QUANTITATIVE MODELS for Agricultural Policy Analysis

editors

Mohd Rusli Yacob
Alias Radam
Emmy Farha Alias

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PENERBIT UPM PRESS

Universiti Putra Malaysia Press
Serdang • 2014

First Print 2014

UPM Press is a member of the Malaysian Book Publishers Association (MABOPA)
Membership No.: 9802

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data

Mohd Rusli Yacob
Quantitative Models for Agricultural Policy Analysis / Mohd Rusli Yacob, Alias Radam, Emmy Farha Alias.
ISBN 978-967-344-403-8
1. Economy policy--Mathematical models.
I. Alias Radam. II. Emmy Farha Alias. III. Title.
338.9001

Cover design:Mohd Ghazali Razak
Type face: Times New Roman PS
Type size: 11/ 14.5

Printed by
Percetakan Mesbah Sdn. Bhd.
No. 11, Jalan Tun Perak 6
Taman Tun Perak
43200 Cheras
Selangor Darul Ehsan

Direct orders to
Universiti Putra Malaysia Press
43400 UPM Serdang
Selangor Darul Ehsan
Tel: 03-89468851/ 89468854
Fax: 03-89416172
E-mail: penerbit@upm.edu.my

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INTRODUCTION

Agriculture is an important source of livelihoods in the world, especially in developing countries, providing ways of life for billions of people. Of the world's 6.5 billion inhabitants, 5.5 billion live in developing countries, 3 billion in the rural areas of these countries. Of rural inhabitants, an estimated 2.5 billion are involved in agriculture, 1.3 billion are smallholders, while others include farm laborers, migrant workers, herders, fishers, artisans and indigenous peoples who depend on agriculture and natural resources for their livelihoods (World Bank, 2007). The developing world will remain predominantly rural until around 2020 and millions of people in those countries will continue to rely on agriculture for their livelihoods for the foreseeable future (Thomson, 2006).

In such situation, developing good practices in policy making, decision making as well as operation related with agricultural system is indispensable. The challenges faced by world of agriculture today is the continuous changes resulted from the dynamic interactions of a range of environmental and socio-economic drivers, including global environmental change, agricultural intensification, concentration of production, vertical integration and coordination, industrialization, deregulation and economic liberalization as well as urbanization. Today, agricultural system is becoming much more complex, starting with a firm's involvement in (bio) technology, extending through agro-chemical inputs and production, and ending with highly processed food (Bonnano *et al.*, 1995; McMichael, 1994).

Accurate responses to complexity and uncertainty are essential elements in sustainable agricultural systems. Many researches have been carried out to study variables and their relationship of the system, but most of the research has been concentrated on just a few of these aspects at a time as, understandably, it would be very difficult to solve the problem analytically integrating all the important variables and their interactions. It is also difficult to quantify accurately some of the relationships in any form since they are non linear and change with the time. It would be almost impossible to fit the entire system into any known method of mathematical analysis (Gupta, 1988). Modeling and computer simulation seems to be a reasonable alternative. Although it was stated that all models are wrong (Sterman, 2002), thousands of scientists and practitioners do believe that some of them are useful. This indicates that modeling is considered to be one of the useful methods/ approaches for problem solving.

There is an even more fundamental reason why modeling and simulation is essential. There is no learning without feedback, without knowledge of the results of our actions. Traditionally, scientists generated that feedback through experimentation. But experiments are impossible in many of the most important systems. When experimentation is too slow, too costly, unethical, or just plain impossible, when the consequences of our decisions take months, years, or centuries to manifest, that is, for most of the important issues we face, simulation becomes the main – perhaps the only – way we can discover for ourselves how complex systems work, where the high leverage points may lie (Sterman, 2002).

One of popular modeling approaches is the system dynamics modeling. System dynamics is the idea of a two-way causation called feedback and is very convenient to represent dynamic behavior in a system, such as one finds in business and other social systems. System dynamics is also a rigorous modeling method that enables us to build formal computer simulations of complex systems and use them to design more effective policies and organizations (Sterman, 2000). It has been applied successfully to structure and represents various systems for computer simulation and analysis.

FUNDAMENTAL CONCEPT

Jay W. Forrester, a professor at the MIT's Sloan School of Management is considered to be the father of system dynamics methodology. To help improving decision making and policy formation, Forrester created this methodology in the 1960s at MIT (Forrester, 1961).

System dynamics is a methodology for analyzing complex systems and problems with the aid of computer simulation software. It is an approach for understanding the behavior of complex systems over time which includes all the relevant cause-effect relationships, and more important, time delays and feedback loops in those systems which account for most of their unexpected behavior. What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops, stocks and flows. These elements help describe how even seemingly simple systems display baffling nonlinearity.

A causal loop diagram is a visual representation of the feedback loops in a system. There are two types of feedback loop, i.e. positive feedback loop that indicates reinforcement loop and negative feedback loop that indicates negative reinforcement (or "balancing"). A stock is the term for any entity that accumulates or depletes over time. A flow is the rate of change in a stock.

System dynamics models are not derived statistically from time-series data. Instead, they are statements about system structure and the policies that guide decisions. Models contain the assumptions being made about a system. A model is only as good as the expertise which lies behind its formulation. A good computer model is distinguished from a poor one by the degree to which it captures the essence of a system that it represents. Many other kinds of mathematical models are limited because they will not accept the multiple-feedback-loop and nonlinear nature of real systems. On the other hand, system dynamics computer models can reflect the behavior of actual systems. System dynamics models show how difficulties with actual social systems arise, and demonstrate why so many efforts to improve social systems have failed. Models can be constructed that are far superior to the intuitive models in people's heads on which national social programs are now based (Forester, 1995).

System dynamics modeling involves five steps; namely (1) identification of the real system through field observation and literature study; (2) articulation of the problem to be addressed; (3) formulation of dynamic hypothesis or theory about the cause of the problem; (4) formulation of computer simulation model to test the dynamic hypothesis and testing the model; and (5) designing and evaluating policies for improvement (Sterman, 2000). Understandings about the system gained from the first step can be articulated in the form of causal loop diagram. It is then transformed to the system dynamics flow diagram, which contains components of the system, inter component interactions and its behaviors. Computer simulation model can be developed by using commercially available software. Validation of the model can be done by using historical statistical data. Several scenarios can be simulated to understand the possible problems and its solution of the system.

MODELING TOOLS

For years, system dynamics was the domain of university academics and researchers, requiring large mainframe computers to create and run complex models (Alessi, 2000). At the very beginning, a mainframe computer program called DYNAMO was developed to facilitate creating simulation models of systems. However, microcomputers became available in the late 1970s and in the early 1980s Micro-DYNAMO made system dynamics modeling possible for everyone with a microcomputer.

In the years since, far more powerful computer programs for system dynamics modeling have been created for both Windows and Macintosh computers, including PowerSim (PowerSim), STELLA (High Performance Systems), ithink (High Performance Systems), Extend (Imagine That) and Vensim (Ventana Systems). An even simpler program for system dynamics modeling called Model-It has been created at the University of Michigan for use by elementary and secondary school students (Alessi, 2000). With some of the software, users can create a simulation by dragging and dropping icons and entering fairly simple algebra, after which programs create the complex differential equations necessary to actually run the model as a simulation.

However, it is important not to equate the original system dynamics methodology with the current system dynamics software packages. Some of the software has expanded beyond the mathematical methods and functions of the original system dynamics, including many logical functions, statistical and probability functions, and queuing functions. The inclusion of logical (If – Then) functions permits the software to be used for more qualitative modeling.

Everyone may have an opinion about what system dynamics software is best: Powersim, STELLA, ithink, Extend, Vensim or Model-It. In fact, there is often no sense arguing with people about it. Choosing a package should be done intelligently, taking into consideration the following factors: the computer operating system, the areas to which modeling will be applied, local availability of the software, local availability of expertise and support for the software, whether the models will be put on the web, whether the model equations to be transferred to other software, the budget, amount and quality of documentation required and the complexity of models to be created.

POSSIBLE APPLICATION AND EXAMPLES

System dynamics as a method has been successfully applied in a wide variety of business and socio-economic fields to understand the problems and gain an insight into various policy interventions.

Originally, Forrester applied system dynamics to modeling and problem solving in industrial corporations. Subsequently, he generalized the approach and applied it to social issues such as economics, crime and health and later to the physical and biological sciences such as ecology (Alessi, 2000). With system dynamics modeling, Forrester demonstrated how simple problem solutions often had unintended and undesirable effects, and how problems could be better solved with more sophisticated levels of analysis. He concluded that people are not good at dealing with complex systems in which many factors influence outcomes, such as the success of a business depending on employees, consumers, middlemen, the economy and the weather (in agricultural businesses), to name just a few.

The use of system dynamics in agricultural policy making as well as decision making is rapidly increasing as more and more policy makers and decision makers discover that it is an excellent way of problem-solving in a systematic way with good feedback for them. In Indonesia it started in 1970s after several scholars taken their graduate studies in USA. The followings are to illustrate only a few examples of its recent application in agricultural sector in Indonesia.

Handoko (1992) developed a wheat simulation model to study the possibility of growing wheat based on a weather model. The wheat simulation model wheat productivity (yield) and harvest time of various sets of cultivation scenario can be predicted together with prediction of the daily gains as well as losses of crop biomass, water balance and nitrogen balance. The study indicates that some highlands in the eastern parts of Indonesia are potential for wheat growing. The model then was used by Gusmayanti *et al.* (2004) in developing a decision support system (DSS) for determining the wheat potential areas in Lombok Island. Basically in combines crop simulation model and spatial compromise programming technique. Five criteria were considered in determining suitable area for wheat, i.e. wheat productivity, crop age, labor sufficiency ratio, economic relative value of the crop, and potential profit. Based on application of the DSS in Lombok island, wheat potential yield was about 1.5 – 3.0 ton/ha while crop age was in range of 80 – 100 days. Better yield was found in highland areas (northern part of the island).

Pertiwi (2003) reported a study result on developing a system dynamics model that can reflect food security system in Indonesia and also demonstrate the possibility of using the model as analytical instrument in undertaking policy analysis that would direct the food security system. The model was developed by focusing on the process and factors that govern the dynamics of food supply and consumption in the country. The system elements included in the model are, among others, population, labor, land use, price policy and input technology. In general it consists of three sub-systems, i.e. sub-system production, sub-system distribution and sub-system consumption. These three sub-systems are strongly influenced by the dynamics of population change.

The gain in food production is a result of interaction between land, labor, input materials, technology and potential yield of the crops. Level of inputs for food production given by food producers to certain extend is influenced by the gain in previous production season. In the model, food production is represented only by rice production, the most important staple food in the country. However, the probabilistic nature of agro-climate, which affects the crop growth, has not been incorporated in the model. There is also an assumption that there is no technological change that can affect the crop productivity during simulation time horizon. Availability of access roads and market price of commodities govern food distribution system in the region. It is including the common behavior of food producers on determining the portion of food they produce that will be consumed by them selves or delivered to the market. This will determine the level of food availability (food stock) in rural area as well as in urban area. Nutrition status of the people is determined by the level of food consumption and health. Level of food consumption is determined not only by the level of food availability, but also by the accessibility of the food to the people. This factor is naturally influenced by food price and people income. In turn, nutrition status will affect the reproductive capability of the people.

Simulation on Central Java case indicated that ten percent (10 percent) increase of net (outgoing) food trading will result to lower food stock in rural area as well as its nutrition status while decreasing net (outgoing) food trading for about 10 percent will serve better to the people in the province in terms of food availability and nutrition status. The generate policy scenario responses revealed that the food security system are vulnerable to strategies that will require land use change. Tolerating land use change from agricultural land to another type of use will cause the decrease of food production, also causes the greater increase in population. Therefore food availability becomes lower and the nutrition status of the people becomes lower as well. From this result, it is understandable that maintaining the current status of agricultural land use is an important point.

Still related with rice, Budiharti *et al.* (2008) used the approach to analyze the dynamism of rice recovery problems. A rice mill is an important chain in rice production. The performance of a rice mill can be measured from the milling recovery obtained. Meanwhile, milling recovery is influenced by many complex factors, such as farm operation systems, climate, social, culture and government policies. The study was aimed to find out the interaction among the elements of rice mills related to each other. The modeling and simulation were carried out to estimate the rice production increase by improving the machine configuration of small scale rice mill that could increase the rice recovery and quality and to decrease the loss. Three sub-systems were incorporated in the model, i.e. dried paddy production system, rice production at rice mills processing sub-system and sub-system of rice demand. Social elements were not included in the model. From the simulation outcome it was found that for the years 2007-2010, without post harvest technological improvement there will be a significant high rice deficit ranging from 500,000 to 600,000 tons. The deficit can be reduced by improving the technologies such as the improvements of production process (on farm), the post harvest by utilizing mechanization technologies, especially the renovation on machine configurations of small scale rice mills. Rice mill renovation can increase the average national milling recovery from 62.75 to 63.68 percent.

A watershed nutrient management model was developed to assist decision makers and stakeholders with watershed management planning for the conservation of water resources and rural development (Kato, Purwanto and Setiawan, 2006). One parts of the system dynamics model comprises six sub-model (population, land use, industrial capital, agricultural capital, water resources and water quality), simulate changes in socio-economic factors such as population, land use and economic indices; another parts simulates in-stream nutrient loads by using nutrient transport rates, population, and land use area. Using the models developed, scenario analyses were conducted to demonstrate the functionality of the models. Cianjur watershed located in West Java, Indonesia was selected as case study area. The model was calibrated using measurement data collected during field investigations in 2003 and 2004. It was found that rapid changes in the population and land use in this region have caused associated environmental problems and have adversely affected surface water quality. The maintenance of a balance between rural environment conservation and development is an important concern.

PITFALLS AND GOOD PRACTICES ON SYSTEM DYNAMICS MODELING

Several pitfalls on using system dynamics modeling are extracted from Sterman's reflections (Sterman, 2002). This, among others, is the failure to recognize the feedbacks in which the modelers embedded. This failure will lead to policy resistance as the modelers persistently react to the symptoms of difficulty, intervening at low leverage points and triggering delayed and distant. The ''pattern matching'' heuristic, i.e. assuming that the output of the system should follow the input is also considered as one of the pitfalls. Pattern matching often leads to wildly erroneous inferences about system behavior, causes people to dramatically underestimate the inertia of systems and leads to incorrect policy conclusions. It is fundamentally wrong with a modeling process and peer review system that encourages modelers to build and allows the publication of models in which many of the factors the modelers themselves view as important are omitted. Many modelers are not so forthcoming, and the audience and client are left to discover the limitations of the models on their own. Modelers often fail to document their work, preventing others from replicating and extending it. Modelers and clients often suffer from confirmation bias, selectively presenting data favorable to their preconceptions. Such behavior only succeeds in generating mistrust of the model and suspicion about the intentions of the modelers, counter to the modeler's goals. Models fail because more basic questions about the suitability of the model to the purpose weren't asked, because a narrow boundary cut critical feedbacks, because the assumptions are kept hidden from the clients, or because of failure to include important stakeholders in the process. Another pitfall is the failure on testing the model. In practice many important tests are simply never done. Many modelers focus excessively on replication of historical data without regard to the appropriateness of underlying assumptions, robustness and the sensitivity of results to assumptions about model boundary and feedback structure.

To avoid the pitfalls, it is important for the modelers rigorously defining constructs, attempting to measure them, and using the most appropriate methods to estimate their magnitudes to antidote to casual empiricism, muddled formulations, and the erroneous conclusions drawn from the mental models. It is important to use proper statistical methods to estimate parameters and assess the ability of the model to replicate historical data when numerical data are available. Failing to use these tools increases the chance that the insights you derive from your model will be wrong or harmful to the client.

The system dynamics modelers are also suggested to have the highest standards of documentation. Models must be fully replicable and available for critical review. Build into the budget and time line sufficient resources to assess the impact of the work and document it fully so others can help improve it. The modelers must open the modeling process to the widest range of people they can, including critics. Assessment into the work from the start should be designed so errors can be discovered more quickly.

A far greater role for model testing is emphasized as a good practice for system dynamics modeling. System dynamics has long had a sophisticated, flexible approach to testing (Sterman, 1984). Multiple tests are stressed, from dimensional consistency to extreme conditions tests to tests of sensitivity to structural assumptions and aggregation. It is emphasized the use of all types of data, not only statistical tests on numerical data, but both numerical and qualitative. Model results are usually far more sensitive to assumptions about the model boundary, level of aggregation, and representation of decision-making than to variations in parameters, yet sensitivity to these issues is only rarely assessed.

CONCLUDING REMARKS

To summarize, system dynamics modeling is a well formulated methodology for analyzing the components of a system including cause-effect relationships and their underlying mathematics and logic, time delays and feedback loops. It began in the business and industry world, but is now affecting many other disciplines, including those in agricultural sector. More and more people are beginning to appreciate the ability of the system dynamics methodology to bring order to complex systems and to help people learn and understand such systems.

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Contributors

Abdul Rahim Abdul Samad (PhD)
Department of Economics
Faculty of Economics and Management
Universiti Putra Malaysia

Abu Zeid Mohd Arif
Macro Economic Section
Economic Planning Unit
Level 4, Block B5
Prime Minister's Department
Federal Government Administrative Centre

Akram Hasanov (PhD)
Department of Econometrics & Business Statistics
School of Business
Monash University Malaysia

Alias Radam (Assoc. Prof., PhD)
Department of Management and Marketing
Faculty of Economics and Management
Universiti Putra Malaysia

Amin Mahir Abdullah (Assoc. Prof., PhD)
Department of Agribusiness and Information System
Faculty of Agriculture
Universiti Putra Malaysia

Amna Awad Abdel Hameed (PhD)
Institute of Agricultural and Food Policy Studies
Universiti Putra Malaysia

Nitty Hirawaty Kamarulzaman (PhD)
Department of Agribusiness and Information System
Faculty of Agriculture
Universiti Putra Malaysia

Nurjihan Idris
Institute of Agricultural and Food Policy Studies
Universiti Putra Malaysia

Setyo Pertiwi (PhD)
Faculty of Agricultural Engineering
Bogor Agricultural University
Indonesia

Shri Dewi d/o Applanaidu (PhD)
College of Arts and Sciences
Universiti Utara Malaysia

Tan Kay Kiang
Economic Planning Unit
Level 4, Block B5
Prime Minister's Department
Federal Government Administrative Centre

Tey Yeong Sheng (PhD)
Institute of Agricultural and Food Policy Studies
Universiti Putra Malaysia

Tirso Paris (Prof., PhD)
Department of Economics
College of Economics and Management
University of the Philippines Los Banos College