Interdisciplinary Description of Complex Systems 4(2), 89-101, 2006

AID COMPETITION – A SIMPLE AGENT-BASED MODEL OF COMPETITION FOR FINANCIAL AID

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Category: Conference paper *Received:* 1 May, 2006. *Accepted:* 15 January 2007.

SUMMARY

The research into the effectiveness of financial aid is gaining momentum lately. Some say it is ineffective, some say it could be effective, but all seem to agree that some of its aspects are currently unmapped.

This article aims at showing a rather simplistic agent-based model that might hint at a possible useful approach of the issue. It will be shown, that the donor policies do influence stability, convergence and the path of economic growth.

KEY WORDS

aid, agent-based modelling, competition

CLASSIFICATION

JEL: C65, I38

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INTRODUCTION

The issue of financial aid is getting more and more into focus these days. The International Monetary Fond releases study after study discussing the theoretical and empirical problems arising in their day-to-day practices.

The general idea behind financial aid is to induce economic growth in the recipient nation. There can be various reasons for wanting that: humanitarian (improving the quality of life, health, life expectancy of the population) economic (generating market, developing the extraction of natural resources) and social (prevent migration). Most of these reasons emphasize the need to increase the per-capita output of the recipient nation, even though some of these goals are easier to achieve using a different approach. Thus the theory of financial aid developed from the theory of economic growth.

In the 1950s-70s many western nations actively engaged in the aiding movement. Billions of dollars were spent on improving the productivity of low income nations, but the expected expansion never happened. Starting from the 1990s economists started to question the efficiency and even the effectiveness of financial aid. Many studies, e.g. [1 – 4], showed that financial aid has dubious effects (at times it even hinders growth).

The goal of this paper is to build up a simple and efficient agent-based modeling framework, that makes it possible to investigate the relationship between donor policies and the resulting economic growth. It will be shown, that it is possible to create a relevant model using even the simplest possible agent-based approach. It will be demonstrated, that the proper donor policies can lead to converging macrosystems and better life expectancy across multiple regions.

AGENT BASED SIMULATION

Agent-based simulation is a bottom-up approach to building models. It focuses on modeling the low level entities, and then drawing the conclusions after seeing how they interact in the modeling environment.

POSSIBLE APPROACHES

Since financial aid is such a complex issue, agent based modeling can be utilized in various ways. These approaches differ mostly in their depth – and consequently, in their speed and execution cost. The three models discussed are: (1) the high-level Nation model, (2) the low-level Family model, and (3) the integrated Hierarchical model.

Nation model

The Nation model, or “Agents as nations” model basically focuses on the national level. The agents in this simulation approach are the members of the aiding process. The modeled activities are the interactions of the nations. Since the internal workings of every agent can be as complex as necessary, the end result can contain information about the internal states of the nations, too.

The agents in this approach face macroeconomic decisions. How much value should be spent on consumption? How much of the savings should be channeled to investment? Does the government intervene? How much aid should be given/how should the received aid be used?

This approach is advantageous in may ways. It provides for fast simulations, since the processing power requirements are relatively small. The results which can be obtained from

this model are easy to interpret, since the agents are the modeled nations themselves, so their rvariables can be read directly. It is easy to introduce a form of decision making process to the national level that mimics "planning", that might lead to unforeseeable outcomes. Last but not least, using a Nation model one can observe the relationships among different countries. Which national strategy could lead to a dominant position? Which strategy could lead to the highest amount of aid received?

The significant problem of this model is that it is oversimplified. The internal workings of the agents are – no matter how detailed – given as macromodels, so this proves no true micro-macro synthesis.

Family model

The Family model, or Agents as Families focuses on the "atomic" entity within a society. This could either be interpreted as the individual or as the family. In case of most short-run models this distinction is irrelevant, as these agents face decisions about consumption, savings and work. If, however, the simulation deals with health care issues or individual consumer choices, families cannot be equated with individuals. A further problem is, that long run models also have to deal with mortality and birth. (Models based on "families" are better at dealing with communal consumption, since they do not have to worry about the formation of "micro-societies". Individual based models are better at dealing with birth and death.)

The Family model is significantly more detailed than the Nation model. It provides a detailed micro-macro synthesis: the relationships modeled are microeconomic in nature (the "agents" decide how they are spending their time, "where" they work, "what" they buy, etc.) These models are capable of dealing with various different corporate sectors in the economy, thus does not have to use a unique product – or a unique price level within the nation. Sectoral shocks can be introduced/modeled, which enables the observation of phenomena like the development of dutch disease.

A further advantage is, that "thinking" can easily be simulated in this environment. Thinking is, once again, at the agent level – but at this time agents are individuals/families, firms, government entities (or even banks), not nations. This allows for more natural approach to modeling thought, what will enhance the model's verifiability.

This model is not without its share of problems, however. It requires a large amount of agents to run, thus will consume huge amount of processing power. This leaves simulations more costly in terms of processing power, time and money, making experimentation in this environment both slower and pricier. The other issue is even more worrisome: since only a single nation is modeled, international relationships (like financial aid) are not incorporated. (An example of these kinds of models is the Scandia National Laboratories' ASPEN model, that simulated the US economy and three of its sectors, supported by government and the bank sector [5].)

Hierarchical model

The hierarchical model is an attempt to blend the multiple-nation approach of the Nation model with the detail of the Family model.

The Nation model focuses on the fact that its entities are models of nations, whereas the Family model models nations. It is, then, easy to see that by "plugging in" one or more Family models into the Nation model, the accuracy of some aspects of the high-level Nation model can be increased. One could, for example, model aid donors and aid beneficiaries with simple macroeconomic models, and replace one beneficiary with a family model. This

approach would slightly increase the complexity of the Family model, but would enable the nation to engage in international trade and receive financial aid. Another possibility would be to include a family model to the donors. This could help evaluate the positive effects of giving aid. The most detailed picture could be gained if all nations were modeled with Family models, but that would slow down modeling speed considerably.

Comparison of the different approaches

It is easy to see that there is a strong trade off between detail and processing speed among the various modeling approaches. There is no obvious "good" or "bad" among them, one has to choose the appropriate approach for a given task. The following table summarizes the relevant attributes of the different approaches.

Table 1. Comparison of different approaches to modelling of financial aid.

	Nation model	Family model	Hierarchical model
Detail	-	+	++
Ease of extraction of results	++	-	-
International connections	+	-	+
Speed	++	-	--
Complexity	-	+	++

MODELING ENVIRONMENTS

The problem with agent-based modeling is that its rather computer-intensive. There are various environments to help the social scientist, but these usually place severe restrictions on the models themselves. For this reason it is important to be able to quickly review the various environments helping the modeling process.

Mathematical frameworks

The most simplistic agent based models can be depicted as a set of equations, in essence as a symbolic model. In this case simulation can be done using some general mathematical framework[1]. The advantage of this approach is, that it allows the social scientist to use known tools, resulting in a flatter learning curve. The disadvantage is also obvious: this leaves the agent-based approach a thought experiment, and disables most of the opportunities presented by agent based modeling.

Agent-based modeling frameworks

These frameworks are designed especially for aiding the development of agent-based models. They usually require some degree of programing knowledge, but allow for rapid development of agent based models. The usual trade-off is between ease of use and model complexity.

Programing languages

If the concern is the runtime of the simulation, then using a programing language to develop the agent-based model can be the ideal solution. This, of course, requires significant programing skills, but can potentially lead to the smallest possible execution time.

Selected environment

The "Agents as nations" model uses the Repast modeling environment, which is a modeling framework designed for social scientists. It is rather straightforward to use with sufficient programing knowledge, and provides excellent support for model creation and display.

THE NATION MODEL OF AID

The declared goal of the model is to be able to show the relationship between the aiding process and the state of the recipient nations. In order to do so, the model needs to be able to show international connections, so the Family model is unsuitable. Aiming for ease of use and development, the Nation model was chosen, since it can show all the necessary information, but remains small and well-contained at the same time.

THEORETICAL BACKGROUND

The model incorporates two kinds of nations: aid donors and aid beneficiaries. It focuses on the important aspect of the aid relations, so there is no trade among the nations, no consumption in any nation – the model essentially disregards how will income be utilized. A simple assumption can justify this: the aid beneficiaries produce only non-tradable goods. This means, that regardless of their output, they will consume it all, since their product is not sold on the international marketplace. This might seem a strong assumption, but can be valid for a number of low income countries[2].

These agents interact with each other only through the aid distribution process: donors provide aid, whereas the beneficiaries use it to purchase goods and services from the international marketplace.

Donor model

In this model, the donors are kept as simple as possible. Since we only worry about how their decisions and policies affect the recipients, there is no actual need to simulate their internal structure. From the model's point of view, donors are "infinite sources" of aid. Part of this aid gets distributed evenly among the recipient nations (to prevent "aid starvation"; even the worst performers should get a chance to buy tradable goods – which can only be bought from financial aid, since the recipients produce only nontradable products). The other part of the aid will get distributed according to the policies of the donors. Considering that the purpose of the model is to determine the effect of the donor policies, it is important that they should be easily to change.

Beneficiary model

The beneficiaries are modeled with a simple, production-oriented macroeconomic model. They use three resources (labour, capital and land, although land will remain unused in this version of the model), and have a Cobb-Douglas type production function

$$F(K, L, A = \alpha K^{\beta} L^{\gamma} A^{\delta}, \beta + \gamma + \delta = 1.$$

The model does not deal with consumption (assumes that production is always at the potential level). This implicitly assumes a neoclassical model, where consumption and savings only determine the distribution of production[3].

The model emphasizes production, and thus factors of production. The current version uses labor and capital, and treats them both as endogenous variables. In case of the capital goods, this means that although they have an initial stock, their amount will change in time. The model

handles amortization (a parameter described in years, meaning the average time a capital good becomes unusable). As opposed to the standard neoclassical model, these low income nations are completely unable to produce capital goods, thus investment will not be backed by savings, rather a portion of the financial aid can be diverted and utilized for this purpose.

The other factor of production, labor, changes with time, as well. The growth of the labor force is described with the fertility rate $r_{\text{fertility}}$. Its counterpart is the mortality rate $r_{\text{mortality}}$, that shows the percentage of the population that dies by the end of the year. These ratios are fixed for a nation, but they can decide to spend a portion of aid on medication, that will reduce the mortality rate.

These two constraints determine the decisions a nation faces. They get to allocate the received financial aid between medication and capital goods. One helps replace the capital stock, the other makes people live longer. The capital goods are purchased at a price, the medication's cost is unity (in essence, the price of the capital is a relative price between medication and capital).

Capital changes according to the following equation:

$$K_{\text{new}} = K_{\text{old}}\left(1 - \frac{1}{\text{amortization\_years}}\right) + \frac{a_{\text{K}}}{P_{\text{K}}}$$

where a_{K} is the amount of aid spent on capital, P_{K} is the price of capital. It is clear to see, that increasing the average durability of the investment goods (the amortization years) the capital stock would deplete slower. Also, allocating more aid on capital or a reduction in the price of capital would speed up capital accumulation.

Labor is governed by the following rule:

$$L_{\text{new}} = L_{\text{old}} \cdot \exp\left[r_{\text{fertility}} - r_{\text{mortality}}\left(1 - \frac{a_{\text{M}}}{a_{\text{M}} + L_{\text{old}} / \mathit{eff}_{\text{med}}}\right)\right]$$

where a_{M} is the amount of aid spent on medication. The variable $\mathit{eff}_{\text{med}}$ is the medication effectiveness, basically describing the effectiveness of medication to reduce mortality rate. With unity medication effector, if the country spends one unit of aid for each member of its population, they effectively halve the mortality rate. Spending twice that amount cuts the mortality rate by 2/3, etc. If the medication effector is 0, the medication has hardly any effect on the population. If it is infinity, the population becomes immortal.

Model parameters

In order to make the model easier to use, a number of parameters got their graphical controls. Some of these parameters deal with the system as a whole, others determine the workings of the aid donor.

The parameters used in the model level:

- Capital cost: describes the relative cost of capital to medication. Increasing this value would make it more expensive to invest in capital goods.
- Average amortization time: this variable sets the durability of the goods used in the production process. Increasing its value makes capital deplete slower.
- Medication effectiveness: increasing this value will make a unit of medicine do more work.

The parameters of the donor(s):

- Distributed aid: The amount of aid the donor can distribute annually.
- Aid to be distributed evenly: this percentage of the aid gets distributed evenly among the

aid recipients. This allows, that no matter the chosen aiding policy, no nation will be left without the opportunity to prosper.

- Donor behaviour: This is the most important parameter, since we want to evaluate its effect on the output and population of the recipient nations. Notable goals include: output per capita, percentile change in output levels, change of the output level, level of the output and population count.

The parameters for the beneficiaries:

- Initial population: this effectively sets the labor force. Distinction between the two is unnecessary, since consumption is disregarded.
- Initial land: this will not change in this version of the model, only incorporated to make extension easier.
- Initial capital: the starting capital stock
- Fertility and Mortality rates: determine the labor growth rate.

PROGRAMING DECISIONS

The most important programing decision was the extensive use of interfaces. The various elements in the model connect through pre-defined ways, and this makes the model easy to extend.

The most important interface is that of the decision rules. Any object implementing this interface can be used in the model as a possible "rule" for the aid donors to choose how much money would the various possible recipient countries receive. Other interfaces include the one defining the aid donors, and another describing aid recipients.

For easier use, some parameters of the donor(s) are wired to the main console. This makes causing global changes in the system easier to implement.

NOTABLE RESULTS

Even though the model used is oversimplified, a number of significant results are obtained from it.

In the comparative experiments three distinct nations were used. Nation "RED" was the least developed, had low capital stock, and high mortality rate. The fertility rate and the population count was highest here. The "BLUE" nation was the opposite: had relatively high capital stock and comparatively low population, with low fertility and even lower mortality rate. The "GREEN" nation was the middle ground, possessing both average capital stock and population, having intermediate fertility and mortality rates. The initial resource allocation was determined, so that all nations would have the same level of output.

A single donor was used, thus only one donor policy was present at a time. This setup allows to examine how a particular policy affects the recipient nations.

Convergence and stability

Probably the greatest result of the model is that convergence and stability can be achieved. In case the donors choose to award more aid for higher positive change to output, the beneficiaries start to focus on their output levels. This causes the overall levels of production to converge. This has the side effect of stabilizing population, thus stabilizing per-capita GDP stabilizes, as well.

The aid distributed among the nations fluctuate, Fig. 1. Initially the higher population of the RED nation allows it for fast expansion through heavy investment in capital stock, but its growth hits a curb and after that the "average" GREEN nation soars. Throughout all this BLUE has stable growth, until it flats out at its potential output.

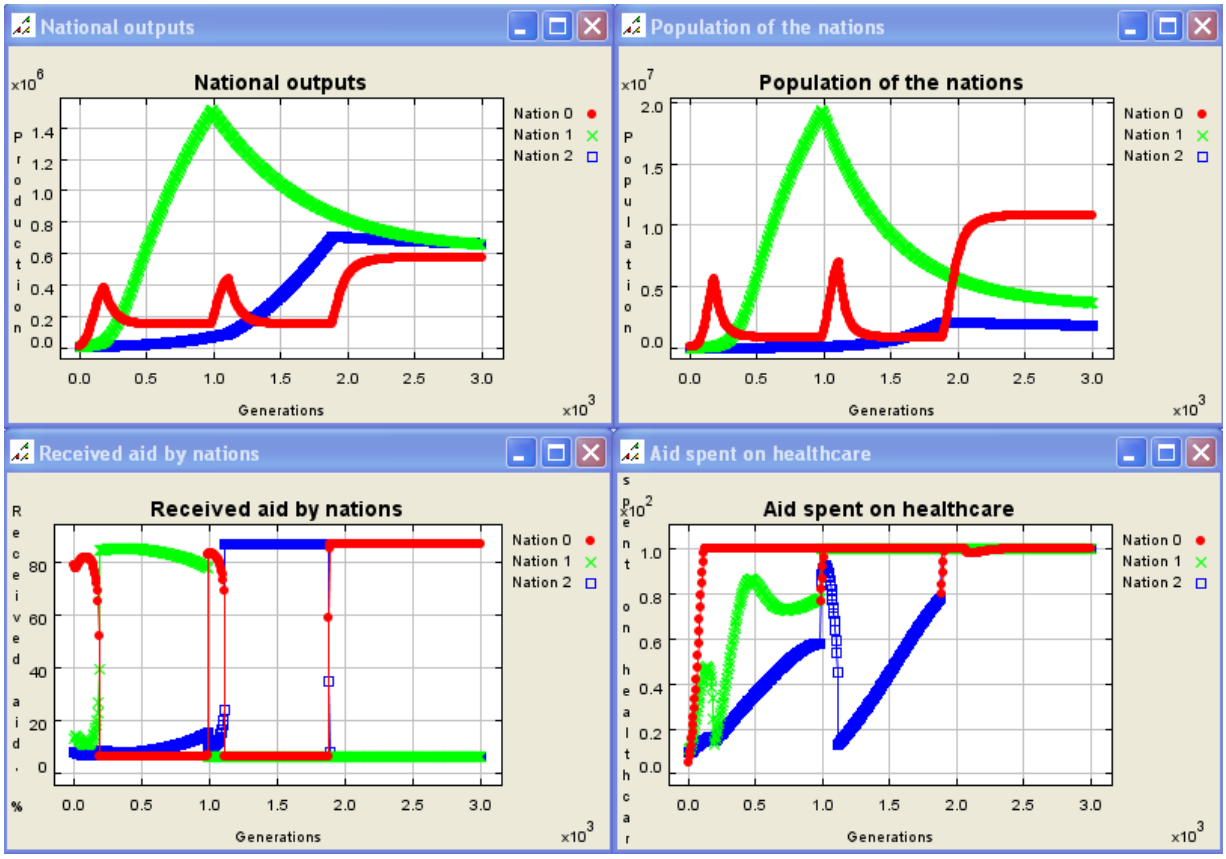

Fig. 1. Time dependence of aid in case of tri nations.

The aid utilization is clearly beneficial for humanitarian reasons. Following its own goals of maximizing production, RED ends up spending nearly all of its aid on healthcare very fast. The other nations adopt this policy later on. It is also important to notice that all nations periodically need investments to replenish their capital stocks, but after that they will return to finance medication.

It is also important to note, that the system stabilizes even if the chosen policy is to maximize the change in the per-capita output. The exact path of the convergence will be different, for obvious reasons, but the end results are comparable. Per-capita outputs do not converge but they stabilize, as before. Population levels stabilize, and the nations have the same order as before, Fig. 2.

The amount of aid received fluctuates here, too. In this scenario the BLUE country can take a good head start, since its low population grants it a high per-capita output, thus ensuring more aid in the early times. The utilization of the aid shows a clear focus on humanitarian benefits. In those countries where the living conditions are bad, a heavy investment in healthcare becomes dominant at a very early stage. Even the relatively advanced BLUE country converges slowly to the all-healthcare policy.

Problem of local maxima

The model also shows the problem of the “greedy” algorithm of decision making. If the countries always do what is best for them in the short run, they might miss out on long run opportunities, Fig. 3.

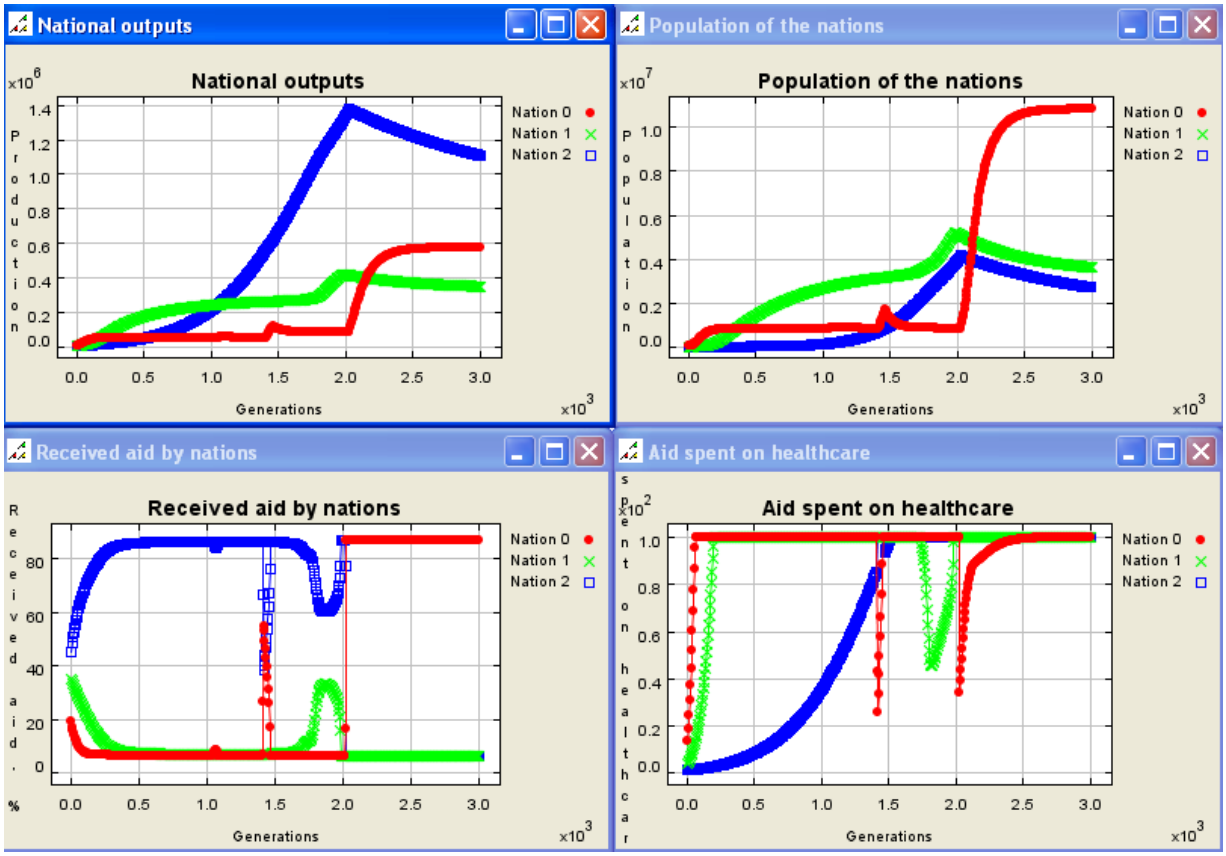

Fig. 2. Time dependence of aid.

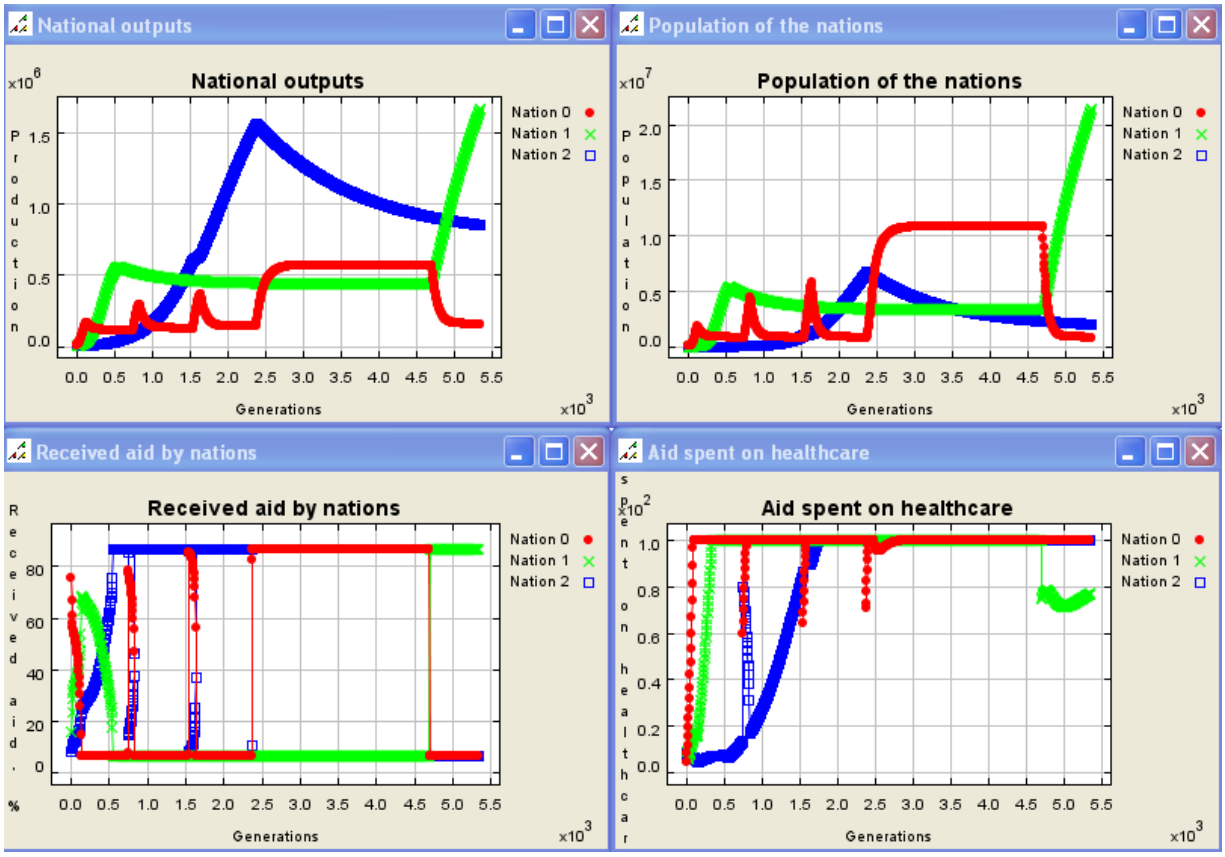

Fig. 3. Consequences of "greedy" algorithm of decision making.

In this experiment, the target was the percentile change of total output. This lead to a weird anomaly:

- it is obvious, that the nations perform better, when they spend heavily in capital (in case of the RED country's three booms, an investment surge is apparent. BLUE moved away from investment, and its production fell. When GREEN finally decided to focus on investment, both its population and production skyrocketed),
- despite this, all nations prefer to invest heavily in healthcare.

It is quite likely, that if the decision making was not simply rule-based, but some sort of "memory" or "experimentation" was built into the model, it would be able to avoid this problem of "local maxima"[4].

Strategy forming

A completely unexpected but welcome result was the parallel to the real-life situation, where the beneficiaries "outsmart" the donors. By knowing the decision making of the aid donors, recipients make their decisions to gain more aid, and not to achieve the initial goals. This might lead to following the donor's intention to the letter, and at the same time causing great damage to other aspects of the economy.

The example scenario looked at what happens if the donor wants great growth in population, when medication is rather ineffective, Fig. 4.

It is clear, that by setting the population goal the donor more or less achieved its aim. It stabilized the population levels in two countries, and the population stabilized even in RED, although after a significant demographic catastrophe. For obvious reasons all nations spend all of their money on healthcare, trying to extract as much aid from the donor as possible. The

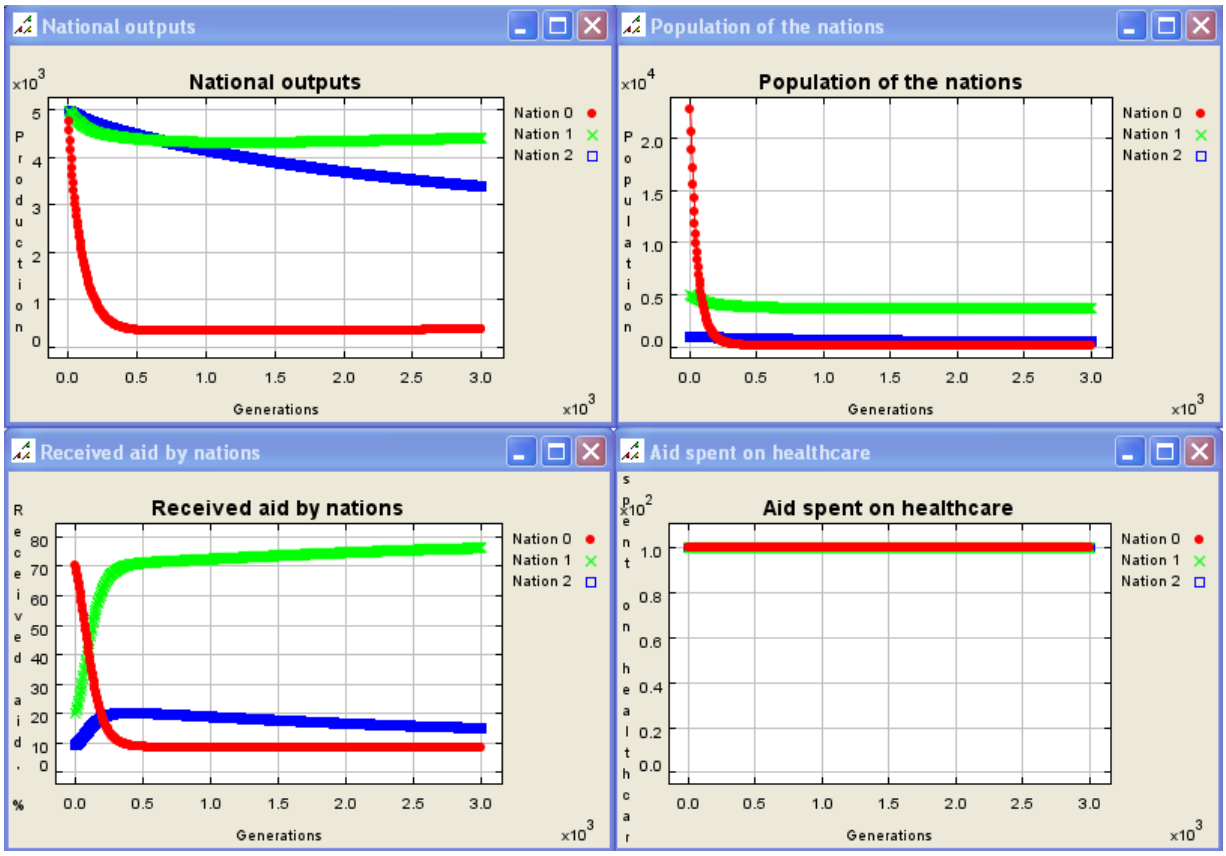

Fig. 4. Time dependence of aid with ineffective medication.

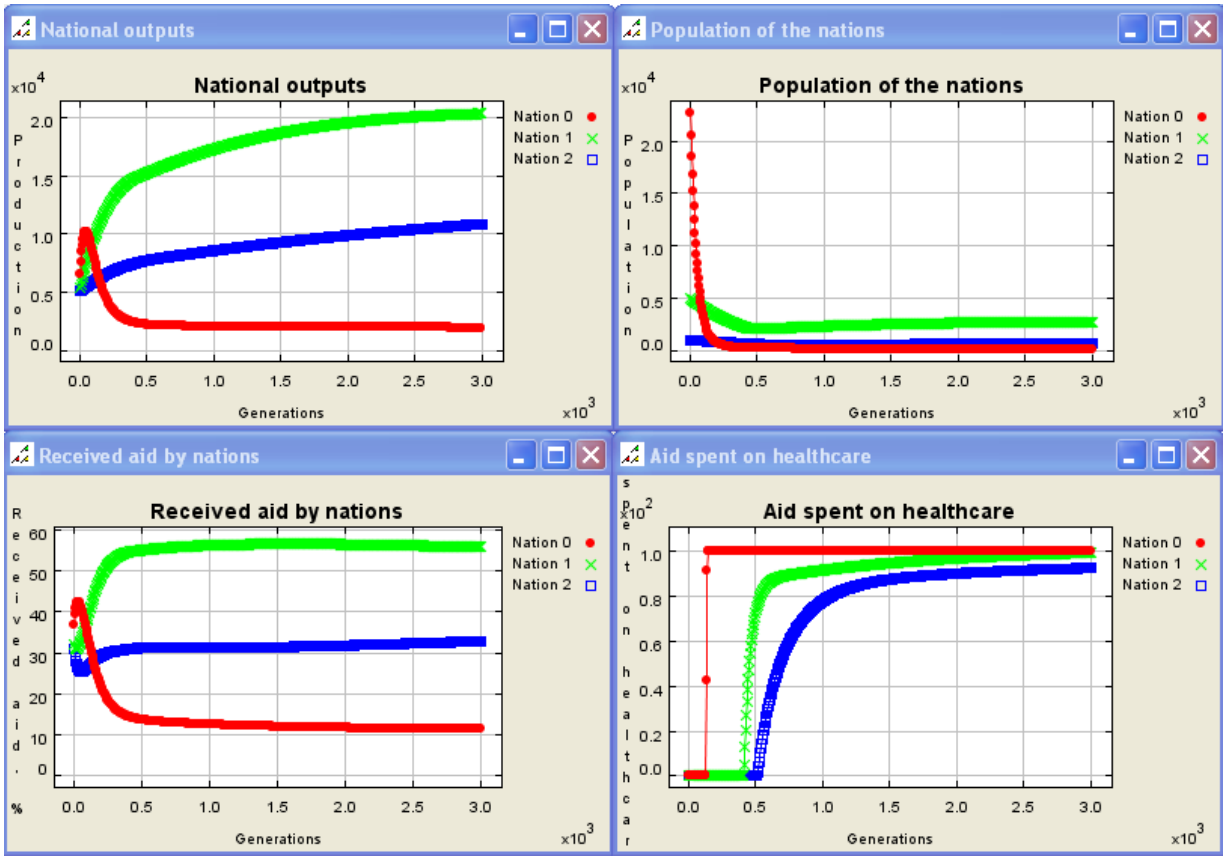

Fig. 5. Time dependence of aid with set goal.

side effect is, that the output decreased in all nations, and there is no sign of recovery, only stability. In addition to that, both aid distribution and utilization are distorted.

Should the aid donor choose a different approach, the end result might be more beneficial overall. In the same basic setup, setting an output growth goal will propel the nations to invest in capital initially. This stabilizes their output, and after a short while their production statistics start to improve. This approach results in more even aid distribution and utilization. Of course even this approach cannot prevent the disaster in RED, but that is a given; in case of a strong infection (high mortality rate) only effective medication could help, and the initial condition was, that only mediocre medication is available, Fig. 5. But in this scenario at least the economy of the nations survive, allowing for greater possibility of recovery and development.

POSSIBILITY FOR EXTENSION

Even without moving out from the "Nation model" approach, this model can be meaningfully extended in a number of ways.

1. Parametrized production functions could be used for the aid beneficiaries. This would allow to better depict different levels of improvement, as resource processing would not be the same across the board.
2. More donors could be simultaneously examined. This would enable conflicting goals. How would the beneficiaries react? Would each nation find the donor best "suited" for its own goal? Would the donor's goals cancel each other out? Would it mean greater or lesser growth in the beneficiaries?
3. The beneficiaries could have different goals. This could allow for even stronger strategy forming. How would the differing donor and beneficiary goals interact?

4. Some feedback between population growth rate and output could be included. It could be in the form of some kind of logistic curve, so that higher output would not always have the same effect on fertility rates.
5. Smarter decision making process could be included for all parties. This could come in many forms (genetic algorithm, neural networks, swarms etc.) but would lead to different, and probably more relevant results.
6. Warfare could be included with the introduction of land to the production set. The nations could spend some of their aid on weapons, and then could use those weapons to wage wars on the other beneficiaries. The wars would reduce the population in both countries, and would increase the supply of land in one country at the expense of the other.

CONCLUSIONS

Even using a simple, high-level agent-based model of financial aid, notable results were achieved. It was shown, that the policies the donors set to distribute financial aid affect the beneficiary nations significantly. This means, that the donors have a great responsibility when providing financial aid, since they have the power to prevent (or even cause!) catastrophes, and can create higher output and even better quality of life.

REMARKS

[1]Loosely based on [6].

[2]It is worthy to note, however, that while it is possible that a nation's entire output would be nontradable, such a nation would probably not attract financial aid. As suggested before, financial aid is mostly given to increase the output of the recipient nation – but if that output cannot be used anywhere else, this increment would only be a form of humanitarian aid.

[3]For the precise definition of the used neoclassical model, see [7].

[4]Memory can be easily modeled trough the usage of neural networks, whereas "experimentation" can be simulated with genetic algorithms.

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SAŽETAK

Istraživanja učinkovitosti financijske pomoći u zadnje se vrijeme intenziviraju. Prema jednom tumačenju financijska je pomoć neučinkovita, prema drugom može biti učinkovita, ali u oba tumačenja neki njeni vidovi sada nisu jasni.

Članak predočava pojednostavljeni model temeljen na učesnicima koji može doprinijeti temi. Pokazano je da pristupi donora utječu na stabilnost, konvergenciju i put ekonomskog rasta.

KLJUČNE RIJEČI

pomoć, modeliranje putem učesnika, kompeticija