Introducing CEES: Complex Economic Environments Simulator*

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Abstract. The combination of powerful computers and complex simulators allows us to accurately simulate the behavior of real system. This is specially important in the case of systems that cannot be manipulated, as the economic behavior of a society. CEES is a program that allows a user to simulate the behavior, both in the short and long-term, of an economy. Besides, users of the system can be part of the simulation by taking charge either of a company or of the State. Let us remark that, in contrast with most economic models, CEES takes into account a huge amount of variables (more than one thousand) in order to compute the current *state* of the economy.

Keywords: Complex Systems; Simulators; Macroeconomics;

1 Introduction

Traditionally, the empirical study of new political, demographic, or 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 manipulating the real environment and, on the other hand, in the disability to generate realistic artificial environments. Hence, these fields have been favored due to the possibilities offered by new powerful computers. 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 [11, 4]. Actually, together with verbal argumentation and mathematics, computer simulation is becoming the third *symbol system* available to social scientists [8]. A good candidate to be *simulated* is the economic behavior of a society. In fact, there are already good simulators and algorithms taking into account partial views of the economy (e.g. [3] at the microeconomic level).

In this paper we present CEES (acronym for Complex Economic Environments Simulator). The economic models underlying CEES are much more complex than most macroeconomics models in use. So, our system is able to explain

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how the economy of a society works in a more adequate way than models found in the literature usually focussing on one particular characteristic. For instance, we consider several productive sectors simultaneously. A new feature that we have considered specially important is that 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. As a measure of its complexity, CEES controls more than one thousand *heterogenous* different variables in order to compute the current state of the economy, while most theoretical economic models control, in the best cases, a couple of tens.

We would like to emphasize two main characteristics of our system. First, our design methodology 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). We generated preliminary models and studied their validity, so that we could incrementally improve the models until they reached the desired behavior.

It is worth to point out how we were dealing with *unexpected* behaviors. By default, we did not consider that they 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 (called *stagflation*). Then, we gathered documentation in the specific literature about this strange behavior in real economies. We found 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. Nevertheless, instead of managing the rules of our model so that the rare situation was not possible, we *generalized* the model so that *both* situations were possible. In the new model, the behavior depended on whether the exceptional factors provoking the situation were present or not. This management of *strange* situations favored the increase *by-demand* of the set of relevant factors, as well as the necessary learning by the authors of advanced concepts in the area. Thus, we may properly claim that the simulator was teaching to the authors and that the design process was guided by the simulator itself.

The second main characteristic of CEES is that the system is a complete and complex simulator that adequately reflects the majority of relevant macroeconomic aspects. In CEES, the 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. [10]). In a wider sense, we assume the Axelrod simplicity principle (*KISS*, *Keep It Simple, Stupid*), which states that very simple agents can generate complex emerging structures [1].

It is worth to point out that CEES is more than a simulator where a user passively observes the behavior of the economy. 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 the demanded amount of both work and 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, CEES 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, CEES 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 algorithm underlying the behavior of CEES. We will concentrate on how the next state of an economy is computed from the current state. In Section 3 we give some implementation details as well as examples of the behavior of our system. Finally, in Section 4 we present our conclusions and some lines for future work.

2 The Algorithm Controlling the Behavior of CEES

In this section we describe the algorithm governing the behavior of our simulator. Given the current state of the economy, the simulator gives the state of the economy in the next instant. So, time is split into *turns* (e.g. weeks, months, years). An iterated execution of the algorithm gives us the state of the economy in any arbitrary future time. As we said before, we slightly depart from the usual conception that economy consists of three sectors. We will suppose 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. As we said in the introduction, CEES allows some of the *players* in the economy to be real persons. By *Society* we denote all of the companies which do not belong to any of the human participants. Human participants will be simply called *Participants*.

The algorithm includes 9 phases split into 20 steps. Next we briefly describe the purpose of each of these phases as well as the different steps included in each of them. We will write phase names in boldface characters while the different steps will be given in italics. Due to space limitations we will not give the mathematical formulation of our algorithm. However we present in Phase 1, as an example, the definition of demand functions for specific products.

Phase 1. Computing the aggregate demand of goods. First, we have to consider the willingness of each individual to save money. Let us note that if the savings of an individual cannot afford his minimal necessities then he will save nothing. So, the rate of money each individual saves depends on the capacity of his wealth (salary and savings) to afford his basic necessities. In the case of the demand of goods by entrepreneurs (as they are also individuals), we must take into account that some money will be taken away from the savings to afford the company costs in next steps. So, it will be necessary to estimate the maintenance costs of their companies. As the quality of their products strongly influences the production cost (more quality requires better supply and more man-power), the selection of future quality will be done in this step.

Next, we will get the way all of the purchasers spend the money they had decided not to save. Let us remark that if the purchasing power of an individual is low then his expenditure rate in alimentation is higher (as well as he will spend less in services). On the contrary, an individual with a high purchasing power will have opposite preferences. In all cases, preferences will be strongly influenced by both the price and the quality of the products. However, quality increases production cost. Thus, it influences the selling price. Essentially, the influence of price on the demand by wealthy people will be less than the corresponding to poor people. As a result, low quality will maximize demand of poor people, while it will be the opposite for well-off people.

As an example of the mathematical basis underlying CEES we present 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 $s : \mathbb{N} \longrightarrow \{1, 2, 3\}$. In addition, $\pi : \{1, 2, 3\} \longrightarrow \mathbb{R}$ 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.

Phase 2. Computing the amount of goods that are sold. In this phase we distinguish four steps. First, we need to compute the *difference between demand and supply of goods*. As demand could be greater than supply, it could be impossible for purchasers to buy all the goods they wanted, so they could save some additional money. In this case, some of this saved wealth could be spent in other goods that were not initially required. This allows some expensive and bad products to be sold after cheap and good products are exhausted. Next, *products will be sold under stock restrictions*. In this case, savings of entrepreneurs will be increased and savings of purchasers (entrepreneurs included) will be decreased according to the purchased products. The stock will be recalculated according to the goods actually sold. In addition, indirect taxes corresponding to these sales will be collected by the State.

Once sales are computed, entrepreneurs will decide whether they *modify the prices of their products* for the next period. In order to do so, they will take into account the demand/supply ratio in the current period. Let us note that new prices will be strongly influenced by the degree of monopolism. Besides, they will also depend on the type of good and on its quality (see e.g. [2] for an explanation on sticky prices). However, only prices of the Society will be automatically computed because Participants make these decisions voluntarily by using the interface provided by the system. The last step in this phase is used to compute the *expectation of future profit rates for each sector of goods using the previously computed prices*. For each company, this rate will be given by the ratio between income and total costs (including taxes).

Phase 3. Computing the amount of wealth devoted to new investments. In this phase we distinguish three steps. First, we have to compute the set of *individuals who desire (an can) invest in each sector*. People in general (i.e. Society entrepreneurs, employees of both the Society and the Participants, and unemployed people) may decide either to invest in a new company or to enlarge an existing one. Participants are not included in this step as they perform their investments from the application interface. The amount of new investment in each company will depend on the ratio between demand an supply in the previous period, on the expectations of profit, and on the current wealth of investors. The higher are those values, the higher amount of money will be invested. So, a sector with excessive production but good profit may receive additional new investment. Finally, in order to consider an investment feasible, it will be required that the invested money surpasses a minimal threshold. Each sector has a specific threshold of minimal supply that has to be purchased to make the investment work. For instance, opening a bakery is cheaper than opening a car factory.

Let us remark that there is not a Stock Exchange market in CEES (we plan to include it in a future release). So, we suppose that companies (or part of them) cannot be sold/bought.

Next, we have to compute the *new investment and add it to the total investment*. The aggregate amount of investment, as calculated in the previous step for each individual, could be either excessive or insufficient. For instance, if somebody decides to open a bakery in its street and notices that 10 other people had the same idea, he could reconsider his decision. So, an optimum of investment will be calculated and compared with the amount of desired investment. Individual investments will be reduced if they were excessive and increased if they were insufficient. In the latter case, this will be done only if it is possible according to the savings of investors.

Finally, we have to *remove those entrepreneurs who give up due to a lack of profit*. The number of entrepreneurs leaving their sectors will be proportional to the amount of money that should be taken away from the corresponding sector. A sector could also be reduced if savings of entrepreneurs are not enough to afford the production costs. In this case, the reduction will ensure that the new size of companies can be afforded by entrepreneurs. Let us remark that size reductions may happen even if the sector has positive profits.

Phase 4. Computing the demand of employment by companies. According to the old companies that stay and the newly created companies, an amount of man-power will be demanded. Each company will require a rate of specialists (i.e. people with specific knowledge on the specific area) and a rate of non-specialists. The man-power required by companies exponentially rises as the desired quality of the final products increases.

Phase 5. Computing the demand of raw materials by companies. Each productive sector has specific necessities of supply to keep the production working each turn. In case of new companies or companies enlarged during this period, we have to add the materials required to create/increase them. Companies will have different preferences with respect to the different available materials. While quality increases the preference, price decreases it. Besides, price will have a lower influence in companies which desire to produce high quality products.

Phase 6. Computing the maintenance/creation of companies. In this phase we consider three different steps. First, according to the demanded man-power, *workers try to find a job as a wage-earner*. Jobs are sorted from the highest to the lowest salary. Then, we take the *best* job and we look for candidates. Specialized jobs require workers with the corresponding knowledge, while everybody is a good candidate for a non-specialized job. Next, we calculate the proportion between suitable candidates and the number of required jobs. The corresponding rate of candidates will take the job. Then, we take the next best paid job and repeat the process. Let us remark that not all of the suitable candidates who are still unemployed will accept the best available job. The decision will be influenced by the relation (given by the utility function of each individual) among the salary of the job, the cost of living, and unemployment benefits. However, current workers lessen the effect of the previous factors in order to continue in the same position. Let us note that a current employee loses his job only if the sector is reduced and he is fired, if he gives up voluntarily to look for another job, or if he thinks that it is better for him to be unemployed.

Next, we have to *provide raw materials to companies*. The total amount of demanded raw materials is added. This quantity is compared with the total stock of raw materials. If demand is bigger than supply then the rate between demanded and available supply is calculated, and companies are supplied in this same rate. Additionally, stocks of some raw materials providers could be exhausted, and companies trying to buy them will save the money corresponding to the amount they could not buy. This money will be available to be spent in supply stocks of other companies. This fact allows again, as it was the case of usual goods, that bad and expensive raw materials enter the market right after cheap and good ones are sold out.

Finally, we have to compute the *amount of man-power and raw materials demanded by companies which has been actually filled*. If the demand was not satisfied, it will be calculated which one of these resources was obtained in the lower proportion. This resource will mark the bottleneck of the productive process: The amounts of the other resources surpassing this rate will actually be spared (but entrepreneurs must still pay for them). Let us remark that new companies which did not surpassed the minimal threshold of needed supply to be *created* will close down.

Phase 7. Computing the amount of raw materials that are bought by companies. Here, we consider three steps. First, for each productive sector, we subtract the demand of raw materials from the corresponding supply. Then we perform the *selling of raw materials*. We reduce the savings of entrepreneurs according to the materials that they bought, and we add this money to the savings of the corresponding owners of raw materials companies. Let us remark that companies that are unproductive have also to pay the quantity of materials that they were ordering. Then, the new stocks will be computed. In addition, the State collects the indirect taxes associated with the selling of these products. Finally, raw materials companies decide whether they *increase/decrease their prices according to the demand/supply relation*. The process is again similar to that in the second phase.

Phase 8. Computing the wages of workers. In this phase we consider three different steps. First, we compute *the difference between demand and supply of employment*. Next, by *paying salaries*, we have that the wealth of entrepreneurs is reduced according to the hired man-power. Simultaneously, savings of employees increase according to their salaries. Let us remark that unproductive companies have to pay the man-power they hired. The State will pay the corresponding unemployment benefits. In addition, both wage-earners and unemployed people will pay their income taxes. Finally, *new salaries will be computed according to the the demand/supply relation*. Once again, Participants may voluntarily modify these values. Let us remark that in a labor sector presenting unemployment, salaries must not necessarily decrease. If unemployment is small then salaries could even rise, because finding employees will be still hard. Otherwise, salaries would decrease continuously as every society has structural unemployment.

Phase 9. Computing the aggregate production. According to the real availability of resources in companies (man-power and raw materials) the final production is computed and added to the corresponding stocks. New theoretical productivity is calculated according both to the suitable or excessive exploitation of natural resources and to technological research. Besides, the limit to consider that the natural resources are excessively exploited is increased according to technological research. Taking into account the proportion of hired employees over the standard amount of needed employees, the quality of the acquired raw materials, and the quality of the machinery (the *raw materials* from which the company was created), the quality of the final products is computed. A part of the stored stock is spoiled each turn as well as a part of the machinery. By doing so we can simulate the effect of obsolete and old machinery.

3 Implementation Details and Experiments

CEES was implemented by using Borland C++ Builder™ and the code is around 11000 lines. 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.).

Let us remark that, depending on the *length* of the turns (i.e., the length of the period of time they represent - days, months, years, etc.), some of the operations described in the previous section are appropriate in all turns but others are not. For instance, while it is clear that all of them are suitable in the case of years, it is in general false that taxes are paid every month or salaries are paid every week. So, depending on the length of turns, some operations will be disabled in most of them, which will reduce their computational cost. Obviously, as the length is reduced, more turns are needed to reach each future time, which dramatically increases the time required to compute the simulation, but the economic precision of the model improves. For example, it allows us to consider the effect of temporal singularities (e.g., paydays or months in which taxes are paid) in real economies.

Next we briefly comment on some of the experiments that we have performed with CEES. First, as we expected, the sector of raw materials was guided by the derivative of the other sectors. In Figure 1 (left) the evolution of the aggregated industry and raw materials sectors is depicted. In order to reduce the required space, we have deleted the rest of the CEES graphical interface. As the given initial conditions were not natural enough, according to the model, there is a first stage of stabilization where the Economy tries to fit properly into the model. Afterwards, the stable cyclic behavior begins. As we can see, the raw materials sector (down) follows almost the derivative of the industry sector (up). The

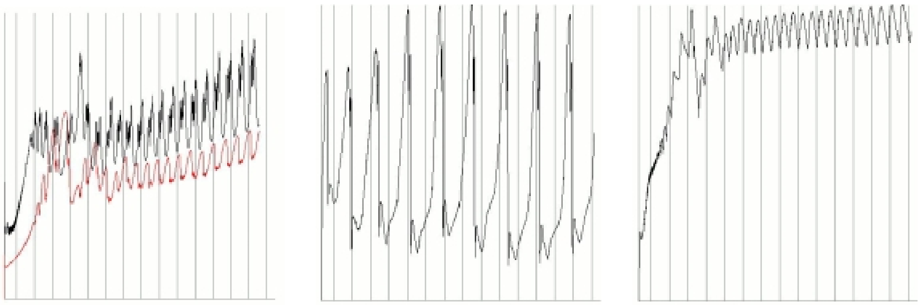

Fig. 1. Industry and Raw Materials sectors (left), completely unrestricted economy (center), and lowly restricted economy (right)

reason is that a great part of the demand of the sector of raw materials comes from the creation of new companies.

We were also trying to determine conditions to soften the cyclic behavior of the economy. In fact, a very reduced form of state can help in this task. In Figure 1 (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. Besides, the cyclic behavior can also be affected if we consider that a huge company appears in the economy. For instance, if we play the role of one of such companies, it is even possible to stop a expansion or a depression as a result of the investments of our company.

Finally, we studied the influence of different company tactics in an economy. In particular, we analyzed 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). As we expected, it worked 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).

We would like to remark that as CEES is endowed with the needed complexity to simulate most of the relevant aspects of the economy, it allows to perform experiments it was not specifically devoted to when it was designed. So, we expect that many other interesting situations will be confronted in the future.

4 Conclusions and Future Work

In this paper we have presented CEES. The interest of CEES consists of two main points. First, its success to simulate complex economical behaviors using basic low level economical concepts. Second, its designing methodology where the learning in the specific area, the development of the model, and the treatment of unexpected behaviors have been jointly and coordinately dealt with.

As future work we would like to migrate the architecture of CEES to a more standardized technology of economic simulation (e.g. Swarm [6]). It would allow us to easily compare simulation results and to share components in order to study design alternatives. Besides, we plan to include some of the main economic factors which actually could not be included in the current version. This is the case of the loan system, a stock exchange, or international commerce. In addition, we plan to apply some of the economical mechanisms underlying CEES to the systems presented in [7, 5]. 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 found in the distributions of resources using (a subset of) CEES. So, basic rules governing the exchange of resources in the previously mentioned systems could be improved so that better distributions are achieved. Finally, we are also working on improving our performance by parallelizing our application using the language Eden [9].

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