Experimental macroeconomics

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1. Introduction

When you examine modern handbooks of experimental economics (Hey, 1991; Davis and Holt, 1993; Kagel and Roth, 1995) experiments in macroeconomics are almost completely absent. Only Kagel and Roth (1995) have included a chapter on coordination problems where attention is given to macroeconomic coordination in an overlapping generations context (Ochs, 1995). Why is the experimental method becoming more and more popular in game theory and microeconomics, and remains it almost absent in macroeconomics?

The complexity of macroeconomic coordination may be the answer to this question. Traditionally, experimental economics focuses on relatively basic theories in simple environments with clear predictions. For this reason expected utility theory, auction markets, bargaining theory and prisoner's dilemma's are very popular for experiments. In most experiments the focus is on testing equilibria.

Macroeconomics studies the economy as a whole. Because the markets in an economy are interdependent, the ceteris paribus condition used in microeconomics can not be applied automatically in macroeconomics. For example, a decrease in employment influences labour income and therefore the demand for consumer goods. The decrease in the demand for consumer goods may influence the demand for investment goods. And the demand for consumer and investment goods determines national income and national employment. This type of circular flow interdependency explains part of the fundamental complexity of macroeconomic theory.

Another part, at least as important, is the irreversibility of investment decisions. "It is by reason of the existence of durable equipment that the economic future is linked to the present. It is, therefore, consonant with, and agreeable to, our broad principles of thought, that the expectation of the future should affect the present through the demand price for durable equipment." (Keynes, 1936, p 146). The existence of credit money makes the problem worse because this creates the opportunity to invest more or to invest less than has been saved. This adds to the complexity of the macroeconomic coordination problem because through credits the current amount of demand may be higher or lower than its long-term equilibrium value.

The combination of circular flow interdependency, the existence of credit money and irreversible investment implies an important role for expectations in the macroeconomic adjustment process. For example, when most investors are pessimistic about future sales, they don't invest much, so aggregate demand will be low and so from hindsight their pessimism is corroborated. But when most would have been optimistic, also this optimism would have been corroborated. It implies that adjustment processes towards equilibrium in one market have consequences for other markets that in their turn may disturb the adjustment process in the original market. The focus of attention in this paper will be on the design of laboratory world that includes these fundamental macroeconomic complexities.

The small amount of experiments that are relevant for macroeconomic theory neglect the interdependencies between the markets for labour, credit, consumer goods and investment goods, and describe economic reality as if the ceteris paribus condition holds. This is consistent with a lot of modern macroeconomic theory. For example, macroeconomic unemployment can be explained as a consequence of inflexibilities in the labour market. Because this type of macroeconomic theory has the same level of complexity as microeconomic theory it is not surprising that most of current experimental research in macroeconomics focuses on this type of theory. Another part focuses on general equilibrium theory by abstracting from the coordination problems that are introduced by money and irreversibility of investment (section 2).

Despite its difficulties in this paper we try to design a macroeconomic laboratory that includes macroeconomic interdependencies, credit and irreversibilities. The purpose of such a laboratory is to investigate how human actors make decisions in such an environment. Such a macroeconomic laboratory requires a very careful design. The macroeconomic laboratory is modelled as a game where the players are the firms (section 3). An experiment with human players shows that the Keynesian type of disequilibrium can emerge in such an environment and illustrates some of the basic dynamic features of the developed laboratory world (section 4).

Experiments with human subjects have as a purpose to investigate human behaviour interacting with its environment. In order to separate the human aspects from the dynamic aspects of the experimental world, you need to investigate the dynamics of the experimental world before you can interpret the results with human players correctly. Therefore, the rest of this paper focuses on computer simulations with the game. In section 5 a set of computer routines for the decisions of the players is developed, while section 6 uses those computer routines to investigate the influence of the focus of firms on the macroeconomic labour market on the performance of the firms and the stability of the economy. In section 7 we will conclude that experiments with human subjects in a macroeconomic system can be useful, but that it requires a long process of development before the use of human subjects adds something to the simulation results.

2. A survey of experimental macroeconomics

2.1 Introduction

The purpose of most experiments in economics is to test theories and to generate new hypotheses. The advantage of laboratory experiments compared with real world experiments is the ability to control many variables and the ability to replicate the experiments in almost identical conditions. Experiments with human subjects fit in a range of research starting from theoretical analysis, aggregate simulation, disaggregate simulation, laboratory experiments with human decisions makers till real world investigations. In this section it will be shown how recent research related to macroeconomic theories combines laboratory experiments with other research methods.

As already mentioned, experiments in macroeconomics are exceptional. Nevertheless, there are some experiments that are relevant for macroeconomic theory. We will discuss them in this section. Sometimes ordinary computer simulations are referred to as experiments. For example, Kydland and Prescott (1994) define an economic experiment as: "the act of placing people in an environment desired by the experimenter, who then records the time paths of their economic behaviour". They assume that

"performing experiments that use actual people at the level of national economies is obviously not practical". Therefore they suggest to construct a model economy where the behaviour of the model's people is simulated by the computer. They illustrate the method by neoclassical business cycle models. Technology, stochastic technology change functions, budget restrictions and utility functions define the model. The coefficients are determined by calibration instead of econometric estimation procedures. They are set in order to investigate some specific questions. For example, they first simulate with only technology shocks, then vary on changing hours per worker or employment with the business cycle, investigate monetary shocks, and compare the results with the behaviour of real world business cycles. Those simulations help to investigate the characteristics of the models, and avoid the necessity to find analytical solutions of complex stochastic models.

The Kydland-Prescott (1994) approach is basically macroeconomic simulation. It forces equilibrium on the markets, and does not investigate the problem of the coordination of independent decision makers in an uncertain world. Furthermore, there is no guarantee at all that the results are consistent with human decision making capabilities. Therefore, in this section we restrict ourselves to experiments where microeconomic decision making is simulated in a macroeconomic context and where the experiments can at least potentially be performed by human actors.

2.2 Inflation and business cycles

Perhaps the best-known experiments in macroeconomics are those of Marimon and Sunder (See Ochs, 1995 and Sargent, 1993 for a summary of this type of work). They focus on equilibrium selection in an overlapping generations framework. Marimon and Sunder (1993) assume that people live two periods in which they try to maximize lifetime utility that depends on consumption in the two periods they live. Saving is the main decision variable. When members of the young generation save, they exchange money for consumption goods. The value of money in the current period depends on the exchange rate between money and goods in the next period, i.e. the inflation rate. There are two equilibrium inflation rates in this model. Disaggregated simulation with the model shows that the Pareto-optimal low inflation rate is stable with adaptive expectations, while the high inflation rate is stable with rational expectations. This implies that the result depends on human behaviour. In order to test this behaviour experiments are conducted with human subjects. The experiments with human subjects show a tendency towards the adaptive expectations equilibrium and not the rational expectations equilibrium. Therefore, the experiments with human players differentiate between two internally consistent hypotheses that are generated by computer simulation.

Arifovic (1993) performed a comparable experiment with two currencies (See Sargent, 1993). Apart from saving the players had to decide about the allocation of their savings over the two currencies. Neither the adaptive expectations model nor the rational expectations model fitted well to the data generated in this experiment. Therefore, Arifovic developed a genetic algorithm to simulate the decisions of the subjects. According to this algorithm players repeat the decisions (combinations of saving rates and portfolio allocations) that generate the highest ex post utility. This genetic algorithm fitted the data generated by human players better than the adaptive and rational expectation routines. But it generated more volatility than in the experiments with human subjects. Arifovic suggests a certain extent of external validity of the experiment by comparing the volatility of the experimental exchange rates with those between real world hard currency countries. This study shows beautifully how analysis, simulation with computer decision makers, experiments with human subjects and "real" world empirical analysis can be combined.

A quite different approach to macroeconomics is the Lucas 'islands' model of the business cycle. According to the 'islands' model each supplier gets immediately information about the local prices on its 'island', but does not know to what extent a change in the local price is an indication of an increase in demand or represents an increase in the general price level. Before the firm knows the market clearing output it has to decide about its own output. The market clearing output is a function of the real component of the observed local price. So, to the extent that inflationary increases in local prices are interpreted as increases in market clearing output there is a positive relation between inflation and national output. When there is more noise in the price signals (i.e. the inflation rate is less predictable) firms can be expected to be less sensitive to changes in local prices.

Langdana (1994) tries to test this theory experimentally. The players were asked to minimize the difference between production and sales. They determined their output after having heard the local price. They knew that the price consisted of a random and a structural component. After they made their production decision they were informed about the market clearing production level. The players had to minimize the difference between their output and the market clearing production level. During the experiment 120 prices were announced, grouped in sets of 30 prices with the same standard deviation of noise. In one experiment the noise increased, in the second it decreased.

Consistent with the Lucas 'islands' model, the experiment shows a positive correlation between output and prices. This correlation could not be exploited by a discretionary monetary policy because such a policy induced extra noise in the economy. When the monetary noise is increased during the experiment, the output-inflation tradeoff becomes less. Surprisingly, the effect did not hold when the monetary noise was decreased. It may be that players who don't expect to find much relevant information in prices have no incentive to search for structural components in the prices and therefore do not find the information. This is a new hypothesis generated by the experiment. Therefore, this experiment not only generates a test of hypotheses, but also generates a new hypothesis.

The Langdana experiment shows how a behavioural assumption (i.e. signal extraction out of prices) in a macroeconomic theory can be investigated by experiments with human subjects. It is evident that the external validity of the results for monetary policy depends on the consistency of the structure of the Lucas' model with the "real" world. The experiment investigates only the consistency of the behavioural assumptions in the model with human behaviour.

2.3 *Unemployment and real wages*

In mainstream economics the inflexibility of wages is seen as an important cause of macroeconomic unemployment. Fehr, Kirchsteiger and Riedl (1992) investigate wage setting and unemployment in an experimental efficiency wage market (see also Fehr/Gächter in this volume). Employers offer contracts in which wage, effort demand and a penalty at non-performance are specified. The suppliers decide on accepting the offer and determine their effort level. At non-performance of the supplier there is a 50% probability that it is detected and the penalty is effectuated.

The results of this experiment seem to be largely consistent with the shirking version of the efficiency wage hypothesis. Due to incomplete information shirking did not vanish in the long run. The probability of shirking depended negatively on (efficiency) wages and positively on effort demanded.

Also this experiment generates a new hypothesis; the emergence of equilibrium unemployment in the experiment cannot be explained by the shirking version of the efficiency wage hypothesis. This may be explained by introducing fairness considerations. This is a reason to investigate another explanation of efficiency wages, the fair wage hypothesis (Fehr, Kirchsteiger and Riedl, 1993). According to this hypothesis employees will work harder when they get a fair wage. As a consequence, it may be rewarding for employers to offer higher wages. In order to test this hypothesis experimentally a two-stage game has been designed. In the first stage employers did bid on a one-sided oral auction for employees. The employers did not know the identity of the employees. The employees were located in another room than the employers. At the second stage, workers had to choose their effort, anonymously. In contrast to the shirking experiment, their choice was completely unconstrained in the sense that there were no sanctions associated with it. Therefore, a utility maximizing worker would always choose the lowest effort. But in practice there was a clear relation between wage and effort. As a consequence, employers paid about 42 percent more than the opportunity cost of accepting a job by the worker. In summary, the results are consistent with the fairness-hypothesis of efficiency wages.

This set of experiments shows how hypotheses about the labour market that are relevant for macroeconomic theory can be tested systematically. But although those experiments are very relevant, they do not focus on macroeconomic coordination, but summarize macroeconomic theory as a one-market problem.

2.4 *General equilibrium theory*

While the theories discussed in sections 2.2 and 2.3 summarize the macroeconomic problem as a one-market problem, general equilibrium theory approaches the macroeconomic coordination problem as a multiple market problem. While general equilibrium theory assumes that equilibrium will be reached or at most shows that there exist algorithms that can generate an equilibrium, the purpose of experiments in general equilibrium theory is to investigate to what extent a multi-market system with human decision makers converges to general equilibrium.

Plott (1991) developed a computerized multiple unit double auction laboratory market system. This laboratory creates the opportunity to investigate general equilibrium theory. Goodfellow and Plott (1990) investigate the simultaneous determination of input and output prices. Lian and Plott (1993) did experiments on general equilibrium systems with fiat money and bonds. Noussair, Plott and Riezman (1993, 1995) used the same type of system to analyze exchange rate formation, factor prize equalization and patterns of trade and specialization. They created a system of countries where inputs can be bought from consumers, transformed into products, and sold to consumers on either the home market or a foreign market. In some of the experiments countries had different types of money and therefore an exchange rate became relevant.

The purpose of the experiments is to test hypotheses derived from general equilibrium international trade theory. Most of the qualitative results about the patterns of trade, production and specialization, the equalization of factor prices and the effects of trade tariffs on economic efficiency were corroborated by the experiments. Nevertheless, quantitative results about for example production levels, prices and export levels differ significantly from those predicted by theory. For example, in contrast to simple microeconomic theory experimental factor prices tend to be lower than marginal revenue product. This may be explained by uncertainty: the production of output involves risk. So, also these experiments generate new hypotheses about important factors that are not included in the model.

The experimental world is much more complex than the very stylized general equilibrium theories, but much simpler than the "real" world. Therefore, the experiments may help to investigate the applicability of the models in a world much simpler than the real world. If the models are not applicable to the stylized experimental world, you must doubt the usefulness of applying this type of model to the much more complex "real" world.

2.5 *Complex decision making and bargaining*

Investment and irreversibility explain part of the dynamic complexity of the macroeconomic system. Sterman (1989a) tries to investigate experimentally to what extent chaos can arise from the behaviour of actors in a macroeconomic system. He did experiments on decision making in a simple multiplier-accelerator economy. Subjects had to manage the investment goods industry of the economy. The production capacity of the investment goods sector depends on its capital stock. Demand for capital goods is determined by aggregate investment of which investment by the investment goods industry is a part. Production is the lesser of production capacity and desired production, where desired production is current demand for investment goods plus the supply line of unfilled orders. This supply line increases when demand is higher than production, and decreases when demand is lower than production. The player, who decides on investment in the investment good sector, has to minimize the absolute value of the difference between demand and capacity in the capital industry.

At the start of the experiment the economy is in equilibrium. After two periods demand for capital goods increases in the (exogenous) consumer industry. This disturbs equilibrium. An optimal dynamic path towards the new equilibrium can be determined. The experiment shows that subjects decide systematically a suboptimal adjustment path that generates an investment cycle, in contrast to the optimal path. Only 4 subjects (8%) achieved the new equilibrium before the end of the trial of 35 periods.

Sterman compares the experimental results with simulation results. He uses an anchoring and adjustment decision heuristic to describe the decisions of the subjects. This heuristic assumes that all depreciated machines have to be replaced, where corrections are made for the difference between desired and actual capital stock, and the length of the supply line of unfilled orders. When the orders react fast to the difference between desired and actual capital stock, the accelerator mechanism destabilizes the economy. The better a subject includes the supply line of unfilled orders in its decisions, the less over-investment will take place. A coefficient that is too high with respect to the supply line may compensate for a high investment accelerator coefficient.

Sterman estimates the two parameters for the heuristic on the time series generated by the players. He shows that for many subjects the supply line adjustment coefficients are very low. This implies chaotic behaviour when the accelerator parameter is positive. Sterman concludes that "it appears to be possible to quantify the decision making heuristics used by agents in such experiments and explain their performance well".

Sterman also suggests that the results represent "actual managerial decision making" in a "common and important setting". This is not very plausible, because no manager will include the consequences for aggregate demand in his investment decision. The result that most players do not use the backlog of unfilled orders in their decision implies that they do not

understand what they are doing; in the real world a manager will know about the supply line of orders and therefore will not make the type of mistakes found in the experiment. Therefore, although the experiment is very interesting, it is not about macroeconomics but about human capabilities for solving a dynamic stock management problem.

The ability to solve dynamic stock management problems is one element that may be relevant for macroeconomic dynamics. But the coordination problems between independent decision makers in such an environment may be more relevant. Sterman (1989b) does such an experiment where more players are involved, although without the macroeconomic rethorics. Therefore, this experiment is more a coordination problem than the multiplier-accelerator experiment. Despite this difference the qualitative results of the two experiments are about the same. This suggests that the results of the multiplier-accelerator experiment can be extended to a multiple player context. Nevertheless we have to be sceptical about the extent to which these experimental results are relevant for understanding "real world" decision making. Such experiments are a first attempt to show the problems delivery lags and stock adjustment problems have for stability.

Some experiments use a macroeconomic model to investigate the interaction between macroeconomic decision making (for example Tietz, 1988; Gremmen, 1989). Tietz (1988) uses a macroeconomic experimental game called "Kresko" to investigate macroeconomic problems such as collective bargaining and central bank decision making. The Kresko game includes a macroeconomic model and provides an opportunity to investigate central bargaining results on their efficiency with respect to growth. He concludes for example that games with students with better grades on macroeconomics generate more efficient economies. The game is an extension of the Sterman-type of experiment because it not only involves the solution of a dynamic problem but also includes a bargaining problem.

These experiments may be relevant to the extent that macroeconomics is seen as mainly a bargaining problem. Methodologically the Sterman type of experiment adds to the experimental research strategy of the other experiments a step of econometric estimation of the decision heuristics used in disaggregated computer simulations. Insight in decision heuristics may be helpful in developing macroeconomic theory, but in itself it does do not tackle the macroeconomic coordination problem.

2.6 *Attempts to investigate complex macroeconomic coordination*

A macroeconomic problem differs fundamentally from a microeconomic problem when interdependencies between the macroeconomic markets in combination with investment irreversibilities, credit and uncertainty are investigated. Fiedler (1979) did experiments in a macroeconomic game with 8 to 16 players that represent firms in the investment and consumer goods industry. The firms operate in a closed economy with exogenous labour supply. The game has been derived from a neoclassical two-sector equilibrium growth model of a closed economy. Half of the firms produce investment goods, the other half consumer goods. The players decide about supply and/or demand for investment goods, supply and/or demand for consumer goods, and labour demand. In making their demand or supply decisions, they have to provide reservation prices. The firms are asked to maximize long term profits. The computer calculates the decisions of the other sectors in the growth model: consumption, labour supply, government and the banking sector.

Traditional experimental economics predicts that because of its complexity this type of experiment can not lead to useful results. It is difficult to track causes because many variables and conditions change. This prediction is correct with respect to Fiedler's study. But in my view the failure is the consequence of limitations in the design of the game instead of a fundamental impossibility. A lot of artificial elements were build into the model, partly because of the limited number of rounds that could be played. For example, the consumer market is always equilibrated by computing a price at which demand equals supply. Market clearing on the investment good market is accomplished by asking the sellers to set a minimum price at which they are prepared to sell and the buyers a maximum price at which they are prepared to buy. This type of adjustment precludes the gradual adjustment process that is so characteristic for the real world. The game becomes more like a gambling game than a simulation of economic decision making in the real world. As a consequence of these problems the results of Fiedler are without theoretical meaning. Fiedler even does not try to analyze the causes of the difference between the equilibrium growth path and the growth path of the game economy. Just as in the macroeconomic experiment of Sterman the results tell more about mistakes of players than about more or less rational managerial decision making.

2.7 *Conclusion*

The purpose of the research described in this section was to test hypotheses and to generate new hypotheses that are relevant for macroeconomic theory. The general approach is that you start with a theory or hypothesis as a point of reference. Based on theoretical assumptions an experimental laboratory can be developed that is useful to test and explore these hypotheses. The design of such a world requires already a specification of the theory in such a manner that human actors can make decisions in it. In complex environments it is difficult to derive results analytically. Therefore, disaggregated simulation may be useful to explore the features of the model. Experiments with human decision makers come in when human behaviour becomes relevant. The experiments about saving in an overlapping generations model, and the experiments of Fehr et al about efficiency wages are good examples. The decision routines used by the players may be investigated by econometric research on the data generated by the experiments. Finally, the results of the experiments may be compared with real world features. The attempt of Arifovic(1993) to compare patterns in real world exchange rates with the experimental exchange rates is an example. These tests of external validity are only relevant if the theory pretends to tell something about real world phenomena. For example, abstract theories about macroeconomic coordination in a free market economy cannot be expected to describe real-world data of mixed economies.

Although the presented experiments are relevant for macroeconomic theory, they avoid the essence of macroeconomic coordination: irreversibility of investment, uncertainty, interdependence as a consequence of interrelations between markets, credit and money, disequilibrium. Although the reason for avoiding these problems is obvious, the problem is important enough to require further investigation. For this reason in the next section we will develop a laboratory for investigating a free market economy that includes circular flow relationships between markets, disequilibrium on markets, independent decision makers, credit and irreversible investment.

3. The design of a macroeconomic game as an experimental setting

From the last section follows that it is very difficult to design experiments that focus on the coordination of economic activities in a closed macroeconomic system. Complexity is the main problem. This explains why most experiments try to investigate very simple models. The macroeconomic models used in experiments avoid so many difficult problems that what remains is simple enough. But the challenge is to develop a manageable macroeconomic system that includes the complexities that Keynes introduced, i.e. uncertainty as a consequence of investment. In this section the general features of such a macroeconomic laboratory world will be discussed.

Keynes's attack on neoclassical economics was focused on the assumption that in a free market economy stability would emerge. This implies that Keynes and neoclassicals have different predictions about the behaviour of a free market economy without government. For this reason the design of the laboratory macroeconomic world will be focused on a free market economy without government, but including irreversible investment and credit.

Because one of the main problems in a macroeconomic game like Fiedler's is the artificial decision situation caused by the limited number of rounds, a first requirement for a laboratory game about macroeconomic coordination is that it behaves like a continuous process. Therefore, the length of the decision period has to be short. We have set it at a month. This implies that the simulation of 10 years requires 120 decision periods. In order to guarantee sufficient speed of information flows the game has to be played on a computer network.

When you like to do the experiment in about half a day, each month in the game is about one minute. Therefore, the number of decisions per period has to be minimized. In the development of the game the focus has been on the minimization of the number of decision variables on the assumption that all important decisions by the firms in a stylized but complete macroeconomic model are included. The firms decide about their output price, labour demand, wage rate, and the amount and type of machine they order. In first instance a one-sector game has been developed, so all firms supply the same product, while the demand for that product equals the sum of consumer demand and investment demand.

The point of reference in most macroeconomic theories is the general equilibrium growth path. Mainstream economics textbooks assume convergence to this equilibrium growth path in the long run. In attacking classical theory Keynes uses implicitly also the neoclassical equilibrium growth as a point of reference. Therefore, we used as a starting point for the derivation of the macroeconomic laboratory a simple neoclassical growth model that is disaggregated with respect to the firms. To include dynamics the assumption of equilibrium on all markets is replaced by specific market institutions that allow for disequilibrium. Instead of a double auction market as used in most general equilibrium experiments, firms set their price and wage. Aggregate demand is the sum of consumption and investment demand. Consumption is defined by a consumption function where nominal consumption depends on lagged nominal labour income and other income. Investment demand is directly related to the machine orders by the firms. Aggregate demand is distributed over the firms by a constant elasticity lagged demand distribution function. This implies that a price difference in a period has a small effect in the first month, but works cumulatively in the long run: in the short run the price elasticity of demand for an individual firm is small, but in the long run it approaches infinity.

Capital in the game has a putty-clay structure. Firms can buy machines at a price and delivery time set by the computer. The computer bases the delivery time on the backlog of ordered but not produced machines divided by the production capacity of the (fictive) machine industry. The machine price is derived from the output price and relative demand on the investment good market compared with that on the consumer market. When a firm orders machines it decides on the type of machine, defined by a Cobb-Douglas production function, by setting the labour intensity of production for the new machine. After a machine has been ordered, its type can not be changed. A machine has a fixed lifetime (i.e. 100 months).

Aggregate labour supply is exogenous to the system, while labour is distributed over the firms by a constant elasticity lagged supply distribution function, analogous to the distribution function of aggregate demand. Firms set their labour demand. The number of employees is the minimum of labour demand and labour supply. Production depends on labour demand and the size and composition of the machine park. A firm can not produce more than the production capacity of its machines. The computer allocates labour to the most efficient machines.

There are a number of restrictions in the game. First, although normally firms can borrow as much as they like on the credit market (they don't decide about it explicitly; it is done automatically when needed), they are rationed when their equity capital is not sufficient or investment is too big compared with current capacity or available labour. Second, there is an absolute minimum wage in the game, while wage and price setting of separate firms is also limited to maxima and minima in comparison with the average of last month. These restrictions are meant to prevent disturbances caused by very irrational decisions of some players.

In summary, firms have to decide about their price, wage, labour demand and investment. The firms have to maximize their long term profits. The environment of the firm depends to a large extent on the behaviour of the other players. Especially, the firms compete with each other on the labour market and the output market, while aggregate output demand depends to a large extent on investment. The laboratory economy is more an economy à la Malthus than a modern economy with labour unions, social security and active government interference. This excludes disturbances of the free competition mechanism as a consequence of interference of government or labour unions. Those complexities have to be introduced in a later phase of an experimental research strategy.

4. An example of an experiment

In order to get a grasp on the macroeconomic dynamics of the game, we will discuss one experiment with 20 firms, each firm managed by two or three first year economics students who played the game for the second time. The focus will be on macroeconomic dynamics. We will distinguish between cyclical and structural problems and focus on their interrelationship.

The structural situation of the game economy can be described by the difference between labour supply and the maximum amount of labour that can be used on the machines in the economy (i.e. labour capacity of machines). When labour supply is higher than labour capacity of machines there is structural unemployment; when labour supply is lower there is a structural shortage of labour.

The cyclical situation of the game economy can be perceived by comparing short term aggregate output supply and demand. Aggregate output supply is the maximum output that is possible with the current stock of machines and labour supply. Aggregate output demand is the sum of the demand for machines and the demand for consumer goods. When aggregate demand is lower than aggregate supply, there is a recession. When aggregate demand exceeds aggregate supply, there is a boom.

The structural condition of the labour market may influence the situation on the output market. For example, when there is a structural shortage of labour, some firms can employ more labour than is available. These firms may either reduce investment or invest in labour-saving technology. The first choice implies a decline in aggregate demand, and therefore may generate a recession. Structural unemployment has the opposite effect on investment and may induce a boom.

Till so far the analysis is consistent with neoclassical and Hayekian theory. Recessions are the consequence of errors in the past and are necessary for adjustment. But during the adjustment process Keynesian mechanisms may emerge. Because during a recession aggregate demand is lower than aggregate supply, firms may expect that the recession is a long term problem. These expectations may survive even after the structural shortage of labour has been solved. When most firms do not invest, aggregate demand is low and expanding firms may have problems in selling their output. Therefore, investment is low because aggregate demand is low, while aggregate demand is low because investment is low. A fiscal Keynesian policy can solve this dilemma. The purpose of the preliminary experiment in this section is to show that human decision makers in the game economy can generate a Keynesian recession.

In order to test this hypothesis, we do the experiment in the most simple version of the game that is possible: the game starts in a steady state general equilibrium with 0 growth on all markets. This implies that the growth rate of labour supply is 0. No exogenous disturbances are introduced. Therefore, all dynamic aspects of the game are caused by the behaviour of the players.

When the economy is in general equilibrium, labour demand equals labour supply (excluding friction unemployment) and production capacity on machines equals sales. The economy starts in such an equilibrium, but soon after its start the decisions of the players may generate major disequilibria. Let us first look at the output market (figure 1). During the first year the players invested a lot. As a consequence aggregate sales rose, stock declined and when stock approached 0, production restricted sales (1991-1992). Because the players had learned from the first game they played that a hausse may be followed by a severe recession, the players ceased their expansion investment before problems on the labour market became visible. Despite this effort, labour capacity on machines became higher than labour supply (figure 2). To adjust for these structural problems, firms decided to invest less than needed for replacement. This caused a recession. This recession was the consequence of over-investment during the first year, and therefore a correction for mistakes in the past: a classical recession.

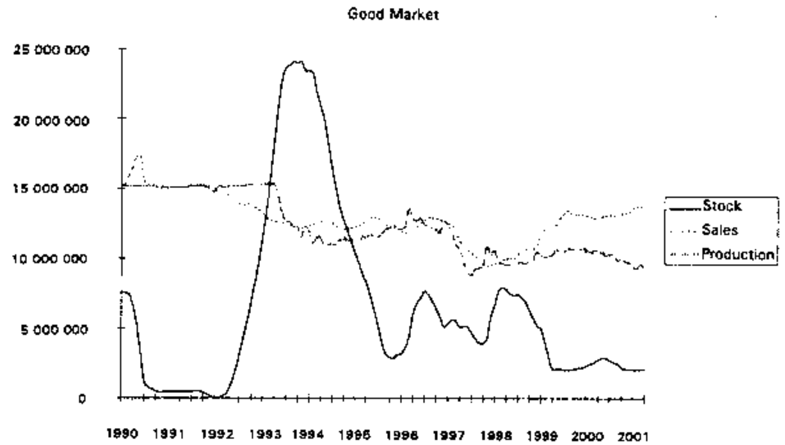

Figure 1: Stock, production and sales

Figure 2 shows that around September 1994 the structural shortage of labour had been solved. Despite this fact the recession continued. The cause was insufficient aggregate demand as a consequence of low investment. Therefore, this recession is Keynesian in character. The recession lasted till 1999 at which moment machines started to be used at full capacity. This induced further investment. Because of the long duration of the recession a long boom can be expected. But the game had been finished at this turning point.

It is evident that the dynamics of the economy can not be explained by rational expectations. The cause of the long duration of the recession is Keynesian: the recession continued even though prices were flexible and the interest rate was as low as possible. In other games we have experimented with Keynesian demand policies and they showed to be effective. Therefore, if the game economy is in a Keynesian recession an increase of government expenditures can stop the recession.

Figure 2: Labour demand, supply and capacity

This experiment shows that a Keynesian recession is possible in a world that is also consistent with neoclassical theory. But it does not prove the empirical relevance of Keynesian theory. It is obvious that this game had the same type of problem as many other macroeconomic experiments have (for example Sterman, 1989, Tietz, 1988 and Fiedler, 1979): the players made mistakes that you cannot expect to happen in the real world (for example the stock of some players rose to very high levels in the beginning of the recession). Therefore, it is possible that at least part of the dynamics of the game is caused by the lack of experience of the players. It may be that managers in the real world are focused on other characteristics of the firm and the economy than the players were.

Although the possibility of a Keynesian disequilibrium in the game economy could have been proved easily by computer simulation alone, the experiment with human actors shows that also intelligent human subjects can generate the effect. Further experiments of this type are not very useful as long as the characteristics of the laboratory economy are not understood better. One line of research may focus on the extent to which selection of players with better results stabilizes the economy. Computer simulation will do this job better than experiments with human subjects because they can be manipulated better. Just as in the experiments by Marimon and Sunder (1993) computer simulation may generate useful points of reference for experiments with human players. The rest of this paper focuses on simulation experiments with the laboratory macroeconomic world.

5. Decision routines

The experiment discussed in section 4 showed that Keynesian recessions are possible. One of the explanations of this type of recession may be a lack of experience of the players. In order to investigate the behaviour of the economy when firms don't make very stupid mistakes decision routines for the firms will be developed in this section. It seems plausible that stability is related to the extent to which firms recognize the macroeconomic situation of the economy in their decisions. Because the macroeconomic situation is especially relevant for the investment decision, investment will be modelled more carefully than the other decisions.

Because it is very difficult to develop decision heuristics in a complex environment like the macroeconomic game from mathematical optimisation theory and because of the doubtful benefits of analytically derived decision routines compared with more or less ad hoc decision routines, we don't try to derive decision routines from mathematical optimisation theory. We just develop reasonable decision routines that are as simple as possible. For each decision variable we will define one or more decision rules, where the first decision rule is performed first and the result is substituted by the next one when the condition mentioned in the second rule is fulfilled. This creates a very flexible structure.

Price policy

In first instance a firm sets its price at the average price corrected for inflation of the last month. When demand is higher than production capacity the firm sets a higher price:

$$P_j = P_{-1} * (P_{-1}/P_{-2}) * (Y_{j,-1}/Q^{cap}_{j,-1})^a$$

where P_j is the price of firm j, P_{-1} the national price of the period before, Y is national sales, Q^{cap} is production capacity and a is a coefficient[1]. This rule would imply that when demand is very high and stock is 0, the firm will set a price equal to the expected average price. In order to compensate for this effect, price is set a fixed factor b higher than the average price when stock is 0:

$$\text{When } St_j = 0 \text{ then } P_j = P_{-1} * (P_{-1}/P_{-2}) * b$$

where St_j is the stock of firm j and b is a coefficient.

When aggregate stock is 0, demand will be very inelastic. Therefore, it is optimal to set price at its maximum:

$$\text{When } St = 0 \text{ then } P_j = P^{max}$$

When price is lower than variable cost it will be more efficient to fire people than to set a lower price. Therefore, each firm requires a minimum profit margin z on its variable cost:

$$\text{When } P_j < (1+z) * P_j^{varcost} \text{ then } P_j = (1+z) * P_j^{varcost}$$

Wage policy

In first instance a firm sets its wage at the average wage corrected for inflation of the last month. When the firm has vacancies it will set a higher wage, when the firm wants to fire employees the wage can be lower:

$$W_j = W_{-1} * (W_{-1}/W_{-2}) * (L^d_{j,-1}/L_{j,-1})^c$$

where W_j is the wage rate set by firm j, L^d_j labour demand, L_j the number of employees and c is a coefficient. When unemployment is higher than e, the firm can set the lowest wage that is allowed for:

$$\text{When } U > e \text{ then } W_j = W^{min}$$

where U represents the unemployment rate.

Finally, the firm adjusts its wage downwards when variable cost becomes lower than price:

$$\text{When } W_j > \frac{Q_j^{cap}}{L_j^{cap}} \frac{P}{1+z} \text{ then } W_j = \frac{Q_j^{cap}}{L_j^{cap}} \frac{P}{1+z}$$

where L_j^{cap} is the number of employees at full capacity use of machines and z is the minimum profit margin on variable cost.

1 All variables are for period t, except for variables with an index -1 or -2 that indicate period t-1 respectively t-2. All variables are for the national economy except for variables with an index j, indicating a specific firm.

Labour demand policy

It seems reasonable to adjust labour demand to the amount needed for sales:

$$L_j^d = \left(\frac{Y_{j,-1}}{Q_{j,-1}^{cap}} \right) L_j^{cap}$$

where L_j^d represents labour demand by firm j, Q_j^{cap} production capacity and L_j^{cap} the number of employees at full production capacity. But this adjustment rule is not sufficient because it does not adjust for the level of stock. Therefore, when stock is high labour demand has to be lower.

$$L_j^d = \left(\frac{Y_{j,-1} - \alpha_1 \, St_{j,-1}}{Q_{j,-1}^{cap}} + \alpha_2 \, \alpha_1 \right) L_j^{cap}$$

The coefficient α_1 is the fraction of stock the firm tries to dispose of per month, and α_2 is the equilibrium stock as a fraction of production capacity per month, i.e. the stock at which the firm tries to equate production and sales.

When stock is 0, sales are determined by production instead of demand. Therefore, labour demand has to be set higher than needed for current sales when stock is 0. We assume that the firm sets its production at production capacity when stock is 0:

When $St_j = 0$ then $L^d_j = L^{cap}_j$

Finally, we did not guarantee that labour demand is not higher than the maximum amount of labour that can be used in production. Therefore, we assume that firms will never demand more labour than can be employed on their machines:

When $L^d_j > L^{cap}_j$ then $L^d_j = L^{cap}_j$

Investment policy

Investment is the main determinant of the business cycle in the game. Therefore, it requires more elaboration than the other decision variables. Consistent with the discussion of the game economy with human players, we will differentiate between structural and cyclical factors. Because the

simulation will be focused on the relation between instability and the focus of firms on structural features of the economy (i.e. the labour market), the investment decision routine will differentiate especially with respect to this item. For this reason we distinguish four levels of structural unemployment at which the policy rule changes. These levels are represented by the coefficients $\beta_1 < \beta_2 < \beta_3 < \beta_4$. The coefficients $\beta_1$and β_2 normally are negative and therefore represent levels of structural shortage on the labour market. Between β_2 and β_3 the cyclical component (i.e. investment accelerator) is the main component of investment, while at higher or lower levels of structural unemployment investment is bounded to a lower respectively upper limit.

We may start in defining accelerator investment, a cyclical component. It seems reasonable to assume that a firm tries to adjust production capacity to demand with a rate β_5 (where the ratio between capital stock and production capacity is used to transform a change in production capacity into a change in capital stock):

$$\text{If } St_j > 0 \text{ then } I_j^{acc} = \beta_5 \, (Y_j - Q_j^{cap}) \frac{K_j}{Q_j^{cap}} + \beta_8 \text{ else } I_j^{acc} = \beta_6$$

where K_j is capital stock, I_j^{acc} investment as a consequence of the accelerator effect, and Q_j^{cap} production capacity of the machines of firm j. Because at a stock of 0 sales will be restricted by production and therefore give no information about demand, accelerator investment is set at a fixed positive value when stock is 0.

To include structural aspects in the investment decision rule, we may follow the phases of the business cycle. When the business cycle is rising and you expect a structural shortage of labour to emerge it is wise not to invest too much. Starting at a structural shortage of labour of $-\beta_2$ the firm will stop with expansion investment and then gradually replaces less machines till investment is 0 at a structural shortage of labour of $-\beta_1$. But to differentiate between the rising and the declining part of the business cycle, we will only replace (part of the) machines as long as there is sufficient demand: this will be the case in the rising part of the business cycle; after the upper turning point you may expect that accelerator investment is negative:

$$\text{If } U^{struct} > \beta_1 \text{ then } I_j^d = \frac{U^{struct} - \beta_1}{\beta_2 - \beta_1} \min\left(I_j^{repl};\; I_j^{repl} + I_j^{acc}\right) \text{ else } I_j^d = 0$$

where I^{repl} is replacement investment[2], $U^{struct} = 1 - L^{cap}/L^s$ is structural unemployment, L^s is labour supply and I^d_j is the number of machines ordered. When the structural situation of the labour market is around its equilibrium value we follow the accelerator mechanism, the more the higher the structural rate of unemployment:

$$\text{If } U^{struct} > \beta_2 \text{ then } I^d_j = \frac{U^{struct} - \beta_2}{\beta_3 - \beta_2} I^{acc}_j + I^{repl}_j$$

When structural unemployment becomes higher, structural opportunities for investment increase. Therefore, it becomes more probable that there is a turning point of the business cycle in the near future. Firms that invest just before the turning point will have large profits: they buy machines at a cheap moment, while they can use all the opportunities generated at the beginning of the rising phase of the business cycle. Therefore, a minimum amount of investment is always invested, beginning at a structural rate of unemployment of β_3 and gradually rising till a structural unemployment rate of β_4. With even higher rates of structural unemployment investment is always at the high level β_7:

$$\text{If } U^{struct} > \beta_4 \text{ then } I^d_j = \max\left[\frac{U^{struct} - \beta_3}{\beta_4 - \beta_3}\beta_7 ; I^{repl}_j + I^{acc}_j\right]$$

$$\text{If } U^{struct} > \beta_4 \text{ then } I^d_j = \beta_7$$

In order to get natural numbers out of this procedure the numbers are truncated and the residual is randomized:

$$\text{IF rnd} < I^d_j - \text{trunc}(I^d_j) \text{ then } I^d_j = \text{trunc}(I^d_j) + 1 \text{ else } I^d_j = \text{trunc}(I^d_j)$$

where rnd = a random number between 0 and 1, and trunc(I^d_j) is the truncated value of I^d_j.

This design provides a good opportunity to differentiate between firms that are very sensitive to structural conditions on the labour market and firms that focus mainly on the output market (the accelerator effect). The structural type of firm has its coefficients β_1 .. β_4 in the neighbourhood of 0, while the accelerator type of firm has those coefficients far away from 0.

2 Modelled as a random variable between 0,5 and 1,5 with an average at the stationary state value of 1.

Decision variable	coefficient	value	Comment
price	a	1.5	reaction of price on excess demand
price	b	1.1	price increase at 0 stock
price	z	0.1	minimum profit margin on variable cost
wage	c	1	reaction of wage on excess demand
wage	e	0.06	when unemployment is higher wage is set on minimum wage
labour demand	α_1	0.5	fraction of stock that firm tries to get rid of
labour demand	α_2	0.8	equilibrium stock as fraction of production capacity
investment	β_1	-0.02	at a lower structural unemployment rate investment is 0
investment	β_2	-0.01	at a lower structural unemployment rate, investment is not higher than replacement investment
investment	β_3	0.01	at a higher structural unemployment rate investment gets a minimum level
investment	β_4	0.02	at a higher structural unemployment rate investment is never lower than β_7
investment	β_5	0.05	accelerator coefficient
investment	β_6	0.25	accelerator investment at 0 stock
investment	β_7	1.25	minimum investment at very high structural unemployment
investment	β_8	0.1	autonomous accelerator investment

Table 1: The Coefficients used in the simulation experiments

The fact that firms generate high profits does not mean that it is good for the stability of the economy that those firms have a higher probability to survive. We will investigate this by simulating four economies: one with the best type of firms, and three that react faster to structural disequilibria on the labour market. We fixed the coefficients β_1 and β_4 as indicated in table 4, and varied the decision routines of the firms with respect to minimal profit margin z and target stock α_2. Table 4 shows that the selection of the optimal firms resulted in much better results for the whole economy. The average unemployment rate was 5.66 % in the optimal economy compared with 21.34 % in the worst economy. Compared to the worst economy the best economy showed an average national income that was 19 % higher where average real wage even was 40 % higher. Also the maximum inflation rate was much lower in the economy with the firms with the highest long term profits. Therefore, the results show that a gradual adjustment rule to the structural situation of the labour market is best both for the firm and for the economy as a whole [Q2].

Game	β_1	β_4	Unemployment%	α_2	z
exp3	-0.02	0.02	16.11	0.5	0.07
exp4	-0.10	0.02	9.11	0.2	0.13
exp5	-0.02	0.06	21.34	0.5	0.04
exp6	-0.10	0.06	5.66	0.2	0.10

Table 5: Four economies compared with respect to optimal profit stock and profit margin

In investigating economies with the same β's we varied two other coefficients: the target stock level in the labour demand function α_2 and the minimal profit margin on variable cost z [research question Q3]. We varied the target stock between 20 % and 110 % of monthly production and the profit margin between 2 % and 13%. We would expect that in economies that are less stable the buffer needed for uncertainties is higher while the minimum profit margin during a recession is lower because a loss of market share has longer consequences. Table 5 shows the combination of the target stock and the minimum profit margin that generated the highest equity capital after 30 years for each of the four economies. These results

are roughly consistent with the hypotheses (except for the reverse order for the two best economies with respect to the profit margin).

In conclusion, the simulations with the game economy show results that can be interpreted easily. The results suggest that selection of the best performing firms improves the stability of the economy: an argument in favour of an evolutionary defense of the stability of real world market economies.

7. Conclusion

The purpose of this paper was to develop an experimental macroeconomic laboratory that is as simple as possible, but can tackle macroeconomic coordination problems where interdependencies between macroeconomic markets, credit and irreversibilities in investment have an important role. The complexity of the game distinguishes it from the traditional methodology in experimental economics. Because the players have to decide about at least 4 decision variables and can use about 160 time series in their decisions, while there is not one optimal decision, the decision problem is complex and open. The interdependence of the players in their decision making increases the complexity even more. But even this system is much more simple than the real world.

As we have seen in the section about the overview of experimental macroeconomics, a complete experimental approach combines analysis, computer simulation, simulation with human players and at least a suggestion of external validity of the results. After a simple experiment with human players that showed that Keynesian recessions emerge in the laboratory macroeconomy with human decision makers, this paper focused on the computer simulation part. Before being able to interpret results of games with human players the characteristics of the laboratory economy have to be investigated more deeply. One step in this direction has been made in this paper by evolutionary simulation experiments. They showed that the selection of the best-performing decision routines increased the stability of the game economy. Comparison of optimal decision routines in different macroeconomic environments gave plausible results. But those results are only tested for one set of decision rules. Therefore, more simulations are necessary before further experiments with human subjects become relevant. When those simulations have generated clear benchmarks for interpreting the results, the macroeconomic game seems to have ample opportunities to investigate human behaviour in this complex environment.

Experiments in macroeconomics have a future. At this moment most experiments about macroeconomic topics are in very simplified environments that neglect the most difficult problem in macroeconomics: the consequences of uncertainty generated by the interaction between different markets in a world where long-term investment decisions have an important role. In this paper we discussed a game that has a potential for tackling this type of problem and showed some first simulation results. Experiments with human subjects in the simulation stage can be useful to get ideas for interesting simulations. Testing theories with human players is only useful when the theories involve assumptions about human behaviour. In such experiments, players have to be experts to such an extent that they do not make mistakes that real world managers obviously will not make. At this stage of development the experimental macroeconomic game described in this paper did not reach this stage. But neither did most of the other macroeconomic experiments.

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