EXPERIMENTS ON MONETARY POLICY AND CENTRAL BANKING

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ABSTRACT

In this article, we survey experiments that are directly related to monetary policy and central banking. We argue that experiments can also be used as a tool for central bankers for bench testing policy measures or rules. We distinguish experiments that analyze the reasons for non-neutrality of monetary policy, experiments in which subjects play the role of central bankers, experiments that analyze the role of central bank communication and its implications, experiments on the optimal implementation of monetary policy, and experiments relevant for monetary policy responses to financial crises. Finally, we mention open issues and raise new avenues for future research.

Keywords: Monetary policy; central banking; laboratory experiments

INTRODUCTION

Experimental macroeconomics is a growing field and the increasing number of publications in this area is likely for two reasons: first, modern macroeconomics is microfounded with many models resting on strategic games or

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(at least) on individual optimization. Since games and optimization tasks can be framed as laboratory experiments, these foundations of macro models can be tested in the lab. Thereby, macroeconomics is catching up in exploiting a method that has already been used with large success in other fields, like industrial organization, auction design, or the design of incentive schemes. The second reason may be a widespread dissatisfaction with models that rest on assuming rational expectations or, more widely, rational behavior. While the rationality assumption is a necessary tool for predicting the effects of systematic policy or institutional changes, the actual biases in behavior and expectations are too systematic and affect economies too much for subsuming them under unexplained noise.

How to rationalize macroexperiments? The explicit microfoundation used in modern monetary macro models such as the "dynamic stochastic general equilibrium (DSGE)" approach allows the programming of small sample economies, in which subjects take the roles of various economic agents, but also calls for testing the microeconomic modules that DSGE models are composed of. While the assumptions and predictions of macroeconomic models have historically been tested using non-experimental field data, an alternative empirical approach that is attracting increased attention uses controlled laboratory settings with paid human subjects. The main advantage of this approach is the ability of the experimenter to control subjects' incentives, their information, and the channels of communication, so that by changing exogenous factors, causality can be established without the need for sophisticated econometric techniques or for constructing disputable instrument variables. Moreover, while pure equilibrium theory does not capture strategic uncertainty and cannot predict the consequences of policy measures if the model has multiple equilibria, experiments can be used to develop and test theories of equilibrium selection.

One may ask how macroeconomic phenomena resting on the interaction of millions of agents can be explored using laboratory experiments with just a few subjects (Duffy, 1998). The same question has been raised with respect to macroeconomic theories that assume homogeneous, often representative, agents. Nevertheless, some of these theories provide valuable insights into the basic mechanisms by which monetary or fiscal policies affect aggregate variables like growth rates, employment, or inflation. Experiments can do even better, because even a small number of, say 10, subjects in a laboratory economy introduce a level of heterogeneity that theories can hardly deal with except by mathematical simulation. The additional insights to be gained by increasing the number of subjects in a well-structured model economy from 10 to 10 Million may be of minor relevance. Furthermore, microfounded macro models assume that agents interact in response to incentives within a framework, where they can understand the consequences of their behavior and of their interaction. By reading instructions (and eventually by playing some training periods), subjects can achieve a level of comprehension of the functional relationships between variables of the game that we can never hope for in real economies. By specifying the payoff functions, the experimenter has the highest control over incentives, while the confounding impact of context and unstructured communication can be kept at a minimum. Thus, laboratory economies are the best environment for testing the behavioral predictions of theories with micro- or game-theoretic foundation. Such tests are hardly conceivable in the field. As Duffy (1998, p. 9) points out: "*Even in those cases where the aggregate predictions of microfoundation models can be tested using field data, it is not always possible to use field data to verify whether behavior at the individual level adheres to the predictions or assumptions of these models*." Of course, the results from laboratory experiments cannot be readily generalized to real economic situations, in which context, ethics, experience, and formal training of the major actors may yield different responses to changes in exogenous variables than observed in an abstract laboratory economy. The same, however, is true for theory. Laboratory experiments may be able to falsify theories. If they do not work in the lab, why should they work outside? But ultimately, economics is a social science, and field evidence is indispensable.

In this article, we argue that experiments can serve as an important tool for central bankers. The focus on monetary policy and central banking is linked to the idea that experimental macroeconomics enables policymakers to "bench-test" competing policy actions, rules, or institutional designs by laboratory experiments. Experiments allow to elucidate the different effects – anticipated and unanticipated – of alternative policy regimes and offer a quick and cost effective way to identify possible consequences of a monetary policy initiative.[1] Experiments may help to advise policymakers by exploring the effects of alternative policies in the lab (Ricciuti, 2008). There is a need for more interaction between experimental macroeconomists and central bankers, both to help experimentalists adjust their research and account for the questions and concerns of practitioners and to help central bankers to interpret the results of experiments and judge their external validity. As shown by the example of Alan Blinder, one can be both a central banker and an experimentalist.

The topic of central banking experiments lies at the scientific frontier of experimental economics and central banking alike. The results from this approach can be informative with respect to questions of equilibrium selection or the efficacy of various government policies. Laboratory experiments addressing central banking issues are useful in several respects:

- Finding out, which out of many equilibria is selected in well-defined environments and testing theories of equilibrium selection provides guidelines for the likely outcomes in macroeconomic environments that are described by models with multiple equilibria.
- Testing concepts of equilibrium determinacy and stability with respect to their predictive power may help settling controversial discussions about the "right" stability criteria.
- Trying out policy rules, decision rules, and communication protocols in their effectiveness to stabilize markets is an almost costless exercise in the lab, while any such experiments at the macro level would endanger the welfare of societies or are simply impossible to conduct in a pure form.
- Understanding how people's strategic behavior interacts with the institutional environment prior to policy implementation can greatly reduce the cost of achieving policy goals. By taking into account the various factors and motivations that may influence human behavior, experimental economics allows testing alternative policy options. For example, laboratory experiments may help selecting instruments and institutional arrangements that are best-suited for implementing policy goals.[2]
- Solving the endogeneity problems. In the real economy, policy parameters respond to economic activity. As expressed by Ricciuti (2008, p. 218), "*the endogeneity of policy in real-world economies (...) makes it difficult to analyze data and formulate correct inferences on changes that have occurred.*" Laboratory experiments allow controlled tests of the effects of changing individual parameters exogenously.

This article surveys laboratory experiments addressing central banking issues following the scheme represented in Fig. 1.[3] While Duffy (1998, 2008a, 2008b) and Ricciuti (2008) focus their surveys on a much larger category of papers dealing with experiments in macroeconomics, we concentrate on issues relevant for central banking and present some recent literature. Most experiments that are presented below focus on specific building blocks or component assumptions of standard macro models.

In the section "Channels for Money Non-neutrality," we look at some causes of non-neutrality of monetary policy. Here, we focus on money illusion and monetary policy experiments applied to environments of sticky

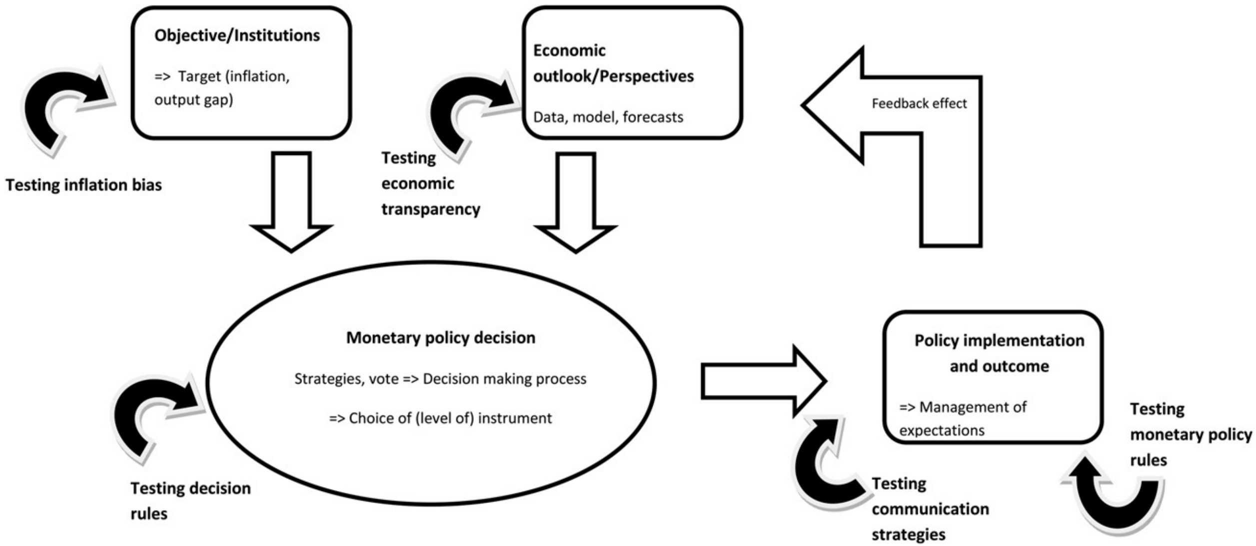

Fig. 1. Central Banking Issues and Experimental Literature.

prices or sticky information. We do not consider experiments on the formation of expectations, although they would have to be considered here, because they are already dealt with in another article of this book (Assenza, Bao, Hommes, & Massaro, 2014). Looking at how subjects behave in the lab and especially studying the effects of communication between the central bank and the public may help predicting the likely effects of policy measures and designing optimal decision processes and institutions. In the section "Subjects as Experimental Central Bankers," we present results of experiments that study how subjects behave in the lab when they play the role of central bankers. These experiments demonstrate that the inflation bias arising from time inconsistency matters in repeated games, even if central bankers are concerned about affecting future expectations. They also provide an argument in favor of following fixed rules, although experimental subjects are quite capable of pursuing optimal responses to shocks in order to stabilize an economy. The section "Transparency and Communication Issues" is devoted to central bank communication and the merits of transparency. There is a vivid debate about the pros and cons of transparency, and while central banks have moved toward higher transparency, theory papers provide mixed recommendations. Experiments are particularly well-suited for testing the effects of information and communication channels, because the experimenter can control information and distinguish communication channels in different treatments. Thereby, experiments yield very clear results about the effects of information, while field evidence is always plagued by the simultaneity of different communication channels and by the problem of identifying which information actually affected real decisions. The interplay between communication and stabilization policy is also studied in the lab. The section "Policy Implementation" deals with the implementation of monetary policy. We distinguish policy strategies that may be described by different rules and the operational policy implementation via repo auctions. Auction design is a classical topic of experimental economics and using experiments for bench testing auctions has become a standard procedure. The section "Monetary Policy During Liquidity Crises" focuses on experiments dealing with financial crisis and central banks' interventions. Finally, we mention open issues and raise new avenues for future research. It seems particularly important to emphasize the behavioral aspects in the transmission process of monetary policy and in the formation of inflation expectations. Specifically, there is a need for thinking about the methodology in designing rules for monetary policy, information disclosure, and financial market regulation that account for private agents' behavior under strategic uncertainty. The global financial crisis has also recast the debate over the scope and instruments of central banking. Experiments may represent a good tool for testing them.

CHANNELS FOR MONEY NON-NEUTRALITY

As witnessed by Adam (2007, p. 603), "*[r]ational expectations models with nominal rigidities, workhorses of current macroeconomics, (…) face difficulties in matching the persistence inherent in output and inflation data*." A possible reason could be that real agents do not behave according to the strong assumptions underlying rational expectations. Laboratory experiments have explored some aspects of bounded rationality that seem relevant for explaining the real and persistent effects of monetary policy. The most promising explanations seem to be money illusion, limited depth of reasoning, nonmonetary costs of information processing, the use of heuristics, and adaptive expectations. Some of these explanations are related and interact in causing real effects of monetary shocks. Looking at how subjects behave in the lab and especially studying the learning processes may help better modeling internal frictions leading to a proper propagation mechanism. Many experiments indeed aim at comparing rational expectations to adaptive learning especially in equilibrium selection. There is a recent and relatively large focus on the formation of expectations in the lab. "*Resorting to laboratory experiments is justified on the grounds that expectations are generally not easily observed. This makes it difficult to identify deviations from rational expectations*" (Adam, 2007, p. 603). In the lab, subjects' expectations can be directly observed. The dynamics of learning models depend on the functional relationship between stated expectations and realizations of the variables about which expectations are formed.[4]

Amongst the monetary policy channels that have been tested in the lab, money illusion (Section "Money Illusion") stands out as it seems to be driven by anchoring on numerical values and is clearly opposed to rationality. However, sticky prices can also be explained by the expectation that other agents are affected by money illusion. We show some experiments in which sticky prices or sticky information (Section "Sticky Prices and Sticky Information/Monopolistic Competition") is explicitly introduced and compared to the behavior in otherwise equal economies without such frictions. The general finding is that even in a frictionless economy, subjects behave *as if* there were some of these frictions. The often observed delayed response of prices to shocks can in parts be explained by money illusion.

Subjective beliefs that other agents are not responding to shocks provides an additional explanation of these delays. In games with strategic complementarities, as they are typical in monetary macro, these two effects reinforce each other.

Money Illusion

Fehr and Tyran (2001, 2005, 2008) study the impact of price level changes on individual price-setting in environments with strategic complements and strategic substitutes. In their experiment, subjects play firms who are setting nominal prices in an oligopolistic market. A change of payoff tables represents a large anticipated price-level shock to which subjects should immediately respond by jumping toward the new equilibrium. Fehr and Tyran investigate whether and how fast subjects converge to the new equilibrium for different strategic environments. Prices respond gradually. When prices are strategic substitutes, they converge faster than when they are strategic complements. Since supply and demand functions depend only on relative and not on absolute prices, the result of sluggish price adjustments may be interpreted as evidence for the non-neutrality of money supply. Due to the different speeds of adjustment to equilibrium, monetary shocks have a stronger impact when prices are strategic complements than when they are strategic substitutes.

Fehr and Tyran (2001) consider a n-player pricing game with a unique equilibrium similar to price-setting under monopolistic competition. Subjects get payoff tables stating how their payoff depends on their own price and the average price of other firms. After T periods payoff tables are replaced by new ones, that differ only by a scaling factor, representing a fully anticipated negative shock on money supply. The game continues for another T periods with these new payoff tables.

Insufficient price adjustments may be explained by two factors: money illusion and the expectation that other subjects are adjusting their prices insufficiently. In order to disentangle these effects, Fehr and Tyran (2001) compare four treatments: in one, payoff tables are given in nominal terms and subjects play (as described above) against other human subjects (Treatment NH). Payoffs are later transformed in real currency with different scaling factors before and after the shock. Treatment NC has payoffs in nominal terms, but the other firms are played by a computer. Here, the only human subject is informed that the computer will always choose a price that is a best response to her or his own stated price. Treatment NC eliminates strategic uncertainty as a potential explanation for sluggish price adjustments. In two further treatments, RH and RC, payoff tables are given in real terms (subjects again play against humans or a computer, respectively), so that money illusion can be ruled out as a source for sluggish price adjustments.[5]

Results show that monetary shocks have real effects, as subjects in Treatment NH need several periods to come anywhere close to the new equilibrium. However, the main cause is neither individual money illusion, nor coordination failure, but the combination of both. Fig. 2 presents the average price before and after the shock in the four treatments. In Treatment RC, there was an instantaneous adjustment to the new equilibrium. In Treatments NC and RH, adjustments toward the new equilibrium took a few periods, but subjects came rather close. In Treatment NH, however, where the coordination problem was combined with nominal payoff tables, there is a substantial delay in price adjustments. An explanation is to be found in subjects' expectations. In Treatments NH and RH, Fehr and Tyran (2001) asked subjects about their expectations of the average price set by others. The difference in stated expectations between treatments was

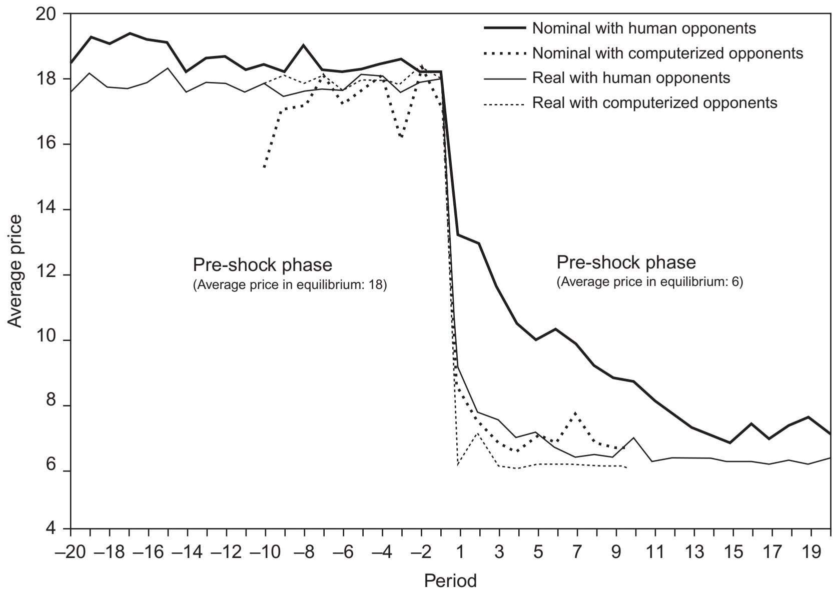

Fig. 2. Evolution of Average Prices. *Source*: Fehr and Tyran (2001, p. 1251).

comparable to the difference between the prices that subjects actually chose in these treatments. Fehr and Tyran (2001) attribute these different price expectations to a "rule of thumb," by which subjects mistake nominal for real payoffs and strive for collusion by setting prices above the equilibrium. This would be another impact of money illusion. For testing this, they added two treatments with positive price-level shocks, where subjects with money illusion who want to collude would speed up the adjustment toward the new equilibrium. Indeed, these sessions showed faster price adjustments than the comparable sessions with negative shocks. However, the treatments differed in several respects from those with negative shocks and are, thus, not entirely comparable.

Note that the deviation from equilibrium in Treatment NH is larger than the sum of deviations in Treatments NC and RH. Deviations resulting from coordination failure and money illusion may reinforce each other in environments with strategic complementarities. Fehr and Tyran (2008) use a similar experiment, where treatments differ by prices being either strategic complements or substitutes. In both treatments, the equilibrium was efficient, ruling out that a desire for collusion can explain systematic deviations from equilibrium. In the substitutes treatment, average prices jump toward the new equilibrium almost instantaneously after the shock. There is some mis-coordination, as some subjects choose prices that are too high or too low, and thus, there is an efficiency loss in the first two periods after the shock. The efficiency loss is, however, much larger in the complements treatment, where prices adjust slowly toward the new equilibrium as in the experiment by Fehr and Tyran (2001). Four control treatments serve to identify the causes for insufficient price adjustments. Fehr and Tyran (2008) find that results can be explained by money illusion and anchoring or the expectation that other subjects suffer from these deviations from rationality. While subjects with money illusion mistake nominal for real payoffs, anchoring means that subjects anchor their expectations at the numbers they saw before. After paying an equilibrium price for several periods, subjects deviate from a rational response to a nominal shock toward the best reply of previous equilibrium prices. With strategic complementarities, deviations from equilibrium due to anchoring, money illusion, and the expectation that other subjects are anchoring or suffer from money illusion are reinforcing each other, while in environments with strategic substitutes, they may actually have opposing effects: if I believe that my opponents adjust prices insufficiently, I should adjust my price more than just toward the new equilibrium. It has been confirmed in various other experiments that subjects converge to equilibrium much faster in games with strategic substitutes than in games with strategic complementaries.[6] Limited levels of reasoning are able to explain these patterns.[7]

Petersen and Winn (2014) argue that the results of Fehr and Tyran (2001) provide less evidence for money illusion, but rather for a higher cognitive load associated with adjusting prices in the NH treatment. Fehr and Tyran (2014) reply to this by explaining that money illusion can only unfold, if adjustment to a new equilibrium is a nontrivial task. Money illusion is not opposed to limitations in cognitive capacity but rather depends on them. As both, Petersen and Winn (2014) and Fehr and Tyran (2014), point out, the cognitive load in finding the Nash equilibrium matters for subjects who take nominal payoffs as a proxy for real payoffs. We conclude from this that money illusion is inevitably linked to the information role of nominal prices. However, the dispute between these authors points at some open issues: what exactly is money illusion and can it be separated from other factors impeding price adjustments after nominal shocks? One may think of experiments comparing responses to nominal and real shocks for identifying money illusion, coordination issues, and anchoring.

Sticky Prices and Sticky Information/Monopolistic Competition

Slow price adjustments to shocks are at the foundation of new Keynesian macroeconomics, such as DSGE models. For justifying the limited speed of adjustment, DSGE models rely on either sticky prices (Calvo, 1983) or sticky information (Mankiw & Reis, 2002). In sticky-price models, firms cannot adjust their prices in every period. In sticky-information models, firms cannot update their information in every period. Both restrictions lead to delayed responses of the price level to monetary shocks and, thus, implement the non-neutrality of money. Both restrictions can be partially justified by more fundamental assumptions: menu costs may prevent firms from adjusting prices every period and costs of information processing may justify why firms update their information only occasionally.[8]

Experiments have been conducted regarding these fundamental assumptions as well as regarding the actual speed of price adjustments in environments with exogenously given restrictions. Wilson (1998) conducts an experiment in which subjects play monopolists who may adjust prices to some shock in their demand function. He finds that menu costs slow down the adjustment process.

Orland and Roos (2013) introduce information costs for uncovering future desired prices in an environment with sticky prices à la Calvo. They find that about one third of all subjects are myopic in the sense that they set prices that are optimal in the current period only. These subjects neglect that the currently set price should be closer to a weighted average of the current and future desired prices. With information costs, myopic subjects acquire less information about future desired prices and rely even more on the current and past desired prices. The presence of myopic agents can explain why aggregate prices are stickier than predicted in a Calvo model with rational agents. Maćkowiak and Wiederholt (2009) explain sticky information by rational inattention and Cheremukhin, Popova, and Tutino (2011) test the theory of rational inattention in the lab. They estimate and compare different models of rational choice and reject models with low or homogeneous costs of information processing. Their main result is that subjects seem to be extremely heterogeneous in their costs of information processing. Caplin and Dean (2014) also propose a test of information acquisition theory. The experimental approach is motivated by unobservable information acquisition costs in the field. They show that participants in their experiment adjust their information collection behavior to incentives and use more time and effort for processing information if the rewards are higher. In a companion paper, Caplin and Dean (2013) show that subjects respond less to changes in incentives than the Shannon Entropy theory predicts. They propose a simplified Shannon model that renders account for this observation.

Davis and Korenok (2011) present a laboratory experiment aimed at evaluating the relative capacity of alternative theories to explain the delayed adjustment of prices following a nominal shock. In their experiment, subjects play price-setting firms under monopolistic competition. Markets consist of six sellers and 80 trading periods during which there is a nominal shock doubling the money supply. Subjects are informed upfront that this shock will occur, but they are not informed about the precise timing of the shock. The experiment distinguishes three treatments: in a baseline treatment (BASE), firms can adjust their prices in each period and are informed about the market result after each period. From this, they can immediately identify the period in which the shock occurred. In a sticky-price treatment (SP), only two out of six subjects in a market can adjust their prices each period, and subjects take turns in adjusting. In a sticky-information treatment (SI), only two firms see the results from the immediately preceding trading period, again taking turns, so that each firm receives an information update after three periods.

With flexible prices and information, there should be an immediate jump to the new equilibrium following a nominal shock, while Treatments

SP and SI should show a delayed response according to theoretical predictions. Davis and Korenok (2011), however, observed a delay in all three treatments. While subjects adjust very well toward the equilibrium before the shock occurs, there is a considerable deviation between actual and equilibrium prices in the periods following the shock. As in the experiment by Fehr and Tyran (2001), subjects stop short of doubling the price after the money supply has doubled. In line with theory, observed deviations in the SP and SI treatments exceed those in the BASE treatment in the first one or two periods after the shock. In the SI treatment, prices adjust more slowly than in the two other treatments. The main result, however, is that observed prices deviate from the respective theoretical predictions in all three treatments for at least nine periods with no significant differences between treatments for most of these periods. One way to look at this result is that although firms may get timely information and adjust prices whenever they want, they may behave *as if* there were frictions like sticky prices or sticky information. Note, however, that the environment by Davis and Korenok (2011) is one of strategic complementarities in which adjustments to equilibrium may be held up by limited levels of reasoning.

Davis and Korenok (2011) consider two alternative explanations for the delayed price adjustment in the BASE treatment: (1) some sellers might have missed the shock or believed that others miss the shock, because the shock was announced privately rather than publicly; (2) some sellers might have imitated their forecasts instead of best responding to them. That is they stated a price close to their own forecast instead of the price that would have maximized their own payoffs given this forecast. To discriminate between these hypotheses, the authors conduct two additional treatments, each of them deviates from the BASE treatment by one aspect: (1) a treatment where the shock is announced publicly and (2) a treatment where sellers submit forecasts instead of prices. The results from these additional sessions indicate that both explanations play a role: a publicly announced shock leads to an immediate jump in stated prices or expectations in both new treatments instead of a slow convergence process as in the BASE treatment. If subjects state their forecasts instead of prices, the economy comes closer to the monopolistically competitive equilibrium before and after the shock. Hence, the privately announced shocks are responsible for the slow convergence process immediately after the shock (which could also be explained by limited levels of reasoning), while the inability to best respond to one's own expectations seems responsible for the long-run deviation from the equilibrium.

While Fehr and Tyran (2001) and Davis and Korenok (2011) test responses of price-setting subjects to price-level shocks, Duersch and Eife (2013) test the stability of collusion in environments with permanently increasing or decreasing price levels. The paper is interesting as it provides an argument for the debate on the optimal rate of inflation. Their experiment implements a symmetric duopoly with differentiated goods in which subjects play the role of firms who repeatedly set prices. Period-specific payoff tables implement a constant rate of inflation or deflation (depending on the treatment) of 5%. There are also two baseline treatments with a constant price level, in which one payoff table is valid for all periods.[9] Duersch and Eife analyze how well subjects coordinate their prices, whether they cooperate by coordinating on prices above the one-period Nash equilibrium, and how these interactions affect consumer surplus. They show that cooperation is higher in the baseline than in inflationary and deflationary treatments. This indicates that it is easier to sustain cooperation in an environment with constant prices than under inflation or deflation, where a given degree of cooperation requires permanent adjustments of nominal prices. Real prices are, however, slightly increasing over time in the deflationary treatments. This effect may result from nominal anchoring or money illusion as it was found by Fehr and Tyran (2001). The lowest average real prices are observed in the inflationary treatments. Here, money illusion and the additional challenge of coordinating prices in an inflationary environment work hand in hand, reduce the firms' profits from collusion, and lead to a higher welfare level than deflation or a constant price level.

Lambsdorff, Schubert, and Giamattei (2013) conduct an experiment on a simple price-setting game, which is reduced to its form as a beauty-contest game. The novelty in their experiment is that one parameter steering the equilibrium price is a random walk. Thus, there are permanent unforeseen shocks in the economy that increase the cognitive load for finding the ever changing equilibrium price. Subjects play the game in groups of six players and the payoff function for each player is:

$$\pi_{it} = 10 - \left| \frac{13}{15} p_{it} - \frac{2}{3} \overline{p}_{-it} - 4 - \frac{1}{10} \mathrm{BI}_t \right|,$$

where p_{it} is the player's own price, $\overline{p}_{-it}$ is the average price of other group members, and BI_t is the realization of a random variable called "business indicator" in period t. The resulting equilibrium price in period t is $p_t^* = 20 + \mathrm{BI}_t/2$. Note that for realizations of BI_t close to 40, the equilibrium price is close to the business indicator. The actual realizations of BI_t in the experiment reached from 20 to 90, and subjects coordinated on stating prices equal to BI_t. Thus, the business indicator served as a focal point or heuristic for choosing prices. By deviating toward 40, subjects could have gained individually. However, the high degree of coordination led to average payoffs that were higher than in a control treatment, where the business indicator was presented in a different way (the number shown was $BI_t/5$, so that it lost its power as a salient coordination device). In the control treatment, individual prices were on average closer to the equilibrium, but had a high variance. The experiment shows that following a simple heuristic is an attractive strategy if the potential gains from finding a more sophisticated strategy are small. This finding seems related to the experiments on money illusion, where subjects take the nominal payoffs as proxies for real payoffs and save the effort of calculating. It is also related to experiments generating sunspot equilibria by providing focal points discussed in Section "Sunspots" below.

Summing up, price-setting experiments show that there are different reasons why monetary policy has real effects, even in environments where prices are fully flexible and information is provided to all agents. Observed delays in price adjustment after a shock can be partly explained by money illusion, anchoring, or monetary payoffs being used as focal points for simple heuristics in a complicated environment. Limited levels of reasoning or, related to this, a lack of trust that other agents notice the shock when it occurs, may explain the pronounced delay of adjustment to equilibrium in games with strategic complementarities. If information processing is costly, it may be even rational to ignore some information or employ limited levels of reasoning. If an economy exhibits strategic complementarities, as is often the case in macroeconomic environments, all of these channels reinforce each other and amplify the real effects of monetary policy. The study of expectation formation in the lab also shows that subjects generally adapt their expectations slowly, which may explain some persistence of real effects. It is helpful to account for those different forms of money non-neutrality to derive effective monetary policy rules.

SUBJECTS AS EXPERIMENTAL CENTRAL BANKERS

Some recent experiments test the abilities of subjects to perform the tasks that standard models expect central bankers to accomplish. In particular, central banks should stabilize inflation, eventually they should minimize a weighted average of fluctuations in prices and employment by using just one instrument, and they should gain reputation so as to avoid an inflation bias. They also must come to an agreement in committee meetings. Each of these aspects of central bank decisions can be tested in isolation using students as subjects in the role of central bankers. In practice, these tasks are complicated and interconnected, and different kinds of quantitative and qualitative information need to be considered. We would not expect undergraduate students to achieve the goals of monetary policy to the same degree as professional central bankers.

While it is obviously convenient to use students as subjects for laboratory experiments, convenience alone is no justification for following this method of research. However, we see four justifications for recurring to laboratory experiments with subjects playing central bankers. First, by testing different aspects of decision making in isolation, we may identify which aspects of decision making are particularly challenging to humans and which kind of biases, heuristics, and fallacies may explain behavior in the lab. These results may carry over to more complex decision situations and well-trained executives to the extent that they describe general aspects of human decision making. The hypothesis that results obtained with undergraduates carry over to professionals has been tested in various experiments related to financial markets, industrial organization, or corporate governance with mixed evidence (Croson, 2010).[10] Second, we learn most by comparing different treatments within an experiment. The qualitative treatment effects are more likely to spill over to real economic situations with trained decision makers than the quantitative effects or behavioral biases within any treatment. Third, the models that are used in most of the macroeconomic literature are far less complex than the real economy. They are stripped to essentials and arguably the relation between expert knowledge of real central bankers and the complexity of real economies may be comparable to the relation between the comprehension of models by students and the complexity of these model economies. Fourth, some parts of the literature on monetary policy assume that central bankers respond to incentives. Central bank contracts have been designed for the purpose to alter the objective functions of central bankers in ways that give rise to more efficient equilibria (Walsh, 1995). In laboratory experiments, students are incentivized *because* we want them to respond to incentives. Thus, the lab is a perfect environment for testing whether an engineered system of incentives has the desired effects on behavior.

Here, we are particularly interested in how subjects deal with time inconsistency and the inflation bias (Section "Central Bank Credibility and

Inflation Bias") and whether they are able to stabilize an economy with saddle-path stability (Section "Stabilization Policy"). Stabilizing an economy is a challenging exercise even in the lab. By analyzing the behavior of human central bankers in the lab we can draw some conclusions about the necessity of sticking to fixed Taylor-type rules, the tension between flexibility and credibility that may also affect the inflation bias, and on the size of the coefficient by which central banks should respond to past inflation. Groups are usually better in solving complicated decision problems than individuals. On the other hand intra-group communication may also induce some costs and reduce success rates of decisions, especially when groups are heterogeneous or several individuals want to lead the groups. Some recent experiments analyze the optimal size and composition of central bank committees (Section "Decision-Making Process in Monetary Policy Committees").

Central Bank Credibility and Inflation Bias

Time inconsistency of monetary policy has worried monetary economists at least since Kydland and Prescott (1979) and Barro and Gordon (1983a) developed models showing that it may explain an inflation bias if private agents form rational expectations and central banks have incentives to respond asymmetrically to positive and negative deviations of unemployment from the NAIRU. The starting point is the existence of a short-run Phillips curve that allows raising employment above the natural rate by unexpected inflation. Ex ante, the central bank wants to achieve a low inflation target, but it also has asymmetric objectives on employment: either the central bank's objective is an unemployment rate below the natural level or deviations toward lower unemployment are viewed as being less costly to society than higher unemployment rates. Ex post, once expectations are fixed, the central bank may exploit the Phillips curve trade-off and realize welfare gains, provided that expectations are close to the efficient level of inflation. Rational agents forecast this response and expect a higher rate of inflation ex ante, such that any further increase of inflation inflicts welfare losses that exceed the welfare gains associated with reduced unemployment. Thus, the equilibrium level of inflation is inefficiently high. Theoretically, there are different mechanisms of containing this inflation bias. The most important is laid out in the work of Barro and Gordon (1983b): in a repeated game, there is a continuum of equilibria ranging from the inefficient one-period Nash equilibrium explained above to more efficient solutions in which the central bank accounts for its effects on future expectations and builds up a reputation for low inflation rates. The precise limits for the range of equilibria, and whether the efficient Ramsey solution is actually part of this range, depends on parameters such as the central bank's discount factor and on observability of central bank actions.

Experiments allow testing which of the many equilibria are actually played, whether and how behavior responds to parameters, and whether observability of actions or communication affect efficiency. Experiments can also test the trade-off between credibility and flexibility that has been postulated by theory. These questions can be tackled by experiments in which the central bank is actually played by one or several subjects in the experiment or by comparing expectations formation in environments with different rules. Van Huyck, Battalio, and Walters (1995) test time inconsistency in a repeated two-player peasant–dictator game. In each round, the peasant first decides how many beans to plant and the dictator then decides on his discretion about a tax on production. This is compared with an otherwise equal treatment in which the dictator pre-commits to a tax rate before the peasant invests. While the commitment treatment has a unique equilibrium at the efficient investment level, the discretionary treatment has multiple equilibria ranging from the one-period Nash equilibrium at zero investment to the efficient Ramsey equilibrium of the commitment treatment. Although investment levels are in general positive, there are significant and sizable differences between the treatments, indicating that reputation cannot substitute commitment.

Arifovic and Sargent (2003) and Duffy and Heinemann (2014) test whether subjects playing central banker can achieve credibility in a Barro–Gordon game. In both experiments subjects are split up into groups of four to six subjects, with one subject in each group playing central banker and the others forecasting inflation. While forecasters face a quadratic loss function over deviations between their forecast and realized inflation, the central banker is paid according to a loss function with two quadratic terms depending on deviations of inflation and unemployment from target levels. The central banker's payoff function can be thought of being the economy's welfare function as in the original model by Barro and Gordon (1983a). The central banker faces a Phillips curve trade-off between unemployment and inflation and can use one instrument (money supply) to choose between the different possible combinations of inflation and unemployment. However, the central banker cannot fully control the inflation rate, leaving the precise outcome of his actions to a random device. Both experiments implement infinitely repeated games by terminating a sequence (supergame) with some constant probability set at 2% in the work of Arifovic and Sargent (2003) and 1/6 in Duffy and Heinemann (2014).[11]

Arifovic and Sargent (2003) neither reveal the relationship between inflation and unemployment nor the incentives of central bankers to forecasters. Forecasters are just told that the policymaker is setting a target rate of inflation and how the actual rate of inflation depends on this target rate and a noise term. In particular, forecasters are not informed about the Phillips curve relationship or the central banker's payoff function, although knowing these functions is crucial for a rational expectations equilibrium. Arifovic and Sargent did not compare different treatments, because their main focus was to explore whether subjects could avoid the inflation bias associated with a one-period Nash equilibrium and whether expectations could be described by a model of adaptive expectations. They found that a majority of their 12 groups arrived more often at inflation rates closer to the efficient rate (zero) than to the one-period Nash equilibrium (5%), but nearly all groups showed extended periods with inefficiently high inflation. Expectation formation could be described by a model of adaptive expectations. Central bankers who tried to get expectations down, were reducing target rates too slowly compared to a best response to adaptive expectations. Since central bankers were not changed between different sequences, one might argue that the actual continuation probability was even larger than 98% in their experiment, which should have favored low inflation and may explain spillovers between sequences and the absence of end-game effects when sequences approached the maximum duration of 100 periods.

Duffy and Heinemann (2014), instead, provide forecasters and central bankers with full information about the model, including the Phillips curve relationship and the incentives of both types of players. Formally, the game can be described by four equations: The Phillips curve is given by $u = w + \pi^e - \pi$, where u represents unemployment, w a supply shock with a uniform distribution in [120,160], π inflation, and π^e the average of subjects' stated inflation forecasts. Inflation depends on the central banker's choice of money supply m and a transmission shock, $\pi = m + v$. The transmission shock v has a uniform distribution in [0, 40]. Central bankers are paid according to a welfare function $6{,}000 - 2(u - 120)^2 - (\pi - 40)^2$ and forecasters receive $4{,}000 - (\pi - \pi_i^e)^2$, where π_i^e is forecaster i's stated inflation forecast. This simple Barro–Gordon model has a one-period Nash equilibrium with $\pi^e = 80$, while the efficient average rate of inflation is 40. Duffy and Heinemann do not tell subjects that they are playing a monetary policy game, but use a neutral framing instead.[12] Subjects are told that the A-player (central banker) has the task to move water from one container (interpreted as unemployment) to another (representing inflation). The ability to move water corresponds to the Phillips curve trade-off. Duffy and Heinemann compare a treatment implementing a commitment regime with discretionary treatments with and without cheap talk, policy transparency, and economic transparency. In total, they had six different treatments, each with eight different groups of subjects. The focus of their study was to test treatment effects on the levels of inflation and unemployment, on the ability of central banks to stabilize employment, and subsequently the level of welfare, as measured by the central banker's payoff function. Building up on the work of Van Huyck et al. (1995), they ask whether cheap talk or transparency can make up for the lack of trust associated with a repeated discretionary game.

In the commitment treatment, the central banker moved first and forecasters knew m, when submitting their forecasts. Here, the inflation bias was not significantly different from zero. In the other, discretionary treatments, forecasts were stated before the central banker decided on m. In these treatments, there was a significant inflation bias that was actually rather close to the predictions of the one-period Nash equilibrium. Thus, neither cheap talk nor transparency worked as substitutes for commitment. Expectations were systematically lower than actual inflation in all discretionary treatments, which resulted in unemployment rates below the NAIRU. This expectation bias was particularly strong in the treatment of cheap talk without policy transparency. Here, the central banker sent a nonbinding announcement about the amount of water that he or she intended to move before expectations were formed. The announcements affected expectations although central bankers regularly cheated on their announcements. In the early rounds of this treatment, the low average unemployment led to an average level of welfare that was comparable to the welfare level under commitment. However, welfare under cheap talk decreased over time with forecasters learning to mistrust announcements. A remarkable result of this experiment concerns the ability of central bankers to stabilize employment. The one-period Nash equilibrium of discretionary games is associated with a policy rule $m = 20 + w \cdot 2/3$, resulting in unemployment $u = 140 + w/3 - v$. In the unique equilibrium under commitment, unemployment is $u = 140 + w - v$. Thus, discretionary policy enables the central bank to partially stabilize employment from the impact of supply shocks w. This is known as the trade-off between flexibility and credibility. In the experiment, however, the standard deviation of unemployment was higher in the baseline discretionary treatment than under commitment, where it was close to the theory prediction. Thus, there was no trade-off: commitment reduced the level of the inflation bias *and* employment fluctuations compared to discretion. Duffy and Heinemann explain this result by the attempts of central bankers to reduce the inflation bias with different policies. These policy experiments contributed to the overall noise level in the economy, because they were not expected by forecasters.

Stabilization Policy

Experiments with subjects playing central bankers are interesting in evaluating how well humans are able to stabilize variables in an environment with saddle point stability. In theory, an optimal stabilization of inflation requires that interest rates respond to expected inflation with a coefficient larger than 1. This so-called "Taylor principle" (Taylor, 1993)[13] is the focus of an experiment by Engle-Warnick and Turdaliev (2010). They find that most experimental central bankers are able to stabilize inflation. The strategies employed obey the Taylor principle if the responses of interest rates over several periods are added up. However, subjects smooth the interest rate and do not respond fully in the first period they see inflation expectations deviating from the target. Such behavior is theoretically optimal for a policy maker who faces uncertainty about the impact of his instruments or the size of shocks. As subjects in the experiment were not informed about the precise relationships between variables in their economy, they actually followed strategies that can be regarded as being close to optimal.

The experiment contains a control problem similar to the task of a policy maker in a New Keynesian macroeconomic environment. The economy is described by a DSGE model in two variants, one where inflation depends on current output and past inflation (Model 1) and one in which inflation today is also directly affected by inflation two periods ahead (Model 2). Subjects were college students and were given the task to stabilize the economy by setting the interest rate. They were not told that their decisions were related to an economy. Instead, instructions talked about "chip levels in two containers labeled Container A and Container B." Subjects were told that these levels are related to each other and that increasing the instrument would lower the chip levels. Container A represented output and Container B inflation. The goal was to keep the chip level in Container B as close as possible to 5 and the payoff depended on how close they got to this target in the 50 periods of the game. Subjects had some practice rounds in which they could get used to the effect of their instrument on the chip levels. Due to the inherent instability of the models, subjects could lose control, in which case they ended up with a negative payoff that was set to zero in the end, leaving these subjects with the show-up fee.

The main result of this article is that more than 80% of subjects managed the control problem in such a way that they received positive payoffs. Engle-Warnick and Turdaliev (2010) try to identify subjects' strategies by running linear panel regressions explaining the instrument by the data that the respective subjects could observe. In this, they follow Taylor (1999) who used a similar technique for identifying monetary policy rules of the Federal Reserve during different historical eras. The regressions reveal that successful subjects[14] responded to current inflation with coefficients that are close to 1. However, they also responded to output and to their own lagged instrument with positive coefficients. The positive response to the lagged instrument represents interest smoothing. Summing these responses up, their strategies obey the Taylor principle, which explains their success. The fit of OLS regressions was high, averaging around an R^2 of 0.8, which can be taken as evidence that the identified "rules" explain a large portion of actual behavior. It is remarkable that the R^2 is comparable in magnitude to the fit of linear policy rules for post-war data in the United States.[15]

Linear rules fit behavior even though subjects had very little information about the control problem and most likely did not consciously apply a linear rule. It is also interesting to note that subjects actually came close to achieving payoffs that would have resulted from the optimal rule.

While most of the literature concentrates on a specific issue in isolation and considers experiments as means to test some particular theory, generally using one market, some recent experiments focus on the interrelations between several markets and the spillovers between them.[16] In these experiments, subjects are given different roles: some play firms, others private households, and sometimes even governments and central banks are played by subjects. These experiments usually have commodity markets, labor markets, and (indirectly modeled) a market for liquidity. Cash-in-advance constraints are implemented using computerized double auctions in interconnected markets.[17] Subjects interact repeatedly and are incentivized by being paid according to the profit or utility level that they achieve. While Lian and Plott (1998) use a general equilibrium framework for exploring the technical feasibility of running such complex experiments in laboratories with student subjects, in another article of this book, Noussair et al. (2014) construct experimental economies with the specific structure of a New Keynesian DSGE model, in which subjects play the roles of consumer/

workers, producers, and eventually central bankers. They study which frictions are necessary for replicating stylized facts, and how persistent shocks are in such an environment.[18] Noussair et al. (2014) study whether menu costs and monopolistic competition are essential for explaining several empirical stylized facts. Their experiment consists of three treatments that allow isolating rigidities in their economy: (1) monopolistic competition treatment; (2) menu cost treatment; and (3) perfect competition treatment. They find that monopolistic competition in the output market is sufficient to generate persistent effects of shocks, while menu costs are not necessary. Patterns of price adjustment follow stylized empirical facts, such as most price changes being positive.

With respect to our focus on human central bankers, we restrict our attention to a fourth treatment of Noussair et al.'s (2014) experiment in which subjects are told to act as policymakers and have incentives for stabilizing inflation by setting the interest rate in each period. This treatment was conducted to explore whether successful human policymakers would obey the Taylor principle. A second goal was to check whether the Taylor principle has the theoretically predicted effect of stabilizing an economy inhabited by human instead of fully rational agents. Noussair et al. (2014) find that most of the subjects control inflation relatively well and obey the Taylor principle. They also show that output shocks are more persistent and welfare is lower if monetary policy is conducted by human subjects than for an automated instrumental Taylor rule.

Decision-Making Process in Monetary Policy Committees

Amongst the various aspects of the decision-making process, one widely debated issue is the size and structure of monetary policy committees. Committee decisions are nowadays standard in central banking. The composition and the decision rules within a committee can affect the outcomes of its meetings and the quality of decisions. While Maier (2010) reviews general "*economic, experimental, sociological and psychological studies to identify criteria for the optimal institutional setting of a decision committee*" (p. 320), we review the experimental literature that has focused on monetary policy decisions.

Decisions rules of monetary policy committees can largely vary. There is usually a leader, but the leader's authority also varies (Blinder & Morgan, 2008). For example, Blinder and Wyplosz (2005, p. 9) characterize the Federal Open Market Committee under Alan Greenspan as autocratically-collegial, the Monetary Policy Committee of the Bank of England as an individualistic committee, and the Governing Council of the European Central Bank (ECB) as genuinely collegial. The size and composition of committees also shows a wide variety: while the ECB Governing Council has 24 members and is dominated by the 18 governors of national central banks, the MPC in the United Kingdom has only nine board members with no regional affiliation, of which four are even external experts. The 12 members of the FOMC consist of seven executive board members and five heads of the 12 regional central banks who rotate annually.

Experiments in other areas have shown before that (small) groups can achieve higher payoffs than individuals confronted with the same problem. However, there are some important differences between monetary policy decisions and the usual tasks performed in group experiments: in monetary policy decisions, the instrument affects payoff-relevant parameters (macro data) only with a severe time lag and decisions have to be taken under incomplete information. This raises the question whether groups are also more efficient in dealing with these particular challenges. A second question regards time: it is often said that groups are slower in taking decisions. While the actual duration of a committee meeting (measured in hours) is irrelevant for macroeconomic performance, the number of meetings that a committee needs, before it agrees to change an interest rate in response to a perceived shock is a matter of weeks or even months and has macroeconomic consequences. Thus, the relevant time dimension can be better measured by the amount of data required before a committee actually responds to some external shock of which it cannot be certain.

Blinder and Morgan (2005, 2008) examine the effectiveness of individual versus committee decisions via laboratory experiments.[19] Blinder and Morgan (2005) propose an experiment in which Princeton University students who had followed at least one course in macro would play the role of central bankers setting the nominal interest rate, either individually or in groups. The economy was modeled using a standard accelerating Phillips curve

$$\pi_t = 0.4\pi_{t-1} + 0.3\pi_{t-2} + 0.2\pi_{t-3} + 0.1\pi_{t-4} - 0.5\,(U_{t-1} - 5) + w_t,$$

in which inflation π_t depends on the deviation of the lagged unemployment rate U_{t-1} from its natural rate (set to 5) and on its own four lagged values, and by an IS curve:

$$U_t - 5 = 0.6\,(U_{t-1} - 5) + 0.3\,(i_{t-1} - \pi_{t-1} - 5) - G_t + \varepsilon_t.$$

Apart from the effects of shocks, unemployment U_t rises above (or falls below) its natural rate when the real interest rate, $i_{t-1} - \pi_{t-1}$, is above (or below) a neutral level, set to 5. The parameters of this model have been chosen in crude accordance with empirical estimates for the US economy.

While w_t and ε_t are small i.i.d. shocks with a uniform distribution in the interval $[-.25, +.25]$, the economy is also subject to a large demand shock G_t that starts out to be zero but switches permanently to either +.3 or −.3 in one of the first 10 periods. The main challenge for the central bank is to adjust the interest rate in response to this large demand shock. The smaller shocks make detecting the permanent shock a nontrivial task. Subjects were not informed about the precise specification of the model. They were only told that raising the interest rate increases unemployment and lowers inflation with some delay, while lowering the interest rate has the opposite effects. Subjects knew that a large demand shock would occur equally likely in any of the first 10 periods. The economy lasted for 20 periods and the payoff per period was given by a linear loss function for deviations of unemployment and inflation from target levels:

$$s_t = 100 - 10\,|U_t - 5| - 10\,|\pi_t - 2|.$$

Finally, subjects were paid according to the average of s_t over the 20 periods. In order to achieve their targets, subjects could change the interest rate at any period at a fixed cost of 10 points. This design feature enables the authors to detect when their subjects respond to the large shock.

The game was played 40 times. Subjects first played 10 rounds alone. Then, they were matched in groups of five for another 10 rounds. In a third part of the experiment, subjects played alone for another 10 rounds, and finally they were matched in groups of five for the last 10 rounds. Out of 20 sessions in total, in 10 sessions groups decided by majority rule, while the other 10 sessions required unanimous group decisions.

The main result of this study is that groups made better decisions than individuals without requiring more time. Time is measured by the number of periods and thus the amount of data required before the individual or group decides to change the interest rate after the external shock occurred. There was no significant difference between the time lags of groups deciding with majority rule and groups deciding unanimously. Blinder and Morgan (2005, p. 801) report that "*in almost all cases, once three or four subjects agreed on a course of action, the remaining one or two fell in line immediately*." While there was no evidence that subjects improved their scores during any of the blocks of 10 rounds, there was a significant difference between the scores that individual decision makers achieved during the first 10 rounds and during rounds 21–30. It is not clear, though, whether the improvement is due to learning from other group members or just to the additional experience with the game.

Blinder and Morgan (2008) repeated the same experiment with students from the University of California, Berkeley, raising two more questions: the relevance of group size and leadership. Are smaller committees more efficient than large ones and do committees perform better in the presence of a leader? Blinder and Morgan (2008) compare sessions with groups of four and eight subjects and designate a leader in half of the sessions, whose vote serves as a tie break and whose score is doubled. The results show that larger groups yield a better performance. Whether the group has a designated leader or not has no significant impact on performance. Neither has the performance of the best individual in the previous rounds in which subjects played alone. However, the average previous performance of group members has a positive, albeit decreasing effect on the group's performance.

Another issue related to the decision-making process in monetary policy committees, underlined by Maier (2010, p. 331), is that both the ECB[20] and the Fed "*have adopted a rotation system to limit the number of voting members – that is the right to vote rotates following a pre-determined sequence*." Maier argues that "*rotation is a useful device to increase the amount of information without compromising the group size*." But, he also notes that the goal of shortening the discussion "*can only be achieved if non-voting members hardy ever participate in the discussion*." It is not clear how they can then increase the information used by the committee for its decisions. Another aspect of rotation is that voting members may pursue their own interests at the expense of nonvoting members. In an experiment on committee decisions, Bosman, Maier, Sadiraj, and van Winden (2013) analyze how subjects trade off common and private interests depending on the rotation scheme. They find that voting members receive higher payoffs than nonvoting members in treatments with rotation of voting rights, while payoffs in a control treatment, where all subjects could vote, are somewhere in between. Decisions were taken faster in treatments with smaller groups of voting subjects, and rotation helped avoiding deadlocks. The total earnings were somewhat lower in treatments with rotation, but the difference is small and Bosman et al. (2013, p. 39) conclude that "*rotation has primarily distributional effects*." It is not clear though, how much this result is driven by the particular payoffs in this experiment. The total payoffs arising from selfish voting behavior are very sensitive to the relative differences between committee members' objectives. Note that there was no information asymmetry between committee members in this experiment. Hence, the question whether rotation decreases the amount of information utilized by the committee could not be addressed here.

TRANSPARENCY AND COMMUNICATION ISSUES

This section is devoted to central bank communication and the merits of transparency. There is a vivid debate about the pros and cons of transparency, and while central banks have moved toward higher transparency, theory papers provide mixed recommendations. In particular, strategic complementarities inherent in macroeconomic models provide incentives to overweight public announcements in comparison to their informational content (e.g., Morris and Shin, 2002). This may lead to public signals reducing welfare.

We present some experiments that measure the relative weights that subjects put on public versus private signals, provide explanations, and draw conclusions for the welfare effects of public announcements (Section "Overreaction to Central Bank Disclosures"). These studies show that subjects may overreact to public information, in the sense that they attribute more weight to public information than the Bayesian weight following from its relative precision. In theory, overreaction can lead to welfare detrimental effects. It is therefore relevant to analyze how central banks may reduce overreaction to their disclosures. Some experiments test different communication strategies and compare their effectiveness in reducing welfare detrimental overreactions (Section "Central Bank Communication Strategies"). Experiments are particularly well-suited for testing the effects of information and communication channels, because the experimenter can control information and distinguish communication channels in different treatments. Thereby, experiments yield very clear results about the effects of information, while field evidence is always plagued by the simultaneity of different communication channels and by the problem of filtering out which information really affected decisions. Communication is an essential tool at the disposal of central banks. A related interesting issue is the interaction between communication and stabilization policy. Only very few experiments focus on this issue (Section "Communication and Stabilization Policy").

Overreaction to Central Bank Disclosures

As Geraats (2002, p. F533) noted, "*central bank transparency could be defined as the absence of asymmetric information between monetary policy-makers and other economic agents*." Central bank transparency has increased rapidly in the last 20 years, especially with the adoption of inflation targeting by many central banks (New Zealand, Canada, the United Kingdom, and Sweden in the early 1990s).[21]

However, financial markets typically exhibit overreaction to public information such as press releases or public speeches disclosed by central banks. Indeed, since central banks interact closely with the financial sector, their disclosures attract the attention of market participants. While it is usually believed that more information improves market efficiency, some literature based on coordination games with heterogeneous information shows that public disclosure may be detrimental.

Morris and Shin (2002) present a stylized game with weak strategic complementarities for analyzing the welfare effects of public and private information. Agents have to choose actions that are close to a fundamental state (fundamental motive) but also close to each other (coordination motive). The game is characterized by both fundamental and strategic uncertainty: agents receive noisy public and private signals on the fundamental state variable. In equilibrium, an agent's action is a weighted average of a public and a private signal. The equilibrium weight attached to the public signal is higher than its relative precision. This "overreaction" is due to the higher informational content of public signals regarding the likely beliefs and actions of other agents. The difference between equilibrium weights and relative precisions rises in the weight put on the coordination motive. This mirrors the disproportionate impact of the public signal in coordinating agents' actions. The model of Morris and Shin emphasizes the role of public information as a focal point for private actions. Strategic complementarities provide incentives to coordinate on the publicly announced state of the world and underuse private information (PI). If public announcements are inaccurate, private actions are drawn away from the fundamental value and reduce efficiency of the action profile.

Cornand and Heinemann (2014) test predictions of this approach by implementing two-player versions of this game adapted for conducting an experiment.[22] They run treatments that vary with respect to the weights on fundamental and coordination motive and experimentally measure the weights that subjects put on public information in the different treatments. In this experiment, subjects are matched in pairs and for each pair a random number θ (fundamental) is drawn out of a large interval with uniform distribution. Each of the two subjects receives a private signal x^i and, in addition, both subjects receive a common (public) signal y. All three signals are i.i.d. with a uniform distribution around θ. Payoff functions are:

$$U_i(a,\theta) = C - (1-r)\,(a_i-\theta)^2 - r\,\left(a_i - a_j\right)^2,$$

where a_i and a_j are the actions of the two players and r is the relative weight on the coordination motive. For $r > 0$, each agent has an incentive to meet the action of his partner.

In the benchmark case without a coordination motive ($r=0$), subjects follow the theoretical advice from Bayesian rationality: they use all information of the same precision with equal weights, regardless of whether information is private or public. When both fundamental and coordination motives enter subjects' utility, subjects put larger weights on the public signal, but these weights are smaller than theoretically predicted. This reduces the effects of public signals on the average action compared to equilibrium predictions. Observed weights can be explained by a model of limited levels of reasoning, where Level 1 is defined by the optimal action of a player who neglects that public signals provide more information about other players' actions, and Level k is the best response to Level $k-1$. Subjects' choices are distributed around the weights associated with Level 2.

Cornand and Heinemann (2014) also elicit higher-order beliefs. As in the game, they match subjects in pairs, draw a random number θ for each pair, and provide each of the two subjects with a private signal x^i and, a public signal y. All three signals are i.i.d. with a uniform distribution around θ. Then, they ask subjects to state an individual expectation for θ. The stated belief of subject i is denoted by e^i. The Bayesian expectation is $e^i = E\left(\theta|x^i,y\right) = \left(x^i+y\right)/2$. Subjects are also asked to submit an expectation of the stated belief by their partner. The Bayesian expectation about the other subject's belief is:

$$E\left(e^j|x^i,y\right) = \frac{E\left(x^j|x^i,y\right)+y}{2} = \frac{E\left(\theta|x^i,y\right)+y}{2} = \frac{1}{4}x^i + \frac{3}{4}y.$$

Hence, subjects should put a weight of .25 on their private signal when estimating their partner's stated belief about θ. The actual weights that subjects put on their private signal were significantly higher.

This deviation from Bayesian higher-order beliefs indicates that subjects underestimate how informative the public signal is in assessing other players' expectations. This may be viewed as an alternative explanation why subjects put lower weights on the public signal in the Morris–Shin game. However, drawing on a simulation exercise in which they derive the best response to non-Bayesian beliefs, Cornand and Heinemann conclude that the observed deviations from equilibrium cannot be explained by deviations from Bayesian rationality alone. Rather, non-Bayesian beliefs must be combined with limited of reasoning.

In the limiting case of a pure coordination game ($r = 1$), equilibrium theory does not yield a unique prediction, but the public signal provides a focal point that allows agents to coordinate their actions. In the experiment, subjects indeed tend to follow the public signal and put a significantly larger weight on it than in games with both fundamental and strategic uncertainty. However, they still put a positive weight on their private signals, which prevents full coordination. Here, the provision of *PI* reduces efficiency.

In a related experiment, Shapiro, Shi, and Zillante (2014) analyze the predictive power of level-*k* reasoning in a game that combines features of the work by Morris and Shin (2002) with the guessing game of Nagel (1995). While Cornand and Heinemann (2014) only look at average weights on private versus public signals, Shapiro et al. (2014) try to identify whether *individual* strategies are consistent with level-*k* reasoning. They argue that the predictive power of level-*k* reasoning is positively related to the strength of the coordination motive and to the symmetry of information.

Cornand and Heinemann (2013) reconsider the extent to which public information may be detrimental to welfare: they consider the use of the experimental results from Cornand and Heinemann (2014) for calibrating the model by Morris and Shin (2002). If agents follow the levels of reasoning observed in the experiment, public information cannot have detrimental effects, while PI may be welfare detrimental if coordination is socially desired. Only if subjects employ higher levels of reasoning, negative welfare effects of public information are possible. Cornand and Heinemann (2013) also analyze the effects of limited levels of reasoning in the model of James and Lawler (2011), in which a central bank can take policy actions against some fundamental shock. In this model, policy and private actions are perfect substitutes with respect to neutralizing aggregate shocks, and the government can provide the optimal response to its own information without the need of publishing it. Private actions are still required to account for the additional information contained in agents' private signals. This distribution of tasks achieves the first best. If, however, the government discloses its information as a public signal, private agents reduce the weight they put on their private signals and, thus, PI enters the total response of the economy with a weight that is suboptimally small. For this reason, it is always optimal to withhold public information completely. This argument is robust to limited levels of reasoning.[23] Overall, Cornand and Heinemann (2013) conclude that for strategies as observed in experiments, public information that is more precise than PI cannot reduce welfare, unless the policy maker has instruments that are perfect substitutes to private actions.

Dale and Morgan (2012) provide a direct test for the welfare effects of public information in the model of Morris and Shin (2002). They argue that adding a lower quality private signal improves the quality of decisions. When the lower quality signal is public, subjects strategically place inefficiently high weights on the public signal, which reduces their payoffs. However, Dale and Morgan do not account for the weight that subjects put on the commonly known prior that serves as a second public signal in this experiment, and they give subjects feedback about the best response after each round of decisions, which may be responsible for the convergence toward equilibrium that could not be observed in related studies.

While Cornand and Heinemann (2014), Shapiro et al. (2014), and Dale and Morgan (2012) do not consider trading, there is a huge experimental literature about market efficiency in aggregating PI into prices.[24] However, the different roles of public and private signals in such markets have only recently been analyzed. Ackert, Church, and Gillette (2004) present evidence from a laboratory asset market in which traders receive public signals of different quality (but no private signals). They show that traders over-react to low-quality public information and under-react to high-quality public information.

Taking the example of information provided by rating agencies, Alfarano, Morone, and Camacho (2011) analyze whether the presence of public signals can impede the aggregation process of PI. To this aim, they replicate a market situation in which at the beginning of each trading period, each subject was endowed with some units of an unspecified asset and another amount of experimental currency. The asset paid a dividend at the end of the trading period. At each trading period the dividend was randomly determined by the experimenter. During each trading period, subjects could post bids and asks for assets or directly accept any other trader's bid or ask. To make his decisions, each subject could purchase as many private signals on the dividend as he wanted during the trading period (as long as he had enough cash). In the treatment with public information, subjects also had access to a free public signal on the dividend. The authors find that when public information is disclosed, less private signals are bought. Thus, public information crowds out PI. However, this effect does not reduce market information efficiency in the sense that the additional public information compensates the reduction of PI.

Middeldorp and Rosenkranz (2011) also test an experimental asset market with costly PI. Their asset market implements the theoretical models by Diamond (1985) and Kool, Middeldorp, and Rosenkranz (2011). In their experiment the provision of a public signal crowds out PI to such an extent that forecast errors may rise with increasing precision of the public signal. In this experiment, subjects participated in two phases. The first phase aimed at measuring subjects' risk attitudes. The second corresponded to the actual market trading (25 periods). Each period was divided in two stages: an information stage and a trading stage. In the information stage, subjects were shown a screen revealing: their endowment consisting of some amount of experimental currency units and a risky asset producing a random payout at the end of the experiment; and a public signal regarding the payout for the respective period and the standard deviation of this signal. To get more precise information on the payout, subjects could buy a noisy private signal about the payout for the considered period.

The trading stage implemented a continuous double auction: subjects could post bid and ask prices in any quantity for 150 seconds and trades were carried out whenever possible. The authors varied the precision of public information between the different periods to measure its impact on the crowding out of PI. To see whether the experimental asset market is incorporating PI into the price, the authors compare the error of public information to the market error: whenever the market price predicts the payout better than public information, the market incorporates PI. However the experiment shows that on average, market prices are less informative than public information that all traders receive. More precisely, prices outperform public information for rather imprecise public signals, while for very precise public information, market errors do not decline proportionally.[25] Middeldorp and Rosenkranz (2011) conclude that their results confirm theoretical predictions according to which a more precise public signal from a central bank can in some cases reduce market efficiency.

Central Bank Communication Strategies

In the Section "Overreaction to Central Banks Disclosures", we presented some experiments that investigate whether public information can be detrimental to welfare. Since overreaction to public information is responsible for eventual welfare reducing effects, it is important to ask how central banks can reduce such an overreaction to its own disclosures. In this subsection, we therefore focus on central banks' communication strategies in the lab and especially, following Baeriswyl and Cornand (2014), on strategies that may reduce market overreaction to public disclosures.

The theoretical literature envisages two disclosure strategies for reducing the overreaction of market participants to public information. The first – partial publicity – consists of disclosing transparent information as a semi-public signal to a fraction of market participants only (see Cornand & Heinemann, 2008). The degree of publicity is determined by the fraction of market participants who receive the semi-public signal. As argued by Walsh (2006, p. 229), "*Partial announcements include, for example, speeches about the economy that may not be as widely reported as formal policy announcements. Speeches and other means of providing partial information play an important role in central banking practices, and these means of communication long predate the publication of inflation reports*." Choosing a communication channel with partial publicity reduces overreaction, as uninformed traders cannot respond anyway, whereas the informed traders react less strongly as they know that some other traders are uninformed. The second strategy – partial transparency – consists of disclosing ambiguous public information to all market participants (see Heinemann & Illing, 2002). The degree of transparency is determined by the idiosyncratic noise added to the public signal by the individual differences in interpreting the signal. The famous quotation by A. Greenspan in 1987, then chairman of the Federal Reserve Board, can represent a good illustration of partial publicity: "*Since I've become a central banker, I've learned to mumble with great incoherence. If I seem unduly clear to you, you must have misunderstood what I said*" (Alan Greenspan, as quoted in the *Wall Street Journal*, September 22, 1987, according to Geraats, 2007). Choosing a communication channel that implements partial transparency reduces overreaction, because ambiguity generates uncertainty on how other market participants interpret the same signal, which mitigates its focal role. In a framework closely related to that of Morris and Shin (2002), Baeriswyl and Cornand (2014) show that these strategies are theoretically equivalent in reducing overreactions to public information, in the sense that a signal with a limited degree of publicity or an appropriately limited degree of transparency can achieve the same response of average actions.

Baeriswyl and Cornand also conduct an experiment comparing the effects of partially public and partially transparent signals, in which parameters are chosen so that both communication strategies are theoretically equivalent. They use a set-up similar to Cornand and Heinemann (2014), but with a relatively high weight on the coordination motive ($r = 0.85$), and with seven participants per group instead of two. The different treatments compare the effectiveness of partial publicity and partial transparency to reduce overreaction along with a baseline treatment in which the public signal is transparently provided to all group members. Partial publicity is implemented by revealing the signal only to four of the seven group members. In the partial-transparency treatment, all group members get the signal, but with an appropriate idiosyncratic noise.

Partial publicity and partial transparency both succeed in reducing overreaction to public information in the laboratory, although less than theory predicts. According to Baeriswyl and Cornand (2014, p. 1089), "*partial publicity reduces overreaction only to the extent that uninformed subjects cannot react to public information, whereas informed subjects do not behave differently than they do under full publicity. In other words, it is the actual lack of information by uninformed subjects rather than the response of informed subjects to the perception that others are uninformed that reduces overreaction. […] Partial transparency reduces overreaction as the ambiguity surrounding public information induces subjects to behave cautiously. Nevertheless, partial publicity turns out to reduce overreaction more strongly than partial transparency in the experiment*."

Yet Baeriswyl and Cornand (2014) advocate partial transparency as a policy recommendation for reasons of reliability and fairness. Arguably, partial transparency may be easier to implement than partial publicity in an era, where media quickly relay information on a large scale. Moreover, partial publicity violates equity and fairness principles: it seems to be "*politically untenable [for a central bank] to withhold important information intentionally from a subgroup of market participants*" (p. 1090) in a democratic society. Central banks should rather prefer controlling the reaction to their public disclosures by carefully formulating their content instead of selecting their audience.

Communication and Stabilization Policy

While papers mentioned in Sections "Overreaction to Central Banks Disclosures" and "Central Bank Communication Strategies" focus on experiments on transparency in frameworks that do not include instruments for stabilizing the economy, this subsection is devoted to the few first papers combining active stabilization with communication.

Inflation targeting (IT) is a monetary policy strategy characterized by the announcement of a target for inflation, a clear central bank's mandate to pursue inflation stabilization as the primary objective of monetary policy, and a high level of transparency and accountability. Empirically, IT regimes largely vary depending on the degree with which these criteria are applied (Svensson, 2010) and the benefits of explicitly adopting an IT regime have long been debated in the literature (see, e.g., Angeriz & Arestis, 2008; Ball & Sheridan, 2005; Levin, Natalucci, & Piger, 2004; Roger, 2009; Roger & Stone, 2005; to mention but a few).

Cornand and M'baye (2013) present a laboratory experiment framed as a standard New Keynesian model that aims at testing the relevance of different IT regimes. More precisely, they examine the relevance of communicating the target for the success of the IT strategy and evaluate how central bank objectives matter for economic performances.

The model is based on three main equations: an aggregate demand equation (IS curve), a supply function (New Keynesian Phillips curve), and a reaction function of the central bank (the interest rate rule). The experiment consists of retrieving subjects' inflation expectations in the lab, and inserting them into the theoretical model to derive the current values of inflation, output gap, and interest rate.[26]

Participants had the task to forecast the next period's inflation in each of the 60 periods of a session. They were presented with the four main macroeconomic variables: inflation, output gap, interest rate, and central bank's inflation target. They were informed that the actual values of inflation and output gap mainly depend on stated expectations by all participants and were also affected by lagged output gap, small random shocks, and (when applicable) the central bank's inflation target. On their screens, participants could observe time series of the first three variables up to the current period. Participants' payoffs were such that they got points whenever their forecast error was below 3%.

Four different treatments[27] were considered. First, implicit strict IT: the central bank's sole objective was to stabilize inflation, but the inflation target was not announced to the public. Second, explicit strict IT: the central bank also had the sole objective to stabilize inflation and explicitly communicated its 5% target to forecasters. Third, implicit flexible IT: the central bank had both an inflation and an output gap stabilization objective and did not announce its target. And fourth, explicit flexible IT: the central bank also had an inflation and an output gap stabilization objective and explicitly communicated its target for inflation.

Cornand and M'baye analyze the impact of individual behavior on macroeconomic outcomes. They find that "*if the central bank only cares about inflation stabilization, announcing the inflation target does not make a difference in terms of macroeconomic performance compared to a monetary policy that follows the Taylor principle*" (p. 2). However, if the central bank has a double objective, communicating the target may reduce the volatilities of inflation, interest rate, and output gap without affecting the average levels of these variables. The first rationale is that communication reduces agents' uncertainty about policy objectives by clarifying these objectives. A second reason is that a flexible IT regime seems more sensitive to fluctuations in inflation forecasts than a strict IT regime and is less effective in stabilizing the economy because subjects need more time to reach the target. Hence, announcing the target is more helpful in reducing forecast errors. Third, subjects tend to rely more on trend extrapolation in the implicit flexible IT treatment than in the explicit flexible IT treatment. Trend extrapolation requires more frequent and aggressive adjustments in the policy instrument to mitigate the high volatility in inflation and output gap.

While Cornand and M'baye consider subjects only as price-setting firms, Kryvtsov and Petersen (2013) analyze the role of central bank communication in a more macro experimental framework. One of the most important contributions of Kryvtsov and Petersen is to introduce a measure of the expectations channel of monetary policy. They demonstrate that public announcements of interest rate forecasts may reduce the effectiveness of monetary policy and increase macroeconomic fluctuations. More details about this paper can be found in another article of this book (Assenza et al., 2014).

POLICY IMPLEMENTATION

Monetary policy implementation has two dimensions that we distinguish here: one is the particular strategy or policy rule by which the central bank adjusts its instrument to observed data, the other dimension is the operational side of how open-market operations are conducted for providing liquidity to the financial system. The ECB conducts weekly repo auctions, while the U.S. Federal Reserve holds auctions on a daily basis. Commercial banks' liquidity demand depends on their refinancing needs and reveals information about credit flows to the central bank. The market mechanism is important in two ways: it should efficiently allocate liquidity and also aggregate information. Hence, an important question is how to actually design these auctions. Auction design is a classical topic of experimental economics[28] and using experiments for bench testing auctions has become a standard procedure.

We first review experiments dealing with the strategic dimension of monetary policy rules (Section "Monetary Policy Rules") before focusing on the rare experiments that are especially designed for repo auctions (Section "Repo Auctions").

Monetary Policy Rules

Pfajfar and Žakelj (2014) analyze how effective different monetary policy rules are in stabilizing inflation. They consider a reduced form of the New Keynesian model[29] with an IS curve, $y_t = -\varphi(i_t - E_t\pi_{t+1}) + y_{t-1} + g_t$, where i_t is the interest rate, π_t denotes inflation, $E_t\pi_{t+1}$ is the forecast made in period t for period $t+1$, y_t is the output gap, g_t is an exogenous shock, and φ is the intertemporal elasticity of substitution in demand. The Phillips curve is given by $\pi_t = \beta E_t\pi_{t+1} + \lambda y_t + u_t$.

Four treatments are distinguished depending on the considered monetary policy rules. In three treatments Pfajfar and Žakelj employ inflation forecast targeting, $i_t = \gamma(E_t\pi_{t+1} - \overline{\pi}) + \overline{\pi}$, with different specifications of the parameter γ (γ = 1.5 in Treatment 1, γ = 1.35 in Treatment 2, γ = 4 in Treatment 3). The fourth treatment implements contemporaneous IT, $i_t = \gamma(\pi_t - \overline{\pi}) + \overline{\pi}$ with γ = 1.5. Target levels are denoted by $\overline{\pi}$. The experiment consists in a simulated fictitious economy of nine agents, described by the three equations above. For each period t, the participants receive a table with past realizations of inflation, output gap, and interest rate. For the first period, 10 initial values were generated by the computer under the assumption of rational expectations. Subjects get a qualitative description of the underlying model. Their task is to provide an inflation forecast for period $t+1$, and a 95% confidence interval around their prediction.

Fig. 3 presents a group comparison of expected inflation and realized inflation by treatment. The authors show that amongst the rules targeting inflation forecasts, a higher degree of monetary policy aggressiveness γ reduces the variability of inflation, but may lead to cycles. Contemporaneous IT performs better than inflation forecast targeting with the same degree of monetary policy aggressiveness.

Pfajfar and Žakelj also analyze how subjects form their expectations by identifying different strategies and estimating the share of subjects who are

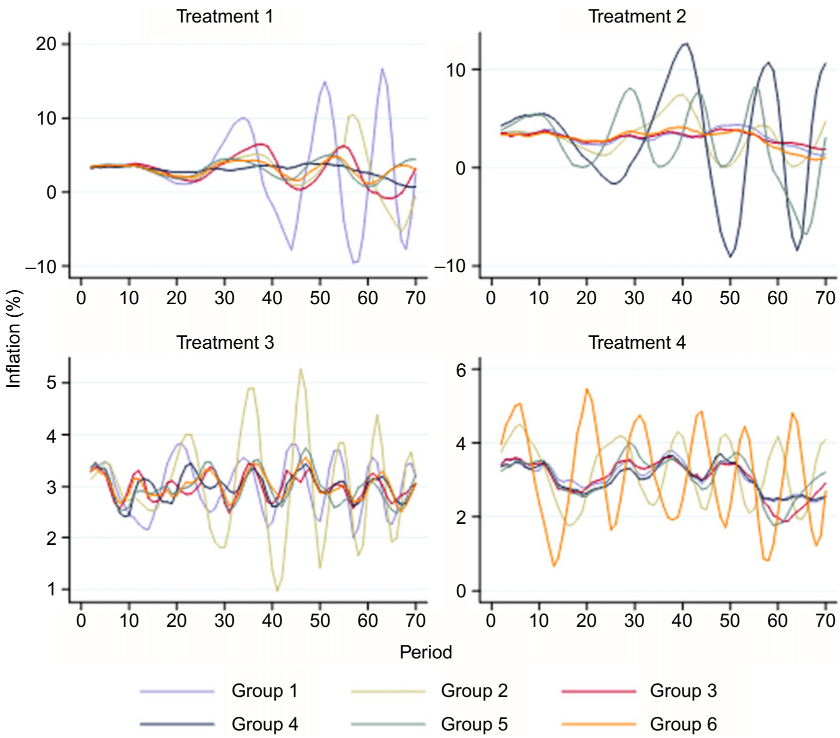

Fig. 3. Group Comparison of Expected Inflation (Average Subject Prediction) and Realized Inflation by Treatment. *Source*: Pfajfar and Žakelj (2014).

following these strategies. A significant share of subjects follow either a trend extrapolation model for inflation or a general adaptive model, in which the inflation forecast is a linear function depending on the three macroeconomic variables of the last period.

Luhan and Scharler (2014) use a learning-to-optimize experiment for analyzing the role of the Taylor principle. Their main result is that violations of the Taylor principle need not be destabilizing, because subjects use the nominal interest rate as a proxy for the real interest rate and may reduce consumption demand in response to high nominal rates even if the real rate has fallen. In their experiment, subjects play 20 rounds of a two-period game. In each round, subjects decide how much of a given endowment to consume and how much to save for consumption in the second period of the same round. The inflation rate in any round is determined by subjects' consumption decisions in the previous round of the game.[30] Savings yield an interest with a nominal rate that is determined by the central bank in response to the inflation rate. If the central bank obeys the Taylor principle, the real rate rises with increasing inflation. Theoretically, this should induce lower consumption and, thereby lead to a lower inflation rate in the next round. If the Taylor principle is violated, one should expect the opposite response and the economy should converge to corner solutions in which all subjects either consume their total endowment and inflation is high or save it all and inflation is low.

Between treatments, Luhan and Scharler (2014) vary whether the central bank obeys the Taylor principle or not and whether the current period's inflation rate is revealed to subjects before they decide or just ex post. Note that in New Keynesian models, agents base their consumption decisions on the real interest rate that consists of a known nominal and an expected, yet unknown, future inflation. Thus, withholding information about the inflation rate that is relevant for the current decision problem is the more relevant case. Luhan and Scharler observe that mean inflation is close to the target if the Taylor principle holds. If the Taylor principle is violated, and inflation is known ex ante, inflation rates converge to either of the extremes. But, if inflation is not revealed ex ante, average inflation rates are more evenly distributed and close to the target in many economies. The explanation is that many subjects do not learn the inflation dynamics and take the nominal interest rate as a proxy for the real rate. If this observation carries over to real economies, the central bank may be able to stabilize inflation even when it violates the Taylor principle.

Amano, Engle-Warnick, and Shukayev (2011) examine how subjects form expectations when a central bank changes from IT to price-level targeting. The recent financial crisis casts doubt on the IT consensus.[31] An alternative approach − theoretically studied for example by Svensson (2003) − is price-level targeting.[32] While IT helps stabilizing inflation, it does not correct for past deviations from the target, leaving some uncertainty on the future *level* of prices: under IT, shocks to inflation may have a permanent effect on the price level. Price-level targeting precisely aims at bringing the price level back to the target after some deviation. In theory, price-level targeting should generate more stable output and inflation (Kahn, 2009).

However, price-level targeting remains largely untested in practice and its efficacy rests on the assumption that "*economic agents must forecast inflation rationally (…) and in a manner consistent with the price-level* *targeting regime*" (Amano et al., 2011, p. 1). In theory, price-level targeting provides a better anchor to inflation expectations, which allows the central bank to achieve greater stabilization of inflation and economic activity.

Amano et al. (2011) aim at evaluating whether economic agents understand the implications of price-level targeting for the rate of inflation. They analyze whether moving from IT to price-level targeting leads subjects to adjust their inflation expectations in a manner consistent with price-level targeting. They simulate a macroeconomic model with exogenous shocks in which they consider two scenarios: one in which the central bank targets a zero inflation rate; and a second in which the central bank targets a constant price level. All subjects start out with IT for 20 periods (plus 20 practice periods). Then half of all subjects are exposed to a regime with price-level targeting. The screen shows them a history of inflation and aggregate price levels from the past eight periods. Subjects' task consists in predicting inflation for the next period. Instructions clarify the role of the central bank: under IT, the central bank is not concerned with the past price level; under price-level targeting, the central bank acts to bring the price level to its constant target. While subjects rely on past inflation only for predicting future inflation rates under IT, they partially adjust their expectations in the direction implied by price-level targeting, when this policy becomes effective. Thus, their expectations are qualitatively consistent with the regime switch but not in quantities.

Marimon and Sunder (1995) compare different monetary rules in an overlapping generations framework and analyze their influence on the stability of inflation expectations. In particular, they focus on the comparison between Friedman's k-percent money growth rule and a deficit rule where the government fixes the real deficit and finances it by seigniorage. They find little evidence that Friedman's rule can help to coordinate agents' beliefs and stabilize the economy. The inflation process might be even more volatile when Friedman's rule is announced. In unstable environments, subjects behave more in line with adaptive learning models instead of forward looking rational expectations. Thus, a constant money growth rate does not necessarily anchor inflation expectations. Bernasconi and Kirchkamp (2000) conduct a similar analysis and find that the monetary policy following Friedman's rule reduces inflation volatility but also leads to higher average inflation than a revenue equivalent deficit rule. The reason is that subjects save too much and over-saving reduces inflation rates under the deficit rule. The design of experiments on overlapping-generations economies are described in more detail by Assenza et al. (2014) in this volume.

Repo Auctions

Ehrhart (2001) studies the fixed-rate tender mechanism used by the ECB before June 27, 2000. According to this mechanism, the ECB was setting an interest rate and a maximum amount of liquidity, while banks announced how much liquidity they wanted to borrow at this rate (bids). If the aggregate demand for liquidity exceeded the maximum, banks were rationed proportionally. During the 18 months in which this mechanism applied, the bids were exploding such that the allotment was finally below 1% of the bids. Banks exaggerated their demand for refinancing, because they expected to be rationed. The problem associated with this strategic response is that refinancing operations were also supposed to help the central bank evaluate and plan monetary policy and it became difficult to extract the relevant information about liquidity demand from this increasing number of bids. The ECB, therefore, switched to an interest-rate tender that does not suffer from possible bid explosions, but has the disadvantage that it provides incentives for underbidding. In this context, Ehrhart (2001) proposed an experiment aimed at evaluating whether and under which conditions a fixed-rate tender leads to a strategic increase in bids and how this affects the information content of these bids.

The experiment tests different fixed-rate tender games. Subjects play the role of banks, while the central bank is automated. At the beginning of each round, subjects were informed about the interest rate. The maximum ("planned") allotment is a random variable unknown to subjects when they submitted their bids; they only knew the distribution of the maximum allotment. They were aware of the proportional rationing mechanism and observed on their screen the payoffs resulting from different allotments at the current interest rate.

Treatments differ with respect to the interest rate and the distribution of maximum allotment in order to evaluate the link between the maximum allotment and the optimal demand. In Treatment 1, the expected maximum allotment is set equal to the optimal demand, so that there is a unique equilibrium in which demand is slightly higher than optimal. In Treatment 2, the expected allotment is smaller than the optimal demand, but still allows a larger than optimal allotment. Treatment 3 did not allow for the maximum allotment to be larger than the optimal demand. While the interest rate is kept constant for the 20 rounds of the experiment in the first two treatments, it changed from a low to a high level in Treatment 3 from round 11 onwards. The games in Treatments 2 and 3 (first 10 rounds) have no equilibrium in finite numbers, as banks would always try to overbid each other. The games in Treatments 1 and 3 (last 10 rounds) have a unique equilibrium in which demand slightly exceeds the optimum.

The results show exploding bids in treatments without equilibrium, while the bids were close to the equilibrium in Treatment 1. The sad news is that for two out of six groups in Treatment 3, after playing 10 rounds of a game without equilibrium, bids continued to explode in the second half of this treatment. The bids grew to at least twice the equilibrium level in all six groups. Thus, Ehrhart (2001) concludes that after a phase of continually increasing bids, switching to an accommodative policy (game with a unique equilibrium) need not stop the growth of bids beyond the equilibrium level.

Overall the experiment indicates that an explosive trend in bids cannot be stopped just by changing the allotment rules or the equilibrium values. Under a fixed-rate tender bids may remain uninformative, because bidders may respond more to strategic considerations than to their own demand conditions. In 2000, the ECB switched to an interest-rate tender with banks bidding for different amounts at different interest rates, which reveals the complete demand function and reduces the incentives for strategic bids.

MONETARY POLICY DURING LIQUIDITY CRISES

When an economy is on the brink of a currency or banking crises, central banks may use their instruments to stabilize exchange rates or insert liquidity for preventing bank runs. In these events, communication may have effects that are quite distinct from its effects in normal times, because pure liquidity crises are a phenomenon of equilibrium multiplicity. In this section, we discuss some experiments on equilibrium multiplicity (Section "Equilibrium Multiplicity") and show how interventions, but also informative and extraneous signals may affect the equilibrium selection (Sections "Global Games" and "Sunspots").

Equilibrium Multiplicity

Many models in monetary macroeconomics suffer from multiple equilibria. Here, theory cannot give a clear answer how changing exogenous variables affects endogenous variables, because any change intended to improve the fundamental conditions on financial markets may adversely affect expectations and lead to the opposite effect. Which out of many equilibria will be played by real agents is ultimately an empirical question.

Equilibrium Stability

In overlapping-generation models or DSGE models with long-run neutrality of money, equilibrium multiplicity arises from indeterminate long-run expectations. In these models, an equilibrium is a path $(p_t)_{t=0,\ldots,\infty}$ that satisfies certain conditions and can usually be written as a function $p_t(p_{t-T}, \ldots, p_{t-1}, E_t(p_{t+1},\ldots, p_\infty))$ or, in a reduced form, $p_t = f(E_t(p_{t+1}))$. If expectations are rational, a transversality condition fixing $E_t(p_\infty)$ yields uniqueness. Unfortunately, these transversality conditions are purely mathematical and lack any microeconomic or behavioral justification. If agents expect hyperinflation, the price level rises faster than for a bounded inflation expectation, and the expectation of hyperinflation becomes self-fulfilling. Note that a perfect foresight path reads $p_t = f(p_{t+1})$ and adaptive expectations of the form $E_t(p_{t+1}) = p_{t-1}$ yield $p_t = f(p_{t-1})$. The dynamic properties are exactly reverted. If expectations are adaptive, the selected path is determined by starting values that are inherited from the past and a transversality condition is not needed.[33] As price paths in the reduced-form example take opposite directions depending on whether agents are looking forward or backward, stability of equilibria is also reverted by using adaptive instead of rational expectations.

Stability of equilibria has been analyzed by Marimon and Sunder (1993, 1994) with experiments on overlapping-generations economies. The economies have two stationary equilibria, one is stable under rational expectations, the other under adaptive expectations. The experiment shows that the observed price paths tend toward the low-inflation equilibrium that is stable under adaptive expectations. Adaptive learning models can also explain most subjects' expectations in experiments on DSGE models (see Assenza et al., 2014, in this volume). However, subjects also switch between different forecasting rules depending on the relative success of these rules.

Financial Crises as Coordination Games

In financial crises, maturity or currency transformation makes borrowers vulnerable to liquidity crises and speculative attacks out of self-fulfilling beliefs. If depositors expect their bank to become illiquid, they withdraw their funds, which reduces the bank's liquidity. If traders expect devaluation of a currency, they sell it and create an additional market pressure that may force the central bank to devalue. The bank-run model by Diamond and Dybvig (1983) is a perfect example. In order to prevent a bank run, depositors must coordinate on rolling over. The common feature of these models is that they are binary choice coordination games in which one action yields a higher return than the other if and only if sufficiently many players choose this action.

The experimental literature on coordination games shows regular patterns of behavior and also highlights that it can be extremely difficult to achieve coordination on the efficient equilibrium (see Schotter and Sopher, 2007).

Global Games

Morris and Shin (1998, 2003) applied the theory of global games to a currency crisis model and demonstrated that the model has multiple equilibria if the fundamentals of the economy are common knowledge amongst the potential speculators, while there is a unique equilibrium if agents have private information (PI) that is sufficiently precise compared to public information. In this equilibrium, the central bank can actually reduce the likelihood of speculative attacks by increasing the interest rate or imposing capital controls. Heinemann (2000) showed that this also holds, when the noise of private signals converges to zero. Using the same approach, Heinemann and Illing (2002) argued that increasing transparency of government policy reduces the likelihood of speculative attacks. In a recent paper, Morris and Shin (2014) apply global games also to a model of the risk taking channel of monetary policy.

A global game is a coordination game with an additional state variable where actions can be ordered such that higher actions are more profitable if other agents choose higher actions or/and if the state variable has a higher value. The state is random and its realization is not commonly known. Instead, players receive private signals that are drawn independently around the true state. The equilibrium of a global game is unique provided that the noise in private signals is small. In equilibrium, agents follow threshold strategies and switch to a higher action if their signal exceeds a certain threshold. By letting the noise converge to zero, the global game selects a unique threshold in the state space distinguishing games for which in equilibrium (almost) all players chose the lower action from states in which they choose the higher action. For a particular realization of the state variable, the global game coincides with the original coordination game. Thus, for vanishing noise in private signals, the global game selects a unique equilibrium in the original coordination game. This limit point is called global-game selection.

Heinemann, Nagel, and Ockenfels (2004) tested the currency crisis model by Morris and Shin (1998). Each session had 15 subjects who repeatedly chose between two actions A and B. Action A was a safe option, providing a fixed payoff of T that was varied between treatments. Option B can be interpreted as a speculative attack and gave a payoff R, provided that a sufficient number of group members chose this action. The number of subjects needed for the success of action B depended on R and another parameter that was varied between treatments. R served as a state variable and was randomly drawn for each decision situation. In treatments with common information (CI), subjects were informed about R in each situation and knew that the others were also informed. In treatments with PI, subjects received noisy signals about R, where the noise terms were independent between subjects. Theoretically, games with CI have multiple equilibria for a wide range of realizations of R. Games with PI are global games that always have a unique equilibrium.

Heinemann et al. (2004) observed that in all treatments, more than 90% of all subjects were following threshold strategies, choosing B if and only if their information about R exceeded a threshold. The percentage of threshold strategies was about the same for CI and PI. Under both information conditions, 87% of the data variation of group-specific thresholds could be explained by parameters of the payoff function and there was no evidence that CI led to a lower predictability of behavior that could be attributed to the existence of multiple equilibria. Thus, the major conclusion from this article is that even if information is public, subjects behave *as if* they receive private signals. The numerical prediction of the theory of global games was not generally supported. In most treatments, subjects deviated in the direction of more efficient strategies. However, the comparative statics of the global-game equilibrium gave a perfect description of the qualitative responses to changes in parameters of the payoff function. In sessions with a higher payoff for the safe option or with a higher hurdle for success of action B, the threshold to choosing B was higher.

There was one significant difference, though, between sessions with CI and PI: under CI, thresholds were lower than in the otherwise equal treatments with PI. In the interpretation, this means that speculative attacks are more likely if payoffs are transparent. This result is in line with other experiments on coordination games in which subjects are more inclined to choose a risky option if they have better information about the potential payoffs from this option.

Heinemann, Nagel, and Ockenfels (2009) conducted a similar experiment in which subjects had to choose between a safe option A paying an amount X with certainty, and an option B, paying an amount of 15 Euros, provided that a fraction k of all group members decided for B in the same situation.

Parameters X and k were varied between situations. They showed that behavior could be described by an estimated global game in which subjects behave as if they had only noisy private signals about the payoffs. The estimated global game also had a descriptive power in out-of-sample predictions. Subjects treated coordination games with multiple equilibria similar to lottery choices, which indicates that strategic uncertainty can be modeled by subjective probabilities for other players' strategies. When subjects' beliefs about others' actions were elicited, the average stated probabilities were surprisingly close to average behavior. The global-game selection for diminishing noise of private signals was close to a best response to the observed distribution of actions amongst players. This reveals that the global-game selection can be used for individual advice to financial market participants who are in a coordination-game situation.

Duffy and Ochs (2012) compare behavior in the experiment designed by Heinemann et al. (2004) with treatments in which subjects decide sequentially. In their experiment, 10 subjects are first informed about the realized state either with CI or with PI. Subjects have 10 periods for choosing B. Once they have chosen B, they cannot reverse their decision. In each period, subjects get informed about how many other group members have chosen B before. This entry game resembles the dynamic nature of financial crises that allows for herding and strategic entry. The game is repeated and subjects converge to entering in the first period provided that the state is above a group-specific threshold. The main conclusion of Duffy and Ochs (2012, p. 97) is that "*entry thresholds are similar between static and dynamic versions of the same game*."

Qu (2014) extends a global game by introducing a communication stage before the actual decisions are made. In a "Market" treatment, subjects may trade contingent claims that pay one unit depending on whether the risky action in stage 2 is successful or not. In a "Cheap Talk" treatment, subjects send nonbinding announcements whether they intend to choose the risky action. In the "Market" treatment prices are observed by all subjects and aggregate PI about the fundamental state. In the "Cheap Talk" treatment, subjects get to know how many subjects announced to take the risky action. Market price and number of intended entries are public signals. Qu observes that in both treatments subjects learn to condition their actions on the respective public signal. However, with cheap talk subjects coordinate on equilibria that are significantly more efficient than the equilibria achieved with markets or in the one-stage baseline treatment.

For monetary policy, the most important conclusions from these experiments are comparative statics and predictability of behavior. Subjects respond to changes in the payoff function in the direction that is predicted by the global-game selection. Comparative statics follow the intuition – an improvement of fundamentals makes financial crises less likely. CI about fundamentals does not per se reduce the predictability of behavior, but is possible to influence behavior by communication.

Sunspots

Even though predictability of behavior in coordination games seems to be fairly high, there is always a range of parameter values for which these predictions are rather uncertain, even if the theory of global games is applied. With positive noise of private signals, the theory of global games delivers only a probability for a speculative attack being successful or a bank run to occur. If this probability is close to 50%, this is a unique equilibrium, but no reliable prediction for the final outcome. Arifovic and Jiang (2013) show that in these critical cases, subjects may condition their actions on salient but extrinsic signals. Their experiment implements a bank-run game, in which 10 subjects repeatedly decide whether to withdraw funds from a bank. Withdrawing yields a higher payoff than not withdrawing if and only if a sufficient number e^* of subjects withdraw. This critical number is varied across treatments. In each period, subjects receive a random message that may be either "*The forecast is that e* or more people will choose to withdraw*" or "*The forecast is that e* or less people will choose to withdraw*." All subjects receive the same message and are informed that it is just randomly generated. If $e^* = 1$, subjects reliably converge to the bank-run equilibrium. If e^*=8, they coordinate on not running the bank. However, for an intermediate value e^*=3, four out of six groups coordinate on a sunspot equilibrium, in which they run the bank if and only if they receive the first message. This result shows that behavior in coordination games may be unstable and affected by messages that are not informative about agents' payoffs.

Extrinsic events ("sunspots") may affect behavior in experiments as has been established by Marimon, Spear, and Sunder (1993) and Duffy and Fisher (2005). In a pure coordination game, Fehr, Heinemann, and Llorente-Saguer (2013) show that salient extrinsic messages can lead subjects to condition their actions on these messages, even if no sunspot equilibrium exists. In their experiment, subjects are matched in pairs and must simultaneously choose a number from 0 to 100 inclusive. Their payoff only depends on how close the chosen numbers are, the closer, the higher are both players' payoffs. Obviously, any number chosen by both players is an equilibrium. The game is repeated 80 times with subjects being randomly matched each period. In this baseline treatment all groups of subjects converge to choosing 50, which is the risk-dominant equilibrium. Fehr et al. (2013) compare this with various sessions in which subjects receive public or correlated private signals. These signals can be either 0 or 100. In a public information treatment, both subjects in a match receive the same number. Here, they coordinate on choosing the action that is indicated by the public signal 0 or 100. The signal works as a focal point and causes a sunspot equilibrium. If the two subjects receive signals that are not perfectly aligned, their actions should not be affected by the signal, because there are no sunspot equilibria. In the experiment, however, highly correlated private signals had a significant effect on behavior. Four out of 12 groups in which private signals were highly correlated even coordinated on non-equilibrium strategies in which players chose at least 90 when the private signal was 100 and at most 10 for a private signal of 0. When public and private signals were combined, the presence of private signals made half of the groups to choose numbers closer to 50 than in the treatment with pure public signals. This shows that private extrinsic signals may affect behavior even if this is no equilibrium and they may reduce the impact of extrinsic public signals that might otherwise cause sunspot equilibria.

Vranceanu, Besancenot, and Dubart (2013) analyze whether uninformative messages with a clear connotation can affect behavior in a global-game environment. As in the work of Heinemann et al. (2009), subjects can choose between a safe and a risky option, where the risky option yields a higher payoff provided that sufficiently many group members decide for it. They compare groups that before making their decisions, receive a positive message with groups who receive a negative message. The positive message reads "In a past experiment, subjects that had chosen the risky option were satisfied with their choice." The negative message: "In a past experiment, subjects that had chosen the risky option were disappointed by their choice." The number of risky choices by subjects with the positive message was higher than for subjects with negative messages. The difference is not significant at 5% but close to significant. The meaning of these messages cannot be quantified and they give no clear recommendations for behavior. However, they may raise or lower the subjective beliefs for success of risky choices. The authors conclude that "*rumors and other uninformative messages can trigger illiquidity in asset markets*" (Vranceanu et al., 2013, p. 5).

Sunspot equilibria are equilibria in which strategies depend on extrinsic signals that are unrelated to the players' payoff functions. Any game with multiple equilibria also has sunspot equilibria, in which all agents coordinate on playing a particular equilibrium for the respective realizations of the random variable. Once agents are coordinated, the extrinsic signal selects the equilibrium. Agents condition choices on the realization of an extrinsic signal. The experimental evidence indicates that in games with strategic complementarities, chosen actions are rather sensitive to extrinsic signals. The reason may be that any message with a connotation that refers to a higher strategy, provides an incentive to raise one's own strategy if one believes that others might be affected by the message.

CONCLUDING REMARKS AND OPEN ISSUES FOR FUTURE RESEARCH

This article provides a survey of applications of experimental macroeconomics to central banking issues. We have argued that experiments are helpful to better understand the channels by which monetary policy affects decisions, the impacts of different communication strategies, and for bench-testing monetary policy rules. We hope this article also contributes to a better understanding of the prospects (especially policy implications) and limitations of the use of experiments in monetary policy and central banking.

We view laboratory experiments as complementary to other methods used in macroeconomic research. Replication of an experiment is possible so that many economies with the same patterns can be created and allows multiple observations, which is necessary for testing theories. Although the created economies are synthetic, they can preserve the main features of a real economy and allow answering specific research questions. Experiments are particularly useful in testing responses to incentives, formation of expectations, effects of communication and information, and equilibrium selection.

We now suggest some avenues for future research where macro experiments could be useful. In Fig. 4, shaded arrows indicate some topics that could benefit from experimental analysis. These topics are largely inspired from the discussions about monetary policy tools and strategies during and after the recent financial crisis. Indeed, the global financial crisis has recast the debate about the roles and objectives of central banking.

Regarding objectives and institutions, it would be useful to analyze how government debt and political pressures may affect the objectives of central banks. Games of political economy can and have been tested in the lab.

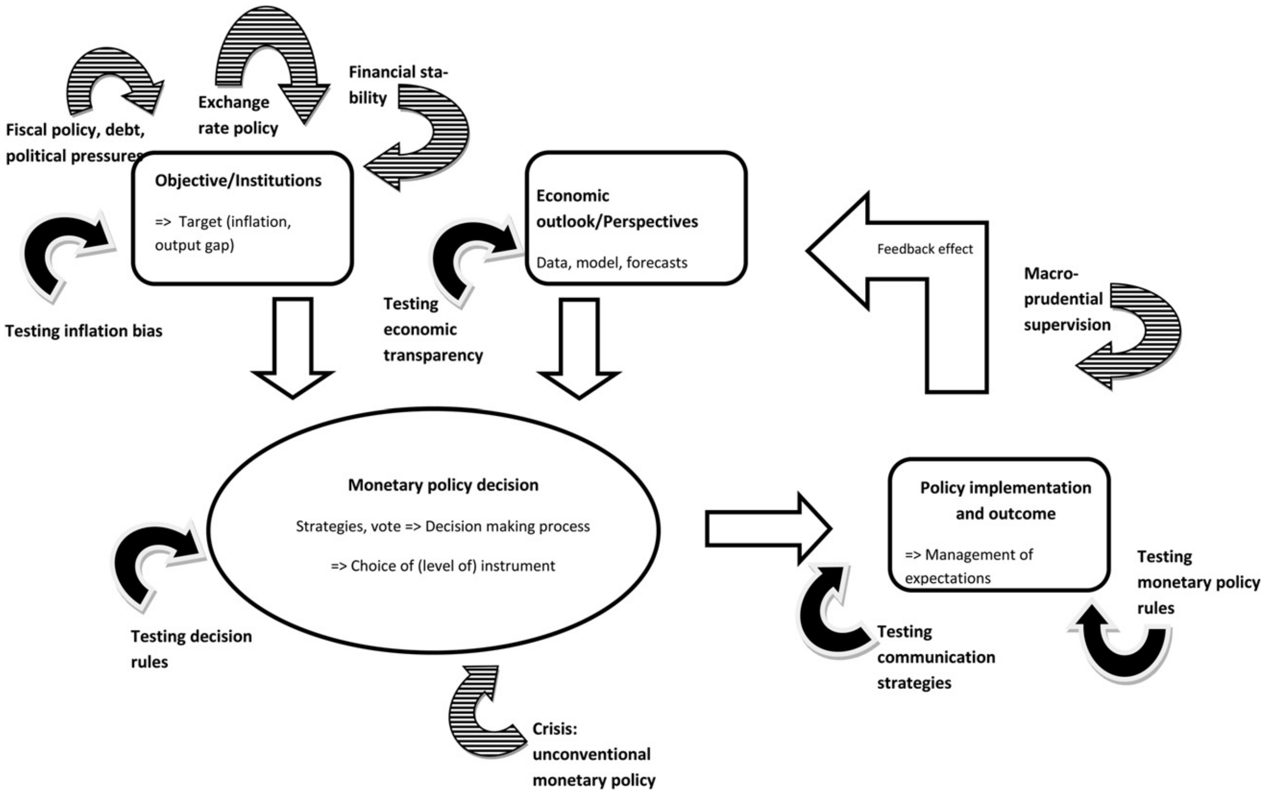

Fig. 4. Perspectives for Experimental Research in Central Banking.

Central bank independence and its pursuit of inflation stabilization may be compromised by debt, fiscal and political pressures, especially in an era of bank distress and sovereign debt problems. The credibility of the inflation objective relies on central bank independence. To what extent may political pressures force the central bank to deviate from stabilizing inflation? A related issue regards the possible time inconsistency of monetary policy. While we described some experiments related to the inflation bias of conventional policy, there is no work yet analyzing the time inconsistency of exiting unconventional monetary policy after a crisis. The issue is dawning on the horizon.

How well do central bankers manage several objectives with a single instrument and to what extent should central banks rely on market forces and automatic stabilizers? Experiments can offer an appropriate framework to treat these issues. The experiments of Engle-Warnick and Turdaliev (2010) and Duffy and Heinemann (2014) could be starting points with which these questions can be dealt with. How challenging is it for experimental central bankers to stabilize an economy when these objectives are competing? Think about stability of inflation and exchange-rates. Do subjects manage to find simple heuristics or rules to deal with these objectives or do they lose control?

Channels of monetary policy need to be better researched also by experiments. DSGE models already borrow heavily from behavioral economics by including habit formation, limited capacities of information processing or particular assumptions about risk aversion. Loss aversion can be included in modeling the monetary transmission channel and debt aversion matters as soon as one accounts for the heterogeneity of consumers.[34]

Another issue related to central bank objective is the relationship between price stability and financial stability. The crisis has shown that the traditional separation between a monetary authority targeting price stability and regulatory authorities targeting financial stability independently is no longer viable. More experimental research is needed for analyzing how rules of monetary policy and financial regulation interact in containing asset-price bubbles.[35] A recent paper by Guisti, Jiang, and Xu (2012) makes a step in this direction. It shows that bubbles disappear with high interest rates in an experimental asset market. Fixing the dividend process and terminal value of the asset, the time trend of the fundamental value of the asset becomes positive with a high interest rate and subjects are more likely to follow the fundamental value.

While Giusti et al. (2012) only study the impact of a constant interest rate, Fischbacher, Hens and Zeisberger (2013) implement a rule by which the interest rate is positively related to asset prices. The authors observe only a minor impact of the rule on the size of bubbles, which indicates that opportunity cost for speculative trades are not a powerful instrument to contain speculation. Expected liquidity restrictions, instead, seem to have stronger effects on the size of bubbles.

Another interesting issue would be to test whether specific forms of macro-prudential regulation achieve stability of asset prices and inflation simultaneously or whether there are inherent conflicts between these goals. One could also test the impact of macro-prudential equity or liquidity ratios on financial stability. The lab offers an environment for testing alternative macro-prudential tools. A large variety of instruments have been considered (see, e.g., Shin, 2011) to limit pro-cyclicality of the financial system. While real data only give examples, in the lab one could test the effectiveness of countercyclical capital requirements or time-varying reserve requirements systematically. Jeanne and Korinek (2012) propose a model of crisis occurring under financial liberalization, in which they evaluate the effect of macro-prudential regulation in terms of the reduction of crisis occurrence and increase in growth. Such a model could serve as a basis to construct an experimental environment in which one could test alternative measures.

One of the biggest advantages of laboratory experiments is the experimenter's control on subjects' information. In the aftermath of the crisis, communication and forward guidance have gained in importance. A pressing question is how central banks can achieve negative real interest rates that are desired in a liquidity trap. The central bank must coordinate expectations on a positive long-run inflation target, but private agents must also apply backward induction as in the Cagan (1956) model of the price level. With purely adaptive expectations, it may be impossible to leave a liquidity trap.

The last issue also highlights that traditional monetary policy instruments may become ineffective during or after a financial crisis, justifying the use of unconventional policy measures (as, e.g., quantitative easing or credit easing). Because these measures are adopted under particular circumstances, real data only provide very specific illustrations of their effects. Instead, experiments can offer a way to study more systematically their implementation and isolate their effects in the lab.

A related, but more general question is linked to equilibrium indeterminacy in DSGE-models with long-run neutrality of money. While models usually apply a transversality condition to establish uniqueness, experiments can be used to analyze under which conditions the equilibrium selected by the transversality condition is most likely to occur.

NOTES

1. In fact, experiments are already used as a policy tool to design regulated markets for utilities and auction schemes (Ricciuti, 2008).

2. "*A common argument of skeptics against the use of laboratory experiments (...) as a policy advice instrument (...) is its supposed lack of external validity. (...) [I]f regularities observed in the laboratory do not carry over to the field, any conclusions and policy advice (...) could be dangerously misleading*" (Riedl, 2010, p. 87). In research that is concerned with policy advice, laboratory experiments should be viewed as an important complementary research method. "*In the ideal case, an economic policy reform is evaluated with* all possible *scientific methods before a political decision is made. That is, theoretically, experimentally in the lab- and the field, and with traditional applied econometrics*" (Riedl, 2010, p. 88). Since field experiments are difficult to pursue in central banking, lab experiments gain importance. For a general discussion of external validity, see for example Druckman and Kam (2011) or Kessler and Vesterlund (2014).

3. This figure – as well as Fig. 4 – is inspired from Geraats (2002, Fig. 1).

4. In particular, Woodford (2003) has stressed the importance of managing expectations for the conduct of monetary policy. Laboratory experiments are appropriate to improve our understanding of the relationships between monetary policy, agents' expectations, and equilibrium outcomes as the underlying model can be kept under control and expectation formation processes are observable. Hommes (2011) gives a literature review of laboratory experiments that can be used to "*validate expectations hypotheses and learning models*" (p. 3). He is particularly interested in the role of heterogeneity in expectations and discusses learning to forecast experiments in order to find a general theory of heterogeneous expectations.

5. In Treatments NH and RH, the number of periods T was set to 20, in NC and RC, $T=10$.

6. For further examples see Heemeijer, Hommes, Sonnemans, and Tuinstra (2009) or Bao, Hommes, Sonnemans, and Tuinstra (2012).

7. See Sutan and Willinger (2009) for an experiment on guessing games with positive and negative feedback. They show that levels of reasoning are about the same in both environments but lead to faster convergence towards equilibrium in the environment with strategic substitutes (negative feedback).

8. The frequently assumed *constant* probability of updating prices or information is of course a technical simplification that cannot be justified by microfoundation if inflation rates are volatile or if the probability of shocks varies over time.

9. The second treatment variable concerns the degree of product differentiation.

10. Fréchette (2009) surveys 13 studies that compare experiments with students and professionals. Most of these experiments are close to financial-market or management decisions. He summarizes that in 9 out of the 13 experiments there are no differences in behavior between subject pools that would lead to different conclusions.

11. Actually, Arifovic and Sargent (2003) set a maximum length of 100 periods to avoid that a game exceeds the maximum time for which subjects were invited.

12. In fact, many experimental papers in macro – mentioned all along this paper – present contextualized experiments, in which subjects are confronted with variables like employment, wages, or inflation, rather than formulating them in an abstract manner. The context may be responsible for some biases in observed behavior, because subjects may be affected by value judgments or by experience from real data of their own economy (e.g., when asked for inflation expectations). For avoiding this, some papers – as those of Duffy and Heinemann (2014) and Engle-Warnick and Turdaliev (2010) – design experiments in an abstract way with neutral framing.

13. The same principle was simultaneously discovered by Henderson and McKibbin (1993).

14. Subjects are classified as being successful if they achieved positive payoffs.

15. Taylor (1999) uses linear rules with only two explanatory variables and finds an R^2 of 0.58 for the period 1954–1997.

16. These experiments implement New Keynesian dynamic stochastic general equilibrium (DSGE) models in the laboratory. Even though they are much simpler than the real economy, these large-scale experimental economies have a "proper" macro content. As already discussed, DSGE models represent the workhorse of current monetary policy analysis. As explained by Noussair, Pfajfar, and Zsiros (2014, pp. 71–108), "*the objective is to create an experimental environment for the analysis of macroeconomic policy questions*." In this respect, it is important to study "*whether a number of empirical stylized facts can be replicated in (…) experimental economies*".

17. See for example, the work of Bosch-Domenech and Silvestre (1997) who show that raising the credit levels has real effects when credit constraints are binding, but only leads to inflation when a large quantity of credit is available.

18. Petersen (2012) also uses a DSGE experiment for studying how households and firms respond to monetary shocks.

19. Lombardelli, Proudman, and Talbot (2005) replicate the work of Blinder and Morgan (2005) at the London School of Economics and Political Sciences.

20. ECB's rotation system will be effective, once the number of members exceeds 18, which is expected to happen in 2015, when Lithuenia joins the Euro.

21. Geraats (2009) provides an overview of recent changes in central bank communication practices.

22. Compared to the model of Morris and Shin (2002), Cornand and Heinemann (2014) required the number of players to be finite and also changed the distributions of the signals from normal to uniform in order to have a simple distribution with bounded support for the experiment. Moreover, while in the work of Morris and Shin the coordination part is a zero-sum game (so that aggregate welfare depends only on the distance between actions and fundamental state), Cornand and Heinemann change the utility function to make subjects' tasks simpler without affecting equilibrium behavior.

23. There is no direct experimental evidence for this claim, yet.

24. See, for example, Plott and Sunder (1982, 1988) and Sunder (1992). Plott (2002) and Sunder (1995) provide surveys of this literature.

25. This result should be taken into account with care. As the authors argue, while prices that outperform public information show that private information is being

impounded into the prices, the reverse is not true: supply will always contribute to market errors. "*Even when the market price reflects both public and private information, the effect of the random supply can still result in prices that are less predictive of the payout than public information alone*" (Middeldorp & Rosenkranz, 2011, p. 26).

26. The paper is closely related to the learning to forecast experiments and especially the works of Pfajfar and Žakelj (2014) and Assenza, Heemeijer, Hommes, and Massaro (2011): they use the same model and the results come from agents' inflation expectations. However, while these two papers study agents' inflation expectations formation process and its interplay with monetary policy in stabilizing inflation, Cornand and M'baye focus on the role of announcing the inflation target on agents' inflation expectations and on macroeconomic outcomes. They also consider a different reaction function for the central bank (allowing for output gap stabilization).

27. For each treatment, there were four sessions with six subjects each.

28. See Kagel (1995).

29. Assenza et al. (2011) focus on the analysis of switching between different rules. They show that an aggressive monetary policy described by a Taylor-type interest rate rule that adjusts the interest rate more than one point for one in response to inflation is able to stabilize heterogeneous expectations.

30. The time structure in this experiment is a clever experimental design that preserves stationarity of the environment and still allows inter-temporal feedback effects.

31. Starting with New Zealand in 1990, the use of IT by central banks has increased over time. IT is now implemented by more than 25 central banks around the world.

32. "*Under a price-level target, a central bank would adjust its policy instrument – typically a short-term interest rate – in an effort to achieve a pre-announced level of a particular price index over the medium term. In contrast, under an inflation target, a central bank tries to achieve a pre-announced rate of inflation – that is, the change in the price level – over the medium term*" Kahn (2009, p. 35).

33. Benhabib, Schmitt-Grohé, and Uribe (2002) introduce yet another source of indeterminacy. They show that the response function of monetary policy has two intersections with the Phillips curve relationship, because monetary response is restricted by the zero-lower bound on nominal interest rates. The equilibrium at zero interest is the liquidity trap.

34. Ahrens, Pirschel and Snower (2014) show how loss aversion affects the price adjustment process. Meissner (2013) provides experimental evidence for debt aversion.

35. Following Smith, Suchanek, and Williams (1988), there is a vast literature showing that speculative behavior may lead to bubbles and crashes (see Camerer & Weigelt, 1993). See also Palan (2013).

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