A Tutoring System Supporting Experimentation with Virtual Macroeconomic Environments*

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Abstract. In this paper we present the capabilities and behavior of the tutoring system MAS, a system to experiment with (simulations of) complex macroeconomic environments. The users of the system may assume either the role of the State or the role of a company belonging to a specific productive sector. In fact, our system allows students to interact and modify the behavior, both in the short and long-term, of a real scale economy.

1 Introduction

One of the main disadvantages that students of Social Sciences confront is the disability to *practice* with systems close enough to what they will find during their professional lives. For the purpose of this paper let us consider the case of Economics. More specifically, let us take the topic of economic theory. A student will be usually confronted with exercises and assignments where he has to show his command on the theoretical models that he has learnt. A typical advanced exercise in microeconomics consists in calculating a general equilibrium for an economy with one producer, one consumer, and two goods. If we consider the macroeconomic side, students may expect to compute the GDP (Gross Domestic Product) according to some given data, or to discuss whether a given differential equation (with at most half a dozen parameters) adequately reflects reality. Obviously, the gap between these assignments and the *real world* is huge. In fact, students often miss to have something close to a *hands on* experience. Even though there exist tools to support some of the topics (most notably to analyze econometric data) they are usually very biased to numerical calculations.

Actually, the empirical study of new political, demographic, and social systems has been confronted with the difficulty of managing, with enough precision, environments containing a huge amount of relevant variables. Thus, the definition of new models has been sometimes lessened because it was difficult to verify their validity. The main problem consisted, on the one hand, in the impossibility of

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manipulating the real environment and, on the other hand, in the disability to generate realistic artificial environments. Hence, these fields have been favored with the combination of powerful computers and complex simulators. This is specially important in the case of simulating the behavior of systems that cannot be manipulated, as the economic behavior of a society. Thus, the validity of a new theory can be contrasted by simulating the environment and by comparing the obtained and expected results. Afterwards, by using different test values, one can estimate the behavior of the real system in conditions that could never be applied to the real environment. Examples of such systems can be found in [16, 4]. In fact, together with verbal argumentation and mathematics, computer simulation is becoming the third *symbol system* available to social scientists [12].

The development of simulators is turning Social Sciences in general, and Economics in particular, into more *inductive sciences* [5]. Let us remark that this current trend is useful not only for research but also for didactic purposes. In fact, students may profit from the ability to manipulate environments that without these programs could not been studied. Besides, they can observe the relation among *low level* factors (that is, the value of the corresponding variables) and high level factors (that is, the global behavior of the system). Thus, by using these simulators, students can have an overall vision of the considered system. In addition, they can even define new models and contrast their utility. A good candidate to be *simulated* is the economic behavior of a society. In fact, there are already some experimental simulators and algorithms taking into account partial views of the economy (e.g. [3] at the microeconomic level).

In this paper we present a new tutoring system that we call MAS (acronym for MAcroeconomic Simulator). MAS is built on top of CEES [14], which represents the core of the tutoring system. CEES was a *toy simulator* in the sense that users could interact with an economy but were not *guided* out of their mistakes. However, the complex computations and algorithms underlying the implementation of CEES have been reused in the creation of MAS, which presents, in particular, new tutoring capabilities. The main technical characteristic of MAS is that the underlying economic model (i.e. the algorithm computing how the economy evolves, and that is based on classical text books like [15]) generates a simulation that adequately reflects the majority of relevant macroeconomic aspects. In our tutoring system high level behavior (at the macroeconomic level) appears as a consequence of the interrelation between the different economic agents (providers of goods and providers of work) when they try to increase their own profit (microeconomic level). Actually, traditional economic theory was always separating macroeconomics from microeconomics. However, it is nowadays recognized that macroeconomic phenomena cannot be correctly explained without taking into account the microeconomic side (see e.g. [15]). Let us remark that the economic models that we consider are much more complex than most macroeconomics models in use. So, our system is able to explain how the economy of a society works in a more adequate way than models found in the literature usually focussing on one particular characteristic. As a measure of the complexity of the underlying economic models, MAS controls more than one thousand *heterogenous* variables in order to compute the current state of the economy,

while most theoretical economic models control, in the most involved cases, a couple of tens.

It is worth to point out that the current version of MAS is more than a mere passive simulator where a user observes the behavior of the economy without interacting with it. On the contrary, it is an *interactive* system that allows a user to play the role of the most important economic institutions (i.e. the State or a private company), so that the effect of different decisions on the global economy can be checked. Thus, adequate interfaces are provided where the relevant parameters can be modified. For instance, if the user plays the role of an entrepreneur then he can regulate both the demanded amount of work and of raw materials, the price of his products, the salaries of the workers, etc. Besides, as State, the player regulates parameters as the progressiveness of income taxes, the indirect taxes rate, and unemployment benefits. Actually, MAS allows various users to play the role of different institutions in the same simulation (e.g. one user is the State, and several users represent private companies), so that the decisions of each player affect the others. Finally, MAS provides several *views* of the economic behavior, by means of graphical representations, according to the different parameters to be considered (e.g. prices, employment levels, stocks, etc).

The rest of the paper is structured as follows. In Section 2, we describe the main features of the tutoring system MAS. We will also briefly introduce the idea of *business cycle*. This notion is essential to our system. For example, a student playing the role of the state might be assigned to ease the length of the waves, while another playing the role of an entrepreneur might try to take advantage of the peak of the cycle. Next, in Section 3, we comment on the algorithm underlying the behavior of MAS. In Section 4 we give some examples of typical assignments and how they are developed in MAS. In Section 5 we give some details concerning the implementation of the system. Finally, in Section 6 we present our conclusions and some lines for future work.

2 Main Features of MAS

In this section we explain the main functionalities of our system. The main aim of MAS consists in providing students with an *easy-to-use* tool where they can practice the knowledge previously gained in the classroom. So, students will be able to check whether they have fully assimilated the concepts they were supposed to. We have designed MAS to help undergraduate students having another (main) source of learning (i.e. a teacher, or even a good book). However, the current system contains features to provide students with some independence. Actually, taking as starting point the help subsystem developed for our tutoring system WHAT [6, 7], the concepts covered by an intermediate course on macroeconomics can be documented by means of a friendly navigation interface. Topics can be accessed in three different ways: by using an index of topics, by incremental searches, or by an alphabetic list of keywords.

In order to ensure a personalized treatment, students login into the system by giving their ID-number and password. This allows the system to recover the data from previous sessions. This mechanism tries to avoid *attacks* to previous sessions of students. For example, an attacker could ask the system for either previous or partially solved assignments and provide wrong answers. Then, when the *real* student logs in, he will find out that his economies are in a different (for worst) point.

Exercises and assignments are temporally and thematically classified according to the underlying curriculum model. MAS offers three different categories of exercises.[1] In the first category we consider exercises where students are confronted with a given situation and they have to deduce properties such as how the situation was produced, or how it can be *repaired*. Since most (families of) exercises do not have a unique correct answer, these exercises are solved by filling successive multiple-choice forms. Depending on the previous answers (e.g. there is big demand of raw materials) the next form will be generated. In the second category we find exercises where the student gets a running economy and is asked to modify some of the parameters under his control (e.g. if he plays the role of the state then he can modify the tax rate) to change, in a given way, the behavior of the economy. Finally, in the last category students are asked not only to modify the values of the parameters but to change the proposed economic model to vary the behavior of an economy. For example, a student may be required to change the way in which aggregate demand is formed.

2.1 An Introduction to Business Cycles

Next we briefly present the struggling forces which provoke *business cycles* in real economies. Business cycles are patterns of growth/decrease of the economy which repeat themselves cyclicly. These theories are nowadays well-established in the economic theory literature. In order to avoid technical details we give a naïve, but intuitive, view of this concept, by considering only supply and demand. Actually, current theories of business cycles fit into this explanation (including the so-called *real business-cycle* and *new Keynesian* approaches) because they explain cycles by shocks in the supply and/or the demand sides (see for example [9, 1, 2] for additional explanations on these models).

Let us consider an economy where the demand of goods surpasses the supply. In this situation prices rise, so profit expectations increase. In order to boost production, entrepreneurs hire new employees. Thus, unemployment decreases, so entrepreneurs are forced to rise salaries to attract new man-power. Salaries, in general, are higher and unemployed workers who found a job have a new additional purchasing power. This situation induces an increase of the aggregate demand which surpasses again the recently boosted supply. The unsatisfied demand makes prices to grow up. So, once again, predictions suggest an increment of profit. Entrepreneurs boost again production and the whole process repeats. The chain reaction is based on this vicious circle which makes the wealth of an economy to grow constantly. We have an *expansion* stage.

[1] In Section 4 we present some concrete examples of typical assignments in MAS.

But this process does not last forever. Economic growth lies in the fact that aggregate demand and production costs rise *coupled*, so that profit margins stay more or less stable. Thus, an unbalance in this tradeoff can break the chain reaction. If production costs increase with respect to the demand then the profit of the entrepreneur is reduced. This unbalance will eventually happen in the long term mainly due to two reasons. First, good sources of natural resources will be all under exploitation. So, in order to boost production, companies will be forced to look for some other cultivation lands or deposits which actually are not so productive. Second, the decrease of unemployment will induce an increment of salaries. These two reasons will force entrepreneurs either to give up their business or to attempt to balance income and costs by rising prices. In the former case, fired employees lose their purchasing power. In the latter case, employees would reject to buy expensive goods. In both cases we have that the aggregate demand retracts. Thus, the accumulated stock will not be sold and employees will be fired. The rise of unemployment will induce a decrease of salaries. Besides, unemployed people have no more money to spend. So, the aggregate demand deteriorates even more. This situation forces entrepreneurs to reduce again the production and to fire more people. This process is repeated in a new chain reaction. The decreasing stage finishes when the retraction of aggregate demand and the reduction of production costs get unbalanced. If production costs decrease more than demand then investment will generate profit again. This unbalance will be induced by reasons opposed to those explained above. So, the economy starts to grow and the expanding part of the cycle starts again.

3 The Algorithm Controlling the Behavior of MAS

In this section we give some hints about the algorithm governing the economic behavior of our simulator. As we have previously said, this algorithm was originally introduced in the CEES system. Thus, the interested reader is referred to [14] for a detailed explanation. Given the current state of the economy, the algorithm computes the state of the economy in the next instant. So, time is split into steps (e.g. weeks, months, years). An iterated execution of the algorithm gives us the state of the economy in any arbitrary future time. We slightly depart from the usual conception that economy consists of three sectors. In order to have a more precise description, we split the primary sector into two sectors: *Alimentation* and *raw materials*. In this case, the latter must be understood in a broad system as it contains those industries needed to assure the productive cycle of companies. That is, in addition to proper raw materials we consider sectors as energy, industrial machinery, industrial construction, etc. Let us remark that some of these industries are usually included in the secondary sector. Thus, we will consider four productive sectors: *Alimentation*, *industry of goods*, *services*, and *raw materials*. We denote the first three productive sectors by *sectors of goods*. The latter sector must be understood, in a broad sense, as those materials that are needed by companies to perform the productive process. For instance, it includes industries as energy, mining, heavy industry, construction, etc.

The algorithm includes 9 phases split into 20 steps. In Figure 1 we depict them. All the steps are influenced by previous ones, as all of them modify the whole state of

the economy. In that diagram, only non-obvious relations are depicted (i.e., those needing the creation of specific relationship data).

Fig. 1. Structure of the algorithm of MAS.

As an example of the mathematical basis underlying MAS we present the default definition of the rate of expenditure by an individual in each of the available products. From the total amount that an individual decides to spend, $ProductDemand_i$ indicates the percentage to be spent in the product i. Each product i is associated with a *consumption* sector (alimentation, industry, and services, respectively) by means of a function s:N$\longrightarrow${1,2,3}. In addition, π:{1,2,3}$\longrightarrow$R computes the *priority* that the individual assigns to consumption in each of the sectors. Finally, b and c are constant and different for each individual. They indicate the minimal quality threshold for the product and the additional influence of price in demand, respectively.

$$aux_i = \frac{PurchasingPower^{\pi(s(i))} \cdot \left(b - \frac{1}{Quality_i}\right)}{Price_i^{\frac{1}{PurchasingPower}+c}} \qquad ProductDemand_i = \frac{aux_i}{\sum_j aux_j}$$

The terms aux_i compute the *rough* percentage of money to be spent in each product. These terms are afterwards *normalized* so that $ProductDemand_i$ gives the real percentage. Let us remark that the demand increases with quality and diminishes with price. Besides, the influence of price in demand is bigger if the purchasing power is low.

4 Examples of Exercises in MAS

Even though the previous sections have described the general behavior and characteristics of MAS, it may not be yet clear the kind of exercises that students have to confront. In this section we will show a couple of examples presenting *typical* assignments to be solved in MAS.

The simplest assignments consists, as explained in Section 2, in trying to understand what is going on in a partial view of an economy. For example, let us consider Figure 2 (left) where, in order to reduce the required space, we have *deleted* the rest of the MAS graphical interface. The student has to determine which two sectors can generate such a joint behavior. First, he has to deduce that the given initial conditions were not natural enough, according to the model, so that there is a first stage of stabilization where the Economy tries to fit properly into the model (students know that they have to discard the *beginning* of the analyzed data). Afterwards, the stable cyclic behavior begins. In order to solve the *mistery*, it is enough to realize that the sector depicted in the down part of the graphic almost follows the derivative of the other one. Thus, it easily follows (at least, we expect so!) that the first evolution represents the sector of raw materials while the second one represents the industry sector.

One of the main requirements for a *good* government is to soften the cyclic behavior of the economy. Even though it will be almost impossible to avoid cycles (even undesirable) big *waves* produce a lot of instability and uncertainty in the economic agents. In fact, a very reduced form of state can help in this task. In Figure 2 (center) we show a simulation of a completely free market, while in the right hand side we present the behavior of an economy where a simple state (with no public companies) collects some taxes that are used to pay low unemployment benefits. Thus, one of the assignments is to change the relevant parameters in the state (tax collection, public expenditure, etc) so that the economy is converted from the first to the second graphic.

We will also ask students to deal with the influence of different company tactics in an economy. In this sense, it is worth to point out that a *huge* firm can strongly influence the evolution of cycles. In fact, it is even possible to stop a expansion or a depression as a result of the investments of our company. Another typical assignment regarding firm policies is to analyze the effects of *price dumping*. This technique consists in selling products under the production costs until the competence disappears. Once the market is controlled, the company can monopolistically act (with the consequent increase of prices). We will give initial conditions for the firm of the student and we will ask him to apply this policy. He should be able to realize that these initial conditions are very relevant in the success of dumping. Actually, it works only after a minimal threshold of portion of the market was initially owned and a great stored capital was available by the company (in order to confront the initial loses).

The last exercise that we are going to comment was created as a consequence of our experimentation with CEES [14], the subsystem used by MAS where the algorithm to compute the state of the economy is located. While testing the reliability of CEES we did not consider, by default, that *strange* behaviors were due to

conceptual errors. Actually, it is a fact that in any society almost *anything* can happen if the specific conditions appear simultaneously. Hence, we tried to take advantage of these behaviors instead of discarding them. For example, during the development of the simulator we found out the existence of a very rare situation where a depression was accompanied by an inflationary spiral. This phenomenon is called *stagflation* and we were not previously aware of it. We found out that one of its possible causes is that, due to some factors, companies are forced to increase salaries though their profit is negative. Afterwards, we compared this situation with standard behaviors, where salaries use to decrease in depressions. We identified the main factors provoking this rare behavior in our model (e.g., excessive influence of the *still* low unemployment in the beginning of the depression), and we corrected them. Thus, one of the assignments (at the end of the course) consists in showing an economy presenting stagflation and asking the student to take the economy out of it.

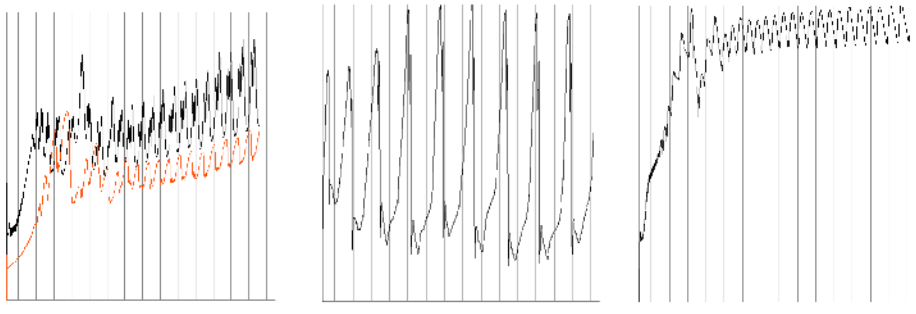

Fig. 2. Industry and Raw Materials sectors (left), completely unrestricted economy (center), and lowly restricted economy (right).

5 Implementation Details

In this section we give some details about the implementation of our tutoring system MAS. We will also review the main characteristics of the implementation of CEES since this subsystem is vital for the correct behavior of MAS. We would like to emphasize that the methodology that we followed to design the integrated system MAS/CEES can be described as a *symbiosis* between the implementation of the simulator and the learning of advanced macroeconomic concepts. Initially, we identified the set of basic operators (at the human level) producing the economic process (e.g. purchasing, selling, work, demand of goods, etc). Next, we identified the main results giving raise to the correct interrelation among these concepts (e.g. business cycles and their control, state regulations by means of taxes and unemployment benefits, monopolies and oligopolies, etc). Afterwards, we looked for economic explanations to the basic forces producing the high level behavior of the system (e.g. if there is an excess of supply then the entrepreneur will decrease the prices).

The architecture of MAS is split into different components. First, the client-side component provides a Web interface for users. This component consists of HTML pages with embedded Javascript code that are dynamically generated by the server in response to queries of users. Through this environment users are confronted with the proposed assignments. The server-side component selects the questions to send to each user, composes the HTML pages before sending them to the client, records the answers, provides simple statistics of the system use, and computes the results of questions concerning complex economic behaviors by forwarding the suitable initial conditions to CEES and executing the algorithm it provides. This feature allows MAS to dynamically create new questions by performing random small modifications to the initial conditions of other already known questions. In this case, MAS obtains the correct answer to the new question in advance by executing the algorithm provided by CEES and considering the values returned by it. Finally, the last component of MAS is the economic engine that provides such analysis, that is, CEES. MAS runs on top of CEES, since the latter implements the algorithm governing the economic predictions performed by MAS. The structure of the economy model guided the decomposition of the design in classes (State of the Economy, Productive sector, Labor sector, Entrepreneur, Worker, etc.), the needed operations (buy, sell, consume, invest, look for a job, migrate of sector, etc.), and the needed attributes (salary, savings, amount of people, etc.).

6 Conclusions and Future Work

We have presented MAS, a tutoring system to deal with macroeconomic environments. We think that MAS is indeed a very useful tool to help students in the task of learning the main characteristic of a complex economic system. It is worth to remark that MAS is built on top of CEES, a powerful subsystem that implements the algorithm governing the behavior of an economy.

As future work we would like to migrate the architecture of MAS/CEES to a more standardized technology of economic simulation (e.g. Swarm [10]). This change would allow us to easily compare simulation results and to share components in order to study design alternatives. A second line of future work consists in including some of the main economic factors which have not been included in the current version. This is the case of the loan system, a stock exchange, and international commerce. Finally, we plan to apply some of the economical mechanisms underlying MAS to the systems presented in [11, 8, 13]. In these works, simple microeconomic concepts are applied to concurrent and e-commerce systems, respectively. We are confident that relevant *high level* emerging properties can be indeed found in the distributions of resources.

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