An approach for Modeling the economy as a complex system using agent-based theory

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Abstract—**As our aim is to explore the future and anticipate economic changes, we have tried to analyze the economic system by performing an empirical study of the interactions between different economic agents.**
Therefore, the purpose of our work is to propose an agent-based model, in which interactions between different types of agents are modeled in an economic context; and that by introducing different economic activities; including hiring, firing, production and consumption. Furthermore, what can make this paper special is that the consumption of a group of agents will depend on their wealth and also on the consumption of their neighbors.
However, to highlight this work, it will be edited later by simulating it using the Netlogo platform; in order to discover the effect and the outcome of some economic policies.

Keywords—agent-based modeling; economic complex systems; interactions; agent's behavior

I. INTRODUCTION

The vision of the economy as a complex system is very old, since the time of Adam Smith who describes the economy and the social well-being it creates, as an emerging process based on the self-organized behavior of an individually motivated actor. The complex systems that characterize modern socio-economic systems defy conventional thinking. Indeed, these systems are based on a big number of interacting individual elements,

According to Simon [2], a complex system consist on a large number of entities that interact in a no simple way. For market economies, it seems to have properties that allow coordination of actions of multiple agents and competitors who compose without the analysis permits identification of specific organ able to ensure the observed coordination; As if the whole was “superior” to the sum of the parts.

Accompanying this economic development requires the modeling of many markets and their interaction through various feedback mechanisms between labor, goods, financial and credit markets. After having languished for several decades, different approaches began to emerge, various ambitious projects such as 'Eurace @ Unibi Model' [3]; which try to expose a micro-founded macroeconomic model that can be used as a means for the analysis of economic policies and for the treatment of macroeconomic problematics. The Eurace@Unibimodel represents interactions between different economic markets.

The aim of our work is first to present an empirical study of the economic system while explaining the equations that govern the main activities of a given economy, and secondly to propose a model adapted to our expectations which are the agent-based modeling of interactions between different types of agents in an economic context.

The paper is structured as follows: Section 2 presents an empirical study of the economy as a complex system, as well as the model proposed by Oliver Blanchard [4]. Section 3 presents the model proposed. Section 4 presents the agent-based theory and its utility for economic systems.

II. AN EMPIRICAL STUDY OF THE ECONOMY AS A COMPLEX SYSTEM

A. From general equilibrium theory to the complex systems

Trying to model a market economy, Leon Walras exposes his first attempt in 1874. His general equilibrium theory of the competitive market economy was renewel by Kenneth Arrow and Gérard Debreu to prove the existence and stability of the equilibrium. Computable general equilibrium (CGE) models are created to establish a numerical framework for empirical analysis and evaluation of economic policies [5].

We have explained in details; in the context of the evolution of economic systems over time in our last work [7], the disadvantages of CGE models and subsequently the introduction of economic complixity.

Simon [2] points out that classical economics does not provide an absolute way to describe the process that managers use to make decisions in complex situations. One of the alternatives he proposes is the study of the economy through the complexity theory.

The work of Simon [6] had a decisive contribution to the renewal of economic thought. These contributions have

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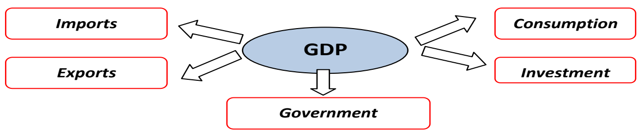
allowed to consider the social aspect and to migrate from a purely economic to social-economic view by introducing the concept of ‘’bounded rationality’’. Simon explains also that the transition from the individual level to the group level that generates an unexpected emergent phenomenon defines the bottom-up approach; which is a characteristic among others of complex systems [7].

In the following parts we will present a part of the model proposed by Oliver Blanchard [4]; in which he tried to express each economic activity taken separately to obtain a model representing a simplistic economy; with the study of some parameter of the model.

First, let's take the most significant economic indicator; gross domestic product (GDP) and try to see its components.

B. *The Composition of GDP*

Seek the determinants of demand for goods returns to decompose the aggregate output or gross domestic product (GDP).
The macroeconomists decompose generally the GDP as follows:



- Consumption: which we note by the letter C, they are goods and services bought by the consumers. The consumption is the biggest and the important component of the GDP.
- Investment: It is the sum of the non-residential investments, and the residential investment.
- Government spending: It represents the purchases of goods and services by the federal, state and local governments. The services include services supplied by the employees of the government.
- Imports (IM): are the foreign goods and services purchasing by different agents.
- Exports (X): are the purchases of goods and services by foreigners.

C. *The Demand for Goods*

According to the decomposition of GDP we saw above, we can write Z ; the total demand for goods as [4]:

$$Z \equiv C + I + G + X - IM \qquad (1)$$

Where:
C : Consumption
I : Investment
G: Government spending
X: Exports
IM: Imports.

We assume the following hypotheses [4]:
- Firms produce the same product;
- The economy is closed.

Under the second assumption, X = IM = 0, so the demand for goods Z becomes:

$$Z \equiv C + I + G \qquad (2)$$

1) *Consumption*

Many factors influence consumption decisions, but the main frequent is income, or, in other words, disposable income (Y_D),
We can then write:

$$C = C\,(Y_D) \qquad (3)$$

It would be better to specify the form of the function; therefore Oliver assumes that the relation between consumption and disposable income is given by a linear function:

$$C = c_0 + c_1 Y_D \qquad (4)$$

- c_1: is the propensity to consume. It reflects the impact of an additional monetary unit of disposable income on consumption. There are two natural restrictions regarding c_1:
  - *First*, c_1 should be positive; indeed an increase in disposable income necessarily leads to an increased consumption.
  - *Second*, the value of c_1 is less than 1; in fact, people will generally consume just a part of the increase in disposable income.
- c_0: is the value of consumption in the case where disposable income was zero, this means that if current income was zero, consumption would still be positive, in other words, people still need to eat, which implies that c_0 is positive.

The relation between consumption and disposable income shown in (4) is drawn in *Fig. 1, [4]*:

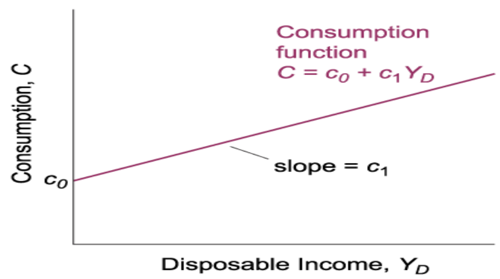


Fig.1. Consumption and Disposable Income.
Consumption increases with disposable income but less than one for one. A lower value of c_0 will shift the entire line down.

2) *Investment (I) and Government Spending (G)*

Unlike consumption which is considered as an endogenous variable, investment and government spending are treated as exogenous variables.

Oliver accepts this hypothesis to keep the model simple, although he is aware that this implication may be a bad description of reality, however, he have treated the inverse case separately.

D. Movements in Unemployment

The variation in the aggregate unemployment rate affects workers on several levels:

- The well-being of workers,
- Wages.
- The chances of an unemployed person finding a job decrease
- Employees risk losing their jobs.

Fig. 2 and *Fig. 3,* [4] show some of these effects at work over the period's 1970 to1985 and 1996 to 2014:

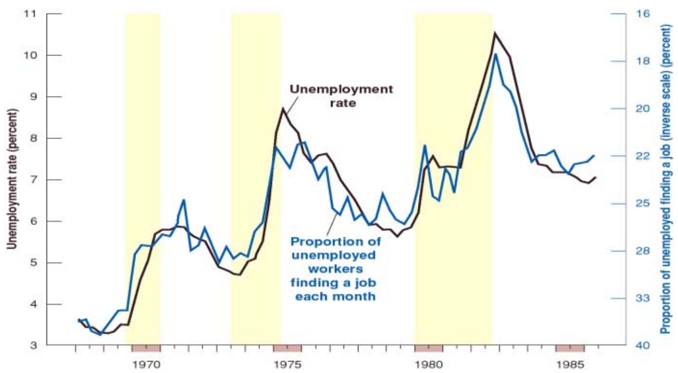


Fig. 2. The Unemployment Rate and the Proportion of Unemployed Finding Jobs, 1970–1985. [13]

The scale on the right is inversed. We notice that when unemployment is higher, the number of unemployed finding jobs is lower.

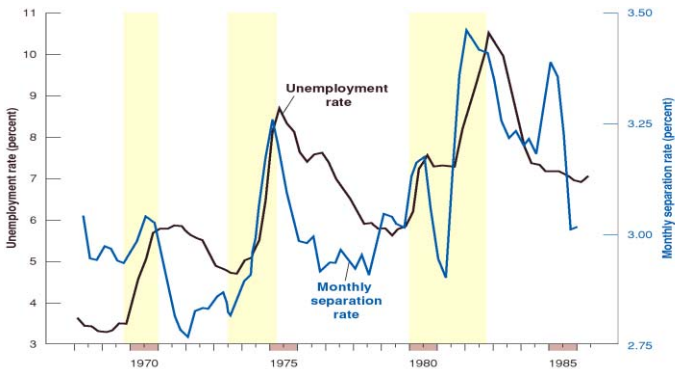


Fig.3. The Unemployment Rate and the Monthly Separation Rate from Employment, 1996–2014. [14]

When unemployment is higher, a higher proportion of workers lose their jobs.

The relationship between changes in the proportion of unemployed people finding a job and the unemployment rate is enormous. In 1983, for example, for a 10% of unemployment rate, only about 16% of the unemployed found a job within a month, as opposed to 27% in 1979, when unemployment was much lower.

⇨ To summarize:

When unemployment is high, two results are possible:

- Employed workers are more likely to lose their jobs.
- Unemployed workers are less likely to find a job.

III. AN AGENT-BASED MODEL FOR THE INTERACTIONS BETWEEN AGENTS IN AN ECONOMIC CONTEXT

In this part, we propose a model which might be consider as an attempt to provide a microfoundation of the interactions between labor-market; production goods market; consumption goods market and credit market.

The model describes an economy which is constituted by numerous instances of different types of agents: firms, workers (who are also consumers) and bank.

In the consumption goods sector, Firms use its monetary capital; that it obtain by taking a bank loan and repay it in the form of annuities; added to the labor input to produce consumption goods.

The interaction in the labor market is represented by a simple process where companies advertise job offers and workers accept or refuse. The wages of the workers are defined, on the one hand, by the expectations of the employee and, on the other hand, by the average of the wages wished by all the agents in search of employment.

In the following sections, we list the different activities defining the proposed model.

A. Borrowing from the bank

Firms borrow a loan from the bank to start their activities; it will repay what it owe the bank gradually throughout the period of the simulation by pouring a constant repayment noted "annuity" and calculated; according to the formulas of financial mathematics; as follow:

$$\text{Annuity} = \frac{\text{loan} * r * (1+r)^{T}}{(1+r)^{T} - 1} \qquad (5)$$

Where:

- r : interest rate;
- T : number of periods corresponding to the loan.

Then the firm`s wealth at the first period (t=1) is equal to the loan borrowing from the bank:

$$\text{Wealth.Firm}^{t} = \text{loan} \qquad ; t=1 \qquad (6)$$

B. Hiring and firing

The hiring process follows these four steps:

- ***Step 1:*** all existing unemployed in the simulation environment receive indemnity of unemployment from the government; however, on the basis of this indemnity every unemployed defines its own desired salary, for every period, in case there is an offer of employment from firms;

$$\text{Desired.salary}^t = \text{Indemnity.unumployment}^t * (1 + z) \quad (7)$$

Where:

z: is a random normal number distributed on all unemployed.

- ***Step 2:*** at each period, each firm specifies a salary on which it is based in order to decide on recruitment of an unemployed or not; and of course this will take place only after checking if there is a recruitment needs. This reservation salary fixed by the firm is equal to the average of desired salaries of all unemployed; it is given by [8]:

$$\text{reservation.salary}^t = \frac{\sum \text{Desired .salary}^t}{\text{number of unemplyed}^t} \quad (8)$$

- ***Step 3:*** To decide about the number of unemployed that the firm will recruit at the time t, we calculate the numbers of employees that the firm suppose have at time t, noted n^t [8];

$$n^t = \frac{\text{price}^{t-1} * \text{quantity}^{t-1}}{\text{reservation .salary}^{t-1}} \quad (9)$$

Where:

- ✓ price^{t-1}: is the sale price at time t-1,
- ✓ quantity^{t-1}: is the quantity produced at time t-1,
- ✓ $\text{reservation.salary}^{t-1}$: is the reservation salary fixed by the firm at time t-1.

For the first period; we take as price; quantity and reservation salary the average market values after benchmarking.

- ***Step 4:*** we compare the number of employed that the firm suppose have at time t that we note by n^t with the number of employed at time t-1:

  - If $n^t > \text{number.employed}^{t-1}$: the firm recruits a number of unemployed corresponding to the difference (n^t-number.employed^{t-1}), and which satisfy the following conditions:

$$\text{reservation.salary}^t > \text{Desired.salary}^t \quad (10)$$

  After that, these unemployed become employed with a salary noted by :

  And

  Salary= desired.salary

$$\text{nombre.employed}^t = n^t$$

  - If $n^t < \text{number.employed}^{t-1}$: the firm fires a number of employed corresponding to the difference (number.employed^{t-1}-n^t) .

  And $\text{nombre.employed}^t = n^t$

C. *Production*

The quantity produced by the firm is determined by the following equation:

$$\text{quantity}^t = \alpha^t * \text{nombre.employed}^t \quad (11)$$

Where:

- α^t: is the productivity, it is updated from one period to another by the following equation :

$$\alpha^t = (1 + \mu) * \alpha^{t-1} \quad (12)$$

- μ: is a random normal number.

Then we can define the firm's profit as follow:

$$\text{profit} - \text{firm}^t = \text{quantity}^t * \text{price}^t - \sum salary^t \quad (13)$$

$$\text{firm.wealth}^t = \text{firm.wealth}^{t-1} + \text{profit} - \text{firm}^t - \text{annuity}^t \quad (14)$$

D. *Consumption*

Gradually as the firm recruits people; it remains nevertheless unemployed in the environment; so to consume; we have distinguished two different groups to differentiate the employee consumption level; who receive salaries, and the one of unemployed who gets an unemployment allowance.

In addition to this distinction and among the assumptions of our model, we identified two groups of consumers; a first group which is based only on his wealth to consume; it is called: ‘ independent consumers’, and a second group where the agents determine their levels of consumption not only from their wealth but they also take into account the level of consumption of their neighbours, we call this group of consumers: ‘dependent consumers’.

Therefore, we have four groups of consumers to study theirs behaviours:

- Independent employees,
- Dependent employees,
- Independent unemployed,
- Dependent unemployed.

For the consumers wealth; it is given by the following equation:

$$\text{consumer.wealth}^t = \text{consumer.wealth}^{t-1} + \text{Salary}^t - \text{consumption}^t \quad (15)$$

1) *Independent employees*

For an independent employee, he spends a part of his salary and another propensity of his wealth to ensure his consumption:

$$\text{Consumption}^t = \delta_1 * \text{Salary}^t + \delta_2 * \text{wealth}^{t-1} \quad (16)$$

Where:

- δ_1: is the marginal propensity to consume out of salary;
- δ_2: is the marginal propensity to consume out of wealth.

2) *Dependent employees*

In addition to salaries; dependent employees take into account the neighbors consumption level to decide on their own consumption:

$$\text{Consumption}^{t} = (1-\lambda) * [\delta_1 * \text{Salary}^{t} + \delta_2 * \text{wealth}^{t-1}] + \lambda * \bar{c}^{t-1} \quad (17)$$

Where :

- λ : is the weight consumption;
- $\bar{c}$: is the average consumption of the other agents.

3) Independent unemployed

It is like for independent employees; except that instead of wages; the unemployed receive an indemnity of unemployment; and therefore their consumption is expressed as follows:

$$\text{Consumption}^{t} = \delta_1 * \text{Indemnity.unemployment} + \delta_2 * \text{wealth}^{t-1} \quad (18)$$

4) Dependent unemployed

Finally, we present the consumption of dependent unemployed:

$$\text{Consumption}^{t} = (1-\lambda) * [\delta_1 * \text{Indemnity.unemployment} + \delta_2 * \text{wealth}^{t-1}] + \lambda * \bar{c}^{t-1} \quad (19)$$

IV. AGENT-BASED TOOL FOR SIMULATING COMPLEX SYSTEMS

During the last years, the economists of the behavior made big progress in understanding the way that the real people behave in economic environments. Agent-based modeling is inspired by behavioral economics, while integrating its ideas to model agent behavior, and at the same time uses the power of the computer to simulate their behavior so that they can track their interactions, their consumption, production, budgets, loans, flow of goods and services, investment, negotiation, etc.

The techniques adopted in the analysis of complex systems are very different from those used in the conventional economy. They include data mining, network analysis, systems dynamics, agent-based modeling, nonlinear dynamics, disaster theory and critical phenomena theory [1]. The majority of the study of economic theory is based on agent-based modeling, knowing that the economy is composed of individual agents, each with the ability to act in his environment and evolve according to the behavior of others.

Agent-based models are radically different from conventional models. They are inherently decentralized computer models. They do not consist of a system of equations linking macroeconomic variables.

Agent-based simulation proposes to model explicitly the behavior of the entities; called agents and considers that the global dynamics of a system, at the macroscopic level, is the direct result of the interaction of behavior at the microscopic level. Indeed, agent-based approach allows modelling each individual's behavior and interactions that result from the pooling of these individuals. The global dynamics of the system is then a conclusion of all of these individuals [9].

Ferber [10] notes that agent-based simulation is designed for the analysis of complex systems. The complexity of a phenomenon is traduced by the interaction of a number of simple entities called agents. Each agent is characterized by the following properties:

- Autonomy: the agent controls his actions according to its internal state and its environment, without external intervention,
- Proactivity: the agent has his own business and his own goal and not just reacting to the environment,
- Adaptation: the agent is able to regulate his skills (communication, behavioral, etc.) depending of the agent with which it interacts and / or of the environment in which it operates [11].

The agent-based simulation models provide in general solutions to the limitations of the mathematical approach.

V. CONCLUSION

The individual behavior of an entity is directly influenced by the system as a whole, and at the same time the interactions of all entities have as a result an emergent behavior at the aggregate level of the system. The causal relationship between the size of an event and its consequences is no longer valid. Small changes have the ability to trigger large scale events.

We have therefore defined a model which allows us to dissect economic activities, specifically that of consumption; indeed we have presented the consumption of four types of agents, and this may surprise us after the simulation of the model, and therefore we expect the emergence of an emerging phenomenon as well as important results.

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