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ABSTRACT. Global modeling has evolved remarkably in the last two decades. Such evolution led it to perform today's role as an experimental laboratory for the social sciences, and particularly for applications to policy planning. Two of the most interesting applications to policy are to resource economics and to economic models of North–South relations, i.e., the relationships between industrial and developing countries. Examples of North–South policy issues instigated by global modeling are developed in the context of a United Nations Model of Technology and North–South Relations which evolved from the Bariloche global model. Further applications of global modeling are then outlined.

Introduction

Global modeling emerged twenty years ago in an effort to address the world's long-term problems (Meadows et al., 1972) and to predict important trends and crisis points. The field has evolved methodologically to become an experimental laboratory for the social sciences. This paper examines the Bariloche model, one of the first global models, and offers an analysis of its implications for trade policies and North–South relations.

The early global models were very dependent on the assumptions of their creators and on the initial data that were fed into them: this reduced their reliability and limited their usefulness for policy applications. One way to overcome these drawbacks was to construct simplified and smaller versions of the model, and to perform qualitative analyses of the results and of the model itself.

The smaller models have the advantage that they can be subjected to qualitative theoretical analyses of policies. The global model itself remains a laboratory in which numerical experiments are performed and potential findings suggested. This process has resulted in many important policy insights, including a United Nations Model for Technology and North–South Relations.

The Last Two Decades

Global modeling has evolved remarkably during the last two decades. In the beginning it was, admittedly, naive to hope computers would address ambitious global and long-term issues. At the time, it was believed that computers could provide magical solutions to new problems, particularly to large scale problems which required the analysis of massive amounts of data and the study of complex interactions. Global modeling certainly focuses on large issues: geographically, it pertains to the whole world; in time, it studies long-term problems; and intellectually, it encompasses a multitude of disciplines.

World resources, pollution, population growth, and hunger were originally the main issues addressed by global modeling. Ten years later, as the dust created by the first three major models (Meadows et al, 1972; Leontieff et al, 1977; Herrera et al, 1976) settled, it became clear that computers are not omnipotent. Disenchantment with their ability to solve humanity's largest and most difficult problems set in, and led to the attempt to incorporate more traditional scientific tools into global modeling. Economics was introduced to study the world's resources and the world's basic needs (Chichilnisky, 1977); sociology and political science to study world scenarios (Cole and Miles, 1984; Cole et al, 1973; Freeman and Jahoda, 1978) sociology and political science to study aspects of resources and pollution (Heal, 1973).

Global modeling became more respectable as it integrated with the established disciplines. Yet its bold insistence that the world as a whole mattered and that it could be studied as a scientific object, albeit by less conventional means, remained unchanged. Global modeling also continued to provide a link between computer technology and the social sciences, thus creating an experimental laboratory through which social scientists could explore issues and problems, rather than turning to computer systems to resolve them.

Structural Stability in Global Models and in the Social Sciences

One of the problems global modeling has faced from the outset is the extreme sensitivity of the results to the mathematical assumptions of the models and the models' initial data. Structural stability refers to the "robustness" of the results to small errors or omissions in the initial data (including both parameter values and functional specifications). Without it, very small variations in the data can lead to drastically different results, and therefore the results are not "robust" or reliable.

Consider, for example, the hypothesis that resources are fixed, while population is growing exponentially. For that matter, consider a linear increase in resources, with an exponential growth in population. Simple arithmetic shows that a catastrophe will occur: the population will run out of resources. This will also occur, unless resources grow at least in a similar exponential fashion. It is clear that the assumptions made on the rates of growth of the different variables determine to a great extent the results. This means that the results are extremely sensitive to the assumptions, and in particular to the mathematical assumptions, which are usually less obvious to the reader than other types of assumptions. In the above example, we do not need a computer to predict a catastrophe. We do not need to analyze large amounts of data either. Furthermore, and this is the point about structural stability, the specific date of the catastrophe depends strongly on the mathematical assumptions about the different rates of growth of the different variables, which are the initial data of the model. We are, in effect, dealing with issues of sensitivity analysis: this is the study of how the results depend on the assumptions and the initial data.

A model is "structurally stable" when its qualitative results are independent of small changes in the assumptions and the initial data. Given the paucity of data in the areas studied by global models, as well as the uncertainty underlying the measurement of data, structural stability is clearly an important feature: it guarantees that small mistakes or omissions in the assumptions and initial data do not radically alter the results. We can, therefore, rely on the results despite the fact that the data are imperfect, and that our assumptions may be a bit off.

The desirability of structural stability extends to most areas in the social sciences. The reasons are the same: the results are very dependent on the assumptions, and lack of proper data, or small errors in the observations, are more the rule than the exception in the social sciences. This is an important methodological difference between the social and physical sciences.

This issue of structural stability lies behind many of the criticisms made of the results of the "Limits to Growth" exercise. It was the thrust behind the development of the Bariloche model,[1] which set out in 1970 to answer the worst predictions of the "Limits to Growth" for the developing countries, so as not to exhaust the world's resources, or alternatively their position in the world economy without threatening other countries.

These results were seen as a threat to the efforts of developing countries to improve their position in the world, in an era when the "New International Economic Order" was introduced proposing advances for the developing countries by means of economic growth. The Bariloche model saw the "Limits to Growth" results as a simple consequence of certain assumptions, which were considered as unacceptable, between population growth in the developing countries, per capita consumption of resources in the developing countries and in the world, and certain exponential assumptions about population growth. More importantly, Bariloche saw the "Limits to Growth" exercise as assuming that human beings do not adjust to their environment, since the trends of the different variables (e.g., consumption patterns, and resource availability) and their relationships, are assumed to proceed blindly without any corrections even as the catastrophe nears. Mathematically, there are no functional adjustments between the different trends.

We used the Bariloche model to investigate alternative assumptions and the results which would ensue, again using a computer model of the world economy, but this time assuming certain rational features or adjustments of the economic agents: the maximization of consumption of "basic needs," a term which was introduced by Bariloche for the first time in the literature and which had a widespread and illustrious following throughout the world for many years. As the author of the economic model within Bariloche, I still remember the incredulity encountered in trying to introduce such a novel concept within an economic model of a traditional type.

Of course, as Bariloche made different assumptions, it obtained different results; in particular, it found that the growth of the developing countries was indeed possible within existing resources and reasonable assumptions, provided economic agents were rational. It also found that developing countries did not threaten the world economy in their attempts to grow: no surprise here. However, at the policy level, both "Limits to Growth" and Bariloche encountered the same difficulty: How much structural stability did those models have? In order to use the results for policy analysis we needed to know how much the results depended on the numerical and functional assumptions and how much was, instead, an intrinsic property of the structure built into the model by its authors. Rephrasing this: Was Bariloche structurally stable? Was "Limits to Growth" structurally stable?

From Bariloche to the United Nations Model: Technology and North–South Relations

A large global model is a time-consuming exercise, as any of the authors will attest, and Bariloche was no exception to this rule. There was little time to study methodological issues which were outside its scope, such as the question of structural stability. Yet this question remained and its importance became to me clearer as time passed. This is partly because, disguised as a methodological question, this was a major issue in deciding the desirability of alternative economic development policies.

In 1978 the UNITAR Project on the Future, led by Philippe de Seynes, gave me the opportunity to co-direct a United Nations project which we called "Technology and North–South Relations." This project was to produce a global model that would revise Bariloche and focus on North–South issues of importance for the United Nations' development strategies. Technology was certainly one such issue; North–South relations was another. Here I was given a unique opportunity to improve upon the shortcomings of the Bariloche model which still haunted me. I could add a market structure, and prices as a most important class of variables in the economic model (Bariloche did not contemplate markets or prices). Thus I could really look at the issue of structural stability and dig deeply into the structure of the world model which we produced, in cooperation with my team at Harvard and Columbia Universities, and with another team led by S. Cole at Sussex University (Chichilnisky, 1980; 1981; 1983; 1984a; 1986).

As already mentioned, the methodological issue was really a cover for some of the most interesting policy issues I have encountered in many years. Judging by the interest and the published comment and criticism generated by the work following publication of the United Nations model in the *Journal of Development Economics* in 1983 and 1984, and in other journals and books, it was apparent that others were also attracted to these issues. The policy issues involved include some of the major concerns in international trade policy: the desirability of export-led growth and of specialization into "relative advantages"; the international market's role as an "engine for growth", and the role of aid in sustaining development.

From now onwards I will refrain from discussing the methodological issue of structural stability except in the context of these major policy issues: it will be more fitting to the theme of this journal issue to do so. But I must alert the reader that the methodological issue is not exhausted by these policy examples. It is a fundamental issue within the social sciences and it deserves to be treated as such, in its proper context.

Global Models and North–South Relations

The first task of our United Nations project "Technology and North–South Relations" was to produce a model which would deal best with the major policy issue of developing countries. The starting point was the question of satisfaction of basic needs, an issue central to the Bariloche model. Producing the United Nations model was a demanding task because most existing economic models were manufactured with the industrial countries in mind, and therefore were not adequate for the study of developing countries. For example, a country's demand was typically aggregated into one economic statistic, thus preventing the study of certain fundamental issues regarding the difference in demand by different groups—i.e., the distribution of income.

We decided that one of the most interesting and difficult issues which had to be addressed was how different policies affected different income groups, and for this we disaggregated demand by income groups. This leads to the problem of how to divide the population into different income groups in a meaningful way that is, in a way which would actually be useful in understanding the impact of alternative policies.

To achieve this, the separation of goods into different types was required, particularly types of goods which were consumed in different proportions by the different income groups. Similarly, market prices became quite important, because often (voluntary) policies are followed by (involuntary) price changes. For example, tariffs lead to changes in market's relative prices. Price changes have a welfare effect of their own, affecting the income groups which consume most intensively the goods whose prices have changed. Such welfare effects could, therefore, work in the opposite direction from that which was initially intended.

With these problems in mind we created a global model with several income groups, and where goods were disaggregated according to their consumption by the different groups. Prices for the different goods were determined by market forces. For example, basic goods were introduced, defined as a bundle of goods which were consumed most intensively by the lowest income group. Each region was modeled as a market economy which produced and consumed several groups of goods, and which had several groups of consumers each consuming a group of goods in different proportions.

Having modeled each region accordingly, we set out to model the international economy, and then proceeded to compute international market equilibria. All goods were internationally traded, and the international market, save for tariffs where applicable, was assumed to be competitive. An algorithm was developed to compute the solution, which for simplicity described a positive adjustment between goods exported and their prices until a market clearing equilibrium was reached, under the assumption that if more goods were exported, international demand should have increased, and this would naturally lead to higher prices. The purpose was to approximate an "export-led" policy, in which the developing countries faced a larger demand for their products, and exported more.

At this point our experimental laboratory, the numerical global model, started producing surprises. More exports were associated with lower, not with higher, prices, even if the increase in exports derived from an increase in the demand from the rest of the world. After considering several possibilities, including, of course, numerical errors, we had to admit that in the world represented by this model a policy resulting in the North (the industrial countries) importing more from the South (the developing countries) lowered the prices for the South's exports. Since these exports are labor intensive, this in turn led to lower wages, to lower levels of output, and to lower levels of employment in the South as well. In the logic of the model, increasing exports reduced the welfare in the South.

The surprises did not end here. The numerical results also showed that the North was consuming more of all goods in all income levels due to the added purchasing power derived from lower import prices. The policy which led to increasing imports in the North was beneficial for the North but certainly not for the South. It is important to note that all of this took place in stable markets; if the world's demand for a product increased, then prices increased correspondingly. The reason was that as the North's demand increased, the South's did not, thus prices did not increase with an enlarged market for exports. Even with stability, exporting more was no better for the South: it was worse. So much for export-led policies.

Having reached such a point, the only alternative open to the scientist is to try to understand the reasons producing these results from the numerical experiments. The results did not appear to tally with existing theory, although in fact, they did. These results brought to our attention issues which are seldom discussed in economic theory, and which were not understood until then.

These issues can be described as follows: if a country is exporting a labor-intensive commodity mostly consumed by wage earners, and if the country's demand response to prices is strong while supply responses are weak, then any increase in prices of basic goods increases domestic demand more than domestic supply, thus lowering exports. Under these conditions, the only way exports can increase is by lowering domestic demand, which in turn is achieved by lowering wage income, and reducing employment and production. The increase in exports would be accompanied by an increase in imports by the rest of the world, but this does not alter the results. A dismal outcome; but a very real one: subsequent empirical studies agreed with the theoretical results (Chichilnisky and McLeod 1984c, Chichilnisky, Heal and McLeod 1984d).

This outcome was understood only after simplifying the global model to a two-country two-good model, similar to the classical Heckscher-Ohlin model,[7] but having two differing features: (1) the supply of factors (capital and labor) is not fixed, and it increases strongly in the South depending on prices, and, (2) technologies are different in the two regions. In the South the modern and the traditional sectors differ considerably, while the North exhibits a rather distributional homogeneous technology across its entire economy. These two features were denoted abundant labour supply and dual technologies, respectively. The North was construed to be homogeneous, and its factors to be relatively supply inelastic.

In the context of a simplified model, these results were proven by mathematical theorems, in which the above conditions were formalized. The consequences of export-led policies already discussed were formally proven for markets with all stability properties.

These results for export-led policies in the South with abundant labor and dual technologies, led to a number of publications (Chichilnisky, 1981; 1984a; 1986). These led in turn to very considerable comment and criticism in the *Journal of Development Economics* in 1983 and 1984 because they were considered very surprising. As to be expected, they were not welcomed by advocates of export-led growth. The issue was complicated further because a certain mathematical dexterity was necessary to prove the above results, which went beyond the average level in conventional trade theory, effectively introducing new theoretical tools in the field.

As the theory became better understood, it became possible to determine the range of parameters under which such results could occur, and those under which the opposite would happen. Export-led policies then could only be advised in the latter case but not in the former. The range of parameters determining the outcome included technology parameters such as the input-output coefficients in the production functions of the different goods. Thus, technological considerations could be used to recommend export-led policies, or to the contrary, to avoid them. Reciprocally, if export-led growth was a goal, certain technologies were needed to guarantee positive results. Technology and basic needs were thus tied up in export-led policies, by means of the experiments with a global model.

A second experiment was conducted related to another major issue in North–South relations: foreign aid. A similar sequence of events, which by now the reader can reconstruct without narrative, led to a theorem proving that in stable world economies with at least three countries, a donor country can make itself better off, and make the receiving country worse off after the transfer aid from the former to the latter. This occurs as a result of the impact the transfer has on equilibrium prices, which reverts the primary positive effect of the transfer into a negative one called the *transfer paradox*. The same results take place after one country disposes of some of the goods it exports (the *destroy paradox*). The latter example was reminiscent of several incidents involving the destruction of coffee and other basic export crops in developing countries.

The first issue, namely the transfer paradox, was a classical problem in trade theory going back to John Stuart Mill, but with an important twist. In the 1950s Paul Samuelson had contended that this paradox could only happen in unstable markets, and therefore that it was of little practical interest. The stable results of Chichilnisky (Chichilnisky, 1980; 1983; 1984b) took several authors by surprise, leading to a large number of publications intended to clarify and explain the results in the *Journal of Development Economics* in 1983. The United Nations global model, our experimental laboratory, was responsible for obtaining these results, by opening our eyes to possibilities not envisaged before.

The next step following the theoretical analysis is the actual fitting of the model to data, and the development policy recommendations. This was achieved in a number of publications, (Chichilnisky, 1981; 1984a; 1986; Chichilnisky and Cole, 1978) dealing with specific countries as well as with the global economy (Chichilnisky, 1984c,d).

The theoretical analysis of reduced versions of the global models, which led to the understanding of these results, disclosed also the degree of stability of these conclusions. In each case, a range of parameters was identified within which export-led policies would be favorable, or not, and in the latter case, where aid would have a favorable effect or not. The structural stability of the results was established. This meant that within a wide range of parameters we were assured that the qualitative predictions would be preserved. Despite small errors of observations, we could still apply the results of policy analysis with a certain measure of confidence.

Export-led Policies and Aid: Two Major Issues of North–South Relations

These two major policy issues, the impact of aid and of export-led policies, served to illustrate the applications that global modeling has had to North–South relations. The numerical global model used as an experimental laboratory disclosed rather unexpected results which had not been known before. The analysis of smaller versions of the model led to new theories and to new insights into policy, all based on the experimental laboratory provided by the global model.

This is in a way the most successful type of application of global modeling in the social sciences. It points to a strategy which represents a substitute for experimental work which can be performed and which, along with theory, leads to a desirable balance of both.

Conclusion

The last twenty years have witnessed major changes in global modeling. It was initially a rather diffuse and all-encompassing computer discipline addressing major global issues and detecting points of crisis and possible solutions. It is now mostly a substitute for experimental laboratories in the global agenda.

We have discussed the evolution of global modeling, using as an example that of the Bariloche model, one of the first global models, into the United Nations model "Technology and North–South Relations." The former was used to investigate humanity's ability to satisfy basic needs; the latter, to focus on and evaluate more specific trade policies and other major issues of North–South relations, such as aid. In the process of developing the model a methodological question, the structural stability of the results, led to a new modeling methodology. Global models were used for conducting policy experiments and to test numerical responses; smaller versions of the model were used to investigate in depth the structure of the results, and their reliability for policy. The global model itself remains an experimental laboratory for the social sciences.

Notes

1. The Bariloche model is an interdisciplinary computerized model of the world economy divided into five regions, which correspond roughly to the continents. It was created by a team of Third World scientists in Fundacion Bariloche, Provincia de Rio Negro, Argentina, between 1971 and 1976, and subsequently published in several languages. The thrust of the model was its economic model, a mathematical one that introduced and defined the concept of Basic Needs, and put this concept at the center of the development objectives, or plans, for Third World countries and the world economy. I was the author of the concept of Basic Needs, and of the economic model of Bariloche.
2. The Heckscher-Ohlin model depicts a world economy with two countries (or regions) which trade with each other in a competitive market fashion. Factors of production are labor and capital. Both regions use the same technologies or production functions to produce two goods. The two regions are identical except for factor endowments. One is labor-rich; the other is capital-rich. The reason they trade is their relative advantages: the labor-rich region exports the labor-intensive goods and the capital-rich region exports the capital-intensive goods. This model is taught as a foundation of international trade, but it has been shown to be empirically incorrect for about 50 years.

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