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BRINGING MACROECONOMICS INTO THE LAB

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WORKING PAPER

Abstract - This paper reviews experiments in macroeconomics, pointing out the theoretical justifications, the strengths and weaknesses of this approach. We identify two broad classes of experiments: general equilibrium and partial equilibrium experiments, and emphasize the idea of theory testing that is behind these. A large number of macroeconomic issues have been analyzed in the laboratory spanning from monetary economics to fiscal policy, from international trade and finance, to growth and macroeconomic imperfections. In a large number of cases results give support to the theories tested. We also highlight that experimental macroeconomics has increased the number of tools available to experimentalists.

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“When an engineer wants to find out how the temperature affects material’s conductivity, she builds an experiment in which she changes the temperature, makes sure that everything else remains the same, and looks at the changes in conductivity. But macroeconomists who want to find out, for example, how changes in the money supply affect aggregate activity cannot perform such controlled experiments; they cannot make the world stop while they ask the central bank to change the money supply”.

Olivier Blanchard (1997)

1. Introduction

Although the experimental method has gained considerable standing in the study of many areas of economics, experimental macroeconomics has still a long way to go, as exemplified by the above quotation. Probably no experimental macroeconomics would have been possible without the microfoundation revolution that hit macroeconomics in the 1970s. Since then macroeconomists have started obtaining macroeconomic propositions originating from the maximizing behavior of consumers, given some constraints. This revolution gave birth to the New Classical Economics in which general equilibrium propositions were extended to macroeconomics. Subsequently, in response to the puzzles opened by this theory, New Keynesian Macroeconomics has originated to look at the frictions that prevent markets to clear. Therefore, the work surveyed here - in which motivated agents interact in the laboratory to give rise both to individual and aggregate outcomes - can be seen as a partial assessment of the power of micro-models in macroeconomics. For this reason the reader may not find a distinctive feature of macroeconomic experiments over microeconomic ones: the working of the economy is based on agents and the only flavor of macroeconomics is the explicit analysis of aggregates such as inflation, investments, and employment.

There are two classes of experiments in macroeconomics. The first is concerned with system effects, studying equilibration and spillovers between markets. This approach is maintained by Charles Plott in several of his experiments. The second approach concentrates on a specific issue in isolation and looks at experimentation as a way to test specific theory, using only one market. In principle, only the first kind of experiments has a proper macroeconomic content, since these are interested in the inter-relations between several markets and the spill-over between them. The economy at the aggregate level is a complex system in which consumption decisions affect supply, which in turn have an effect on investments, which determine the employment level, and changes in the latter impinge on aggregate demand. Laboratory economies are of course much simpler than the real economy, and the implicit message of this work is: if a simplified version of the economy rejects a model of macroeconomic behavior, this model cannot be applied to the more complex real world. Therefore, non-rejection provides first evidence of the plausibility of a model. The other view is more widespread: most of the experiments reported here fall within this category. It is usually centered on a single market, and there are no feedbacks to the rest of the economy. In fact, these experiments are akin to microeconomic experiments, where the *ceteris paribus* condition can be easily applied. This view is consistent with most current macroeconomic modeling, in which a single market is considered at a time. Since the “testing theory” approach is dominant within experimental macroeconomics, there is no surprise that this kind of experiments have such a prominence.

There are mainly three specific reasons to look at experiments in macroeconomics. Let us draw some examples from the papers we will consider below. The first relies on theoretical models that are primarily concerned with steady-state equilibrium and are based on rational expectations, therefore neglecting any out of equilibrium dynamics. This is the case of the existence of stationary solutions in inflationary processes and reputational models

of monetary policy. Therefore, running experiments may shed some light on issues on which models are silent: dynamics towards the equilibrium, the process of expectations formation and coordination is left undefined because expectations are assumed to be fulfilled, and the complexity of particular market structures and policies is not taken into account. Moreover, some of these models predict multiple equilibria, and experiments become a natural way to look at which one is most likely to occur when individuals are placed in the conditions of the theory. In addition, many models are based on expectations formation, which are typically unobservable and therefore cannot be operationalized in econometric analysis. In contrast, within an experiment subjects may be requested to make conjectures about the future values of a variable, therefore one can follow and evaluate the expectations path.

The second argument is related to empirical work with deficiencies in field data. To see whether a theory is confirmed by data one needs to impose some restrictions. For example, tests on demand of money would require identification of money demand, separation of the transaction demand from other motives, and inclusion of all important determinants of money demand as explanatory variables. It is difficult to get all this information to run an econometric analysis with field data: the identification problem is virtually unsolvable, whereas experiments allow constructing economies where only the transaction motive exists. When it comes to international trade, a direct test of the law of comparative advantages is not possible because autarky is never observed in the real world. To test for theories on exchange rate, one needs to unambiguously measure the price level of the economy, and in the field data price indices may not be uniformly accurate measures of the short-term buying power of a good. The experimentalist supplies consistent inflation data that have a known generating process.

Another argument in favor of experiments is related to the endogeneity of policy in real-world economies that makes it difficult to analyze data and formulate correct inferences

on changes that have occurred. In the lab the experimenter has full control over the parameters, one can make “what if” experimentation perfectly knowing which parameters have changed and in which direction. Therefore, modeling is flexible since one can implement as many changes in parameters and rules of the game as time and budget constraints allow. Furthermore, results may be replicated by other scholars.

Three main problems can be detected in the use of the experimental method in macroeconomics. Firstly, there is a motivation issue: individuals in macroeconomic systems take several roles: they are workers paid a salary that is necessary to fulfil basic needs, consumers using their rewards, and savers that make both short- and long-term decisions choosing between alternative assets. At the same time, firms co-exist and interact with them with their own features. Students in a laboratory are just motivated by a small amount of money that cannot be representative of the needs and aspirations of an agent interacting in a large economy.¹ A second and related problem is concerned with the number of people involved, which in macroeconomics is huge and in a laboratory economy is rather small. Taken together, these issues put into doubt the realism of experiments. The position we take is that models themselves are simplifications of the working of an economy, and these experiments have their scientific strength in building on economic theory. Furthermore, we share the view that “Laboratory methods allow a dramatic reduction in the number of auxiliary hypotheses involved in examining a primary hypothesis” (Davis and Holt, 1993: 16). The issue of inadequacy of rewards has been extensively analyzed, and there is evidence maintaining that payoffs may matter – higher payoffs reduce “noise” and also bring down, but not eliminate, deviations from theoretical behavior - but it is very difficult to ascertain in

¹ However, it is a common opinion among experimentalists that professional players do not perform better than students, because they may try to show their skills, and therefore, their behavior is biased by other considerations rather than induced value.

which situations this can occur, and in which direction (Smith and Walker, 1993; Camerer, 1995).

A third problem is related with learning. Macroeconomic experiments are often complex, matching and exchanging rules may interact in a rather artificial way, and therefore it is necessary to repeat the experiment many times to get subjects acquainted with the rules of the game. Referring to their overlapping generations experiment, Marimon and Sunder (1995: 125) point out that “Assets cannot be carried from one ‘life’ to the next but memory and experience obviously are.” In some situations learning processes are the objective of the study, as in their experiments where they aimed at comparing rational expectations and adaptive learning in equilibrium selection. In others we cannot distinguish between learning the rules of the game and just learning how to play with a given set of parameters.

The reader will notice that almost a single exchange institution is used in the following experiments: the double auction, i.e., a market in which buyers and sellers can make asks (offers to sell) and bids (offers to buy) for standardized units of well-defined commodities and securities. This institution is used at the Chicago Board of Trade. It has been popularized by Vernon Smith in market experiments since the birth of experimental economics, and there is a significant body of literature (see Friedman and Rust, 1993 for a comprehensive review) that maintains the superiority of this institution in terms of efficiency and ability to simulate a competitive market. Therefore it is not surprising that it has also been extensively used in macroeconomics. Given the properties of this market institution in the domain of partial (static) equilibrium notion of induced demand and supply, is its overwhelming use in general equilibrium experiments justified? Macroeconomists used to think in terms of short-run disequilibrium and dynamic feedback between different markets would not recognize this as an approximation of how the economy works. We think that there are several reasons that made this exchange institution so popular in experimental

macroeconomics. First, its widespread use in experimental markets has made this tool easily available to experimenters that have moved to macroeconomics. Second, and more important, many of the macro models are inherently neoclassical, therefore they rely on the notion of perfect competition, and the experimental market that performs in this way is the double auction one. In this sense the experimenter attempts to mimic one of the conditions of the model, therefore this choice is coherent with the theory testing approach. For example this is particularly clear in the experiment reported in Section 2, when a general equilibrium model is put under experiment, and one of the key theoretical features of these models is perfect competition. At the same time the reader must bear in mind that the result may be institutionally-sensitive. In this respect, comparisons of the same model with different trading institutions would be an interesting task for the future, since it has been substantially overlooked until now. This also represents a different undertaking compared to model testing, being much closer to the approach put forward by Sunder that experiments are useful to find which hypotheses are crucial in obtaining a result and which other mainly represent nuisances of the model (Sunder, 2001).²

The paper is organized as follows. Section 2 reviews macroeconomic experiments in which a system of interrelated markets exists. In this Section topics are drawn from general equilibrium, international trade, fiscal policy and credit constraint theory. In Section 3 we are concerned with experiments that test specific building blocks or component assumption of standard macroeconomic systems. Topics in this Section cover overlapping generation models of monetary and fiscal policy, the role of money, growth, dynamic inconsistency of monetary policy, money illusion and search models. Section 4 concludes. In this paper we do not consider two groups of experiments that have already been surveyed elsewhere: co-

² Other experiments concerned with simpler general equilibrium models include Goodfellow and Plott (1990) and Aliprantis and Plott (1992).

ordination games with strategic complementarities and experiments on inflation, expectations and coordination (Ochs (1995) and Duffy (1998)).

2. System experiments

2.1 A general equilibrium experiment

Lian and Plott (1998) study the general equilibrium properties of an economy in which consumers sell labor and buy goods to maximize their utility, competitive firms hire workers and sell goods to achieve maximum profits, a financial market exists, and money supply may be changed. This paper tries to answer the question on the technical possibility of running experiments characterized by such complexity and then, provided that this answer is positive, to qualify the results in light of the neoclassical model.³ General equilibrium models do not need to be perfectly competitive. The experiment is meant to capture the characteristics of this class of models.

In Figure 1 the circular flow model of the economy is represented. There are two groups of agents (consumers and producers) in equal number and two goods (X and Y). Consumers desire both goods and in each period they have an endowment of ten units of Y (labor) and none of X (output). Therefore they have to sell labor in exchange for fiat money (francs) to buy X . Producers use labor as an input for X , have a desire to consume Y , and no preferences over X . They also have a non-linear production function that enables them to transform labor into output. Producers buy Y on the market, use some of it to produce X , and sell it into the market for fiat money. The money could be used to purchase additional labor or to obtain rewards for the period. Only in the first period producers had an endowment of three units of output and some cash (together with consumers) to let the experiment start.

³ Other experiments concerned with simpler general equilibrium models include Goodfellow and Plott (1990) and Aliprantis and Plott (1992).

There is a financial sector: agents can borrow money by selling bonds. Two types of bonds exist paying a fixed number of francs with certainty at specific dates, and return the capital at different dates after selling. The financial sector is aimed at reducing possible binding effects deriving from the cash in advance nature of the economy. The experiment consists of a series of trading periods; all markets are organized as double auctions. One period before the end, the end is announced, and at the end of the experiment, all fiat money was converted into real values (X and Y) using the average price during the final period. The process was entirely controlled by the experimentalists, no specific probability of termination at each period was given to subjects. This procedure was implemented to avoid the backward induction argument that makes the value of money equal to zero in every period, therefore refraining from trading.

[Figure 1]

This economy is a quite complex system, nonetheless it does not show disequilibria, cycles, instability and coordination failures. System efficiency is defined as

$$E_s = \frac{TI}{MPTI}, \quad (1)$$

where TI is the real total income in dollars, and $MPTI$ is the maximum possible total income in dollars, and reveals that the median efficiency is equal to 88.9% per period. Production efficiency is defined as:

$$E_p = \frac{\sum_{j=1}^N X_{jp}}{X_p^* \left(\sum_{j=1}^N Y_{jp} \right)}, \quad (2)$$

where X_{jp} is the amount of X produced by j , and $X_p^* \left(\sum_{j=1}^N Y_{jp} \right)$ is the maximum X that can be produced when $\sum_{j=1}^N Y_{jp}$ is used in production. Production efficiency is virtually equal to

100%, meaning that substantial gains from trade are achieved. Furthermore, the variability of allocations (consumption, production and inventories) decreases over time, together with the variability of the price ratio. This finding does not mean that the competitive equilibrium model is accepted, although convergence toward its predictions is uncovered in a weak sense. When moving the analysis towards the partial equilibrium models, both the input and the output markets are in disequilibrium, with volumes that are lower than the theoretical demand and supply quantities. However, a movement towards the partial equilibrium is found in both cases. In addition, given the price ratio, too much Y is consumed by consumers, producers under-produce X and over-consume Y .

So far we have underlined the microeconomic properties of the economy. Macroeconomic variables can of course be analyzed too, in particular those which are concerned with inflation and unemployment. With a constant money supply the price level increases and approaches asymptotes, while the inflation rate approaches zero. The constant level of money supply has a positive effect on prices but no effect on real GDP, therefore supporting money neutrality. The Okun's law – a negative relationship between changes in unemployment and the percentage change in real GNP - is strongly observed in the data, while the same support is not found for the Philips curve. The authors claim that an overall confirmation, in terms of comparative statics, of the neoclassical model is found, and poignantly ask skeptics to be able to analytically compute the competitive equilibrium solution from the set of given parameters. They observe that this task is rather difficult without the help of the invisible hand of the market that was in place during the experiment.^{4,5}

⁴ Tietz (1972) proposed an early macroeconomic experiment. The framework was built around five sectors (industry, households, credit banks, the central bank, and the government). Sectors are connected through five markets. The key market is the labor market where the employers association and the labor union bargain over

2.2 International trade

A small area of research is concerned with international trade. Noussair *et al.* (1995) provide the first experimental framework to test for competing theories on trade, in particular they look at patterns of trade and output predicted by the law of comparative advantages. The authors construct two environments, for the sake of brevity we only consider the first one, which is a version of the Ricardian model. There are two output goods, Y and Z , and one input L , and two types of agents, consumers and producers. Consumers own factors of production and have induced preferences over the two consumption goods. Producers have initial endowments of input, and earn profits buying L and selling Y and Z . Half of the agents belong to a country, half to another, with an equal number of consumers and producers in both countries. The two countries differ in their production functions, but have the same currency. Consumers sell their endowment of L to producers of their own country (the factor of production is not mobile between countries), and then buy production goods from either country. Consumers get utility from consumption and any profit made by price speculation. Producers buy L in their own country and produce Y and Z for consumers in either country, getting utility from profits attained in the production and market activity. In some experiments a tariff on Z is imposed in order to mimic the effect of transportation costs.

the wage. Bargains occur on a table between the two counterparts with the assistance of the central bank. Bargainers have information on about 200 variables computed by means of software. Individuals are assumed to be bounded rational, taking an aspiration level approach. The software produces new values of the economic variables that are consistent with the decisions taken by players. With respect to the Lian and Plott experiment it is easy to note the differences in these approaches: formal bargaining instead of anonymous trading; central role given to the labor market; computer simulations to obtain economic values as a cascade from the labor market opposed to different trading in different atomistic not explicitly linked markets.

⁵ Bosch-Domenech and Silvestre (1997) analyze a general equilibrium economy with credit-constraints.

Therefore the experiment includes six markets that are organized according to a double auction.

An important contribution of this paper is on the empirical side of its analysis. To test whether the data converges over time to the equilibrium predicted by the theory, usual regression models are not good because data exhibits serial correlation and heteroscedasticity. The estimated model is the following:

$$z_{it} = B_{11}D_1\left(\frac{1}{t}\right) + \dots + B_{1k}D_k\left(\frac{1}{t}\right) + B_2\left(\frac{t-1}{t}\right) + u_{it}, \quad (3)$$

where i indicates the particular experiment, t represents time measured by the number of market periods in the experiment, D_i is a dummy variable that takes value 1 for i and 0 otherwise, and B_{1i} is the origin of the possible convergence process. B_2 is the asymptote of the dependent variable, as t gets larger the weight of B_{1i} becomes smaller because $1/t$ approaches 0 while B_2 is larger $(t-1)/t$ approaches 1. The model is used to test the hypothesis that the data converges to the predictions of various models by testing whether or not the estimates of B_2 are significantly different from the predictions of the models (strong convergence). In contrast, if the B_2 term is closer to the model's prediction than B_{1i} is, data is partially converging.

Data generated by the experiment generally supports neither the competitive equilibrium nor the autarchy model in the point estimates (which include prices, production, and net exports), whilst at the same time, the law of comparative advantages predicts trade patterns. However, convergence towards the free-trade competitive model predictions is found for aggregate production and individual consumption patterns, as well as, output and factor prices. As in the competitive model, tariffs reduce international trade and market efficiency. Overall the results lend support to the competitive equilibrium model.

In a companion paper Noussair *et al.* (1997) aim at testing the law of one price and the flow of funds theory. The framework closely resembles the previous one with the addition of two currencies that enter into the utility function of the agents of the home country. In the absence of tariffs, taxes, transportation costs, and other frictions, the law of one price maintains that the prices of the two goods will be the same in both countries after prices are factored by exchange rates.

The results support the competitive model over the autarchy one in a number of ways. Data on exchange rates strongly supports convergence to the competitive model predictions, whilst those on the volume of exchange show a bias towards a level lower than the one predicted by this model. Prices in both countries partially converge to those predicted by the competitive model, as well as prices for X and Y . The flow of funds are moving towards the competitive prediction, the law of one price is only supported in the market for Y , whilst the purchasing power parity theory is not supported by the data. Failure of the law of one price is attributed to the asymmetry in the adjustment speed of the price discovery process of local markets. In addition, the flow of funds theory determines the supply and demand of currency and therefore the behavior of the exchange rate from one period to another.

2.3 Fiscal policy

An interesting experiment founded by the Dutch Ministry of Social Affairs and Employment under the auspices of the Dutch Second Chamber of Parliament on the effects of the wage tax on budget deficits and unemployment in an open economy is made by Riedl and Van Winden (2001). Unemployment benefits are usually funded via a tax on labor, which may have a negative effect on the working of the economy. The economic system has many features in common with Noussair *et al.* (1995) but countries have different size (a

small “home” country and a large “foreign” one) and a public sector. Four goods are traded: two input goods (capital and labor) and two consumption goods called X and Y (output). In each country there are two types of agents, consumers and producers.⁶ Consumers wish to consume the two outputs and enjoy leisure. In each trading period they are endowed with some units of labor and capital but none of X and Y . They can sell their endowments on the input market to producers for fiat money and buy the outputs from producers with the proceeds. Consumers have an additional source of money through unemployment benefits. For each unsold unit of labor (which counts as leisure) they receive a given benefit. Consumers’ real money payoffs are determined by their consumption of X , Y , and leisure. On the input market producers buy capital and labor to produce output, therefore X and Y are produced and sold on the market. Producers’ payoffs are determined by the profit they earn. The labor market is local, consumers can sell their labor only to producers in their own country. The capital market and the X -market are international, the Y -market is local. The economy consists of a sequence of trading periods: at the beginning of phase one, consumers receive their endowments and, together with producers, they receive some cash to allow for trading. After labor and capital are traded, production takes place automatically, and agents are allowed to trade X and Y via a double auction, then the period ends. In this stylized economy government expenditure is represented by the unemployment benefit, and the revenue side is represented by a tax on employed labor levied on producers needed to fund the latter. There are two treatments concerning the government budget. In the first, a “constant tax regime” is obtained fixing the wage tax at a rate that ensures a balanced budget, according to the general equilibrium solution. In the second, called “dynamic tax regime”, taxes can be adjusted in period $t + 1$ after a deficit in period t . The first treatment

⁶ In each economy the number of agents is the same, the scale effect is obtained giving the large economy seven times the resources of the small one.

allows the economy to stabilize and to see whether this happens running a deficit or a budget surplus. The dynamic treatment allows for an assessment of what happens to the economy when all parameters but the tax wage are held constant.

For the constant tax regime in both countries a large and persistent budget deficit is observed, which does not vanish over time, whilst unemployment converges to its equilibrium value from above. Nominal wages appear to be too low for a balanced budget. The reason for this is twofold. On the one hand consumers tend to supply too much labor, therefore reducing its nominal value. On the other hand producers are reluctant to employ labor. The authors believe that the former effect has its roots in the risk-compensated price-mechanism: producers face uncertainty about output prices and consequently their revenues. Together with risk neutrality, this can explain why they use fewer resources (in particular labor) than the optimal level. This also brings unemployment to a higher level. In the dynamic tax regime there is still a tendency to run a budget deficit, even though they are small and tend to vanish over time in both countries. Unemployment (defined as the amount of unemployed units of labor relative to the total labor force – endowment - in the respective country) is high with a close to balance government budget: it increases from 6% to 12% in the small economy and from 4% to 18% in the large economy. There is also a sharp decrease in the long-term real GDP. The negative effect of a wage tax is therefore confirmed by this experiment. With the same framework Riedl and van Vinden (2003) analyse the economic effects for a small open economy to switch from a wage-tax system to a sales-tax-cum-labor-subsidy system while the rest of the world uses the latter system. They found that the sales tax system outperforms the wage tax one.

3. Partial equilibrium experiments

3.1 Fiscal policy

When implementing an experimental version of the OLG model, one faces two main problems. First, in such models there is an infinite number of agents, and due to laboratory size and money constraints this condition cannot be met. In this environment, N agents are recruited and n of them played the role of the young generation, n played the role of the old generation, while the remaining $(N - 2n > n)$ were outside the game. At the beginning of each period, n of the $(N - 2n)$ players that were outside in the previous one are randomly selected to enter into the game. This procedure makes sure that each subject stays out of the game after exit and before re-entering, and avoids the possibility of playing a supergame. A long series of trades is played, and when parents die in the t period, they are reborn as children in the $t + 1$ period. Second, the infinite horizon of the model needs avoid the outcome of no-trade when fiat money is involved; therefore it is necessary to construct a terminal condition that does not affect the strategies and the outcomes available to agents. A solution is conceived by Lim *et al.* (1994)⁷: subjects temporarily outside the market play a forecasting game. At the beginning of each period they conjecture the market-clearing price for the current period, and the best forecaster(s) is (are) rewarded accordingly. Without any previous announcement, and after forecasts for period $T + 1$ have been submitted, the experimenter announces that period T is the last of the game. At this point money holdings of agents who entered in the economy in period T are converted into chips using the average predicted market price for period $T + 1$ by outside market participants.

⁷ Marimon and Sunder (1993) show that this procedure does not affect the set of equilibria of standard OLG models, as long as they behave competitively. In turn, a random termination date without the forecasting game distorts the model introducing an implicit discount rate.

Devising an experimental method to deal with an infinite horizon had also a role in experimental tests of Ricardian Equivalence. According to Barro (1974), given a pattern of government expenditure, a reduction in taxes today implies their rise in the future. Therefore, provided that parents care for the well-being of their descendants, they will save the tax cut to enable them to repay the debt the government has to incur. Cadsby and Frank (1991) developed an overlapping generations model independently of Lim *et al.* (1991) designing an environment in which two groups play the game for eight years, each year is made of three periods, and the two groups overlap in the medium period. In contrast to the previous setting the game is stopped and restarted every time a pair of generations has played, and in each game subjects enter only once. In the first period, the current generation has to allocate a given endowment between certificates and savings. In the second period a further endowment, which represents government deficit, may be given to them. Then they decide the allocation between certificates and savings. In this case savings represent the bequest left to the future generation. The future generation receives an endowment and the bequest, and allocates this sum between certificates and savings. An amount equal to the second endowment given to the first generation is then subtracted from their resources. In the third period the second generation may only buy certificates. The experiments examined both expansionary and contractionary fiscal policies. Parents' utility function includes first and second period consumption, together with the utility level attained by descendants, which in turn is given by their second and third period consumption. The utility function is multiplicative in the arguments, which entails a high degree of consumption smoothing. If a descendant is left with a poor bequest, he may not be able to repay the debt, and therefore, by convention consume zero, which becomes the utility level of the parent.⁸ Whenever the

⁸ Some different specifications of parents' utility function are also studied using an additive form or a function in which the utility of the descendants counts less than the own consumption of the parents.

theory predicted a positive bequest, outcomes close to those predicted by Ricardian equivalence occurred, with some allowance for learning. Moreover, deviations are not unbiased as they display a tendency towards Keynesian behavior.

So far we have encountered different approaches to mimic the infinite horizon and to implement an OLG environment, two design features that often go together. We believe that all these alternatives have pros and cons and they should be implemented when the theory that is tested requires a specific design to keep the experiment closer to the model. For example, the infinite horizon with a given probability of stopping the game at some period has the advantage of providing a measure of time discounting, but may be a bit more complex for agents to understand and the experimenter loses some control of the process (the experiment may finish too soon or last too long). By the same token, the Lim *et al.* (1994) OLG approach has the advantage of avoiding the supergame effect but requires a more demanding environment to subjects that play different roles (and sometimes do not play at all), are required to take more decisions (for example, the forecasting game).

The Ricardian theorem requires some strong assumptions; subsequent experiments have focused on their violations to test for the robustness of the theory. Ricciuti and Di Laurea (2003) look at two different possible departures from Ricardian equivalence: liquidity constraints and parents' uncertainty of their future income. In both cases the theory predicts that agents engage in too much early consumption and bequeath an amount of money that is unable to offset the debt repayment that descendants have to make. The authors construct three treatments: the first one resembles Cadsby and Frank except for the fact that they use a matching rule similar to the one used by Sunder and his associates to avoid a supergame effect, and therefore, possible backward induction. In the liquidity constraint treatment parents face increasing income in the two periods in which they live; whilst in the uncertainty treatment they do not know at the beginning of each game the

income they will have in the second period. To implement this difference between the two periods the disposable and extra income (which Cadsby and Frank and Slate *et al.* gave respectively at the beginning of the first period) is given in two installments. For the sake of comparison this procedure is also applied in the baseline. Results for the baseline treatment are substantially in line with the two previous experiments although there is a larger number of parameters, and therefore, more computational difficulties. Results for the two departures do not completely confirm the theoretical claims: whilst under uncertainty subjects tend to equate consumption over the two periods and to leave insufficient bequests, in the credit-constraint case agents do not equate consumption over time and do leave positive bequests, a behaviour that is not expected by the theory.

Bernasconi et al. (2003) provide an interesting method to test for anti-Keynesian effects of fiscal policy. According to the “expectation view” on fiscal policy, government expenditure cuts may have expansionary effects on private consumption in contrast with the standard Keynesian view. The mechanism at work here is based on the expectations of the future tax burden. Bertola and Drazen (1993) and Sutherland (1997) develop two models in which, with rational expectations, a simple optimizing consumers’ behavior may give rise to some anti-Keynesian effects when government expenditure and debt reach some unspecified critical levels. A restrictive policy at this point may have an expansionary effect.

Once again the problem with these models is related with the unobservability of expectations. The lab is therefore well suited to induce agents to express their views about future values of the variables of interest. However, generating *ad hoc* variables, and telling them that fiscal series follow a Brownian motion would be too demanding. The problem is circumvent exposing players to real data on public debt; changes in public debt, taxes and government expenditure from fifteen European countries without giving them references on

the countries and the period considered. Then players are asked to submit forecasts of the subsequent values of taxes and government expenditure.

Agents' expectations are found neither to be consistent with rational nor with purely adaptive expectations. Expectations follow an augmented-adaptive scheme, which embodies the “spend and tax hypothesis” on the relationship between taxes and expenditure. This is a short-run causal relationship that holds regardless of the actual causal relationship between taxes and expenditure in the field. These results are consistent with the anti-Keynesian view of fiscal policy, but data reject possible nonlinearities of its effects.

3.2 The role of money

Money is valuable because it is a “medium of exchange”, and people should hold it because of this reason. However, people will hold it only if it has value, i.e., money as a “store of value”. McCabe (1989) provides the first experiment on this topic, in which money acts in these two ways. Players trade experimental money (tickets) for bonds over six periods. In each period they are endowed with at most one bond, for example in period 1 A- and B-type players have one bond, whereas C-type players have no bonds, and similar combinations of bond/type in each period. Only in period 1 there is an endowment of one ticket, given to player A-type. Tickets are valueless at the end of the six periods, whilst in each period bonds provide a dividend, which is either 50 or 25¢. Therefore tickets are fiat money in the six-period economy. Agents can propose to buy or to sell these bonds at a unit price, and the market institution in this experiment is a clearing house that randomly assigns buyers to sellers. At the end of the six repetitions money is valueless, therefore nobody would like to hold it, but if nobody wants to hold it in the sixth period, this will also be true in the fifth. A backward induction argument applies here, and money will not be accepted in any period.

Figure 2 graphs the number of trades in each 6-period trial (referred as play) in two representative economies. It shows that the Nash equilibrium of no trade is rejected: in two out of nine experiments trading ceased completely whilst in the others it continued at a reduced level. Trades in the last three periods (triangles) are much lower than in the 6 periods (circles) but usually are not equal to zero. No trade is reached only when players with previous experience of this experiment were recruited (lower panel). The conclusion drawn on the dual nature of money is that individuals use it as a medium of exchange even though it is an unstable store of value.

[Figure 2]

Whilst the previous experiment does not aim to test any particular theory, in a pair of experiments the Kiyotaki and Wright (1989) model is tested. In this model money arises as a medium of exchange because of trading frictions existing in the economy. The framework is the following: there are equal numbers of three types of agents (type 1, 2, and 3); each of them produces a good that he does not want to consume (agents of type 1 want good *A* but produce good *B*, agents of type 2 want good *B* but produce good *C*, and agents of type 3 want good *C* but produce good *A*). In every period agents are randomly paired and have to decide whether to trade their good or to keep it, entering in the next period with the same good. In this case they have to pay a storage cost, which is different across goods (in particular, $C_A < C_B < C_C$). In case of trading, the agent will consume that good at the beginning of the next period, receiving the related utility, and produce the next good. Individuals are infinitely lived. Individual payoffs are equal to the utility derived from the good held at the end of the period (therefore only if coincides with the type, otherwise is equal to zero) minus the incurred storage cost. In the experiment there is not a double coincidence of wants, and some agents have to act as a middleman, buying a good that they do not want to consume in hope of forming a double coincidence in the future. Thus, at least

one commodity has to emerge as a medium of exchange. Two pure strategy equilibria can arise: a “fundamental” equilibrium where agents always prefer lower storage cost good to one with higher storage cost. Agents only buy a good if it has a lower storage cost than the one they are currently storing. The decision is made considering the only the fundamental factor of storage costs. This equilibrium is characterized by type 1 and 3 never trading for any good other than their own consumption good. The type 2 agents trade with type 3 for good *A* and then trade it with type 3 for good *B*. Good *A* is the medium of exchange because of its low storage cost. The other equilibrium is “speculative” and occurs when the storage cost of good *C* is not “that much” higher than the cost of storing good *B*. Doing this, the agent expects that incurring in a higher storage cost will reduce the waiting time before trading this consumption good. Besides the previous medium of exchange, another one emerges (good *C*): type 1 trades with type 2 for good *C* in order to exchange it with type 3 for good *A*. The parameterization of the model induces the existence of one or two equilibria.

The main reason to run experiments on this model is that it is interested only in the equilibrium predictions, it is silent on the path towards this equilibrium. Brown (1996) implements an experimental version of the model that has speculative equilibria only. Subjects are randomly assigned their types with the respective production abilities and consumption needs. At the beginning of each period players are randomly assigned a trading partner and have the opportunity to exchange their goods according to their decisions, which are taken before being paired. Decisions consistent with the speculative strategy are taken by type 2 and 3 subjects in 99% of cases (but for them the two strategies are identical), and in roughly 30% of cases by type 1. This subject-type appears to follow a pure rather than a mixed strategy, especially when they gain experience. These choices are fairly consistent with profit maximization given that only 4 out of 36 players would have earned higher incomes using the speculative strategy subject to their partners’ choices. However, the

average income was only 80% of the income resulting from the speculative strategy. This effect was mainly due to individual parameters. Furthermore, average losses tended to increase over time. Overall results support the idea that subjects trade for goods that do not give them immediate utility, but the support to the speculative strategy is mixed given the failure of type 1 players to implement it.

Duffy and Ochs (1999) improve on Brown's experiment in three ways in order to stay closer to the Kiyotaki-Wright environment. Firstly, they induce risk-neutrality paying subjects according to a binary lottery. Secondly, an infinite horizon environment with a discount factor is implemented (at the end of each round there is a 10% probability of stopping the game). Thirdly, the common knowledge assumption is operationalized, informing subjects of the historical average proportions of goods held by each player type in the population. The last two changes are meant to improve coordination in the speculative strategies.⁹ However, these modifications had little impact on behavior. Subjects showed a tendency to play fundamental strategies regardless of treatment conditions. They looked more motivated by past payoff experience than by marketability considerations that the theory emphasizes.

3.3 Dynamic inconsistency of monetary policy

A new area of research is concerned with reputational models of monetary policy. They show that when the policy maker cannot commit to an inflation policy, optimal equilibria (Ramsey) are time-inconsistent, while sub-optimal ones (Nash) are time-consistent (Kydland and Prescott, 1977; Barro and Gordon, 1983). Therefore there is an inflation bias, and a large number of outcomes are possible among these two in repeated games. Arifovic and Sargent (2003) provide an experimental framework that links expectations and decisions made by

⁹ On the same issue see also Duffy (2001) and Duffy and Ochs (2002).

policy makers and the public through a Phillips Curve that relates actual and expected inflation with unemployment, in a world where monetary policy authorities have an incomplete ability to set the inflation rate.

A group of $N + 1$ subjects make up the economy. N forms the public (typically 5 subjects); they have to forecast the inflation rate for each period of the experiment. Call agent i 's forecast x'_{it} and let x'_t be the average of the citizens' forecasts. Citizens receive payoffs that rise as their session-average squared forecast errors fall. Agent i 's payoff at the end of time period t is given by $-0.5(y_t - x'_{i,t})^2$, where y_t is the rate of inflation in the economy. One agent is the policy maker. In each period he sets a target inflation rate, x_t , then a random number generator sets v_{2t} and the actual inflation rate equals $y_t = x_t + v_{2t}$.¹⁰ Unemployment is then generated by the Phillips curve: $u_t = u^* - (y_t - x'_t) + v_{2t}$, where u^* is the *natural rate of unemployment* which prevails in the economy if the actual rate of inflation is equal to average forecasted inflation rate. Agent $N + 1$'s payoff is given by $-0.5(u_t^2 + y_t^2)$. A random stopping rule is used to implement an infinite horizon: at the end of each period, the computer program draw a random number from a uniform distribution over $(0,1)$. If this random number was less than 0.98, the session would continue for one more period, otherwise the session would be terminated. An upper bound on the duration of a session is set at 100 time periods, but students were not informed about this. Each subject received a fixed \$10 payment. They could also earn a prize of an additional \$10, according to a variation of the Roth and Malouf (1979) binary lottery to control for risk attitude. The

¹⁰ This information is given to subjects: "the shock is normally distributed and has the mean value equal to 0 and the standard deviation equal to 0.3. This means that approximately 68% of the values of the shock will be between -0.3 and 0.3. In addition, approximately 95% of the values will be between -0.6 and 0.6. Almost all the values, 99.7%, will be between -0.9 and 0.9".

probability of winning the prize is then calculated in the following way: $1 - (\text{maxpoints} - \text{totalpoints})/\text{maxpoints}$.

Subjects demonstrate a remarkable attitude in forecasting actual inflation. Figure 3 shows forecasted (dotted) and actual inflation (solid) in one of the experimental economies. On the horizontal axis periods are reported, while the vertical axis reports the inflation rates. In nine out of twelve experiments the outcome is close to the Ramsey equilibrium, although four economies experience backsliding to the non-optimal equilibrium after having achieved the optimal one. Transitions from Nash to Ramsey equilibria are slow and do not cause dramatic increases in unemployment. On average, inflation estimates by the public are good and do not contain systematic errors. Individuals put more weight on the recent past when forming expectations concerning the inflation rate. The policy prescription from this experiment on containing inflation is the “just do it” proposition: once an independent central bank has been set up, it is likely that it will be able to curb inflation to the low equilibrium. The monetary authority is able to manipulate the expectations of the public with its actions and to coordinate them to the optimal equilibrium.

[Figure 3]

3.4 Money illusion

Fehr and Tyran (2001) consider a source of non-neutrality of money that has been overlooked, and in fact is not considered in standard analysis of business cycles: money illusion. It is defined as a violation of the homogeneity postulate, i.e. supply and demand functions are homogeneous of degree zero in all nominal prices, so they only depend on relative and not on absolute prices. The typical first-year textbook example is that when prices and income double, the optimal choice is unchanged. Fehr and Tyran consider an n -player pricing game with strategic complementarity and a unique equilibrium. There are two

types of players: x -type chooses lower prices with respect to y -type. After T periods a fully anticipated negative shock on money supply occurs and the game continues for other T periods. Subjects are endowed with payoff matrices that are changed after the shock hits the economy. To see whether an exogenous and fully anticipated monetary shock creates money illusion, the experiment should be framed in nominal and real terms. However, there are two ways in which individuals can make this kind of mistake. A direct way is that the individual decision-maker is unable to fully adjust for the shock. An indirect way occurs when the decision-maker understands that his optimal choice should not change, but believes that other agents are unable to completely adjust, therefore he can change his choice to take advantage of this situation. To cope with these two sources and disentangle their effects, there are two different treatments. In the first, all subjects are human and therefore both sources are possible and may reinforce themselves, in particular the coordination problem based on expectations about other players' behavior is in place. In the second treatment $n - 1$ players are computerized, and the human agent knows that they only play optimal responses, so there is no coordination problem. Effectively, the experiment consists of the combination of four conditions: computerized/human opponents with payoff in real/nominal terms.

Results show the relevance of money illusion in explaining nominal inertia. As Figure 4 represents the average price before and after the shock for the four conditions of the experiment. The human/nominal treatment (thick solid line) clearly shows sizable price inertia, with the average price that adjusts slowly to the new equilibrium level. In the other treatments inertia is much lower. In the computerized/real treatment (small dotted line) subjects instantaneously adjusted to the post shock equilibrium, nominal inertia was completely absent. The human/real treatment (thin solid line) shows an initial amount of nominal inertia that leads prices above the equilibrium, but it vanishes quickly, bringing prices quite close to the equilibrium. The computerized/nominal treatment (large dotted line)

lays closely the last two. Which is the main cause of money illusion: individual myopia or coordination failure? The answer to this question can be given by looking at the relative pattern of pairs of treatments. The human/real and computerized/real treatments show a remarkable difference, and given that both treatments are in the real frame, their discrepancy can be attributed to the coordination problem in the setting with human subjects. The Computerized/real and computerized/nominal environments share a much similar pattern. In this case the coordination problem does not play any role (being both treatments with virtual counterparts), and the money illusion is only be credited to the individual level, and appears small. Taken together the results of these experiments suggest that the individual money illusion plays a small role in explaining nominal inertia, and that the coordination problem exacerbates its relevance. Furthermore, a human treatment in the real and nominal frame with a positive monetary shock is run. It shows that price stickiness is much lower, perhaps bringing evidence to the Keynes' idea that price flexibility is asymmetric: it works mainly upwards.

[Figure 4]

3.5 Growth experiments

A new research topic is represented by experimental research on economic growth models. The idea of these experiments is not to replicate any real economy, but to compare the numerical predictions of the models with the observed data. Lei and Noussair (2002) analyze the exogenous optimal growth model based on Cass (1965) and Koopmans (1965), in which the level of investment is endogenized in an economy where a representative agent makes optimal consumption and investment decisions over time for a given technology. If production and utility functions are concave, there is a unique optimal steady-state level of consumption and capital stock.

Two main different treatments are implemented. In the *social planner* treatment, each agent represents a single economy, which has to choose between consumption today and investment for future consumption in the future. There is no trading between these individual economies. This treatment is closer to the literal formulation of the model. Two cases are considered: the low and high endowment, that is situations in which the endowment is lower or higher than the equilibrium level of capital. The model predicts that in the first case convergence occurs from below, whilst in the second it is achieved from above. In the *market treatment* each economy includes five heterogeneous agents that are allowed to trade their capital good through a double auction. This treatment has been added because of the properties of this market institution to achieve efficiency. Each agent has his own production function and an individual utility function, which indicates the number of experimental currency units the agent can get when he consumes the good. The overall amount of experimental money is converted into dollars at a given exchange rate at the end of the experiment. The individual and aggregate production and the utility functions are concave. In each period a market for capital takes place: agents can make ask or bids for multiple units of capital at a named per-unit price. At any time buyers or sellers may accept offers made by another agent, or a part of an offer. To achieve aggregate efficiency capital must go from low- to high-productivity agents. To allow trading, each agent has an endowment of capital and another endowment of money that decreases as long as units of capital are bought, and increases when they are sold. The infinite horizon of the model is obtained imposing a 10% probability at the end of each period to stop playing.

Using the linear regression method outlined in the previous Section, in both treatments consumption, capital stock, the price of capital and the realized levels of consumption converge to the optimal steady-state levels predicted by the theory, after a few initial periods. Convergence to the equilibrium is faster and stronger under the market

treatment than in the social planner treatment, showing that the price mechanism helps agents at making intertemporal choices. There are no significant differences between the low- and high- endowment treatments both in the market and in the social planner experiments.¹¹

Lei and Noussair (2003) build an economy with two Pareto-rankable locally stable equilibria and find that without specific reasons the economy may end up in the lower equilibrium, which they interpret as a poverty trap. This occurs more likely under the low endowment treatment, and affects both the market and the central planner environments. This experiment opens the way to future investigations on which institutions and policies may help agents to coordinate to the Pareto-superior equilibrium.

3.6 Search models

In labour economics models of search have a strong impact on the macroeconomic equilibrium. In markets with heterogeneous workers and jobs, firms and workers meet in decentralized one-to-one markets in a costly process of matching idiosyncratic preferences, skills and needs. Among others, Diamond (1982) characterize this environment. Abrams et al. (2000) analyze search behaviour in the market.¹² In the experiment a buyer can buy only one unit per trading period, and the buyer's valuation for this unit is common knowledge. A

¹¹ Noussair and Metheny (2000) analyze a dynamic optimization problem that is similar to the one presented in this growth experiment. Subjects have to choose over consumption and investment. They consider different treatments: a fast ($f^F(k_t) = 25.23k_t^2$) and slow ($f^S(k_t) = 0.884k_t^9$) production function; a high and low capital endowment, and a fixed or random ending rule. They find that overinvestment relative to the optimum occurs under the fast treatment whereas underinvestment under the low treatment. Investment suboptimality does not depend on the initial endowment of capital stock, nor the termination rule. Sudden episodes of maximal consumption called *binges*, which are always suboptimal, are widely observed.

¹² See Davis and Holt (1993) for a survey of experiments on individual search.

seller can sell any number of units in a trading period at zero cost. In each trading period, sellers post prices and buyers are initially matched with sellers. Buyers can then buy from a seller with whom they are initially matched, or can choose not to buy and search for another seller. This setup resembles a posted offer market, except that buyers do not observe all posted prices, but only see the prices of the sellers with whom they are matched. In sessions involving the “Diamond” treatment, buyers are matched with one seller at a time. Under this treatment, sellers are predicted to post a price equal to the buyers’ valuation and buyers are predicted to accept the initial price. This implies that sellers in the Diamond treatment appropriate the entire surplus, and there is no search. In the “Bertrand” treatment buyers are matched with two sellers at a time. Here, the theoretical prediction is that sellers post zero prices, which buyers accept, and again there is no search. Thus, in theory, simply allowing two quotes per search, rather than one, enables buyers to get the entire surplus. The experiment also involves treatments with “high” and “low” transaction costs.

Results show that transaction prices in the Diamond treatment differ substantially from the equilibrium prediction. Transaction prices offer close to an equal division of the surplus. For the Bertrand treatment, there is also a divergence between observed and predicted prices. Nevertheless, observed transaction prices in the Bertrand treatment are significantly lower than in the Diamond treatment. These findings hold for either search cost.

4. Conclusions

In this paper we have extensively reviewed the applications of the experimental method to macroeconomics. Although it is based on a relatively limited number of papers, with respect to other more established fields in experimental economics, experimental macroeconomics covers a large number of macroeconomic issues and it is characterized by an increasing number of papers.

About ten years ago Friedman and Sunder (1994) wished that “perhaps macroeconomics too, like meteorology and astronomy, will become an indirectly experimental science, one that relies on experimentally verified results in constructing his central theories, although the central theories themselves are not amenable to direct experimentation.” We think that the works discussed in this paper show that ten years later macroeconomics has become a field in which experimentation is viable and able to offer specific insights. However, to some extent their hope has not been fulfilled: although experiments are able to test specific theories, the results of these experiments have not brought new ideas and hypotheses in the making of macro models. Several factors may underlie these circumstances. First, experimental macroeconomics has not yet reached a critical mass that makes it a reliable source of inspiration for macroeconomic modelers. Second, most of the experimental work surveyed here offers a substantial confirmation of the theoretical models, therefore, apparently there is no need to build new models based on experimental results. Third, the feedback from experiments to theory - even in a success field such as microeconomics - has proven to be difficult: for example, poor experimental evidence of the expected utility model has not been matched by a new convincing model of decision under uncertainty that has been able to take over the incumbent.

An interesting area for future work is the use of laboratory experiments for policy experiments, as it has already been done in designing markets for regulated sectors (e.g., water and electricity) and for comparing auctions rules (see the design of auctions for allocating the spectrum between mobile phone companies). In some sense we are all unintentional subjects of real world macroeconomic experiments that may cause economic disasters because of their unforeseen consequences (for example on work incentives, or on the price level). The experiment of Riedl and van Winden (2001) designed to advise the Dutch government on taxation (the so-called van Elswijk plan) opens the way to explore in

the lab the effects of alternative policies and to have an approximation of their possible effects.

What do macroeconomists learn from these experiments? Is there a need for experimental macroeconomics? Some issues on microfoundation are probably satisfactorily dealt by microeconomics experiments? For example, weaknesses in backward induction are shown in several papers¹³ and macroeconomists do not have to “reinvent the wheel” to reproduce these results. Rather, macroeconomists should learn from this experimental literature when laying the foundations of their models. To some extent this view is held by Akerlof (2002) in his Nobel lecture. He argues that reciprocity, fairness, identity, money illusion, loss aversion, herding, and procrastination are behavioral reasons that help to explain departures from the general equilibrium model. He advocates for a “behavioral macroeconomics” that builds on them. Although some of these issues come from the experimental literature, he does not make any reference to the experiments reviewed in this paper. However, we believe that this is only a part of the complete picture. In some topics (e.g., coordination failure that we have encountered a few times in this review) the contribution of experimental economics has been substantial, and in many issues reviewed in this paper the test of a specific theory involves much more than the test of a specific microeconomic assumption. To this extent, the body of results consistent with the neoclassical general equilibrium model (for example, Section 2) appear to tell us that even if we assume that there are departures from the standard microeconomic assumptions (bounded rationality, frictions, etc.) the system of interacting decentralized markets allows agents to extract most of the gains from trade. Moreover, all the experiments describing the path towards equilibrium are *per se* important and say something on which theoretical

¹³ See Roth (1995b) for a survey.

macroeconomics is often silent, as models of equilibrium selections. We believe that these are among the most important reasons to build an experimental macroeconomics.

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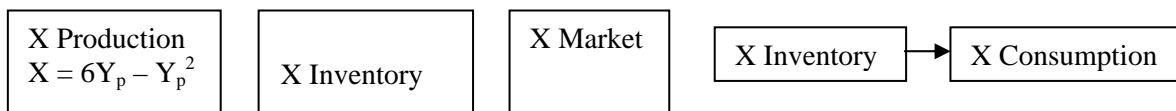
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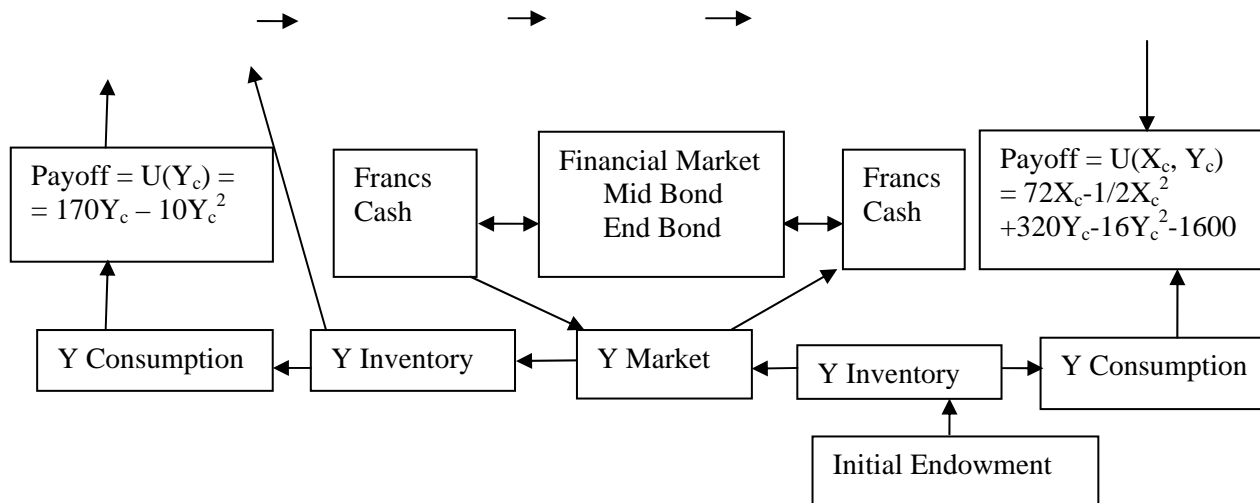


Figure 1 – Circular flow of the economy
Source: Lian and Plott (1998)

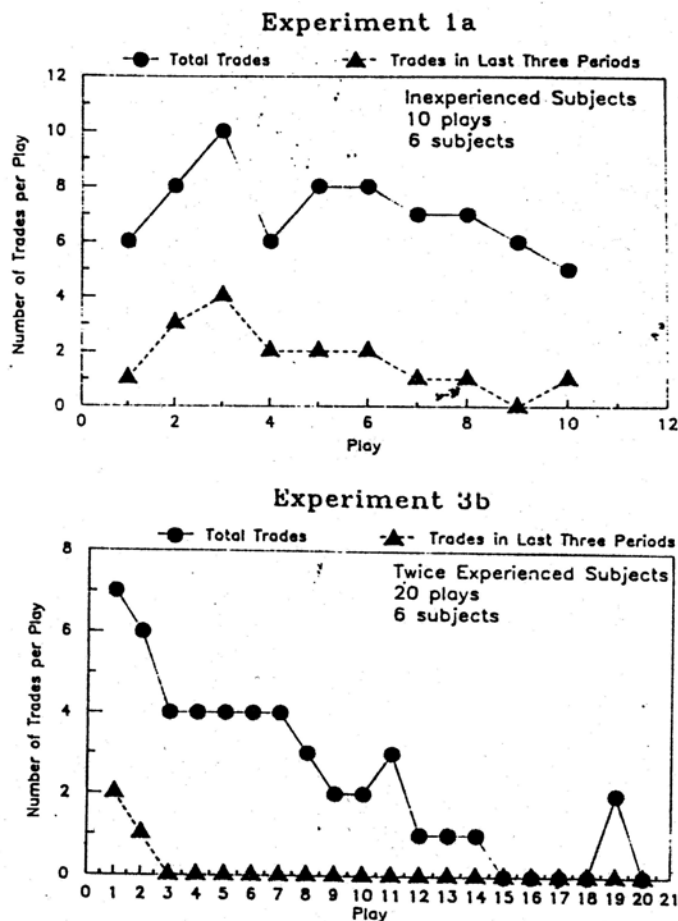


Figure 2 – Trades: experienced and inexperienced subjects.
Source: McCabe (1989)

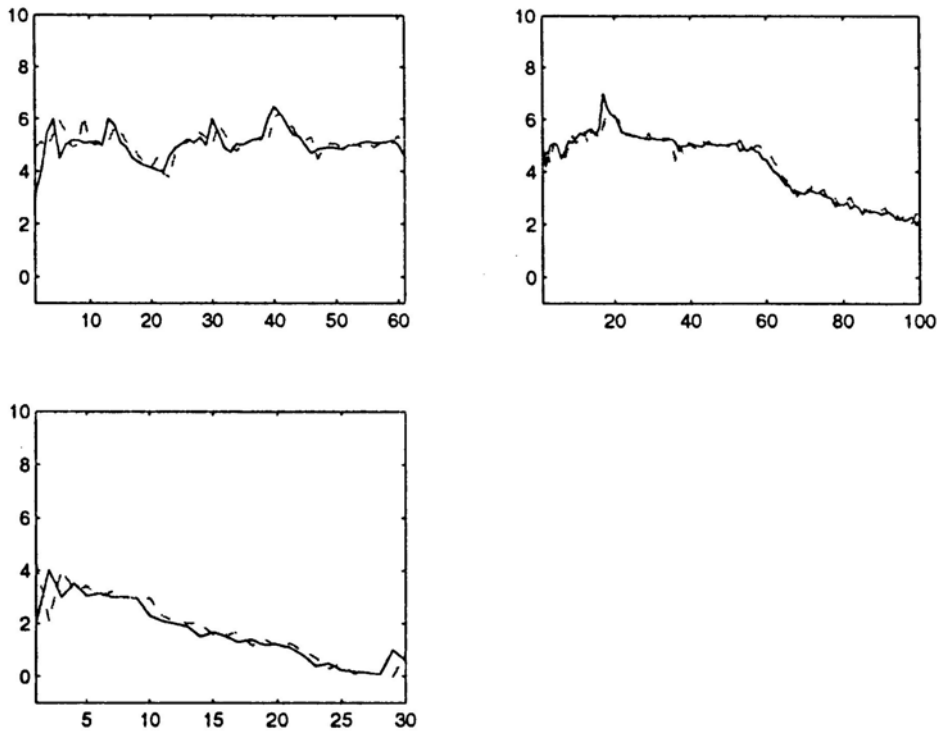


Figure 3 – Inflation forecast (dotted) vs. actual inflation (solid) in economy 1.
Source: Arifovic and Sargent (2003)

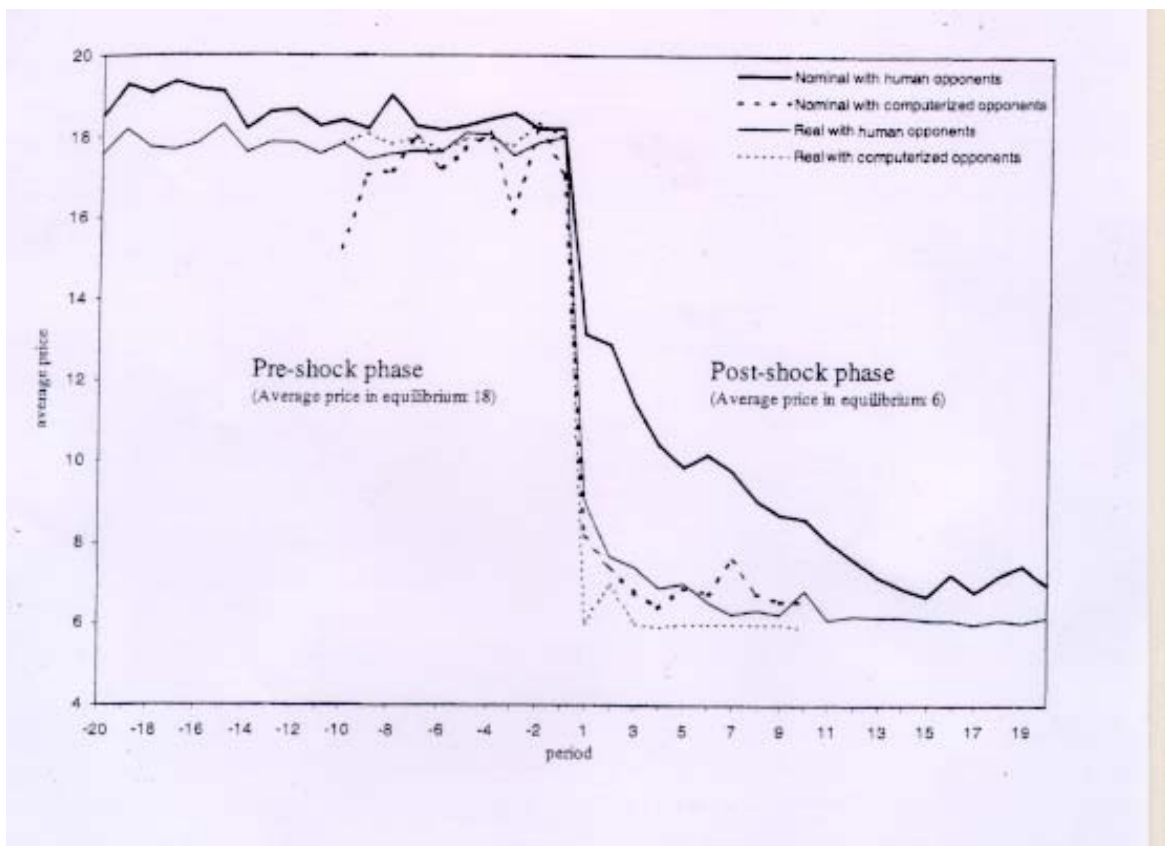


Figure 4 – Evolution of average prices.
Source: Fehr and Tyran (2001)