Experiments in macroeconomics: methods and applications

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Abstract

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Introduction

Modern macroeconomists make great efforts for a microfoundation of their theories. But, while experiments have been used to advance microeconomics and game theory, experimental methods are only slowly entering the territory of macroeconomics. Most macroeconomists use the word experiment for a simulation of a dynamic stochastic general equilibrium (DSGE) model. The main applications in this literature are based on rationality assumptions and homogenous beliefs: agents process information rationally, optimize their objective functions, and prior beliefs are restricted by a rational expectations equilibrium (REE). Parameters of these models are calibrated to match a real economy and simulations allow exploring the likely effects of shocks or different policies in impulse response functions.

Laboratory experiments, instead, involve deliberate choices of humans who reveal their preferences, beliefs, and strategic concerns. They inform us about behavioral biases from optimal actions for any given belief, biases from Bayesian updating in forming beliefs, the effects of strategic interaction, and strategic uncertainty. Experiments reveal heterogeneities in beliefs and behavior and allow us to test models of strategic interaction and adaptive learning. The results from laboratory experiments can be used to improve macroeconomics by providing a better microfoundation and advancing theories of equilibrium selection in models with multiple equilibria. They also tell us how real agents converge to a new equilibrium after a shock, whereas DSGE models assume that agents always are on a dynamic equilibrium path. Experiments help to advance macroeconomic modeling, precisely because modern macroeconomic theories rely on strong microfoundations. In fact, many macro-models have already been justified with behavioral assumptions stemming from experimental evidence.[1] Fairness, money illusion, loss aversion, informational frictions, learning, herding, and strategic uncertainty can help to explain systematic departures of real-world economies from the REE of a competitive general equilibrium model. For Akerlof (2002, p. 428), "*the implication (…) is that macroeconomics must be based on such behavioral considerations*." It is important to account for

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[1] For the implications of various biases on macro-modelling, see Driscoll and Holden (2014), especially section 4.2. for the field of labor, and section 3 for consumption issues. Some more recent examples of monetary macro-theories inspired by experimental evidence are provided in this chapter.

behavioral biases to predict the likely course of an economy, but also to design rules of conduct for monetary and fiscal policies. The Lucas critique (Lucas 1976) may be put forward against employing experimental evidence in macro-models. Only a REE, so goes the argument, gives us the stringent frame in which we can analyze the effects of systematic policy changes on behavior. However, if biases from rationality are systematic and do not disappear over time, policy rules must also account for them, and not doing so bears the risk of giving misleading or non-robust recommendations. Furthermore, the process leading towards a macroeconomic equilibrium is slow and, thus, relevant for evaluating the consequences of different policies.

This chapter discusses how experiments may be helpful to deal with macro issues and which potential limits they face. We are not the first to propose a survey of experiments in macroeconomics. Duffy (2016) provides a very comprehensive overview. Driscoll and Holden (2014) analyze how experimentally identified biases have been included in macroeconomic theory. Ricciuti (2008) and Cornand and Heinemann (2014b) particularly emphasize the relevance for policy makers to resort to monetary macro-experiments. We instead focus on *methodological issues*, including recent advancements in the design of experiments and challenges for applications in macroeconomics. The chapter is structured as follows. Section 1 presents the general advantages and difficulties associated with the use of laboratory experiments in macroeconomics. The following sections focus on three categories of experiments: Section 2 details how DSGE models have been implemented in the laboratory. Section 3 discusses experiments that are used to test the different components of the so-called microfoundations of DSGE models. Section 4 focuses on uncertainty and the modes of information processing that are relevant for macro-models and that may arise naturally in the context of laboratory experiments. Section 5 points to the challenges the approach still needs to overcome and concludes this chapter.

1. Advantages and potential difficulties

Laboratory experiments provide several advantages over field empirics that can be exploited for macroeconomic research. However, there are also some specific difficulties that arise from the macroeconomic interpretation of laboratory interactions.

1.1. Advantages of the experimental approach for macroeconomics

Macro-models have usually been tested using field data. However, 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."* The first advantage of laboratory experiments is to provide data that are unavailable in the field. This is particularly true regarding the effects of information.[2] Such data are needed to test rational inattention, multiplier effects of public information in models with strategic complementarities, the effects of monetary policy and financial-market regulation on bubbles, or the extent to which extrinsic events (sunspots) affect behavior. In the field, the fundamental values of assets are unknown. In the laboratory, fundamental values can easily be implemented or observed. Finally, it has become common in recent years to combine the indirect elicitation of preferences and beliefs, revealed through subjects' decisions, with direct belief elicitation.

[2] See Section 4 for further details.

The second advantage is that experiments offer direct tests of important elements of the microfoundation of macroeconomic models. In particular, the experimenter can measure certain characteristics of preferences as risk aversion, discount rates, dependence on reference points, or social concerns in controlled environments. One can test whether behavioral biases accord with theoretical predictions and how groups of subjects converge to a new equilibrium after a shock.

The third advantage is the ability to control exogenous variables, enabling the experimenter to replicate studies, and to establish causal effects. This point is particularly important in macroeconomics, in which field data do not allow for replications once the environment has changed, and where policy actions are often endogenous. Treatment comparisons within an experiment yield the most powerful results. Experimenters are most interested in qualitative comparisons rather than quantitative effects or behavioral biases within a treatment. These qualitative treatment effects are likely to carry over to economic situations outside the laboratory, so that their external validity may be higher than the external validity of results based on numerical simulations. Control of subjects' information and communication protocols are further advantages, helpful, for example, in analyzing effects of transparency and central bank communication.[3]

A further advantage is the possibility to test the effects of macroeconomic shocks or policy rules in a laboratory economy, while this is problematic or even unethical outside the laboratory, because such tests might be extremely costly or strongly affect many people in negative ways. Smaller field experiments are an alternative to gain external validity, but they seem difficult to implement when it comes to monetary issues or policy rules. Laboratory experiments offer a test bench. By comparing treatments with different policy measures or rules, their effects can be tested and, as qualitative results are likely to spill over, inform the policy maker about likely consequences outside the laboratory. The endogeneity of policy responses to macroeconomic problems complicates the analysis of field data and the formulation of correct inferences. By contrast, in the laboratory, the experimenter has the ability to control all the parameters of the tested model. Experiments allow to elucidate and approximate the different effects of alternative policy regimes by comparing different treatments and "*offer a quick and cost effective way to identify possible consequences of a monetary policy initiative*" (Cornand and Heinemann, 2014b, p. 169).

1.2. Presumed difficulties

Macroeconomic phenomena arise from the interaction of a large number of agents. Can theories aiming to explain such phenomena be tested by laboratory experiments with a limited number of subjects?[4] For small numbers of subjects, strategic effects may matter, because each subject has a significant impact on the average. In a meta-analysis of oligopoly games, Huck et al. (2004) show that for a group size of two, markets deviate from the Cournot-Nash equilibrium towards a collusive solution, for a group size of three to four, they come close to the Nash equilibrium, and for larger groups, even with only five subjects, the outcome deviates significantly in direction of the competitive equilibrium. Most subjects seem to neglect their impact on the aggregate, when it is too small and when they get no account of their personal influence. In a macroeconomic context, heterogeneity of agents' behavior may be important to explain the dynamics of aggregate fluctuations: in a learning-to-forecast experiment,[5] Bao et al. (2016) study the effects of group size on the stability of asset markets. In markets consisting of 21 to 32 participants, bubbles emerge faster and more often than in markets

[3] See Section 4 for further details.
[4] See also Duffy (1998) for a discussion.
[5] This class of experiments will be explained below in Section 2. See Hommes (2011) and Assenza et al. (2014) for surveys.

of 6 subjects, but a similar experiment by Hommes, Kopányi-Peuker and Sonnemans (2017) with 100 participants does not seem to produce different outcomes. Large-scale experiments are still very rare. While one needs to be cautious with respect to the generality of experimental results in an aggregate macroeconomic framework, 10 subjects may be sufficient in the laboratory to capture agents' heterogeneity. At least, 10 subjects are probably better than a theoretical model with a single (representative) agent. Indeed, the models that are used in most of the macroeconomic literature are far less complex than any economy in the field, and arguably less complex than a laboratory economy with heterogeneous subjects.

A second presumed difficulty – that experimental economics faces in general – is that there may potentially be systematic differences between subjects' behavior in the laboratory and decisions of professionals in the real economy. We cannot be sure that results carry over to the field. But still, a theory that survives the laboratory test is probably better than a theory that does not. Indeed, running experiments with students helps to identify biases, heuristics, and fallacies. The latter may carry over to more complex situations: some experiments in the field of financial markets, industrial organization, or corporate governance have tested whether the behavior of undergraduates differs from the behavior of professionals. The evidence is mixed; see Croson (2010).[6] Moreover, models with microfoundation rely on the effects of incentives. The laboratory is an ideal environment to create the incentives assumed by a model. Subjects are incentivized as required by the theory. If the incentives are appropriate, the subject pool should not matter.

If external parameters are varied, the distribution of choices is shifted in the direction to be expected by rational agents. Thus, the vast majority of subjects tries to make reasonable decisions and is motivated by incentives. One question, though, is whether the ability of students in the laboratory of making good decisions is comparable with the skills of professionals. It is not. Decision makers outside the laboratory know better how to make appropriate decisions, while subjects in the laboratory cannot achieve this expertise in an hour. Experimental data – particularly those collected during the first rounds of an experiment – seem noisy compared to panel data obtained in the field. Subjects need time to learn and experience. Hence, many macro-experiments start with some unpaid training periods, in which subjects do not interact yet, but rather play against computerized robots to get a feeling for the consequences of their decisions. As laboratory experiments are much simpler than economic decision problems outside the laboratory, a few periods of learning and experience in laboratory interactions may raise subjects' skills in dealing with laboratory situations to levels that are comparable to professionals' skills of mastering real life.

In macro-experiments with dynamic general equilibrium models, it is particularly difficult for subjects to understand the entire system of equations. Therefore in many macro-experiments, the parameters are not perfectly known by the participants, who are instead told only the qualitative features of the environment they face. In addition, they may be provided with calculators and data screens that allow them to analyze past data like an economist would do.[7] Subjects' understanding of the laboratory economy is a key issue in macroeconomic experiments. To improve subjects' understanding, many macro-experiments are contextualized, and instructions rely on macro vocabulary, so that subjects are confronted with variables that are called employment, output, wages, or inflation. This method contrasts with micro-experiments, in which parameters are usually known by

[6] See also Fréchette (2011) who surveys 13 studies in the fields of financial markets or management decisions that compare experiments with students and professionals: in 9 out of the 13 experiments there are no relevant differences between subject pools.
[7] See Kryvtsov and Petersen (2013) for an example.

participants but the context is often hidden so that subjects decide solely based on controlled incentives and strategic opportunities given by the rules of the game. Each of these methods has advantages and shortcomings.[8] Contextualization, in particular, may exert psychological effects on decision makers or may cause some biases in subjects' behavior that are not accounted for by incentive schemes: subjects may be affected by value judgments, by experience from real life, or by their knowledge about the functioning of an economy. Such experience and knowledge are advantageous when it comes to explaining an experiment. Providing subjects with the economic connotation may improve their understanding of the situation they face in the laboratory. But, it may also alter their behavior to the extent that it is not purely driven by controlled incentives and interaction. Thus, the experimenter loses some degree of control over incentives. On the other hand, this method may, arguably, align the incentives closer to those in the field. Furthermore, treatment effects may not be affected by connotation biases if these biases are the same in all treatments.[9]

Another challenge that is not specific to but important for macroeconomics is the implementation of an infinite time horizon. In the laboratory, the horizon is necessarily finite (and short). Different methods to address this problem have been developed. The predominant method is to randomize the number of periods such that the laboratory interactions will continue with constant probability; this corresponds to implementing an indefinite horizon with a constant discount factor. There are various ways of dealing with the small probability events of the laboratory interaction exceeding the time frame of a scheduled session.[10] Key is that subjects are kept in uncertainty about how many periods will come in the future. Subjects do not apply backward induction to large extent and do not expect others to do so (Kübler and Weizsäcker, 2004). It may also help to use a middle block of observations for analysis, cutting off noisy responses in the early periods and the last periods that may be affected by endgame effects or significantly declining probability of continuation.

A serious challenge, specific for testing macroeconomic models, is that the short time span of an experiment does not allow us to measure subjects' intertemporal substitution elasticities that are relevant for a dynamic IS-curve. We can induce intertemporal substitution elasticities by paying subjects according to a payoff function that follows a given utility function. To measure subjects' real elasticity of substitution, subjects can be invited to at least two sessions that are scheduled a couple of weeks or months apart, or payments can be transferred at different points in time after the experiment. However, this is a poor instrument for measuring intertemporal substitution of consumption unless subjects are extremely liquidity constrained.

Finally, inducing consumption in the laboratory is a challenge that is, maybe surprisingly, difficult. To keep control, preferences for consumption in the laboratory should not interact with consumption options outside the laboratory. Obviously, this is not possible for food consumption, as this presumably substitutes food consumption outside the laboratory. For example, it is no evidence

[8] See Alekseev, Charness, and Gneezy (2017) for a discussion and comparison of results depending on the context.

[9] To focus on controllable incentive effects, some macro-experiments have used a neutral frame. For example, Engle-Warnick and Turdaliev (2010) and Duffy and Heinemann (2016) do not tell subjects that they are playing a monetary policy game and control or predict inflation. Instead, subjects are told that their task is to control or predict the level of chips or water in a container. In Duffy and Heinemann (2016), one subject in each group plays a central banker and can move water from one container (interpreted as unemployment) to another (representing inflation). The ability to move water corresponds to the Phillips-curve trade-off. The other subjects predict the level of water in the second container, which amounts to an inflation forecast. As this study is interested in the effects of incentives in a repeated game mimicking a Barro-Gordon model, the neutral frame seems more appropriate than a contextualized experiment. It shows that repetition alone is not sufficient for achieving an efficient equilibrium. Thus, we cannot rely on reputation building to solve the problems associated with time inconsistencies of monetary policy. Due to the neutral frame, the results are also informative for problems with time inconsistency beyond monetary economics.

[10] See Duffy (2008) for a discussion.

against time preference if a student postpones eating a sandwich in a laboratory session right after lunch.[11] We discuss the contribution of experiments on consumption smoothing below in Section 3.

2. Implementing DSGE models in the laboratory

In this section, we discuss how DSGE models are implemented in laboratory experiments. In laboratory experiments, different subjects decide (most likely) differently even if they face the same situation and constraints. This is convenient as heterogeneity and real effects of monetary policy may come about without assuming any particular frictions on markets or information. A second advantage is that we may ask subjects directly for their expectations. As decisions in DSGE models are driven by expectations we can use reduced forms that map the vector of stated expectations to macroeconomic outcomes. Both of these advantages are reflected in the research questions addressed by laboratory experiments on DSGE models.

Lian and Plott (1998) is a pioneer paper that proposes an experimental general equilibrium framework with monetary exchanges for exploring the technical feasibility of running complex experiments in the laboratory. Here, different subjects play different roles. Recently, a growing literature documents laboratory experiments on New Keynesian DSGE models, in which subjects play the roles of professional forecasters, producers, consumers, workers or/and central bankers. Most experiments on DSGE models, however, let subjects play only one or two of these roles, while the other roles are played by robots. For example, subjects forecast prices and aggregate output and the computer calculates the optimal responses by price-setting firms or utility-maximizing households. Macro-experiments can have commodity markets, labor markets, and sometimes an (indirectly modeled) market for liquidity. Cash-in-advance constraints are implemented using computerized double auctions[12] in interconnected markets. Subjects interact repeatedly over a large number of periods and are rewarded in accordance with the profit or utility level that they reach in the laboratory. We develop on the methodological aspects and the research questions addressed in Subsection 2.1.

One of the key issues in macroeconomics is the formation of expectations. Neoclassical models, including most of the DSGE-literature, rely on rational expectations (RE). The justification is not that REE provide a particularly good fit of data – unstructured VAR models yield a better fit. However, owing to Lucas' critique, RE provide a consistent way of dealing with the fact that decisions of macroeconomic relevance are future oriented and economic agents use information about the future. Nevertheless, there are some key problems associated with RE: First, real agents are not purely forward-looking.[13] Experimental results show that subjects need time to converge to a REE (if they converge at all) and the convergence process depends on adaptive processes of expectation formation. Second, RE are an equilibrium concept. The rationality of a single agent's expectations cannot be judged without looking at the expectations of other agents. This becomes most obvious in models with multiple equilibria in which expecting a particular equilibrium is rational if and only if all agents are

[11] For references of experiments on optimal consumption/savings decisions, see Duffy (2016, Section 2.1.); see also the recent paper by Crockett, Duffy, and Izhakian (2017). The main idea of this literature is to study whether subjects can solve the standard discrete-time consumption optimization problem. It is shown that behavior is inconsistent with pure optimization.

[12] In a double auction, potential buyers and sellers simultaneously submit their bid and ask prices to an algorithm that determines the market-clearing price, such that all sellers who asked less than the clearing price sell and all buyers who bid more than the clearing price buy at that price.

[13] In laboratory experiments, deviations from RE are so frequent and so well documented that we may judge RE to be a theoretical construct rather than an empirically valid description of individual behavior. While RE seem unrealistic, field data cannot tell us how agents form expectations. Survey data provide snapshots of expectations about future macroeconomic variables (e.g., inflation), but do not tell us how agents' adjust their expectations in a changing environment. Furthermore, surveys provide no incentives for an accurate answer.

expecting the same equilibrium. Real agents need time to coordinate on one out of many equilibria. Finally, focusing on dynamic equilibria neglects the distortions and possible welfare losses that arise from disequilibrium during the adjustment process. In Subsection 2.2, we study how heterogeneity in behavior and expectations have been accounted for.

2.1. Methodology and research questions

Most laboratory experiments on DSGE models use variants of the standard three equations: IS-curve, Phillips curve, and policy rule. These are implemented directly via a computer program, up to the variables that are determined by subjects in the laboratory. If subjects' task consists in repeatedly maximizing profit through an action (e.g., choosing a price in the case of subjects playing the role of firms), we may follow Bao, Duffy, and Hommes (2013) and call it a "learning-to-optimize" experiment (LtOE). If subjects' task consists in making the best possible forecast (stating an expectation on, for example, future inflation or output), subjects play a "learning-to-forecast" experiment (LtFE). In LtFEs, subjects' payoffs depend negatively on their forecast error. They may play the role of professional forecasters whose stated beliefs are aggregated by their mean or median. This summary statistic of stated beliefs then replaces aggregate expectations of the private sector in the model economy. All other variables are determined by the respective model, prices are set by firms that maximize expected profits for the expectation given by the summary statistic of subjects' stated beliefs. As this induces the same expectation by all firms, a symmetric model attributes the same action to all firms. Alternatively, a subject may have the role of an advisor for a single firm that decides upon the subject's stated beliefs. As stated beliefs differ between subjects, their firms' optimal actions are also heterogeneous. This makes a LtFE comparable to a LtOE, in which subjects play the role of profit maximizing firms directly and submit prices instead of expectations. Most macro-models assume an infinite number of agents, while an experiment always has a small finite number of subjects. Thus, the laboratory model needs to be adopted for a finite number of agents if it considers heterogeneous actions.

In a recent experiment, Mokhtarzadeh and Petersen (2017), for example, use a model consisting of four equations: (1) a forward-looking IS curve derived from the private sector's Euler equation, (2) a short run Phillips curve derived from sticky prices, (3) a Taylor rule setting the interest rate in response to current inflation and output, and (4) an AR(1) process for interest rate shocks.

$$x_t = E_t x_{t+1} - \sigma^{-1}(i_t - E_t \pi_{t+1} - r_t^n) \tag{1}$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t \tag{2}$$

$$i_t = \phi_\pi \pi_t + \phi_x x_t \tag{3}$$

$$r_t^n = \rho\, r_{t-1}^n + \epsilon_{t,} \tag{4}$$

where x_t is *the* output gap in Period *t*, π_t is Period-*t* inflation, $E_t x_{t+1}$ and $E_t \pi_{t+1}$ are Period-*t* expectations for output gap and inflation in *t*+1, $i_t - E_t \pi_{t+1}$ is the real interest rate, r_t^n is the natural interest rate, σ^{-1} is the elasticity of intertemporal substitution, β is the discount rate, κ a parameter, and ϕ_π and ϕ_x are parameters of the central bank's response to inflation and output gap. Subjects are told that they are playing the role of professional forecasters in an economy and their payoffs solely depend on the accuracy of their forecasts. Their task is to provide forecasts for next period's inflation and output gap. The instructions provide them with a reduced form of the model, from which they can also see how stated expectations affect the outcome in the present period.

Mokhtarzadeh and Petersen (2017) analyze the effects of forward guidance, where the central bank publishes its own expectations before subjects submit their own forecasts. In two treatments, the computerized central bank provides forecasts (of the future interest rate, or of future inflation and output) calculated from the REE; in one treatment, it forecasts future inflation and output as predicted from a model, in which private agents use a mixture of adaptive expectations and RE. Thereby, the authors can test whether projections based on non-rational, but potentially more realistic expectations gain a larger weight in subjects' expectation formation process than projections based on RE.

Many alternative policy rules have been analyzed in slightly different settings. Amano et al. (2011) compare how subjects form expectations when a central bank implements inflation targeting or price-level targeting. Cornand and M'baye (2018) study the role of central bank's inflation target communication by comparing treatments in which the central bank explicitly announces its inflation target to treatments in which the central bank does not announce the target. Kryvtsov and Petersen (2013) show that public announcements of interest rate forecasts are useful to shape expectations but may reduce the effectiveness of monetary policy by increasing macroeconomic fluctuations.

Pfajfar and Žakelj (2018) compare four different monetary policy rules. They demonstrate that monetary policy rules with stronger responses to deviations of inflation forecasts from the target reduce the variability of inflation, but may lead to cycles, and that contemporaneous inflation targeting outperforms inflation forecast targeting holding the degree of monetary policy aggressiveness constant. Hommes et al. (2017) compare two monetary policy rules, one in which the interest rate reacts only to inflation, and one where the interest rate also responds to the output gap. The experimental results contradict the theoretical prediction that the Taylor principle is sufficient for stabilizing inflation and show that inflation volatility is reduced when the central bank also reacts to the output gap. Luhan and Scharler (2014) use a LtO experiment to study whether the Taylor principle is necessary for macroeconomic stability. They show that this is not required, because subjects may reduce consumption in response to an increase in the nominal interest rate, which may be another form of money illusion.

Arifovic and Petersen (2017) study the effectiveness of alternative monetary and fiscal policies in a LtF experiment at the zero lower bound. They show that fiscal policy is more appropriate than a communicated state-dependent inflation target to influence expectations and thus reduce the severity and duration of a crisis.

Noussair et al. (2014) implement frictions and persistent shocks in order to be able to replicate stylized facts, before analyzing the impact of policy. They show that monopolistic competition in the output market (even in the absence of menu cost) is sufficient to generate persistent effects of shocks. Being able to reproduce the characteristics of a 'real' economy, they study whether subjects playing the role of policy makers and setting an interest rate manage to stabilize inflation. They find that most subjects control inflation relatively well, though less than a simple computerized instrumental rule.

The implementation of DSGE models also comes with some problems that call for compromises. One challenge comes from the fact that DSGE models assume RE. Some policy rules considered in macroeconomic theory depend on the central bank's own expectation about future variables, e.g. an interest-rate rule that responds to expected future instead of current inflation, or forward guidance in which the central bank announces the likely path of some economic variables. For testing such policy rules in the laboratory, the question arises, how central-bank expectations should be modelled.[14] One alternative is to assume that the central bank calculates a REE. This method is best suited to test the predictions of a REE, because the model cannot be rejected if subjects actually comply with RE. For bench-testing policy rules, it may be better to endow the central bank with expectations that account for systematic deviations from a REE, because real central banks account for surveys, market data and other information that does not necessarily reflect RE. If experimental economics provide evidence for adaptive learning, then central bank projections should consider adaptive expectations of the private sector. In the end, we would like to have a model that simultaneously describes a realistic process for private expectation formation and assumes that policy makers are aware of this process and respond rationally, so that the model is not defeating itself. Such an issue arises for example in Mokhtarzadeh and Petersen (2017), who solve it by assuming (in one of their treatments) that the central bank forms its own projections based on a particular form of adaptive expectations by the private sector that was found in previous experimental studies on DSGE models.

A similar issue arises in Cornand and M'baye (2018), who ask subjects to state inflation expectations, but not output expectations, although the macro-model behind the experiment requires both. As Pfajfar and Zakelj (2018) and Assenza et al. (2013 in one of their treatments), Cornand and M'baye assume that firms naively expect the same level of aggregate output as realized in the previous period. While there is substantial evidence (survey and experiments) arguing in favor of such naive expectations, this assumption may have had the consequence of reinforcing inertia in subjects' stated inflation expectations. In particular, the imposition of naive expectations for output could have had implications for the effects of central bank communication. In fact, the backward-looking component may have reduced the impact of information about future inflation rates. Nevertheless, Cornand and M'baye (2018) observe that the explicit announcement of an inflation target affects expectations and reduces the volatility of aggregate variables. It is possible that this effect might have been even more pronounced if they would not have imposed naive expectations for the output gap.

2.2. Capturing heterogeneity in behavior and expectations

Laboratory experiments can be used to develop models that account for heterogeneity in behavior and especially in the formation of expectations.[15] Subjects in the laboratory tend to use heuristics when they face complex decision situations, simplify situations, and ideally, they ignore the unsubstantial, trying to pay attention to the essential facts and connections. The laboratory helps us to identify behavior at the individual level, but more importantly for macroeconomic questions, we get a whole range of different strategies from human subjects. They reflect subjects' different beliefs and change over time, as subjects learn to play in the laboratory.[16]

Modelling heterogeneous expectations by agents with bounded rationality has always been a key challenge in behavioral economic models. While experiments indicate inertia in subjects' expectations, it is not obvious which rules or heuristics subjects use to map past observations and information about the future into their own expectations. There seems to be an infinite number of plausible rules and the dynamic responses of a model to exogenous shocks depend on which rule is assumed. Apparently, it is difficult to find a rule that is plausible for all kinds of situations. In a stable

[14] Such questions arise whenever the macro-model that is brought into the laboratory contains expectations that are *not* determined by subjects.

[15] Modern New Keynesian macro-models already incorporate various forms of heterogeneity: Agents may differ by the time when they can adjust prices in sticky-price models (Calvo 1983), by their information (Mankiw and Reis 2002, Lorenzoni 2010, Angeletos and La'O 2016), or by their wealth or employment status.

[16] Duffy (2016, section 2.4.) provides a survey of experimental evidence on expectations formation in a macroeconomic context. For a recent experimental study on expectation formation and switches in heuristics, see Pfajfar and Žakelj (2014).

economic environment, it may suffice to expect that aggregate variables stay constant. In an inflationary environment, rising prices should be expected. Relevant information about future events or changes of a policy rule should be accounted for, as we also observe that subjects respond to such information. A rule that produces forecasts conditional on all possible past realizations and signals about the future would be extremely complicated or easy to reject. Heuristic switching models provide an efficient way out of this problem.

Brock and Hommes (1997) is a pioneer work that formalizes a heuristic switching model including an endogenous evolutionary selection among the different forecasting heuristics. Agents are assumed to switch more likely to rules that perform better, i.e. provide a more accurate forecast. In this sense, agents are ‘rational’ (although they may not converge to a REE). Anufriev and Hommes (2012) extend the evolutionary selection mechanism introduced by Brock and Hommes (1997) and show that it can be used to describe the results of a LtFE. Each period t, subjects need to state beliefs about the price level in period t+1. Their information contains all past prices. Prices in period t may depend on the subjects’ forecasts of future prices as in a standard New Keynesian macro-model. The model of belief formation consists of three heuristics, a simple adaptive rule, in which the expected future price p^e_{t+1} is just a weighted average of the subject’s previous expectation and the last observed price p_{t-1},

$$p^e_{t+1} = \beta_1 p_{t-1} + (1 - \beta_1) p^e_t,$$

a trend-following rule in which the expected price is

$$p^e_{t+1} = p_{t-1} + \beta_2 (p_{t-1} - p_{t-2}),$$

and an anchoring-and-adjustment heuristic that extrapolates price changes from a reference point that is defined as the (weighted) average between the forward-looking fundamental equilibrium price p^f and the last observed price,

$$p^e_{t+1} = \beta_3 p^f + (1 - \beta_3) p_{t-1} + (p_{t-1} - p_{t-2}).$$

The last equation ensures that information about the future affects beliefs, as the other two are purely backward-looking. One may employ different “heuristics,” add more parameters or pre-specify values of these parameters calibrated to match results from previous experiments. Subjects may not know the fundamental equilibrium price, but in order to capture forward-looking behavior and give subjects a chance to learn the REE, some forward-looking rule(s) should be included. A subject is assumed to switch from one heuristic to another with a probability depending on the past performance of these rules. Using the logit response function, the fraction of subjects employing a particular rule h may be defined by

$$n_{t,h} = \beta_4 n_{t-1,h} + (1 - \beta_4) \frac{\exp(\beta_5 U_{t-1,h})}{\sum_i \exp(\beta_5 U_{t-1,i})},$$

where $U_{t-1,i}$ is the payoff that the subject would have received from applying forecasting rule i in the previous period. Parameter $\beta_5 \geq 0$ is a rationality parameter. The larger β_5 is, the more likely does a subject switch to the rule that performed best in the previous period. Using the data from a LtFE, parameters β_1 to β_5 can be estimated simultaneously, maximizing the likelihood of observations.

Such a heuristic switching model captures heterogeneity in expectations formation. Although it assumes a common process of how subjects switch between the different heuristics, it allows for a heterogeneous outcome, reflected in $n_{t,h}$-values between 0 and 1. Moreover, it captures a common critique on adaptive expectations: by including a forward-looking rule in the specification, announcements about future changes of policy parameters can affect expectations, and, albeit with some delay, raise the relative success of the forward-looking forecasting rule in comparison to purely backward-looking heuristics.

Heuristic switching models can be included in a DSGE framework with heterogeneous agents, where the individuals' expectations are replaced by heuristics and a switching function that is calibrated according to the results from experiments. This procedure generates heterogeneous expectations. The model can be solved by applying solution techniques for heterogeneous-agents DSGE models (see Reiter 2009) or by agent-based models that basically assume a large finite number of agents with heterogeneous expectations, derive optimal consumption or production for each of these agents, and then aggregate decisions into macroeconomic variables. For a DSGE model with a representative agent, heterogeneous expectations derived from a heuristic switching model can be aggregated to an average forecast that is inserted into the model for the representative agent's expectations. Parameters of the heuristics and switching function may be either calibrated from the estimated model of a laboratory experiment or estimated simultaneously with other parameters of the DSGE model.

Relying on Brock and Hommes (1997), De Grauwe (2010) develops a macroeconomic model that combines a heuristic switching model with an otherwise standard New Keynesian DSGE model. The model assumes a representative agent whose inflation expectations are a weighted average of two heuristics (fundamentalist and extrapolative), where the weights evolve according to a switching function as described above. The fundamentalist rule is such that output and inflation equal steady state levels, while the extrapolative rule is such that expected output and inflation equal past levels. Because current inflation depends non-linearly on past inflation rates, the model exhibits boom and bust patterns that are reinforced by the presence of extrapolators and eventually inverted by fundamentalists. De Grauwe defines the changing weights on the two heuristics during boom-bust cycles as animal spirits. During a boom, extrapolators are optimistic, while in a recession, they are pessimistic.

In his review on De Grauwe (2010), Delli Gatti (2013 p. 889-890) points out two main (methodological) problems. The first is that a "*macroeconomic modeller who abandons RE gets lost "in the wilderness" of bounded rationality in which "everything is possible".* [In particular,] *it is up to the modeller to decide how many heuristics are indeed competing in forming expectations and what is their nature. It is not necessarily true that there are only two heuristics.*" But, as he argues, laboratory experiments with human subjects, and, in particular LtFE, can be used to discipline our thinking. A key issue here is to account for 'real'/observed heterogeneity. Indeed, LtFE identify different strategies of inflation expectations formation (rational, adaptive, trend-extrapolative, naïve, etc.) and estimate their shares among subjects. Most subjects are trend extrapolative or adaptive, except when they have information about future variables (for example, the central bank inflation target, as in Cornand and M'baye 2018). Second, it is important to provide suitable microfoundations. Unfortunately, there is no generally accepted model yet that one can use for the microfoundations of information processing in a world in which agents have cognitive limitations. In the light of Matějka and McKay (2015), logit functions seem to be appropriate for modeling probabilities for the different heuristics. It is less clear, though, which forecasting rules should be included. For adaptive rules, it seems realistic to allow the simplest ones and let their relative success determine to which extent they are used by agents. However, forward-looking rules also need to be included, because otherwise the model would not respond to information about future changes of exogenous values, which is at odds with observations in experiments. Cornand and M'baye (2018), for example, show that subjects switch less when the central bank communicates its inflation target and that subjects are less backward-looking when they receive information about future policy.

Agent-based models (see e.g. LeBaron and Tesfatsion 2008) simulate the actions of individual firms and households instead of solving equilibrium conditions. These simulations are no laboratory experiments and agents' actions are often based on ad-hoc assumptions about behavior or expectations. Agent-based models are criticized for these ad-hoc assumptions that contrast the microfoundation that is now standard in DSGE models. Agent-based models can be augmented by heuristic switching models for heterogeneous expectations. Optimal responses to these expectations generate heterogeneous behavior that can be justified by the microfoundation in conjunction with experimental results used to calibrate heuristics. The advantage of agent-based models is that they can capture direct interactions of heterogeneous interconnected agents, while DSGE models generally assume interaction via markets at equilibrium prices. A problem with agent-based models is that most of them are purely adaptive processes in which the state of the world in period $t+1$ depends only on the state in period t and some stochastic process. Information about future changes or a new policy rule have no effects because expectations are purely backward-looking. As the algorithms rely on this dynamic structure, they have, in general, no forward-looking elements and can, thus, not detect responses to announced future shocks.

3. Testing the microfoundations of DSGE models

Experiments allow direct tests of the various elements of microfoundation on which DSGE models are built. When calibrating the microfoundation of a DSGE model, one needs to assume utility functions or (more frequently) the utility function of a representative household. Parameters like risk aversion, time preference, or elasticities of substitution between different goods can be estimated together with the other model parameters to fit observed aggregate data of an economy. Unfortunately, the estimated parameters of utility functions are at odds with some results from laboratory experiments that have measured these parameters directly. There are two potential reasons for this mismatch: modeled parameters are correlated with other unobserved variables (or more generally: the estimated model suffers from omitted variables) and/or parameters estimated in the context of an experiment differ from parameters in the context of labor-consumption-saving decisions. We analyze these biases from standard preferences and discuss their modeling implications in Subsection 3.1. As DSGE models rely to a large extent on consumption smoothing, we discuss recent experiments on this issue in 3.2. Finally, information frictions are used as a microfoundation for New Keynesian models; we discuss experiments on information frictions in Section 4.

3.1. Biases from standard preferences and their modelling implications

3.1.1. Risk aversion and mental accounting

Laboratory experiments are a standard tool to measure risk aversion.[17] Subjects are offered a list of binary decision situations that can be ordered such that the degree of risk aversion determines where the subject switches from a safer option to one with higher expected payoffs. The results sometimes stand in sharp contrast to assumptions made by macroeconomists. With risk aversion experiments, we

[17] See, for example, Holt and Laury (2002).

can estimate the curvature of a utility function over the payoff in an experiment, while macroeconomic models need utility functions over the whole consumption bundle, which is hardly affected by subjects' earnings in the laboratory. Humans seem to have different preference parameters, depending on the setting and environment. Mental accounting and social interaction are at least parts of an explanation for this phenomenon.[18] On one hand, this limits the external validity of such parameter estimates no matter how the data are measured. On the other hand, mental accounting is likely to play a role in decisions of macroeconomic relevance as well. Money illusion, for example, can also be viewed at as a consequence of mental accounting.[19]

3.1.2. Social preferences

Many experiments have reported that human beings, in contrast to the standard assumptions about economic agents, are not just motivated by their own payoffs, but are also concerned about others' payoffs. Such social preferences include fairness, reciprocity and social norms, which are particularly relevant for models of the labor market.[20] The concept of "catching up with the Joneses" (Abel 1990, Ljungqvist and Uhlig 2000) is especially useful to model the idea that preferences for consumption depend on the consumption of others. Carbone and Duffy (2014) provide experimental evidence supporting this view.

3.1.3. Loss aversion and reference points

Loss aversion means that subjects are more averse to losses than they are attracted to gains of the same size. In addition, subjects tend to be risk-seeking in the loss domain. Some macro-theory papers have accounted for this by assuming that the reference point in any period is the utility or profit obtained in the previous period. Prospect theory, developed by Kahneman and Tversky (1979), provides an experimentally validated utility function that accounts for loss aversion as well as for the different curvatures in the gain and loss domain. Loss aversion may also be related to social preferences.[21] Recent work by Pagel (2016a, 2016b) shows that expectations-based loss aversion can explain apparent excess sensitivity of consumption to current income. Loss aversion may also be used to explain price and wage rigidity and, thereby, the trade-off between unemployment and inflation: Ahrens, Pirschel, and Snower (2015) argue that downward wage rigidity may be associated with the perceived losses by workers who use their past nominal wage as reference point. Ahrens, Pirschel, and Snower (2017) show that loss aversion leads to a kink in the consumers' demand function that can explain price rigidities and, in particular, why price reductions are less frequently observed than price increases in response to permanent demand shocks. In this model, rational firms consider reference dependent utility functions of consumers and account for the effects that their prices have on future reference points.

3.1.4. Hyperbolic discounting

The standard approach to derive an intertemporal IS curve assumes that economic agents discount at a constant rate. However, experimental evidence shows that subjects may be willing to wait one day for $10 if the waiting time is somewhere in the future (in one month), but not if they need to wait right

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[18] See Rabin and Thaler (2001) for a discussion and Heinemann (2008) for an estimation of the integration of subjects' wealth in the experiment by Holt and Laury (2002).

[19] For a discussion of the experimental literature on money illusion, see Cornand and Heinemann (2014b, pp. 173-177). Note that the results by Luhan and Scharler (2014) discussed in Subsection 2.1. can also be related to money illusion.

[20] See the survey by Holden (2012) for more details about tests of social preferences in macro-contexts; see also Akerlof (2002, 2007) for a discussion of the relevance of other-regarding preferences for macroeconomic models (especially the existence of involuntary unemployment with the efficiency of wage offers).

[21] See the discussion of Driscoll and Holden (2014, Section 4.2) on labor markets.

now. Such a bias also arises in decisions associated with providing effort. This bias from standard preferences underlying expected utility theory is referred to as present bias or hyperbolic discounting (see Benhabib, Bisin, and Schotter 2010 for an experimental study). It can account for time inconsistencies, for example that many people find it difficult to exert self-control and procrastinate unpleasurable activities. Hyperbolic discounting can apply to intertemporal consumption decisions and may explain undersaving, as agents may prefer to consume their income right away and postpone saving for retirement to the future (Diamond and Koszegi 2003). See Driscoll and Holden (2014, Section 3.2.) for more references and discussions.

3.2. Consumption smoothing

At a first glance, consumer behavior seems easy to test in the laboratory (student subjects are familiar with consumption decisions and would it not suffice to bring some cookies to the laboratory to induce consumption?). The macro-relevant questions, however, about households' abilities and willingness to smooth consumption, or how much a household's consumption level is influenced by consumption of others or by its own past consumption cannot easily be answered by laboratory experiments. The main reason is that preferences for consumption (of cookies, for example) in the laboratory directly interact with subjects' consumption outside the laboratory, which cannot be controlled by the experimenter.

To measure consumption smoothing, several authors have simply induced a concave utility function and tested subjects' ability to deal with it. In these experiments, subjects play multiple rounds in which they receive a non-constant income (experimental currency units, ECUs) that can be stored and may also earn an interest. Subjects can decide each period how many ECUs they want to "consume," where consumption means transferring ECUs into utility points according to the given utility function. At the end of the experiment, they are paid a monetary reward that is linear in the sum of utility points over all periods. Maximizing utility points requires to "consume" an equal number of ECUs each period. Thus, the experiment tests subjects' abilities to understand that it is in their interest to smooth consumption and act accordingly. Actually, these tasks are simple problems of calculus that students should be able to solve. As the utility function is induced, these experiments do not measure subjects' real propensity to consume. To make the situation a bit more realistic, the experiments are contextualized so that subjects can use their experience from outside the laboratory to decide about "consumption" in the laboratory. The experimental evidence, however, clearly shows that many subjects already fail to solve this simple problem, in particular, if consumption smoothing involves taking a credit (Meissner 2016). Although subjects can be sure to be paid a positive remuneration for participating in the experiment, they exhibit debt aversion. It has not been tested yet whether this effect depends on the connotation. In general, "consumption" is correlated with contemporary income and subjects smooth consumption far less than would be optimal. Since solving this optimization problem is a prerequisite for the microfoundation of consumption and savings decisions, the observed systematic biases are likely to spill over to real consumption.

These results imply that the marginal propensity to consume current income is higher than for conventional infinite-horizon Ricardian consumers. In macroeconomic theory there are various ways to model this.[22] Gali, López-Salido, and Vallés (2007) assume that there is some proportion of rule-of-

[22] DSGE models introduce elements of habit formation to account for excess smoothness, a concept that has been supported by experimental evidence. Habit formation is related to the endowment effect and can also be viewed at as an implication of loss aversion, discussed above. The endowment effect means that once a subject owns a good, he values it more (Loewenstein and Adler 1995). It has been documented in many experiments with different settings and implies that there is less trade, because net demand functions are kinked at the endowment.

thumb consumers, who consume their wage instead of borrowing and saving, while the others are Ricardian. This also accounts for the heterogeneity that is observed in the laboratory (although subjects cannot be classified in just two types). In contrast to models with purely Ricardian consumers, the model produces procyclical effects of government spending on consumption.

For some questions, it seems necessary to induce real consumption. Meissner and Pfeiffer (2017) construct an experiment to test for Epstein-Zin preferences. Such preferences are used in macroeconomic theory to get impulse response functions closer to empirical findings. They rely on agents having a preference for an early resolution of uncertainty about their future consumption, even if they cannot change it. Meissner and Pfeiffer invited subjects for 3 sessions at different points in time. During the first session, subjects first did some boring real effort tasks. Afterwards, they were given a couple of binary decisions regarding how to spend their laboratory time in the future sessions. Here they chose between a risky option, in which the number of real effort tasks was random, and a safe option, in which the number of real effort tasks was known ex ante. Subjects were informed that they could spend the remainder of their time surfing YouTube videos. This established a form of consumption in the laboratory that is unlikely to interact with consumption outside. Meissner and Pfeiffer also elicit the willingness to work more for an early resolution of the uncertainty regarding their leisure time in future sessions. The results indicate that very few subjects had a preference for early resolution and the respective parameter is on average smaller than assumed in the macro-finance literature (see, for example, Bansal and Yaron (2004)).

4. Information frictions and uncertainty

New Keynesian models need delayed responses to shocks in order to explain the real effects of monetary policy. The most popular approach assumes sticky prices. DSGE models with sticky information, introduced by Mankiw and Reis (2002) are less popular, because they are more complicated to solve. However, sticky information models have found a solid microfoundation in rational inattention that can also be tested directly in laboratory experiments. Hence, we first discuss some tests of rational inattention in Subsection 4.1.

Standard macroeconomic theories analyze dynamic equilibria and neglect the distortions and possible welfare losses that arise from disequilibrium during the adjustment process. In a real economy, agents need time to acquire and process information and to coordinate their expectations and actions. Given that this process may take several quarters or even years (following an economic crisis), disequilibria are relevant for welfare considerations and policy decisions. We have described above how heuristic switching models can be used to model heterogeneity of expectations and convergence to equilibrium. For experimental subjects as well as for real life decision makers, the slow adjustment process is associated with informational frictions. Strategic uncertainty may exacerbate informational frictions. Strategic uncertainty is particularly important in games with multiple equilibria, because the way that agents deal with strategic uncertainty has a large impact on the coordination process and on the equilibrium to which they finally converge. Public signals may take the role of focal points and coordinate expectations on a sunspot equilibrium. Public signals may, however, also distract agents from taking full account of their private information and evoke overreactions. We discuss

Habit formation is largely used in macroeconomic modeling, especially to render account for the persistence of shocks on output (see Schmitt-Grohé and Uribe (2008) for a survey). Moreover, it is analytically convenient to generate inertia.

strategic uncertainty, sunspots, and the multiplier effects of public information in Subsections 4.2 to 4.4, respectively.

4.1. Rational inattention and probabilistic decision rules

Rational inattention is a way of modeling agents' heterogeneous information in macroeconomics (especially relevant for consumption/saving problems and price setting; see e.g. Maćkowiak and Wiederholt 2009, 2015). The idea is that agents may rationally neglect information, when its acquisition and processing is costly and the expected returns are small. Cheremukhin, Popova, and Tutino (2011) estimate and compare different models of rational inattention. They provide evidence that subjects have heterogeneous costs of information processing. Caplin and Dean (2015) show that subjects collect more information, use more time and put more effort to process this information if the rewards for doing so are higher. Caplin and Dean (2013) emphasize however that subjects respond less to changes in payoff incentives than the Shannon Entropy theory predicts and propose a simplified Shannon model to render account for this observation. Carvalho and Silverman (2017) test how having more options affect the quality of decision-making. They conduct an experiment on a large and diverse population of Americans in order to measure the effects of complexity on financial decisions. They show that complexity leads the lower skilled subjects to more often take the simple option, making them choose dominated actions and earn lower returns. Heterogeneity of information processing costs can explain why posterior beliefs of rational agents may differ, even if they all receive the same information.

Matějka and McKay (2015) show that the optimal strategy of information processing under information costs results in a probabilistic choice rule following a logit model: the probability that an agent chooses action i is given by $\exp(U_i/\lambda)/\sum_i \exp(U_i/\lambda)$, where U_i is the expected payoff from action i and λ scales the costs of information processing. Such logit models have already been widely used by experimental economists to describe choices under bounded rationality. Here, $1/\lambda$ resembles the degree of rationality. If λ converges to infinity all actions are equally likely. If processing costs are negligible or agents are fully rational, λ converges to zero and the agent almost certainly chooses the payoff-maximizing action. Such error response functions have also been used to define quantal response equilibria and heuristic switching models.

In an experiment, Khaw et al. (2017) consider a dynamic setting in which subjects face a forecasting task: one of two outcomes can occur at each decision stage and the decision consists in estimating the probability of a particular outcome. Subjects know that the underlying probability may remain constant for many successive periods, so that they may learn; and they know that the underlying probability may eventually change in some periods. The rational strategy consists of Bayesian updates to new information that arrives each period. Although there are no external adjustment costs in the experiment, subjects keep their estimates constant for several periods and adjust them in the direction of the new evidence only after several periods. As usual in such experiments, subjects also tend to state round decimals. These discrete jumps can be justified by assuming a random fixed cost of adjustment. The same might also hold for price setting firms, which may explain why the observed price rigidities are stronger than can be justified by observed menu costs (Woodford, 2009).

4.2. Strategic uncertainty

When strategies are defined as mappings from an agent's information set to a probability distribution over actions, strategic uncertainty is the uncertainty of agents related to the strategies chosen by other players. A Nash equilibrium (and likewise a REE) is a vector of strategies and beliefs, where agents' strategies are best responses to their beliefs, and beliefs are restricted to put 100% probability on the strategies of other agents that are part of the same equilibrium. Thereby, the notion of a REE abstracts from strategic uncertainty. While a REE may yield a good description of long-run behavior in a stable environment (where agents can learn the strategies of others), strategic uncertainty matters crucially for models that aim to explain short-run fluctuations, responses to shocks, and adjustment to equilibrium. There are different ways to model strategic uncertainty and all of them have been put on test in laboratory experiments. The most prominent concepts for macroeconomics applications are levels of reasoning, quantal response equilibria, and global games.

Nagel (1995) presents experiments on a beauty-contest game and shows that behavior can be described by assuming that subjects follow different levels of reasoning. Level 0 describes agents who decide randomly. Level k is the best response to the belief that all other agents decide according to level $k-1$. For $k \to \infty$, Level k converges to a Nash equilibrium. In Nagel (1995) behavior follows Level 2. Camerer, Ho and Chong (2004) estimate a cognitive hierarchy model that considers positive proportions of all levels, and Kübler and Weizsäcker (2004) combine levels of reasoning with quantal response equilibria that are discussed by Goeree et al. (cf. Chapter IV.2 of this handbook). The educative learning approach by Guesnerie (1992) is closely related to levels of reasoning. These models seem to be particularly well-suited to describe behavior in generalized beauty-contest games and macroeconomic applications.[23] Angeletos, Collard, and Dellas (2015), García-Schmidt and Woodford (2015), Angeletos and Lian (2017), and Farhi and Werning (2017) incorporate level-k in monetary macro-models and assume heterogeneity with respect to agents' levels of reasoning. Woodford (2003) shows how inertia in higher-order beliefs (agents' beliefs about other agents' beliefs) can potentially be superior to sticky prices to reproduce aggregate inflation dynamics. Angeletos and Lian (2016) provide a literature review on how informational frictions may render account for business cycle fluctuations.

Global games, introduced by Carlsson and Van Damme (1993), have been used to address the problem of multiple equilibria in games with strategic complementarities, such as bank runs or speculative attacks on exchange rates. A global game embeds a coordination game in a world of possible games and treats the game under consideration as a random realization. Uncertainty about the game is an effective way of modeling strategic uncertainty. Technically, a global game introduces a random variable that is added to the difference in payoffs when agents switch to a higher strategy. Agents receive private signals about this variable and choose their actions accordingly. The true realization of the random variable is zero and the distribution of signals around it describes heterogeneous beliefs and determines probabilities for different actions. Heinemann, Nagel, and Ockenfels (2004, 2009) show that subjects' behavior in symmetric coordination games can be described by global games. Even if all subjects receive common information, they behave *as if* they play a global game with additional private signals about fundamentals. The theory has been applied to model financial crises and can explain why small changes in information about fundamentals eventually trigger a crisis.[24] It can also explain twin crises.[25] Angeletos, Hellwig, and Pavan (2007) use global games to explain alternating phases of tranquility and phases of distress on financial markets.

[23] See Crawford, Costa-Gomez, and Iriberri (2013) and Nagel, Buehren, and Frank (2017) for discussions.

[24] See Morris and Shin (2003) for an overview of early applications.

[25] See Goldstein (2005) for a global game with currency and banking crises. König, Anand, and Heinemann (2014) use a global game to derive an optimal guarantee on bank debt by the government.

4.3. Sunspots

Some macroeconomic phenomena seem to be driven by market sentiments that cannot be explained by market fundamentals. The higher the degree of strategic complementarity is, the more responsive are strategies to misperceived public signals or to public signals that have a low correlation with fundamentals and payoffs. Signals that are entirely uncorrelated with fundamentals are called extrinsic signals or "sunspots". In games with multiple equilibria, there also exist sunspot equilibria: if all agents believe that equilibrium A will be played if the number of sunspots is even and B if the number is odd, these beliefs are in equilibrium and, hence, the outcome of the game depends on the number of sunspots. Such beliefs are self-fulfilling. As many macro-models and models of financial crises have multiple equilibria, the question arises whether we can test under which conditions sunspots affect behavior.

Experiments have shown that sunspot equilibria arise if the sunspot variable is publicly observed and has a clear connotation for subjects that indicates the equilibrium on which they should coordinate their strategies. Marimon, Spear, and Sunder (1993) and Duffy and Fisher (2005) establish that sunspots can affect behavior if subjects first learn to coordinate conditional on the sunspot. Arifovic, Evans, and Kostyshyna (2013) show that sunspots can lead to an inefficient equilibrium in an experiment on a macro-model in which subjects forecast the average production. Arifovic and Jiang (2013) show that sunspots affect behavior in coordination games in which strategic uncertainty is high, and Fehr, Heinemann, and Llorente-Saguer (2017) also show that highly correlated private signals can lead to stable sunspot-driven behavior, although this is no equilibrium. Their results additionally show that salient public signals that are combined with equally salient private signals are harmful to coordination and reduce efficiency. The reason is presumably that if a public message "100" leads some players to play "100," then others who see this, feel confirmed that they should also respond to a private signal that says "100" or take the average signal if private and public signals do not coincide. Thereby, the co-existence of public and private signals leads to frequent coordination failure.

One lesson to draw from these experiments is that communication by central banks can affect behavior, even if it is cheap talk, as long as it is clear enough to coordinate expectations on an (almost) self-fulfilling equilibrium. This implies that Delphic forward guidance can possibly move an economy out of a liquidity trap. However, the statements should avoid competition with forecasts from the private sector. According to Mokhtarzadeh and Petersen (2017), informative forward guidance can help coordinating beliefs. Ahrens, Lustenhouwer, and Tettamanzi (2017) show that central banks can deliberately use forward guidance as an instrument to guide expectations.

4.4. Multiplier effects of public information

The effects of information are particularly difficult to study in the field. Indeed, field evidence suffers from the simultaneity of different information types (e.g. public versus private) and from the problem of filtering out which information really affected decisions. In laboratory experiments, the experimenter can control subjects' information and, thereby, establish causal effects.

Morris and Shin (2002) have shown that public signals may reduce welfare if different agents' actions are strategic complements. The reason is that equilibrium weights on public signals are higher than the Bayesian weights, because agents have an incentive to coordinate their actions and public signals are more informative about other agents' beliefs than private signals. Some experiments (e.g. Cornand and Heinemann 2014a and Shapiro, Shi, and Zillante 2014) highlight the multiplier effects of public information, by measuring the relative weights that subjects put on public versus private signals when deciding about their actions in a generalized beauty-contest game à la Morris and Shin (2002). The main result of these experiments is that subjects attribute more weight to public than to private signals, but the weight on public signals is, in general, smaller than predicted by the equilibrium and too small to generate welfare detrimental overreactions.[26]

Baeriswyl and Cornand (2016) qualify the previous results in terms of overreaction: They find that the weights that subjects attribute to the more precise signal is smaller than the Bayesian weight. If private signals are more precise than public signals, subjects' behavior gets closer to the equilibrium prediction with its potential negative welfare implications.

While the assumption that economic agents treat information rationally is made very often in macroeconomics, this experiment recalls that subjects do not necessarily follow Bayesian updating and instead may be biased. There are many examples showing that subjects may not deal with information rationally: anchoring effects of initial information, overweighting of memorable and salient information and confirmatory bias to mention but a few.[27]

For central banks, the question arises, whether and how they should release information that has the potential of damaging welfare. In a theoretical analysis, extending Morris and Shin (2002), Cornand and Heinemann (2008) have shown that central banks should never completely withhold information, even if it is imprecise and a publication would reduce welfare. Instead, the (theoretically) optimal communication strategy is a limited degree of publicity, in which the central bank discloses information only to a sub-group of agents. The lower degree of publicity contains overreactions and leads to welfare improvements compared to entirely withholding imprecise signals. Baeriswyl and Cornand (2014) show that a limited degree of transparency (i.e. disclosing public information to *all* subjects as private signals with an added idiosyncratic noise) can achieve the same expected welfare as a limited degree of publicity. They test this prediction in an experiment and show that both information structures effectively reduce the multiplier effects of public information. For reasons of accountability and fairness, they argue that central banks should favor limited transparency when they want to avoid overreactions. However, in the light of the results by Baeriswyl and Cornand (2016), the issue only arises, if a central bank publishes information that is less precise than private information. It is remarkable that negative welfare effects of imprecise public information can be avoided if the precision is deliberately reduced by adding idiosyncratic noise.

5. Conclusion

The experimental literature in macroeconomics and large group dynamics is growing rapidly. Macro is catching up with other fields in exploiting experimental tools. It is now rather common to test the microfoundations of macro-models and it is now also possible to put a DSGE model in the laboratory. The main advantages are: bench-testing of alternative policies, capturing strategic uncertainty and biases from standard preferences or RE, and accounting for heterogeneity in agents' expectations and behavior without getting lost in the wilderness where "everything goes."

The experimental method in macroeconomics should be seen as complementary to field empirics. Both empirical approaches can help us to improve macroeconomic theory and get more realistic impulse response functions to unexpected shocks and changes in policy rules. While

[26] For further details, see Cornand and Heinemann (2014b, 2015).

[27] See Holden (2012, p.5) for more examples and details.

experimental macroeconomics deserves more and more attention and has been useful in many respects already, it still faces some challenges.

First, replicating experiments in different frames or settings allows testing the robustness of experimental results and improves their external validity. Thus, we need studies beyond the mere replication of experiments in identical frames. Associated with this, we need studies that target the external validity directly, for example by providing systematic comparisons of results from laboratory experiments, surveys, and field empirics.

Second, there does not yet exist a generally accepted method for experiments in macroeconomics. We need more interaction between experimental macroeconomists, practitioners from central banks, and theorists to agree on acceptable tests for theoretical predictions or policy measures. This interaction should also foster the development of models that account for experimental results. There are some models that are based on experimental outcomes in the field of labor economics, but much less has been done in the field of monetary or fiscal policy. Key issues are to account for observed heterogeneity and for strategic uncertainty. Heuristic switching models and level-k models may be useful in this respect. Incorporating the findings of experimental economics in macro-modelling are challenging tasks that deserve further attention.

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