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AGENT BASED MODELLING OF AID

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SUMMARY

The issue of modelling international financial aid to underdeveloped countries baffled economists for decades. The initial assumptions (that outside aid could help bolster up the internally insufficient investment, thus helping economic growth) were statistically proven wrong; most of the recipient countries did not experience rapid growth, rather an increasing dependence on foreign aid. The question arises: what causes some countries to use the aid successfully whereas most fail to do so? What is the underlying reason for this difference across regions? And how could it be modelled?

In this paper I would like to show, that a hierarchical agent-based model might be able to model the complex international cooperation among aid-giving organizations and recipient countries, so that some light could be shed on the mechanics of efficient aid distribution.

KEY WORDS

growth, aid, agent-based modelling, adaptive agents

CLASSIFICATION

ACM Categories and subject descriptors: J.4 [Computer Applications]; Social and behavioral sciences – Sociology

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INTRODUCTION

Economists use modeling techniques for the same reason as practitioners of other sciences do: to describe, better understand and predict the workings of a system so complex which it is hard to fathom outright. Physicists, chemists, engineers are all plagued by the same demon: unless they simplify reality through modeling, the object of their research might not become understandable.

Since the time of Adam Smith, economists tried to advise the leaders of nations as to the “proper” path of the economy. The moral philosopher and theologist Smith developed his model to show that it is not immoral to have people work for their own financial gain; and that this greed-propelled individual behaviour is the true source of a nation’s wealth [1] as opposed to the merchantilist doctrines prominent at that time. While this line of thought became the backbone of modern economics, it failed to provide an answer to the real workings of the economy as a whole.

This paper aims at showing the problems of describing the dense social net known as economy. It will be revealed through the example of financial aid, that today’s economic models lack the necessary accuracy to predict the real changes in an economy caused by unforeseen forces like financial aid. An alternative way of modeling an economy will be suggested, that is supposed to have a greater explanatory and predictory power than the standard models. It will also be shown that using current technology it is possible to create such a model, and to use that model to evaluate the possible outcome of outside financial aid in a given economy.

FINANCIAL AID

The issue of financial aid is not a straightforward one. Why do the developed nations help the underdeveloped? Is it to win the goodwill of their people? To build up foreign markets for their own products? To prevent large-scale immigration? Whatever the motive, the theory is simple: giving money to low income countries will improve their quality of life.

It is obvious, that there are many moral and theoretical problems with such a statement, since it implicitly assumes that faster economic growth equals higher quality of living. In reality, many factors have to be taken into consideration (the utility function of the individuals in question[1], the aggregation of the utilities in the economy[2], etc.), but we usually disregard these, since they are not easy to describe numerically.

Even if we agree, that faster growth is better, one would have to know two things before resorting to aid: what determines growth, and how can this growth be affected.

Most models of financial aid use the neoclassical growth theory[3], that states, that stable economic growth depends on the population growth rate and corresponding capital growth rate. Based on this theory, an economy grows too slow if it does not have sufficient funds to provide the necessary capital investment to keep the country on the sable growth path. Ever since Keynes’ time, it has always been understood, that savings are an increasing function of wealth [2], and investment is funded from savings. From here the theory of aid is easy to deduct: investment has to be financed from an outside force, what would allow the nation to grow faster. A nearly similar result can be deducted from Martinás’ new microsynthesis [5]: the growth of money and the possible growth of capital can result in faster economic growth.

There are some problems with these theories. The greatest of them is the fact that they do not work. In some nations the outside financial aid resulted in incredible growth of both output and welfare (most notably in the East-Asian region, in Taiwan, Korea etc.), but in a rather larger number of cases, the aid had different results. Even in the best cases financial aid proved to be ineffective (as shown by Tsikata [6]), but in some nations it crowded out internal investment, increased consumption (thus reduced savings), developed aid-dependence, and in some case, Dutch disease. This gave rise to a large number of questions, most focused on why this happened, and what could be done against this.

If one examines the countries one-by-one, an other, even more relevant factor emerges. The example of Bosnia shows, that aid expenditure, while not achieving what it was meant to achieve, might result in a significant increase of welfare. The rebuilding of the war-demolished cities might show as an increase in consumption in aggregated macrovalues, but they sure did improve the quality of life. It is simply impossible to expect a nation to live in tents and spend aid on investment.

These effects seem to indicate, that it is generally flawed to assume that low income countries are best described by their GDP/capita and growth values, and that a richer description might allow better models to be constructed. With better models, aiding policies could be improved, and it would be easier to guarantee the desired effect.

AGENT-BASED MODELLING

Agent-based modelling is a computerized modeling approach that allows complex models to be constructed bottom-up. As opposed to standard modeling, the so-called individual- or agent-based models are simulations that describe the global consequences of local interactions of members of population. The individuals can represent many things; from cars in traffic through birds in a flock, to economic agents[4].

Agent-based modelling is a subset of multi-agent systems, where the complex whole is composed of several, communicating elements. Agent-based simulation differs from the general by being composed of autonomous agents.

AGENT-BASED VERSUS MATH-BASED MODELS

In an agent-based model, autonomous individual agents act in a predefined environment, and their behaviour as a whole defines the workings of the system. In the standard, math-based modeling, the behaviour of the individuals is "averaged together", and this average is described in mathematical terms. The key differences are:

- **Creation of the model**: in an agent-based model, the creator has to model the behaviour of the agents and the communication between them. In a mathematical model, one has to describe the whole system, and all interactions among the individuals have to be incorporated in the model to begin with. This means, that while in an agent-based scenario one can easily test the relevance of the agents (by comparing them to the real-life counterparts), it is hard to test the emergent macro-behaviour. In mathematical models it is quite the contrary: the model describes the macro-behaviour, which can be tested[5], whereas the underlying assumptions about the individuals remain hidden.
- **Macrobehaviour**: in math-based modelling it is easy to see, since the model describes it. In an agent-based environment, it has to be deducted from the agents' behaviour (it has to be summed somehow)
- **Changes of the outcome**: Once again, it is easier to see the direct changes in a mathematical model; however these changes might not be the relevant changes. In an agent-based system we can gather information about the changes in the members of the population, and not only in their aggregated behaviour.

All in all, agent-based models are more complex, but might be more relevant due to the fact that they are built up bottom-up, as opposed to the declarative construction of the mathematical models.

ADAPTIVE AGENTS

This is where the true power of the agent-based approach lies. Who is to say, that the agents in the system have to be described by static rules? An average agent is described by type characteristics, internalized behavioural norms, internal modes of behaviour and internally stored information about itself and other agents (state information). The internal modes of behaviour usually describes the means of communication an agent has and it's decision making rules; and it is rather easy to implement a set of rules that allow the agents to actually learn. As opposed to math-based models, the individual-based models can learn in a distributed fashion, thus more accurately describe thinking entities. In this regard it is irrelevant how they "think", but it is possible to use advanced artificial intelligence in them, namely neural networks and genetic algorithms, not only the standard if-then structures.

ECONOMIC APPLICATIONS

When discussing the issue of emergence, emergent behaviour in their book about swarm intelligence, the first example Kennedy and Eberhart bring forth is the example of an economy. They quote Smith, and his invisible hand theory, and claim that the seemingly self-organizing nature of the marketplace is nothing else but an emergent behaviour [8]. This clearly shows that the agent-based technology can intuitively be used for economic applications.

The agent-based modelling is very much like a culture-dish experiment: to begin the work, a model economy must be constructed from a set of agents. These agents represent both the economic actors and the environment (social, cultural etc. issues). After the economy is thus initialized, it is left to evolve, and the macrobehaviour emerges from the interactions of the agents, exactly as Smith described it. There can be no external interaction, only agent-agent interactions are allowed (for example, the price cannot be determined externally; it has to evolve from the decision(s) of one or more agents).

A great many issues arise when modelling an economy in this context. One of the greatest questions is: how do the agents "think", how do they behave? In some cases it is not needed that the agents behave like humans do, thus standard learning algorithms can be used. In other situations (when modelling social interactions), it is crucial that the agents behave as humans do, so new types of learning algorithms must be used.

It is also non-trivial to develop the protocols used among the agents. These protocols define the marketplaces (and off-the-market transactions) among the agents in the model, so it has great impact on the actual outcome of the simulation. A related issue is the formation of trade networks. What algorithms do the agents use to determine trade partners? Do they do it randomly? Do they incorporate past experience?[6]

The use of these experiments, however, promises to provide answers to questions which remain unanswerable in the standard terminology. These include:

- The development of cooperation among agents (does this appear in emergent behaviour?).
- The "social utility" of a society is easily calculated, since every agent's utility is known; they can be aggregated using all methods available (this makes it possible to evaluate the outcome of an action using different "preferences", social utility functions).

- The resulting income distribution, the emergent inequality in the economy (in some models, it is not easy to see the difference between social utility and inequality, but the more kind of agents we use, the more colourful the picture becomes).
- The effect of interaction networks, channels of information on the emergent economy (this is, in essence, the relationship between market structures and the emergent macroeconomic behaviour).
- The relationship between legislation and corporate capital structure (where do they get the necessary capital to invest?).

THE ASPEN MODEL

Finally it is useful to look at a rather complex agent-based economy model: the ASPEN model, Fig. 1. It is, in essence, a model of the US economy as a whole.

The early ASPEN model was a rather primitive issue; it only contained market forces: the household (composed of 1000 agents), the "firm", producing food (4 agents), and a government (1 agent). This model was run at a daily decision cycle for 30 simulation years, and it could show a 7-year periodicity in the economy [9]. This alone shows, that the microsimulation is a very powerful tool, and that the model worked according to expectations.

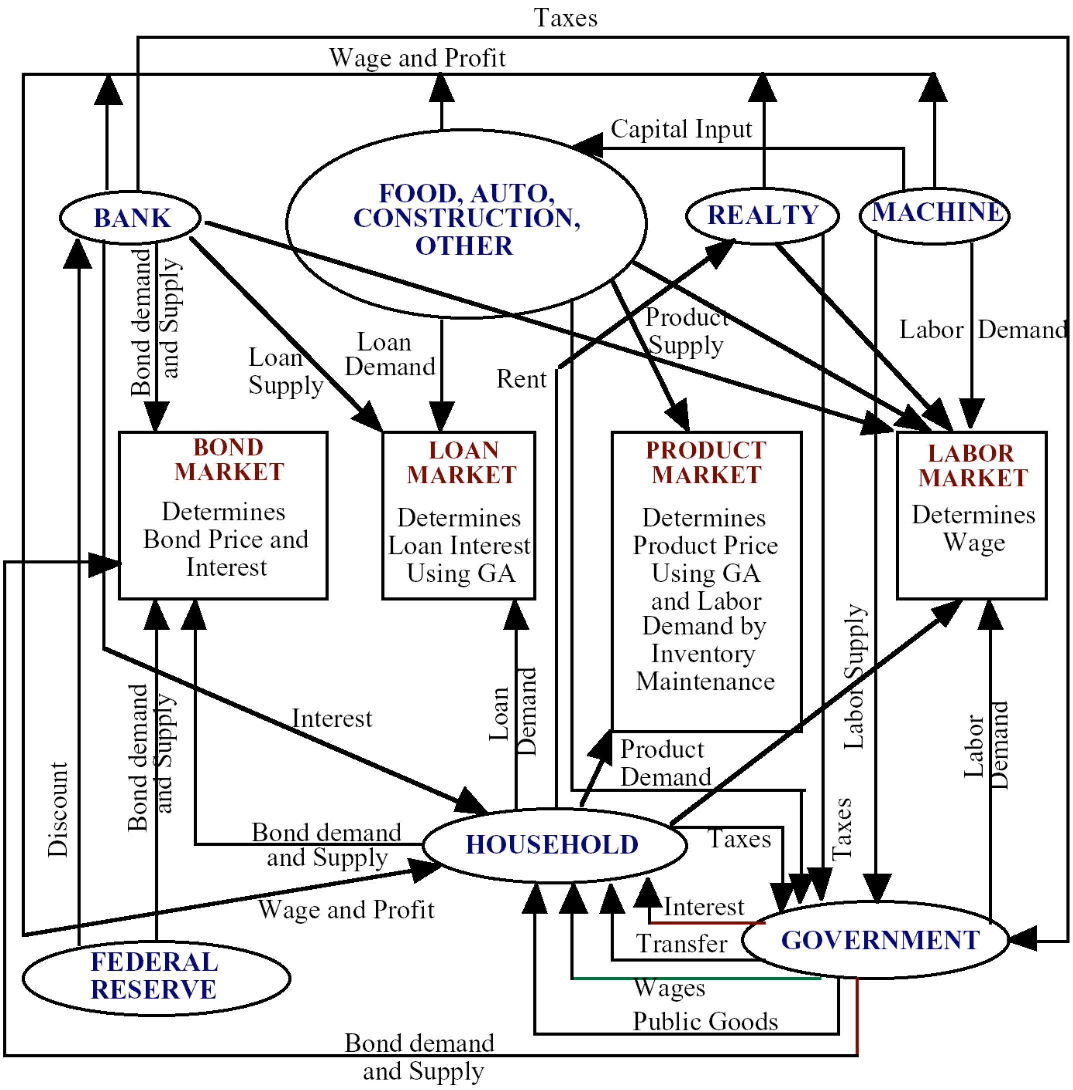

Figure 1. Interaction among agents in the ASPEN simulation [10].

This alone was a great result, but it was far from the intended accuracy. ASPEN was developed to allow:

1. examining the results of legal, regulatory and policy-changes
2. examining the various sectors of the economy independently
3. simulation of the economic agents
4. observing the economy as a whole

and the initial mode was rather far from realizing this ambitious goal.

The next step was to create a more complex model, which could fulfil the promises of the developers. This model needed a more complex structure that incorporated other sectors and the banking system, as well. Using this more complex model they have been able to predict the workings of the market with such a level of accuracy that was not possible before; thus proving the model and the concept sound.

During the past decade, computing and simulation has developed with exponential speed. The initial ASPEN model was run at the US Government's SANDIA laboratory, then housing the fastest computer in the world, the massively-parallel "TERAFLOP" computer. It had 9200 PII processors and 3.1 Teraflop peak performance. Just for comparisons' sake, the new Playstation III gaming console that is to be released coming January will possess 2 Teraflops of computing capacity. What is more, advances in GRID computing could theoretically provide unlimited processing power[7]. This allows the models to become immensely more complex, thus more lifelike.

Seeing that agent-based modelling theoretically provides the answer to many questions which remain unanswerable by other means, and also that there is a working model that has great explanatory power in a given economy, it seems clear, that such a simulation could provide the answers we need about financial aid. But how should such a simulation be constructed?

THE ABMA MODEL

The researchers at Sandia labs successfully used the ASPEN model to predict the changes in price level, output, exchange rate, and even to simulate the possible outcome of an infrastructure loss of the economy. If such a large and complex economy could successfully be modelled, it must be relatively easy to construct a model of the low-income countries that could predict the effect of financial aid. In order to do so, however, we need a structure that allows the modelling of various countries, so that there would be no need to construct brand-new models for every possible country.

BASIC STRUCTURE

The idea behind the ABMA model is simple: let us create the formal workings of a low-income country, and the specifics should appear as differences in the distribution of agents. This would allow a singular framework to be used in all experiments, yet would make possible to incorporate country-specific information in the prediction process.

As shown in Fig. 2, the soul of the ABMA model is a populator module. This takes as its input the statistical data that describes the country to be modelled, and produces the set of agents that can model the given economy. Through this method it becomes possible to use a unified model for the agents, and yet allow different countries to be modelled. The populator module would be ran only once, at the initializing stage, and after it created the necessary number and type of agents, all the changes are internal to the economy.

This process makes it possible to create Petri-dish economies that can be played with. To test any hypothesis, one only has to induce an external change to the economy, for example command the “central bank” agent to reduce the reserve ratio. After the external change had been made, the agents slowly adapt to the new situation (the “bank” type agents will increase their lending, the “corporation” type agents will increase their investment, etc ...), and the emergent behaviour will be the aggregated macro-effect.

KEY PROBLEMS

Creating a framework that would allow the description of low-income countries is a hard task in itself. It needs to possess great descriptive power, yet not contain crucial information about the countries. The country-specific information has to be coded in the composition of the agents, what might be a tougher task than it looks (since it demands, that the key differences among the countries have to be identified and simulated on agent-level).

Creating the framework might not be as hard as the description of the social systems. In an agent-based environment, the social structure is best displayed by having multiple types of “person” agents, that have different characteristics (utility functions, etc., to describe “homo economicus”, “homo custodius”, etc.), and the mixing of these agents in the proper ratio would result in the desired social framework. Here the question of “base” person-types arises: how should one divide up the “human” agents? Along their utility function? The education they received (implying their productivity)? Along multiple dimensions?

Another troublesome issue is the thought processes of the agents. It is pretty moot to make them think differently (so the method of “thinking” should be the same), but it is not trivial whether it can be beneficial to allow some agents to “remember” better than the others.

The creation of the “populator module” contains a large number of implicit assumptions about the modelling technology. These regard:

- input data types: the assumption is, that the key differences among countries can be deducted from statistical data. The term “statistical data” is rather vague: what kind of data do we need to be able to describe the aforementioned social system, for example? What has to be known to be able to tell apart the social framework of Zimbabwe and Timbuktu?
- data availability: is this data available? If not, can they be replaced by other data? If neither, what is to be done?
- population process: It is assumed, that by having the necessary “statistical data”, it is straightforward to create the proper number and type of agents. Is it a deterministic process? Or does the populator module use a stochastic function to create the population of the Petri-dish economy?

It is easy to see, that these problems do not appear with equal weight to each and every kind of agent. The agents representing the bank sector can be relatively easily described from data by IMF. The government itself is a relatively easily describable entity. The households, however, are a lot trickier (for example they need to be described in a hierarchical fashion; their earnings and consumptions are partially individual, and partially family-based). How to create the “families of agents” is a rather complicated problem.

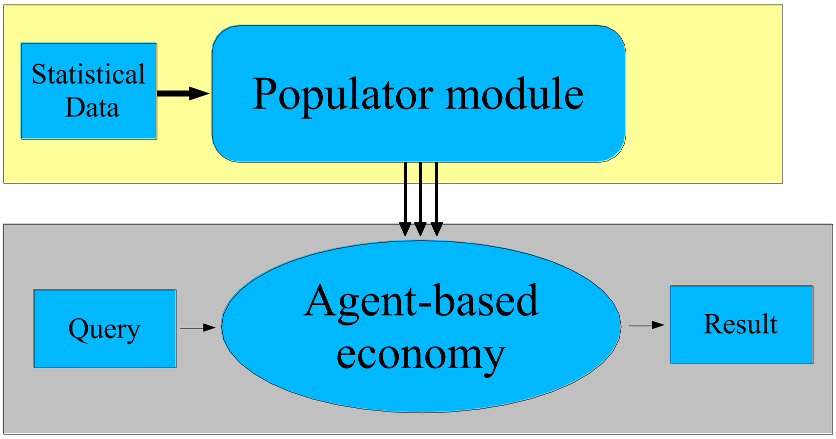

Figure 2. The ABMA model.

Last but certainly not least, it is crucial to be able to depict foreign trade. This is usually done by introducing another agent, the “rest of the world” agent. Whereas it is not a pretty solution modelling-wise, it is not really far-flung, since most low-income countries are “small” countries, meaning that they have precious little effect on the world market as a whole.

CONCLUSION

It was shown, that agent-based modelling is a radically different approach to economic modelling than the standard framework. Agent-based simulation allows the modeller to delve into the micro-workings of the economy, and gather information not only about the economy as a whole, but about the changes in the state of the individuals as well. This might allow a better evaluation of the changes (since we can directly see the changes in the utility and inequality, whereas normally these values would remain hidden in a macromodel), and could also mean better predictive ability regarding the future of our economy.

There are no computational differences in the implementation of this model. Current advances in the information technologies infrastructure make it easy to collect sufficient amount of CPU power to run such a model fast enough to gather the needed data in time.

Theoretical problems persist, however. A transparent agent-based model needs to be developed, that would allow the modeling of all low-income countries. A populator module is also needed, that would be responsible for the creation of the required number and type of agents in the economy. Finally a suitable method for indicating the various ways of providing financial aid is needed, so that the most beneficent way of providing financial aid can be found.

REMARKS

[1]My favorite example here is the hours worked. It is easy to see that if people worked more, they would produce more goods in the economy, what would make the price level lower and the products easier to export, an overall gain for the economy, resulting in faster growth. At the same time, the people would not enjoy themselves so much as before, meaning that their utility would actually decrease from this change.

[2]The two corner-solutions are the max(U_i) and min(U_i) functions; the first leading to dictatorship (only the dictator's utility matters), the last resulting in an extreme social economy, where everyone’s utility would be equal.

[3]The original developed by Samuelson and Solow, described in detail in [3] and in [4].

[4]An agent can be anything that has sensors to percept its environment, and uses its effectors to act on it [7].

[5]See: aid. The model failed.

[6]It is easy to see, that this issue is not unrelated to the “thinking” of the agent. Agents using evolutionary algorithms might choose random partners and evaluate them according to a “fitness” function (more beneficial partners get higher scores, thus will be more likely candidates in the upcoming time). A neural network based agent, however, is less likely to act randomly, and will stick to satisfactory partners more than an evolutionary agent.

The true beauty of the agent-based approach lies in the fact, that it is perfectly easy to create a model economy composed of agents with different behaviours. What is more, the simulation can answer the question: which kind of “thought” is the more successful?

[7]In our case, GRID is not a solution. Whereas it is a marvellous platform to analyse the CERN data, its bottleneck is the communication channel. An adaptive agent-based simulation needs fast communication among the computing nodes, so a large capacity multi-processor system seems a better solution than a computing GRID.

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MODELIRANJE POMOĆI PUTEM AGENATA

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SAŽETAK

Pitanjem modeliranja međunarodne financijske pomoći ekonomisti se bave desetljećima. Statistički je dokazana pogrešnost početne pretpostavke kako vanjska pomoć potpomaže unutarnje, inače nedostatne, investicije čime doprinosi ekonomskom rastu jer većina zemalja koje su primale pomoć nije zabilježila brzi rast nego povećanu

ovisnost o vanjskoj pomoći. Pitanja koje se nameću su: zbog čega neke države uspješno koriste pomoć dok većini to ne uspijeva? Kako objasniti tu razliku po regijama? Kako navedenu pojavu modelirati?

U ovom radu pokazujem da hijerarhijski model temeljen na agentima može omogućiti modeliranje složenih međunarodnih kooperacija između organizacija za pomoć i država primateljica pomoći, radi doprinosa razumijevanju mehanizama učinkovite raspodjele pomoći.

KLJUČNE RIJEČI

rast, pomoć, modeliranje putem agenata, adaptivni agenti