours to **FIRMS** in exchange for a mutually agreed upon number of fruits. Both **WORKERS** and **FIRMS** may submit offers that detail how many fruit should be traded for 1 hour of work.

At the beginning of each period, all players will be informed of how many fruit a single hour of work is able to produce. For example, a **WORKER** may be able to collect 10 fruit in an hour. In another period, the same worker may only be able to collect 2 fruit. **ALL WORKERS ARE EQUALLY PRODUCTIVE.**

HOW DO WORKERS EARN POINTS?

Each period, each **WORKER** has up to **5** hours that he or she can work.

WORKERS may not trade fractions of an hour (eg. 0.5, 0.76); only full hours (1, 2, …, 5). They may only sell 1 hour at a time for an agreed upon number of fruit.

WORKERS may work for any of the **FIRMS**, and they need not be the same firms.

To earn points, **WORKERS** must obtain fruit. In order to obtain fruit, however, they must work – which is costly.

Information about **WORKERS'** value for fruit and cost from working can be found on the sheet next to your terminal. Notice that the value of additional fruit falls as more is obtained. An extra piece of fruit is worth less than the previous piece. On the other hand, the cost from working increases with each hour.

Worker gain from working is given by:

Worker Net Gain = Value of Fruit – Cost of Working

Using the Worker's Value Table and Workers' Cost Table, consider the following example:
Suppose you choose to work for 1 hour in exchange for 5 fruit. The cost of working 1 hour is 0.5 points and the value of 5 fruit is 19.48 points. Your gain from the 1st hour of work is:

Worker net gain from 1st hour of work = 19.48 – 0.5 = 18.98

Now suppose that you choose to work an additional hour for another 5 fruit. Working an additional hour becomes more costly: the 2nd hour of work costs you 1.5 points for a total cost of 2 points. The value of 10 fruit (5+5) is 25.72 points.

Worker gain from 2 hours of work = 25.72 – 2 = 23.72

WORKERS do not incur a cost or benefit to not working. They can earn negative points by working for an amount of goods that is worth less than the cost of working. The computer will keep track of all trades and earnings throughout the game.

HOW DO FIRMS EARN POINTS?

Each period, **FIRMS** hire **WORKERS** by offering them fruit that the workers themselves collected.

FIRMS may offer some or all of the fruit collected to the worker in repayment for their work. Any fruit not paid to the **WORKER** is automatically sold to the **EXPERIMENTER** for a profit.

FIRM points are given by:

Firm Points = Experimenter's Price x (Fruit Collected – Fruit Paid to Worker)

Consider the following example:
Suppose that each worker collects 10 fruit in 1 hour. You hire a worker for 1 hour and agree to pay them 6 fruit. The experimenter's price is 0.5. Your points earned from hiring the 1^{st} worker are:

Points earned from hiring 1^{st} worker = 0.5 x (10-6) = 0.5 x 4 = 2

Now suppose that you choose to hire an additional worker for 1 hour. You agree to pay that worker 7 fruit. Your points earned from the 2^{nd} worker are:

Points earned from hiring 2^{nd} worker = 0.5 x (10-7) = 0.5 x 3 = 1.5

Total points earned in the period = 2 + 1.5 = 3.5

FIRMS do not incur a cost from not hiring. Firms will receive <u>1 point per period</u> if they hire at least 1 worker. **FIRMS** cannot earn negative points as they cannot pay **WORKERS** more than what they have collected.

FIRMS can pay workers fractions of fruit (eg. 0.8, 21.6, 30.25), up to two decimal places. They cannot hold inventories and will automatically sell any untraded fruit to the experimenter for a price 0.5. The experimenter's price will remain constant throughout the game.

HOW TO PLAY THE GAME

You will use a computer interface to trade labor for fruit. **WORKERS** can offer to sell an hour of work in exchange for fruit. **FIRMS** can offer to buy an hour of work in exchange for fruit.

We will now walk you through how to use the computer interface.

Rules of the game:

- If you make an offer to sell labor or an offer to buy labor, it cannot be reversed or changed. Think carefully before submitting or accepting an offer.
- You must always submit an "improving" offer:
  - If you are a **WORKER** and want to submit an offer to work, the amount of fruit that you demand must be <u>lower</u> than the lowest current offer made by another worker.
  - If you are a **FIRM** and want to submit an offer to hire a worker, the amount of fruit that you will pay must be <u>higher</u> than the highest current offer made by another firm.
- You may submit multiple offers at the same time, but they must be an "improvement". They are all valid until one is accepted. Once one is accepted OR if you accept another contract, all earlier offers are removed.
  - If you are a **WORKER**, you will submit offers to work for your <u>first</u> hour. You can submit many possible contracts that you are willing to accept. If one is accepted, your alternative contracts become void. Similarly, if you should accept a firm's offer, all of your contracts will become void. It is only after you work for your first hour that you may submit offers for your <u>second</u> hour.
  - If you are a **FIRM**, you will submit offers to hire a worker for your <u>first</u> hour. As in the case of the worker, you may submit many offers but only one can be accepted. It is only after you have hired a worker for a <u>first</u> hour that you may hire a worker for a <u>second</u> hour.
- Before each period begins, every player will learn how much fruit a worker is able to collect in a single hour. This amount will remain constant until the experimenter informs you that it has changed. The productivity can range from 1 to 7.
- There is a 1/100 probability EACH period that the game will end. A randomized computer program will determine whether the game continues onto the next period.

HOW TO MAKE MONEY IN THIS EXPERIMENT

If you are a **WORKER**, you will earn more points by earning more fruit and by working less. Remember that with each extra piece of fruit, you earn fewer points. Also, with each extra hour that you work, you lose a greater number of points.

If you are a **FIRM**, you will earn more points by hiring more workers and paying them less. Any fruit that isn't paid to workers earns you a profit of 0.5 per piece. You will earn 1 point per period for hiring at least 1 worker.

At the end of the experiment, the computer will select two randomly chosen periods. We will convert your earnings in these two periods into US Dollars and pay them to you in cash along with your show-up fee and earnings from the gamble.

QUIZ

Suppose workers are able to collect 6 fruit in 1 hour. The experimenter's price is 0.5.

1. As a worker, how many points will you receive if you work for 1 hour in exchange for 4 fruit?

   ____

2. Now suppose you work 1 additional hour in exchange for 4.6 fruit. What is your total number of points?

   ____

3. As a firm, how many points will you earn if you hire a worker for 1 hour in exchange for 3 fruit?

   ____

4. Now suppose that, in the <u>same</u> period, you hire an additional worker for 1 hour in exchange for 5 fruit. What is your total number of points?

   ____

5. What is the maximum number of hours a worker can work in a single period? ________________

6. What is the maximum amount of fruit a firm can pay a worker in a single hour? ________________

EXPERIMENT WORKSHEET

To use, input numbers into the YELLOW shaded cells.

Make sure that the amt. of fruit paid to workers is no more than what they collect.

Amount of fruit workers can collect in 1 hour?	2	Experimenter's Price	0.5

Worker Payoff

Amount of fruit paid for		Total hours worked	0
1st hour		Total fruit earned	0.00
2nd hour			
3rd hour		Points lost from working	0.00
4th hour		Points earned from fruit	0.00
5th hour			
		Total points	**0.00**

Firm Payoff

Amount of fruit paid for			
1st hour		Total workers hired	0
2nd hour		Total fruit collected	0.00
3rd hour		Fruit paid to workers	0.00
4th hour		Fruit sold to experimenter	0.00
5th hour			
6th hour		Points earned from sale	0.00
7th hour		Bonus for hiring a worker	0
8th hour			
9th hour		Total points	**0.00**
10th hour			

Workers' Value Table

	Units obtained														
	1.00	**1.20**	**1.40**	**1.60**	**1.80**	**2.00**	**2.20**	**2.40**	**2.60**	**2.80**	**3.00**	**3.20**	**3.40**	**3.60**	**3.80**
Total value of units	5.00	6.64	8.03	9.23	10.29	11.24	12.10	12.88	13.60	14.27	14.89	15.47	16.01	16.53	17.02
Value of extra unit	5.00	1.64	1.39	1.20	1.06	0.95	0.86	0.78	0.72	0.67	0.62	0.58	0.55	0.51	0.49
	4.00	**4.20**	**4.40**	**4.60**	**4.80**	**5.00**	**5.20**	**5.40**	**5.60**	**5.80**	**6.00**	**6.20**	**6.40**	**6.60**	**6.80**
Total value of units	17.48	17.92	18.33	18.73	19.12	19.48	19.84	20.18	20.50	20.82	21.13	21.42	21.71	21.98	22.25
Value of extra unit	0.46	0.44	0.42	0.40	0.38	0.37	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.28	0.27
	7.00	**7.20**	**7.40**	**7.60**	**7.80**	**8.00**	**8.20**	**8.40**	**8.60**	**8.80**	**9.00**	**9.20**	**9.40**	**9.60**	**9.80**
Total value of units	22.51	22.77	23.01	23.25	23.49	23.71	23.94	24.15	24.37	24.57	24.78	24.97	25.17	25.36	25.54
Value of extra unit	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19
	10.00	**10.20**	**10.40**	**10.60**	**10.80**	**11.00**	**11.20**	**11.40**	**11.60**	**11.80**	**12.00**	**12.20**	**12.40**	**12.60**	**12.80**
Total value of units	25.72	25.90	26.08	26.25	26.42	26.58	26.74	26.90	27.06	27.21	27.36	27.51	27.66	27.80	27.95
Value of extra unit	0.18	0.18	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.14	0.14
	13.00	**13.20**	**13.40**	**13.60**	**13.80**	**14.00**	**14.20**	**14.40**	**14.60**	**14.80**	**15.00**	**15.20**	**15.40**	**15.60**	**15.80**
Total value of units	28.08	28.22	28.36	28.49	28.62	28.75	28.88	29.01	29.13	29.25	29.37	29.49	29.61	29.73	29.84
Value of extra unit	0.14	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.11
	16.00	**16.20**	**16.40**	**16.60**	**16.80**	**17.00**	**17.20**	**17.40**	**17.60**	**17.80**	**18.00**	**18.20**	**18.40**	**18.60**	**18.80**
Total value of units	29.95	30.07	30.18	30.28	30.39	30.50	30.60	30.71	30.81	30.91	31.01	31.11	31.21	31.31	31.40
Value of extra unit	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	19.00	**19.20**	**19.40**	**19.60**	**19.80**	**20.00**	**20.20**	**20.40**	**20.60**	**20.80**	**21.00**	**21.20**	**21.40**	**21.60**	**21.80**
Total value of units	31.50	31.59	31.69	31.78	31.87	31.96	32.05	32.14	32.23	32.31	32.40	32.49	32.57	32.65	32.74
Value of extra unit	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.08	0.08

Workers' Cost Table

	Hours worked				
	1	**2**	**3**	**4**	**5**
Total cost of work	0.5	2	4.5	8	12.5
Cost of extra hour	0.5	1.5	2.5	3.5	4.5

Experimenter's Price = 0.5

INTRODUCTION

You will play one of two roles for the duration of this experiment:

Workers	Firms (Store Owners)
	

in a sequence of several **PERIODS (days).**

The sheet by your terminal indicates which role you will play. Please keep this information private.

In this experiment, **FIRMS** may hire **WORKERS** to collect fruits to sell in their stores. Afterward, **WORKERS** may purchase fruit from **FIRMS**.

Each period, **FIRMS** and **WORKERS** form new work contracts that last for only one period.

FIRMS will repay their **WORKERS** in laboratory money wages. **WORKERS** will pay for their purchase of fruit in laboratory money prices.

All quotes and earnings during the experiment will be in lab points. The word "money" will refer to lab dollars that facilitate the hiring of workers and the purchasing of fruit. At the end of the experiment, two (or five) randomly selected periods will be chosen. Your earnings from these periods will be converted into US Dollars at a conversion rate written on the board and paid to you in cash. You will also receive $5 for participating in this experiment and your earnings from the gamble performed earlier.

OVERVIEW

Each period is divided into two parts: first a labor market that lasts for 60 seconds followed by a goods market that lasts for 170 seconds.

The objective of each player is to make as many points as possible. These points will be converted into US Dollars at the end of the game.

WORKERS receive points for every piece of fruit that they acquire. They prefer more fruit to less fruit. At the same time, **WORKERS** dislike working and lose points for every hour worked.

Figure 5.1: RBC Economy: Worker Screenshot

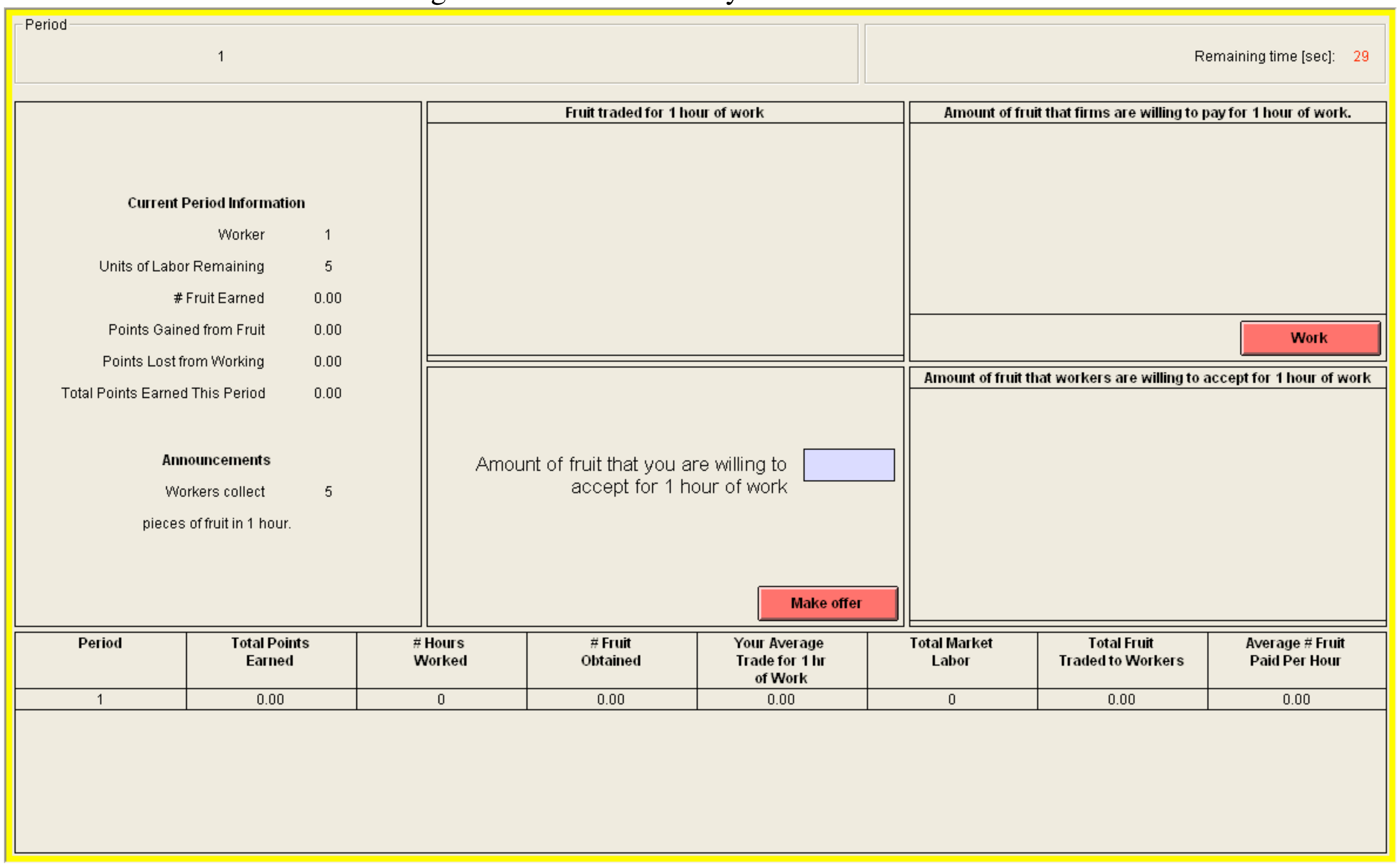
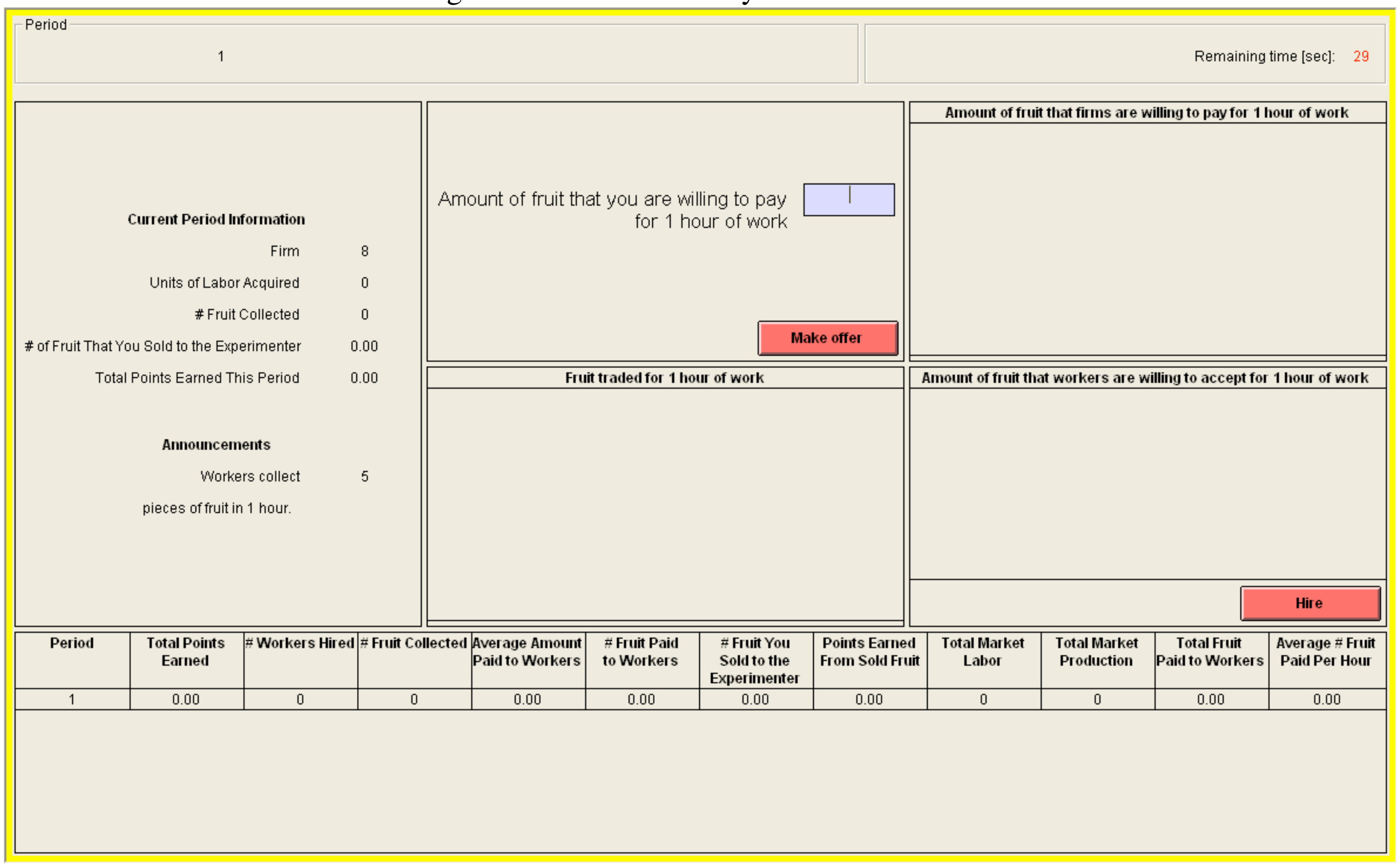


Figure 5.2: RBC Economy: Firm Screenshot



FIRMS receive points for selling their fruit. They prefer to sell their fruit at as high a price as possible. At the same time, **FIRMS** need to hire **WORKER** in order to have any fruit to sell. **FIRMS** lose points by paying wages.

Each player has a bank account in which lab money earned during the game can be stored. At the very beginning of the game, **WORKERS** have no money in their bank accounts and must work if they desire to purchase fruit. **FIRMS** each have the same amount of money in their bank accounts, 50 lab dollars**,** which may be used to hire workers. **You will not earn extra points (ie. $US) in this game by holding more money. Money only helps to facilitate trade between WORKERS and FIRMS.** At the end of the game, you will not be paid for your lab money holdings.

LABOR MARKET

In the labor market, **WORKERS** may agree to trade some or all of their available labor hours to **FIRMS** in exchange for a mutually agreed upon wage. Both **WORKERS** and **FIRMS** may submit offers that detail how much money should be traded for 1 hour of work.

At the beginning of each period, all players will be informed of how many fruit a single hour of work is able to produce. For example, a **WORKER** may be able to collect 10 fruit in an hour. In another period, the same worker may only be able to collect 2 fruit. **ALL WORKERS ARE EQUALLY PRODUCTIVE.**

GOODS MARKET

In the goods market, **FIRMS** may sell some or all of their acquired fruit to **WORKERS** in exchange for a mutually agreed upon price. Both **WORKERS** and **FIRMS** may submit offers that detail home much money should be traded for 1 piece of fruit. **FIRMS** cannot sell more than their workers collected. **WORKERS** cannot spend more money than what they have in their bank accounts.

HOW DO WORKERS EARN POINTS?

Each period, each **WORKER** has up to **5** hours that he or she can work.

WORKERS may not trade fractions of an hour (eg. 0.5, 0.76); only full hours (1, 2, …, 5). They may only sell 1 hour at a time for an agreed upon wage.

WORKERS may work for any of the **FIRMS**, and they need not be the same firms.

To earn points, **WORKERS** must obtain fruit. In order to obtain fruit, however, they must have some money that can only be earned by working – which is costly.

Information about **WORKERS'** value for fruit and cost from working can be found on the sheet next to your terminal. Notice that the value of additional fruit falls as more is obtained. An extra piece of fruit is worth less than the previous piece. The value of the first piece of fruit is 5 points, while the value of a second piece of fruit is only 2.77 points. On the other hand, the cost from working increases with each hour. Working one hour costs 0.5 points, but working a second hour costs more: 1.5 points.

Worker points are calculated as follows:

Worker Points = Value of Fruit – Cost of Working

As a **WORKER**, you may work up to 5 hours and may purchase as many pieces of fruit as you can afford, but you must do so in the time that is available in each market.

WORKERS do not incur a cost or benefit to not working. They can earn negative points by working too many hours and not buying enough fruit. **WORKERS** may spend none, some, or all of their bank account balance on fruit. Any unspent money is carried forward to the next period. The computer will keep track of all trades and earnings throughout the game.

HOW DO FIRMS EARN POINTS?

Each period, **FIRMS** hire **WORKERS** by offering them wages paid from the **FIRMS'** bank accounts.

FIRMS may offer some or all of their money to workers in repayment for work. Any money not paid to workers is kept in the **FIRMS'** bank accounts. It is important to note that, as a **FIRM**, you will not receive any extra money in this game. When your bank account runs out, you will be unable to play any further periods. **FIRMS** lose 1 point for every lab dollar spent on wages.

After hiring **WORKERS**, **FIRMS** can earn points by selling their fruit back to **WORKERS** for a price. **FIRMS** earn 1 lab point for every lab dollar they receive for their fruit. **WORKERS** pay **FIRMS** from money in their bank accounts.

FIRM points are given by:

Firm Points = Total Money Received for Sold Fruit – Total Money Spent on Hiring Workers

As a **FIRM**, you may hire as many workers as you like and sell as many fruit as you have available, but you must do so in the time that is available in each market.

Be careful not to let your bank account balance deplete to zero. Once you have used up all of your money, you will be unable to hire workers and make money.

FIRMS do not incur a cost from not hiring. Firms will receive a bonus <u>1 point per period</u> if they sell at least 1 piece of fruit. **FIRMS** can earn negative points by paying **WORKERS** more in wages than what the **FIRM** collects from its sale of fruit.

FIRMS can pay fractions of lab dollar wages (eg. 0.8, 21.6, 30.25), up to two decimal places. They can charge fractions of lab dollar prices as well. They cannot hold inventories and any unsold fruit automatically perishes at the end of the period.

HOW TO MAKE MONEY IN THIS EXPERIMENT

If you are a **WORKER**, you will earn more points by purchasing more fruit and by working less. Remember that with each extra piece of fruit, you earn fewer points. Also, with each extra hour that you work, you lose a greater number of points.

If you are a **FIRM**, you will earn more points by selling fruit at a high price and paying workers a low wage. Remember, you cannot sell fruit if you do not have workers to collect it. You will earn 1 point per period for selling at least 1 piece of fruit.

At the end of the experiment, the computer will select two (or five) randomly chosen periods. We will convert your earnings in these two periods into US Dollars and pay them to you in cash along with your show-up fee and earnings from the gamble played earlier.

HOW TO PLAY THE GAME

You will use a computer interface to trade labor and fruit. We will now walk you through how to use the computer interface.

Rules of the game:

- Any offers that you make during each market cannot be reversed or changed. Think carefully before submitting or accepting an offer.
- You must always submit an "improving" offer:
    - If you are a **WORKER** and wish to submit an offer to work, the wage that you demand must be <u>less than or equal to</u> the lowest current offer made by another worker.
    - If you are a **FIRM** and wish to submit an offer to hire a worker, the wage that you will be willing to pay must be <u>greater than or equal to</u> the highest current offer made by another firm.
    - Similarly, **WORKERS** wishing to purchase fruit must submit a price that is greater than or equal to than the current highest offer made by another worker. **FIRMS** wishing to sell fruit must submit a price that is less than or equal to the current lowest offer made by another firm.
- You may submit multiple offers at the same time, but they must be an "improvement". They are all valid until one is accepted. Once one is accepted OR if you accept another contract, all earlier offers are removed.
    - If you are a **WORKER**, you will submit offers to work for your <u>first</u> hour. You can submit many possible contracts that you are willing to accept. If one is accepted, your alternative contracts become void. Similarly, if you should accept a firm's offer, all of your contracts will become void. It is only after you work for your first hour that you may submit offers for your <u>second</u> hour.
    - If you are a **FIRM**, you will submit offers to hire a worker for your <u>first</u> hour. As in the case of the worker, you may submit many offers but only one can be accepted. It is only after you have hired a worker for a <u>first</u> hour that you may hire a worker for a <u>second</u> hour.
    - The same is true in the goods market. **WORKERS** and **FIRMS** submit offers for one fruit at a time.
- Before each period begins, every player will learn how much fruit a worker is able to collect in a single hour. This amount will remain constant until the experimenter informs you that it has changed. The productivity can range from 1 to 7.

QUIZ

Suppose workers are able to collect 5 fruit in 1 hour.

Worker Questions

1. As a worker, how many points will you lose if you work for 1 hour for a wage of 3 lab dollars?

   ____

2. Now suppose you work 1 additional hour for a wage of 4.5 lab dollars. What is the total cost of working?

   ____

3. How much money do you have in your bank account? _________________
4. How many points do you earn for purchasing 1 piece of fruit for a price of 2 lab dollars? ________
5. Now suppose you purchase 1 additional fruit for a price of 3 lab dollars. How many points have you earned from buying an additional fruit? ________________. How many points have you earned in total from buying fruit? __________ . What is your net earnings of points? __________________.
6. How much money do you have remaining in your bank account? __________________
7. What is the maximum number of hours a worker can work in a single period?__________________

Firm Questions

8. As a firm, how many points will you lose if you hire a worker for a wage of 3 lab dollars?

   ____

9. Now suppose you hire 1 additional worker for a wage of 2 lab dollars. What is the total cost of hiring workers? ____________________

9. How much money is left in your bank account (assuming that you start at 50 lab dollars)?________

10. How many points do you earn for selling 1 piece of fruit for a price of 2 lab dollars? _____________

11. Now suppose you sell 1 additional fruit for a price of 3 lab dollars. How many points have you earned from selling an additional fruit? ______________ . How many points have you earned in total from selling fruit?_______________ What is your net earning of points? _______________________

12. How much money do you have remaining in your bank account? _____________________

Workers' Value Table

	Units obtained									
	1.00	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**	**7.00**	**8.00**	**9.00**	**10.00**
Total value of units	5.00	7.77	9.39	10.55	11.44	12.17	12.78	13.32	13.79	14.21
Value of extra unit	5.00	2.77	1.62	1.15	0.89	0.73	0.62	0.53	0.47	0.42

	11.00	**12.00**	**13.00**	**14.00**	**15.00**	**16.00**	**17.00**	**18.00**	**19.00**	**20.00**
Total value of units	14.59	14.94	15.26	15.56	15.83	16.09	16.33	16.56	16.78	16.98
Value of extra unit	0.38	0.35	0.32	0.30	0.28	0.26	0.24	0.23	0.22	0.21

Workers' Cost Table

	Hours worked				
	1	**2**	**3**	**4**	**5**
Total cost of work	0.5	2	4.5	8	12.5
Cost of extra hour	0.5	1.5	2.5	3.5	4.5

Figure 5.3: Money Economy - Labor Market: Worker Screenshot

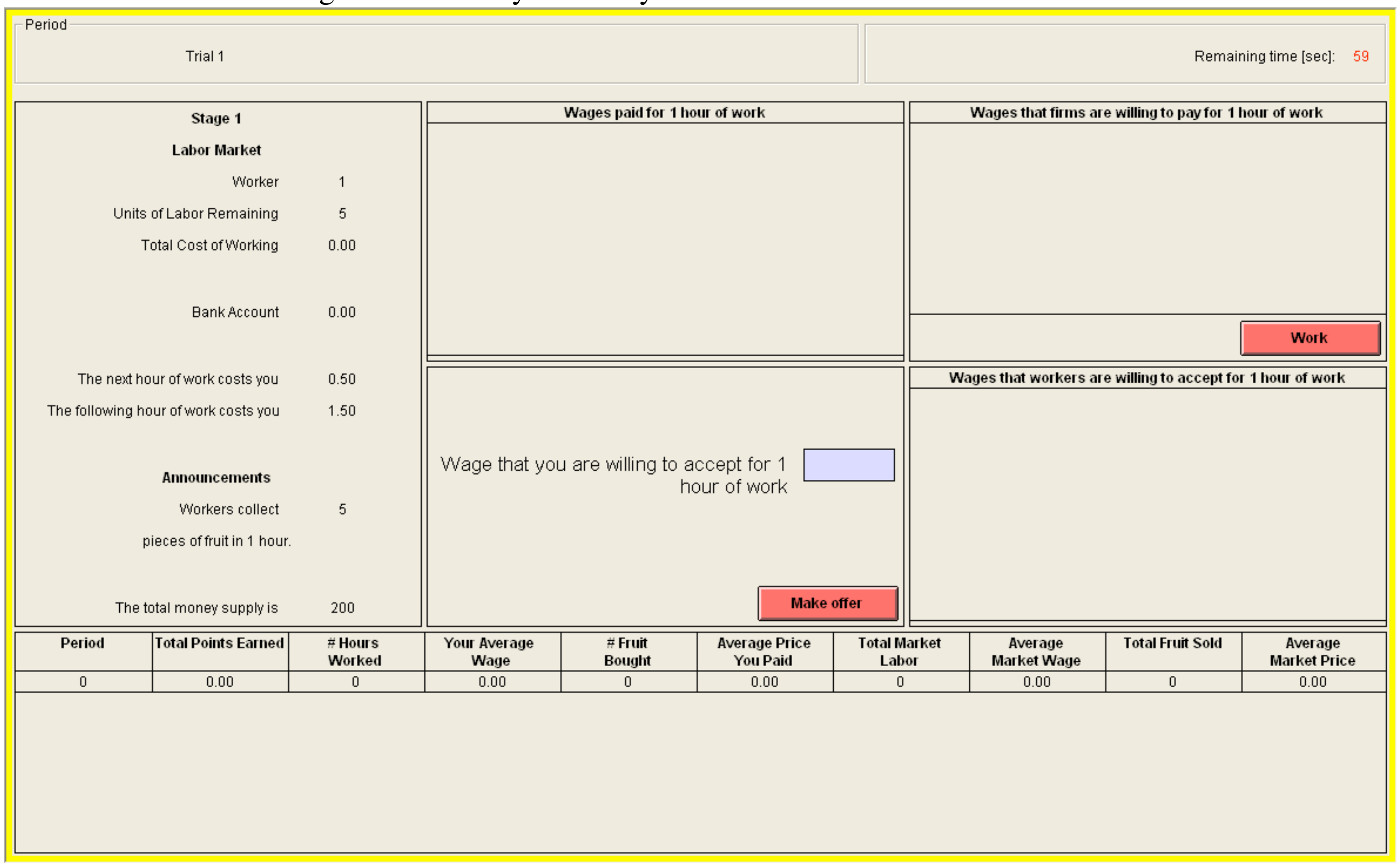


Figure 5.4: Money Economy - Labor Market: Firm Screenshot

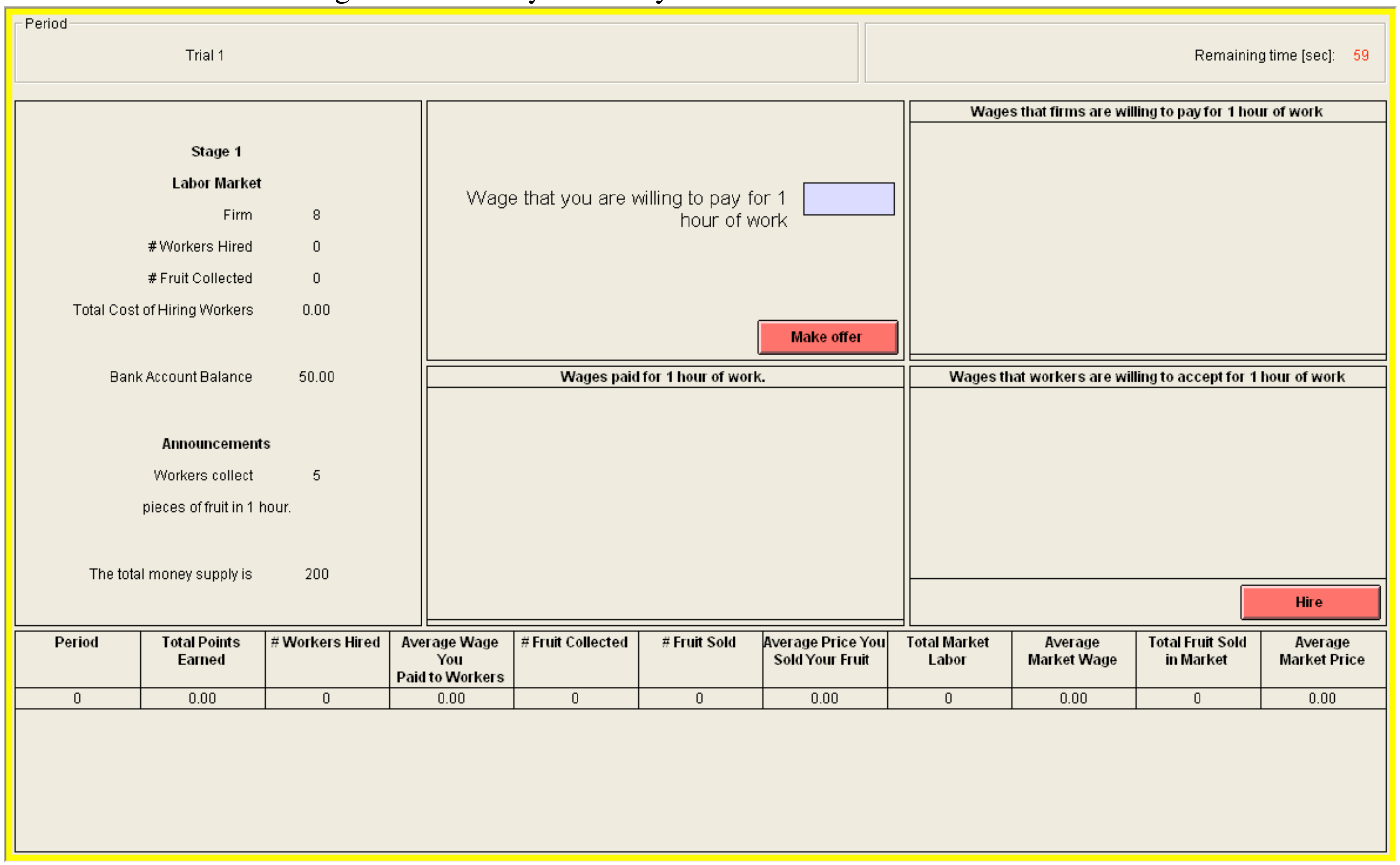


Figure 5.5: Money Economy - Goods Market: Worker Screenshot

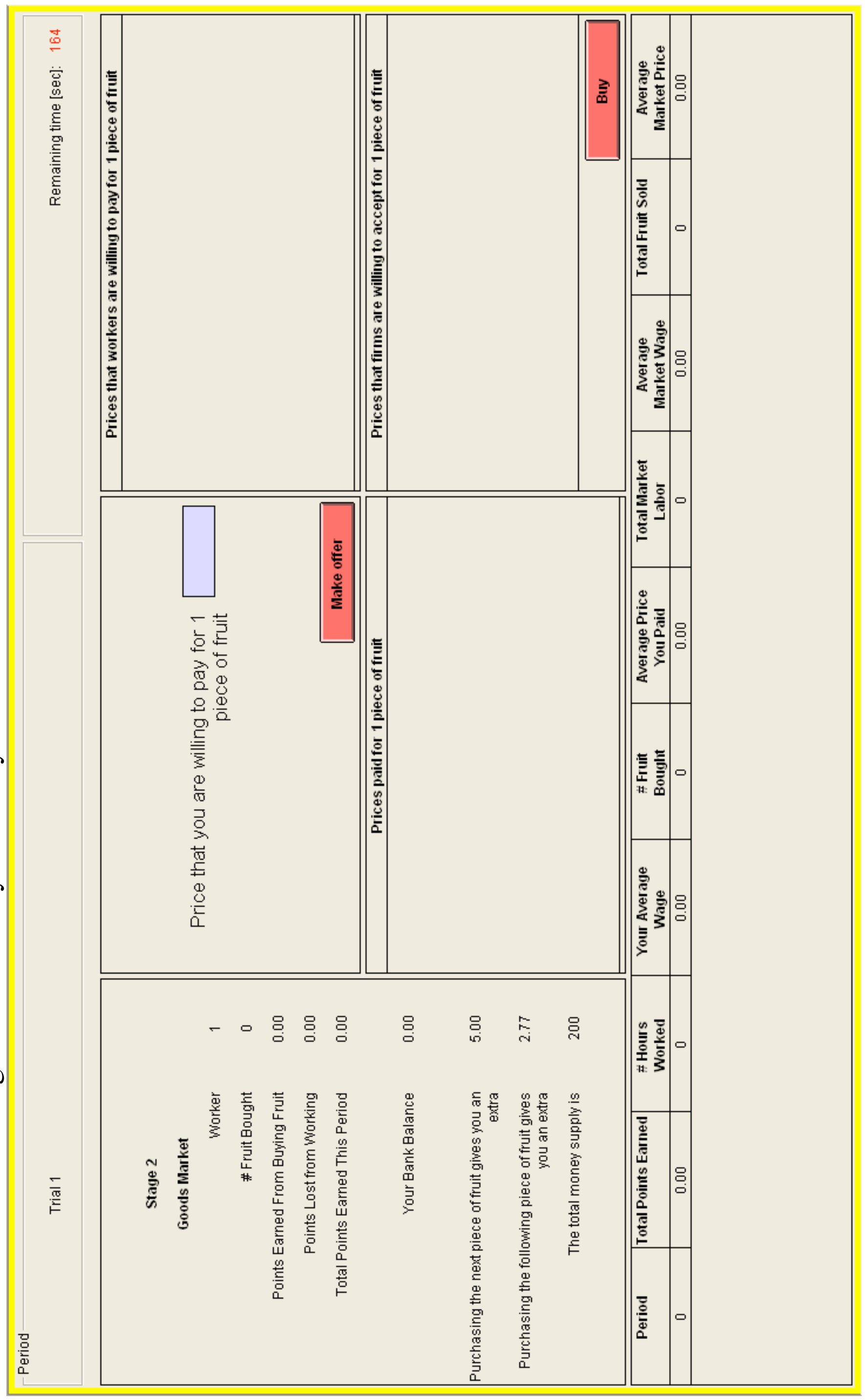
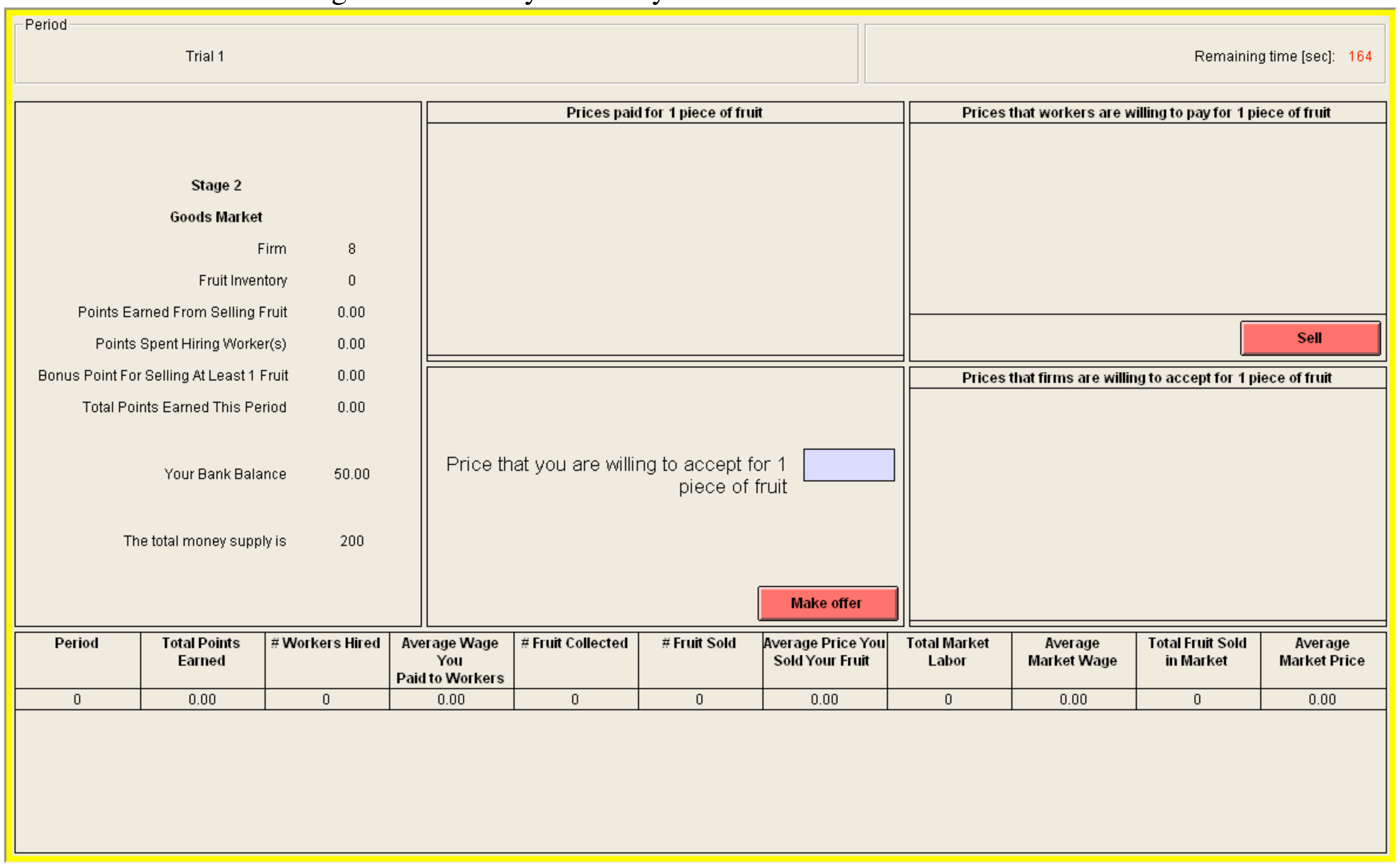


Figure 5.6: Money Economy - Goods Market: Firm Screenshot

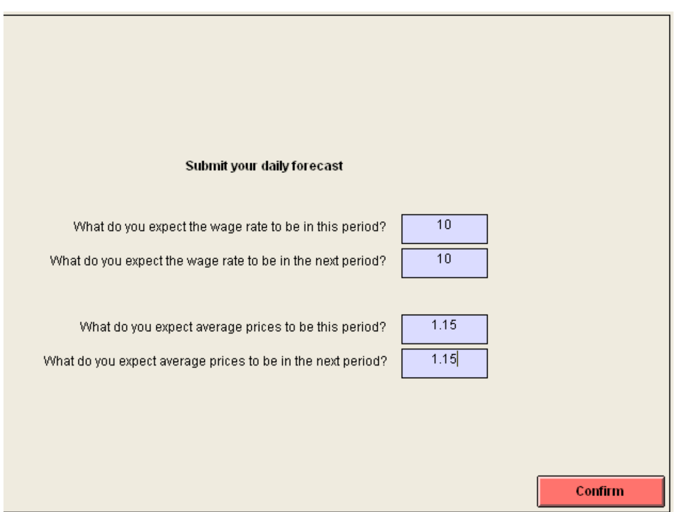


Chapter 6

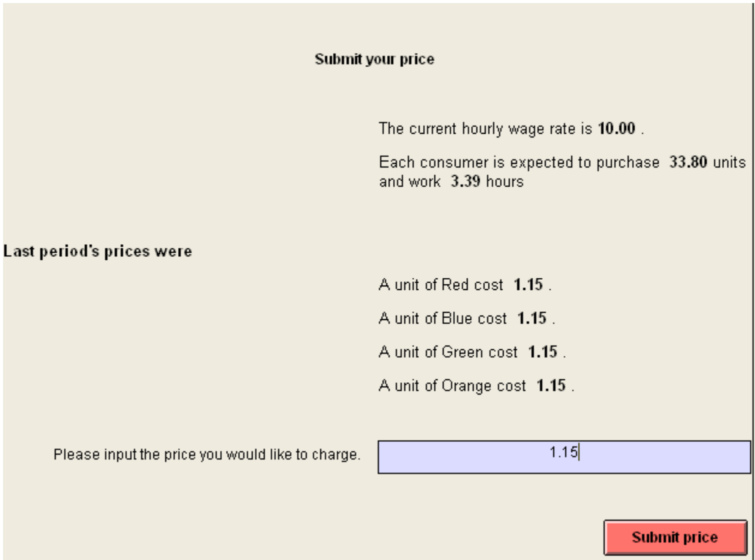
Supplementary Materials for "Laboratory New Keynesian Economies"

6.1 Screen Shots

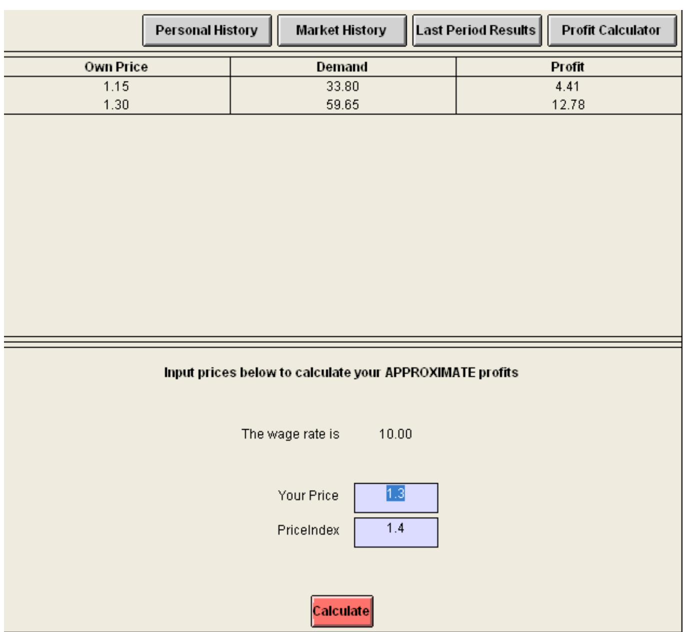
Forecast Input Screen



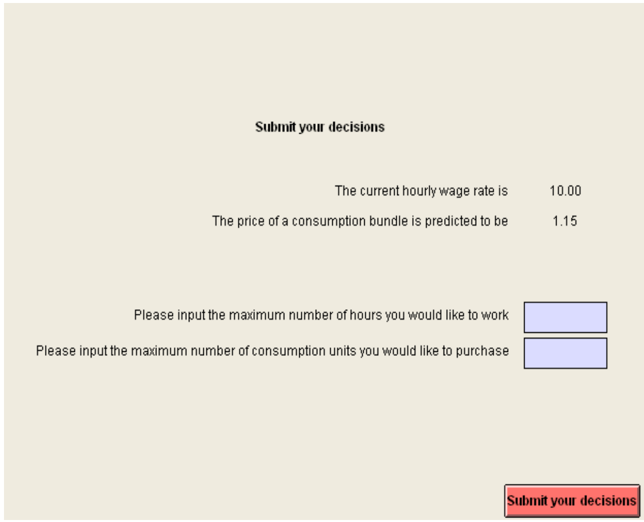
Firm Price Input Screen



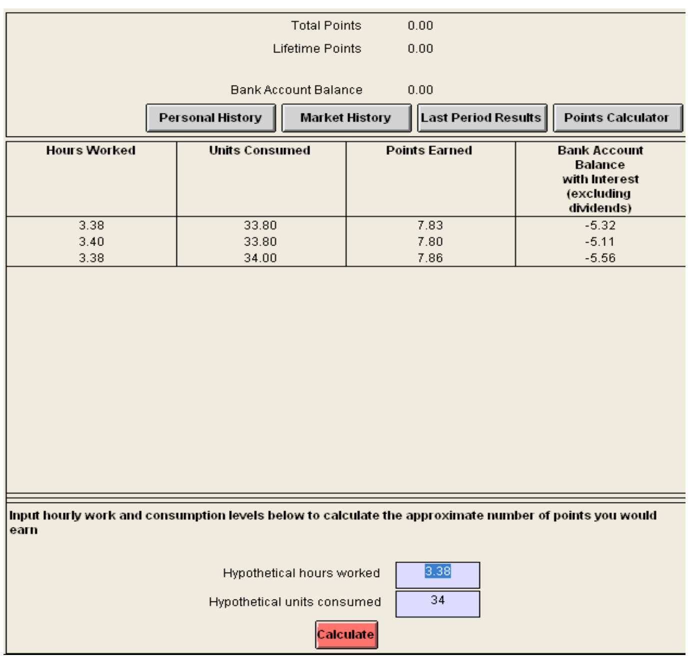
Firm Calculator



Household Labor and Consumption Input Screen



Household Calculator



Chapter 7

Supplementary Materials for "Money Illusion"

7.1 Adaptive Best Responding in FT's Experiments and PW Revised Experiments

7.1.1 Statistical Analysis of Adaptive Best Response and Adjustment Asymmetries in FT's Experiments

At the aggregate level participants' prices are well described by adaptive best responding (ABR) in FT's original experiments. After the first post-shock period, 45 percent of all prices in the NH are exactly equal to the ABR price, and 77 percent deviated by no more than one price increment. For the RH treatment, 40 percent of prices equaled the ABR and 77 percent were within one price increment. We test the hypothesis that participants played their ABR more formally with the following random effects regression model:

$$P_{it} = \alpha + \beta_1 ABR_{it} + \beta_2 NH + \beta_3 NH \times ABR_{it} + \mu_i + \varepsilon_{it} \tag{7.1}$$

where NH equals one for observations in the NH and zero otherwise, ABR_{it} is the ABR price of participant i in period t and μ_i is assumed to be distributed normally with zero mean and constant variance. If participants systematically followed the ABR strategy in both treatments, we would expect to find coefficient estimates of $\beta_1 = 1$ and $\alpha = \beta_2 = \beta_3 = 0$. These expectations are upheld for β_2 and β_3, and the estimates are very close to (but statistically distinct from) our expectations for α and β_1.

The regression estimates a β_1 coefficient of 0.848 ($p < 0.01$), with a 95 percent confidence interval ±0.096 from the estimate (see Table A1). Notice that 1 lies slightly outside of this interval. The estimated constant of 1.657 ($p < 0.01$) is statistically significant, but close to zero. Overall, the regression results indicate that participants in the RH set their prices slightly above the ABR for smaller values of $\bar{P}_{-i,t-1}$ and slightly below it for higher values. Nevertheless, the ABR strategy comes very close to describing participant behavior. Moreover, the coefficients for NH and $NH \times ABR_{it}$ are statistically insignificant, implying that adjustment behavior was identical across the RH and NH treatments after the initial post-shock period.

Regressing model (A1) on the price data from the last T-1 periods of the positive shock experiments we find that participants also followed the ABR strategy in FT's RH+ and NH+ (see Table A2). The coefficients for NH+ $ABR_{it} \times NH+$ are statistically insignificant at the 5 percent level, implying that participants' adjustment behavior was identical in the NH+ and RH+ treatments. The coefficient for ABR_{it} is 0.977 ($p < 0.01$) and not significantly different from 1 at the 5 percent level. Finally, the estimated constant is statistically insignificant.

The adjustment processes in the NH and NH+ were so similar that it is hard to believe that the asymmetry in adjustment speed was primarily due to the natures of the monetary shocks. We look instead at the underlying economic environments in these treatments. Figure A1a shows the best responses of type x and type y firms to the average price of other firms in the post-shock phase of the negative shock experiments. For any $\bar{P}_{-i}$, the vertical distance between a best response function and the 45-degree line indicates the amount by which a firm of that type should submit a price above (or below) the average price of his opponents. These vertical distances drive the dynamics of price adjustment.

To see this, assume four firms who employ the ABR strategy and, in period t, each face their own $\bar{P}_{-i,t}$. By definition, the average price of the group in that period, $\bar{P}_t$, is equal to $\frac{1}{4}\left(\sum_{i=1}^{4}\bar{P}_{-i,t}\right)$. Let δ_{it} represent the difference between $\bar{P}_{-i,t}$ and the best response of firm i to $\bar{P}_{-i,t}$ (i.e., the vertical distance between the 45-degree line and firm i's best response function). In period $t+1$ each firm will submit a price equal to $\bar{P}_{-i,t}+\delta_{it}$, so that $\bar{P}_{t+1}=\frac{1}{4}\left(\sum_{i=1}^{4}\bar{P}_{-i,t}+\delta_{it}\right)$. It follows that the difference in average prices between periods t and $t+1$ will be equal to $\bar{\delta}_t$, the average of the δ_{it}. Consequently, asymmetries in the absolute values of the δ_{it} will determine the rate at which a group of firms will reach the equilibrium if they follow the ABR strategy. When the δ_{it} are symmetrical (i.e., $\bar{\delta}_t=0$) the firms have reached the Nash equilibrium.

For the majority of the set of $\bar{P}_{-i}$ in the post-shock phase of the negative shock experiments, the best response of type x firms is given by $\bar{P}_{-i}-5$ while for type y firms it is $\bar{P}_{-i}+3$. The net effect, in this range of $\bar{P}_{-i}$, is that the average price will fall by one increment per period, provided participants are playing their ABR. This is in stark contrast to the best response functions in the positive shock experiments (see Figure A1b). In those experiments, for most $\bar{P}_{-i}$ the best responses for the type x and type y firms are $\bar{P}_{-i}-1$ and $\bar{P}_{-i}+7$ respectively. This implies an adjustment rate of three price increments per period. Closer to the equilibrium the best responses are $\bar{P}_{-i}-2$ and $\bar{P}_{-i}+6$ for an adjustment rate of two increments per period. Thus, we would expect participants playing their ABR to converge to the equilibrium at a rate of two to three times that in the negative shock treatments.

7.1.2 Statistical Analysis of Adaptive Best Response in Our Revised Experiments

Examination of the participant-level data suggested two main pricing strategies in the post-shock phase of our experiments. The most common was to roughly follow the ABR strategy, but a minority of participants (9 of 124) repeatedly chose their equilibrium price, even when doing so was not the best response to the average price in the prior period. We refer to this practice as "anchoring" on the equilibrium. We categorize a participant as anchoring if, for a majority of the periods $t > T+1$ in which his group was not in equilibrium in period $t-1$, the participant set his price equal to the equilibrium when it was not the ABR to do so.

We fit the data from our three treatments with human opponents to regression model A1, adding a third dummy variable, NH+, so that all three treatments may be analyzed simultaneously. The pricing data from those who anchored on the equilibrium was largely invariant with respect to the ABR. This tends to inflate the constant terms and depress the slope coefficients, despite the fact that only about 7 percent of participants could be described as anchoring. As a result, we exclude their prices from the dataset.[1] We also exclude three observations in which the participant chose no price by the end of the period and a random price was generated for him. Table A3 displays the model estimates.

The model fits the data extremely well, with an R^2 statistic of 0.8890. The hypothesis that participants in the RH followed the ABR strategy is strongly supported. The constant term is small and statistically insignificant and the estimated coefficient for ABR_{it} is 1.001 ($p < 0.01$). None of the dummy or interaction variables are statistically significant, indicating that adjustment behavior was the same across all three treatments with human opponents.

Table 7.1: Results of Regression Model Comparing Actual Prices to the Adaptive Best Response in the Post-Shock Phase of FT's RH and NH Treatments

	Periods 22 – 40	
Regressor	Coefficient (Std. Err.)	95 percent Confidence Interval
α	1.657** (0.356)	±0.699
ABR_{it}	0.848** (0.049)	±0.096
NH	-0.127 (0.466)	±0.913
NH*ABR_{it}	0.021 (0.056)	±0.109
Obs.	739	
Wald χ^2	1,682.42	
R^2	0.696	
** indicates significance at the 1 percent level		

[1]Money illusion was also not a hinderance to anchoring. Of the nine participants who anchored on the equilibrium, only one participated in the RH_R treatment; the remaining eight where divided evenly between the NH and NH+.

Table 7.2: Results of Regression Model Comparing Actual Prices to the Adaptive Best Response in the Post-Shock Phase of FT's RH+ and NH+ Treatments

	Periods 17 – 30	
Regressor	Coefficient (Std. Err.)	95 percent Confidence Interval
α	0.743 (1.352)	$\pm$2.649
ABR_{it}	0.977** (0.055)	$\pm$0.109
NH^+	2.484 (1.669)	$\pm$3.271
$NH^{+}*ABR_{it}$	-0.107 (0.068)	$\pm$0.134
Obs.	298	
Wald χ^2	782.18	
R^2	0.7993	

** indicates significance at the 1 percent level

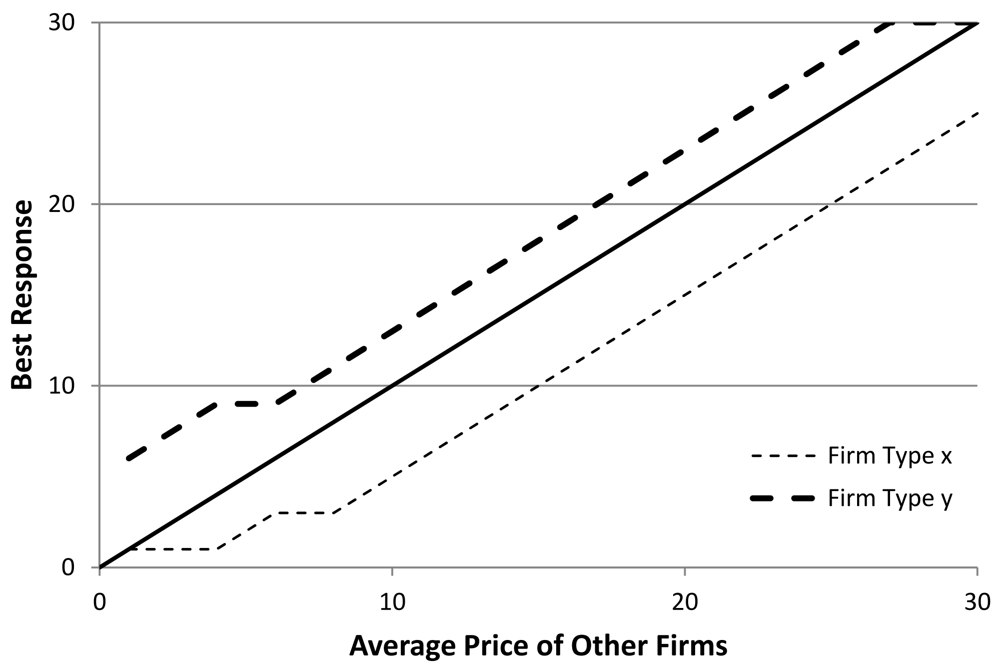
Table 7.3: Results of Regression Model Comparing Actual Prices to the Adaptive Best Response in the Post-Shock Phase of Our Revised RH, NH, and NH+ Treatments

	Periods 17-30	
Regressor	Coefficient (Std. Err.)	95 Percent Confidence Interval
α	0.063 (0.878)	±1.720
ABR_{it}	1.001** (0.125)	±0.245
NH	0.787 (0.954)	±1.870
$NH * ABR_{it}$	-0.053 (0.129)	±0.254
NH^+	2.209 (1.420)	±2.783
$NH^+ * ABR_{it}$	-0.123 (0.138)	±0.270
Obs.	487	
Wald χ^2	3,851.76	
R^2	0.8890	

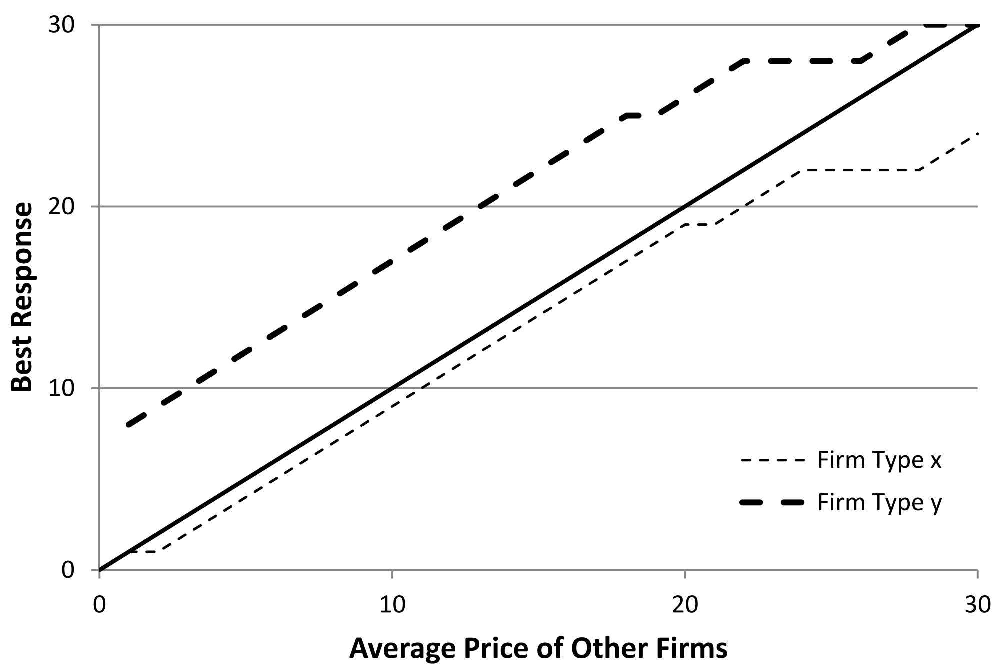
** indicates significance at the 1 percent level

Figure 7.1: Best Response Functions in FT's Experiments with a (a) Negative Monetary Shock, (b) Positive Monetary Shock

a)



b)



7.2 Software and Procedures

Participants were seated in a computer laboratory and given a set of written instructions explaining the rules of the experiment, as well as a pencil and scratch paper. An experimenter read the instructions aloud, while screenshots highlighting the functions of the computer interface were shown on all participants' computer screens. The experimenter paused at several pre-determined points in the instructions to answer questions.

We used a computer interface to display participants' income tables and allow them to enter their decisions. Features of the interface common to all treatments were as follows. The income table for each firm type was shown on a separate tab of the display window, and participants could switch between tabs to compare them. Payoffs in the income tables were designated by a white background for the table of a given participant's firm type, and a green background for the table of the opposite firm type. The prices a participant could charge were designated with a grey background in the first column of the table, and the 30 possible average prices of the other firms, which were also given a grey background, were displayed in the top row of the table.

We provided participants in the nominal payoff treatments with an "income converter" on their computer displays. If a participant entered a hypothetical P_i and $\bar{P}_{-i}$, the income converter would display the real payoff from the income table that was currently displayed. This established a sort of parity in the difficulty of deflating nominal payoffs between FT's experiments and our revised versions, which employed a more complex nominal mapping. In the original study participants could find the real payoff by entering two numbers into an ordinary calculator: the nominal payoff and the average price of other firms. In our experiments participants also had to enter two numbers into the income converter to find the real payoff: their own price and the expected average price of the other three firms.

7.2.1 Computer Interface for Experiments with Human Opponents

Participants selected a price by clicking on one of the prices in the first column of their own income table, which also highlighted the payoffs in the corresponding row in blue. They were allowed to switch prices as often as they liked within a period before finalizing their decision. The computer interface showed each participant the average price of the other firms in his group at the end of the period by highlighting payoffs in the appropriate column in yellow. The income cell at the intersection of the blue highlighting from the participant's price row and the yellow highlighting of the average price column was highlighted in green, and this cell contained the participant's period earnings. This gave them a clear visual cue of the results of the period. Once all participants had indicated a readiness to advance to the next period, the blue, yellow and green highlighting was removed from their screens. An experiment history could be accessed on a third tab. It listed the P_i, $\bar{P}_{-i}$, and π_i for each period that had been completed.

7.2.2 Computer Interface for Experiments with Computerized Opponents

We followed FT's design in disclosing to participants the exact $\bar{P}_{-i}$ that the other three firms would charge in response to every possible P_i. However, while they distributed this information in tables on sheets of paper, we provided it visually on their computer screens. The computer display highlighted each payoff cell that corresponded with one of the thirty possible $(P_i, \bar{P}_{-i})$ combinations in yellow. When a participant clicked on a price in his income table, the highlighting of the cell containing the payoff he would receive was changed from yellow to green, and the other 29 payoffs in the price row were highlighted in blue. This minimized the possibility that a participant would make a mistake about the payoff (real or nominal) that he would earn for setting a given price. We considered this an important detail of the design, because participants in the NC treatment of FT's study had some trouble adjusting to the post-shock equilibrium even though their equilibrium prices generated the highest nominal and real incomes. We surmised that requiring them to look up the best replies, infer the proper income cell, and deflate the nominal income may have generated some confusion.

7.2.3 Computer Interface for Experiments with Self as Opponent

In the self-opponent treatments participants chose four prices rather than one. Accordingly, it used the same basic interface as the human opponent treatments but provided a set of text boxes (labeled "First Type X firm", "First Type Y Firm", etc.) for the participants to enter their pricing decisions. Additionally, the history tab was removed from the interface, as the participants chose prices only once in each phase.

7.2.4 Procedures for Experiments with Computerized and Human Opponents

At the outset, the experimenter explained that the experiment would consist of two phases, each of which would last for T periods and use a distinct set of income tables. Participants completed a practice period using the pre-shock tables before commencing the first of the 2T periods for which they were paid. Each period lasted up to 2 minutes with the exception of the practice period, which lasted up to 5 minutes. A period ended when all participants had submitted their prices or when the time ran out. If any participant had not selected a price prior to the end of the period, the computer software randomly chose a number from a discrete uniform distribution with support $\{1,\ldots,30\}$ and submitted that as the participant's price for the period. After period T, the income tables on participants' screens were populated with the post-shock payoffs. They were given 10 minutes to examine the new tables prior to the start of period T+1. A button on their computer display allowed participants to toggle between the pre- and post-shock tables in order to compare them. This button was disabled prior to period T+1.

7.2.5 Procedures for Experiments with Self as Opponent

The procedures for our self-opponent experiments were the same as above with three exceptions. First, there were only two periods (one pre-shock and one post-shock), each of which allowed participants 15 minutes to select their prices. Second, the practice period was replaced with an instructions comprehension task that required the participants to calculate the $\bar{P}_{-i}$, real income and (if appropriate) nominal income for a set of pre-determined prices from four firms. This task employed a novel set of income tables distinct from the pre- and post-shock tables used in the experiment. Finally, the time limit was not enforced by submitting random prices. Participants who had not submitted their prices within 15 minutes simply received a reminder on their screens to finalize their prices immediately. Shortly thereafter a lab monitor observed each computer terminal to ensure that each participant had chosen his prices.

7.2.6 Screenshots of the Computer Interface

Figure 7.2: Participant Interface in Experiments with Real Payoff Framing and Human Opponents

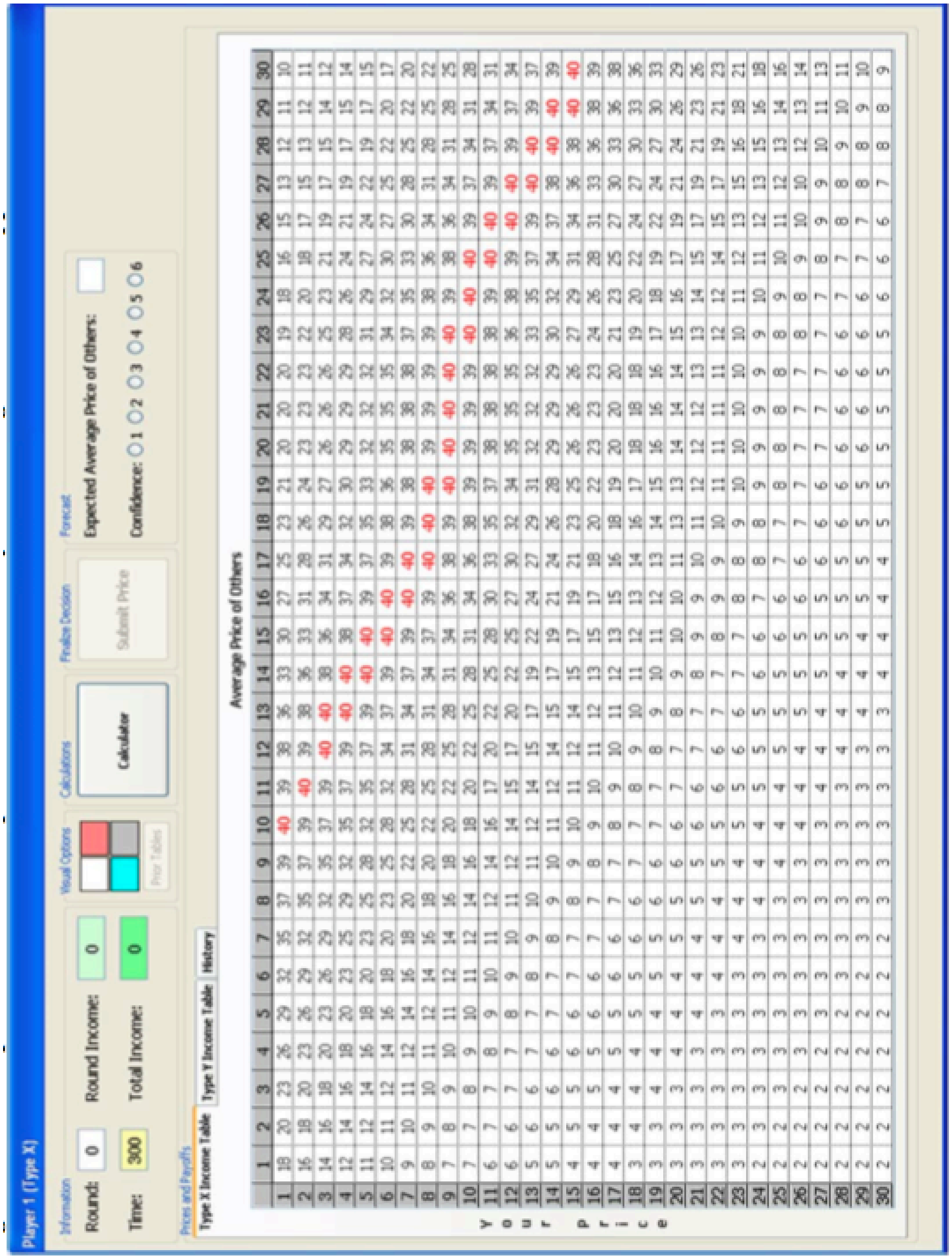


Figure 7.3: Price Submitted, Average Price of Others Revealed in Experiments with Real Payoff Framing and Human Opponents

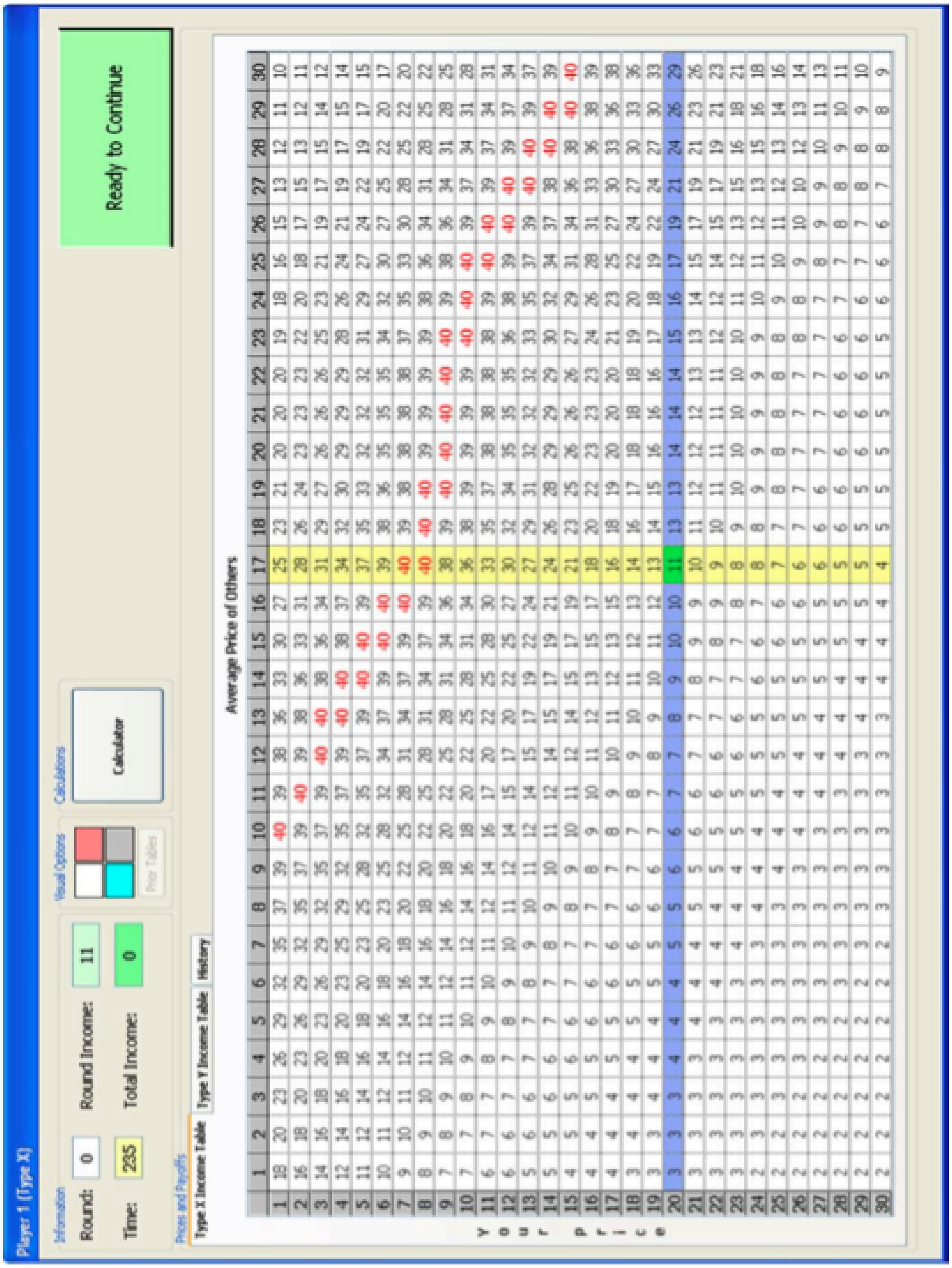


Figure 7.4: Participant Interface in Experiments with Nominal Payoff Framing and Computerized Opponents (Average Price of Opponents Conditional on Participant's Price Highlighted in Yellow

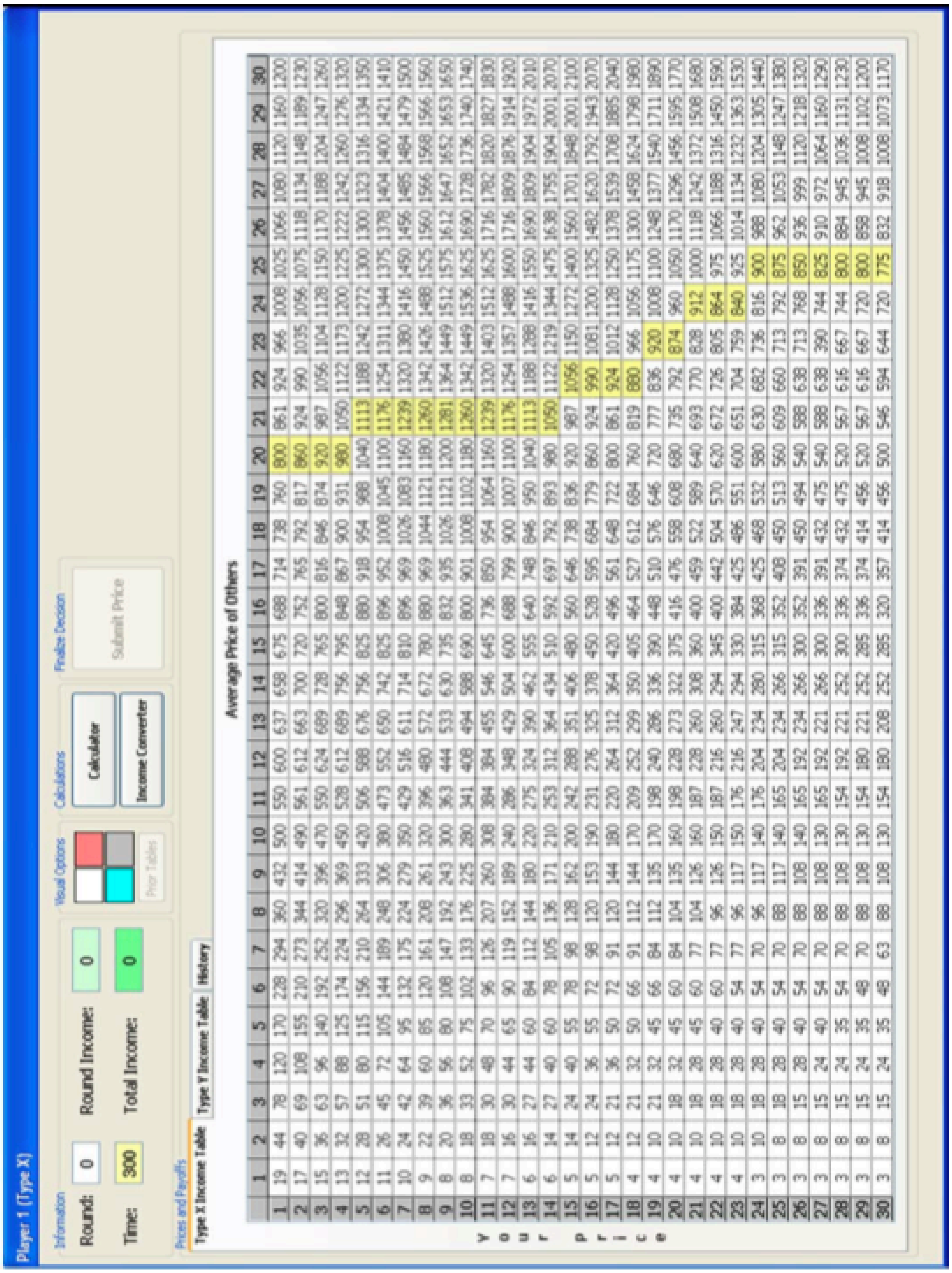
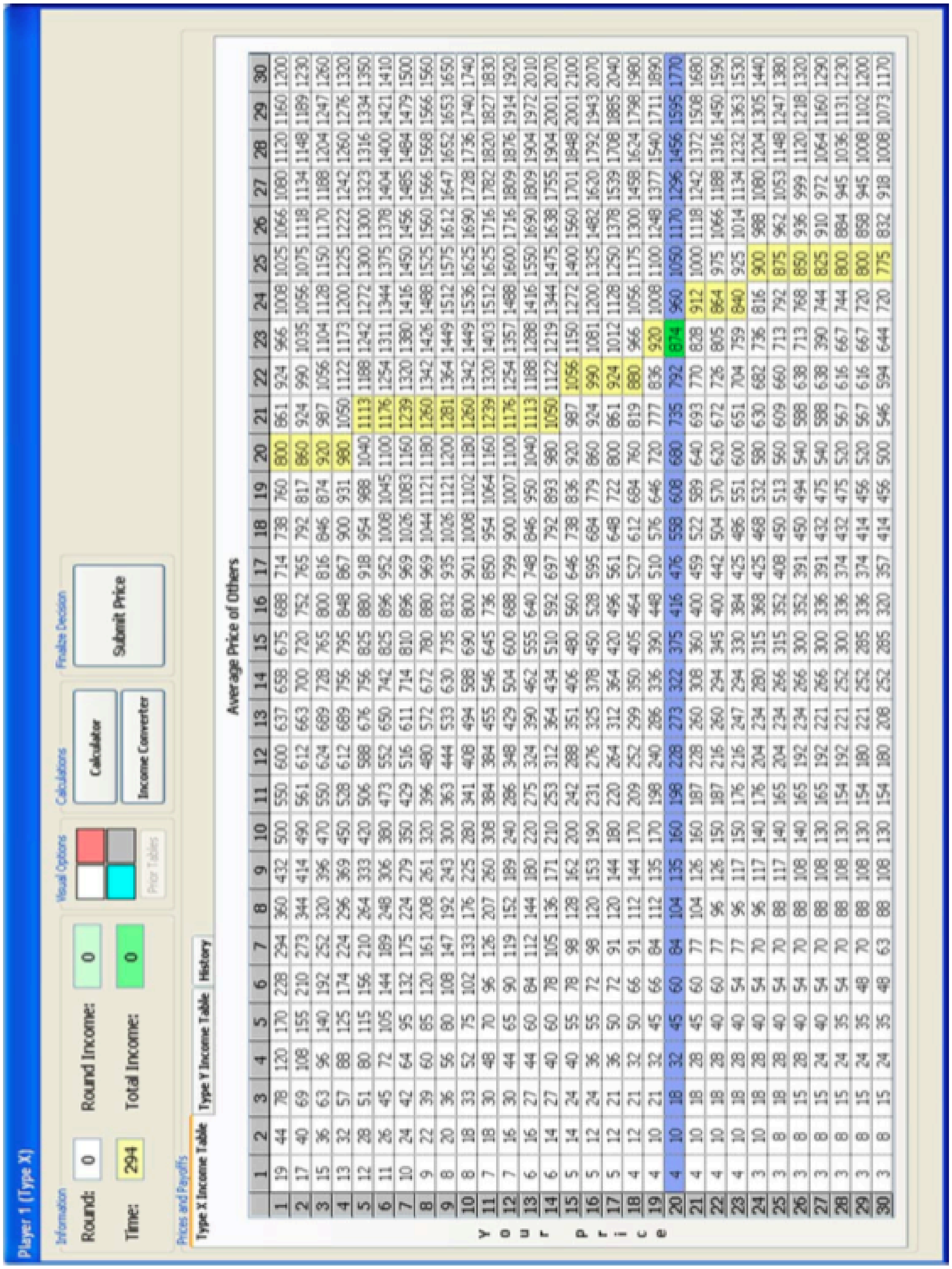


Figure 7.5: Price Selected in Experiments with Nominal Payoff Framing and Computerized Opponents



7.3 Instructions for Experiments with Nominal Payoff Framing and Human Opponents

General instructions for participants

You are participating in a scientific experiment which is funded by Chapman University. The purpose of this experiment is to analyze decision making in experimental markets. If you read these instructions carefully and make appropriate decisions, you may earn a considerable amount of money. At the end of the experiment all the money you earned will be immediately paid out in cash.

Each participant is paid $7 for attending. During the experiment your income will not be calculated in dollars, but in points. The total amount of points you collect during the experiment will be converted into dollars by applying the following exchange rate:

50 points = $1.00

During the experiment you are not allowed to communicate with any other participant. If you have any questions, the experimenter(s) will be glad to answer them. If you do not follow these instructions you will be excluded from the experiment and deprived of all payments aside from the minimum payment of $7 for attending.

[Questions?]

Overview of the experiment

The following is a brief description of the experiment. A more detailed description is given below. The experiment will last for a number of rounds. All participants are in the role of firms, selling some product. In this experiment, there are two types of firms: firms of type x and firms of type y. Each firm has to choose a selling price in every round. The income you earn depends on the price you choose and on the prices the other firms within your group choose.

[Questions?]

Detailed description of the experiment

The image on your screen is a screenshot of the computer display you will use to make your pricing decisions. We will refer to this screenshot several times through the course of these instructions.

The experiment is divided between two phases, the first of which consists of 15 rounds plus a practice round. You are not paid for the practice round. You should nevertheless take the practice round seriously since you may gain experience in this round. This experience helps you to make decisions in the other rounds in which you are paid. The second phase consists of an additional 15 rounds, but no practice round.

[Questions?]

Every participant is in a group with three other firms. There are two firms of type x and two firms of type y in every group. Your firm type will be displayed at the top left of your screen, and you will remain a firm of that type for the entire experiment.

In the example on your screen, the participant is a firm of type x. Consequently, there would be one more firm of type x and two other firms of type y in her group. If she were a firm of type y, there would be two other firms of type x and one more firm of type y in her group. No participant knows which persons are in his or her group. However, you will be grouped with the same participants throughout the experiment. The decisions made by other groups are irrelevant for your group.

[Questions?]

Earning points

In every round all firms simultaneously decide which selling price they wish to set for the current period. Every firm has to choose an integer price from the interval 1 < selling price < 30. How much you earn depends on the price you choose and on the average price of the other three firms in your group. Independent of the firm type, the average price for every firm is calculated by the following formula:

Average price = (Sum of selling prices of other 3 firms) / 3

Consequently, the average price will be in the interval 1 < average price < 30 and will be rounded to the nearest integer number.

Your computer display contains two income tables: one for firms of type x on the “Type X Income Table” tab, the other for firms of type y on the “Type Y Income Table” tab. The income tables are color coded. The income table with a **white** background shows the nominal income in points if **you** (or the other firm of **your type** in your group) choose a specific price and a specific average price results in that round. In the example on your screen, the participant is a firm of type x, so the Type X Income Table has a white background. The income table with a green background shows the nominal income in points that one of the firms of the other type will earn if he or she chooses a specific price and a specific average price results. In the example on your screen, the Type Y Income Table has a green background, because the participant is a firm of type x.

[Questions?]

Both income tables display **nominal** points. However, your income at the end of the experiment is not based on nominal point income, but on **real** point income. The following relation between the two holds:

Real income = (Nominal income / Average price of other firms) – Average price of other firms

This formula holds for all firms. Because this formula may be difficult to calculate mentally, your computer display provides you with a tool to quickly calculate real income from the income tables. We will discuss this tool later in the instructions. Notice that on both tables, some of the incomes are displayed in bold, red font. These are the **highest real incomes** that can be earned in a given round.

[Questions?]

Let's consider an example. The participant in the example on your screen is a firm of type x. Suppose she chose a price of 2. Suppose the average price chosen by the three other firms in her group was 4. In this case her nominal point income would be 108 points. Her real income would be 23 points; that is, (108/4) – 4.

[Questions?]

When you decide which price to choose, you do not yet know which average price will actually result in this period. Your white income table can consequently help you to calculate your real point income given your **expectation** of the average price of other firms. Given your expectation of the average price, you can read off the white table the income you would get by choosing different selling prices.

Suppose the participant in the example on your screen expects an average price of 30. If she chose a price of 17 her expected nominal income would be 2040 points, and her expected real income would be 38 points; that is, (2040/30) – 30. If she chose a price of 10, her expected nominal income would be 1740 points, and her expected real income would be 28 points; that is, (1740/30) – 30.

[Questions?]

Using the computer display to set your price

You may select a price from the income table by clicking on one of the prices in the far left column, labeled "Your Price." Clicking on a price in the white income table will highlight all of the incomes in its row in blue. The highlighted incomes show you what your earnings would be for the round for each average price the other firms in your group might set. In the example on your screen, the participant has selected a price of 15. If you want to revise your decision, you may click on a different price in the far left column.

[Questions?]

You may also click on a price when you are looking at the green income table. Doing so will highlight all of the incomes in the corresponding row in light yellow. However, be aware that clicking on a price in the green income table will have **no impact** on the prices that the other participants in your group will choose. You should also be aware that clicking on a price in the green income table does not count as setting a price for your firm. To set your price, you must click on a price in the white income table.

[Questions?]

In addition to setting your own price each round, please indicate the average price that you expect the other three firms in your group to set. This price must be an integer between 1 and 30. Your forecast of the average price does not affect your income and will not be known to the other firms. Your payoff will be determined by the actual average price. Please try to indicate an expectation that is as exact as possible since this may help you to make your own price decision.

Along with your forecast of the average price, please select a number from 1 to 6 to indicate how confident you are that the actual average price will be equal to your forecast. The numbers stand for:

1 = I am not at all confident that my forecast will be correct

2 = I have little confidence that my forecast will be correct

3 = I am somewhat confident that my forecast will be correct

4 = I am quite confident that my forecast will be correct

5 = I am very confident that my forecast will be correct

6 = I am absolutely confident that my forecast will be correct

In the example on your screen, the participant has entered a forecast of 16 and a confidence of 4. This means that she expects the average price of the other three participants in this round to be 16, and she is quite confident in this expectation.

[Questions?]

When you have selected a price, entered a forecast and chosen your level of confidence, you may click the button labeled "Submit Price" in the upper middle portion of your screen. (The Submit Price button will be disabled until you have completed those three tasks.) Once you have submitted your price, you cannot revise your decision until the following round.

After all participants have submitted their prices, you will receive information on the average price set by the other three firms in your group. The column corresponding to the actual average price will be highlighted in yellow. Where this yellow highlighting intersects the blue highlighting from the price you have chosen for the round the income cell will be shaded green. This cell will contain the nominal point income that you have earned for the round. In the example on your screen, the participant had chosen a price of 20, while the average price of the other three firms in her group was 17. Her nominal income of 476 points can be found in the green shaded cell, in row 20, column 17 of the white income table.

[Questions?]

Round information and the History Tab

Your computer display will provide you with some important information throughout the experiment. The upper left portion of the display contains the following information:

Round: The current round of the experiment. Note that "Round 0" is the practice round.

Time: The number of seconds remaining in the round. During the practice round you will have 300 seconds (5 minutes) to submit your price. During all other rounds you will have 120 seconds (2 minutes) to do so.

You should be aware of two things regarding the time. First, when all participants have submitted their prices, the round will end regardless of how many seconds are remaining. Second, if time runs out before you have clicked the Submit Price button, the software will automatically submit the last price you clicked on during that round. If you have not clicked on any prices during that round, the software will choose a random number between 1 and 30, and submit that as your price.

Round Income: The income, in **real** points, that you have earned in the current round. In the example on your screen, the participant's nominal point income is 476, and the average price of the other firms in her group is 17. The Round Income box displays her real income of 11 points; that is (476/17) – 17.

Total Income: The total income, in **real** points, that you have earned up to this point in the experiment. In the example on your screen, the Total Income box displays zero points. This is because the participant is in the practice round, Round 0, the results of which do not affect her earnings.

[Questions?]

In addition to this information, you can click on the "History" tab to find information from previous rounds. This includes the following:

Round: The round in which you chose a price.

Your Price: The price you set in that round.

Average Price of Others: The average price set by the other three firms in your group in that round.

Income: The income, in **real** points, that you earned in that round. You may access the History at any time during the experiment.

[Questions?]

Advancing the experiment to the next round

At the end of each round, a green button labeled "Ready to Continue" will appear in the upper-right of your screen. Click it to indicate that you are ready to go on to the next round of the experiment.

After all participants have clicked the Ready to Continue button, the experiment will advance to the next round. The income highlighting from the price you set in the previous round will disappear, as will the average price from the previous round.

[Questions?]

Cell shading, income conversion and calculator

Your computer display contains three tools that you can use in the experiment. The first of these tools is cell shading. By default, the background of your firm type's income table is white, while the background of the other firm type's income table is green, but you may change these background colors.

To shade a cell, first click on it. A black box, or "halo," will appear around the cell. In the upper portion of your screen are four colored squares: the default color (white or green, depending on which income table is visible), red, light blue and grey. Clicking on one of these squares will assign its color to the selected income cell. In the example on your screen, the participant clicked the red square.

You may also shade multiple cells at once. First, select a set of income cells in the table in the same manner you would in a Microsoft Excel Spreadsheet: click on one cell and, holding down the left mouse button, drag your cursor to another cell; then release the left mouse button. Next, click on one of the colored squares to assign that color to all of the income cells within the halo.

You may shade cells in both of the income tables. Any cells that you shade in a given color will remain that color for the remainder of the experiment unless you choose to change it. Cell shading does not reset at the end of a round.

[Questions?]

The second tool at your disposal is the income converter. You may access the converter by clicking the button labeled "Income Converter" in the upper middle portion of your screen. The income converter can be used to quickly find the real income that will result from any combination of your price and the average price of the other firms in your group. Once you have entered these prices in the appropriate boxes, click the button labeled "Calculate Income" to see what your income would be in real points.

When you are using the income converter, the software assumes that you want to find real incomes from the income table you are currently viewing. In the example on your screen, you can see that "Type: X" is printed at the top of the income converter because the Type X Income Table is currently visible on the participant's computer display. If you click on the Type Y Income Table tab the income converter will reset to display real point incomes from the Type Y Income Table. The income converter will only show you the real point incomes for the income table that is visible on your computer display. It will not show you any real point incomes when the History tab is selected, because neither income table will be visible.

[Questions?]

The third and final tool on your computer display is a four-function calculator. You may access the calculator by clicking on the button labeled “Calculator” in the upper middle portion of your screen. The calculator functions very similarly to the standard Microsoft calculator application.

[Questions?]

Changing the income tables in Phase 2

As stated above, the experiment will be divided between two phases. The only difference between Phase 1 and Phase 2 will be the income tables that are used. In Phase 1 the income tables will be identical to the two that you have seen in the examples on your screen. You will use these income tables for rounds 0 – 15.

After round 15 has concluded, the income tables on your screen will be replaced by new income tables. As with the original tables, the cells with the highest real incomes will have a bold, red font. (Note that these may be different real incomes than the highest real incomes from Phase 1.) You will have up to 600 seconds (10 minutes) to review these new tables before we begin Phase 2, consisting of rounds 16 – 30. At any time during this review period, you may click the Ready to Continue button to indicate that you are ready to proceed to round 16, and do not need the full 10 minutes for review. If all participants indicate that they are ready to continue before 10 minutes have elapsed, we will end the review period early and move immediately on to round 16.

[Questions?]

You may find it useful to compare the new income tables to the original ones. In the upper portion of your screen, beneath the colored cell shading squares, is a button labeled “Prior Tables.” At any time during the review period or in rounds 16 – 30, you may click this button to see the original income tables. Any cell shading that you performed in Phase 1 will be preserved on the original tables. Additionally, you may use the payoff converter on the original income tables as well as the new ones.

To return to the new income tables, click the same button (now labeled “New Tables”) a second time. Keep in mind that in Phase 2 you cannot set your price using the original income table of your firm type. You must have the new table for your firm type visible in order to set the price for your firm.

Chapter 8

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