Qualitative Economics: New Perspectives

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Introduction

In the absence of complete, accurate quantitative information about the structure and behavior of complex economic systems, economists have long relied on techniques of qualitative modeling and comparative statics to describe economic behavior and predict future events (Samuelson [1947]; Simon [1953]). A purely qualitative model requires only the knowledge of sign (i.e., +, -, or 0) for the level, direction of change, and functional interdependencies of the variables and parameters involved. In general economists do not associate exact, numerical information with a qualitative description of model element. Qualitative modeling requires the model builder to express just what is known in theory and allows ignorance of exact relationships to be expressed.

Under traditional approaches, a qualitative model among a set of economic variables and parameters was represented as a two-dimensional matrix (or array) A of signs: -, 0, +. The value A (i, j) represented the sign of the direction of influence that a change in variable i or parameter j would have on the value of variable i. A value of 0 represented independence of the two variables. Techniques for manipulating qualitative or signed matrices were developed by economic theorists to deal with issues of solvability and stability of economic systems. Matrix decomposition and directed graph were typical for implementing computerized algorithms to perform analyses of qualitative matrix models in economics (see survey articles of Allingham and Morishima [1973], Quirk [1981] and references cited there).

Given Samuelson’s definition of qualitative calculus for economic analysis, qualitative solvability and stability are powerful theoretical properties. However, conditions for these properties to hold are very strict and unlikely to be fulfilled, except for some very small systems. Meaningful applications of such qualitatively well-determined systems are almost never to be found in the real world. Not until recently did anyone investigate the computability issue for solving a large and complex qualitative system (for example see Ritschard [1983]). Using weaker properties than stability and solvability, qualitative models can be used to provide partial answers when searching for unambiguous predictions of a large model.

Qualitative Physics

Stemming from a desire to model commonsense reasoning about the physical world as performed by humans, a research area known as Qualitative Physics recently has developed within the field of artificial intelligence (Bobrow [1985], Weld and de Kleer [1990]). A general approach of this research is that qualitative abstraction is applied both to the value domains of a model’s parameters and variables and to the differential equations forming constraints that describe component and system behaviors. This resultant, purely symbolic model is then manipulated and interpreted according to different automated reasoning methods.

There have been several schemes for representation and simulation proposed within the qualitative physics research community: confluences (de Kleer and Brown [1984], qualitative processes (Forbus [1984]), qualitative simulation (Kuipers [1986]), and causal ordering (Iwasaki and Simon [1986]). In all approaches, systems of qualitative differential equations are represented in symbolic form and solved by methods of value propagation for constraint satisfaction.

Confluences are direct simplifications of differential equations, where coefficients are reduced to signs and all divisions and multiplications are turned into negative and positive summation terms, respectively. Each component of a complex system is represented by a set of confluences, describing its behavior in different states. Qualitative processes capture more global characteristics of system behavior, representing flows and other changes that can become active given various components are in appropriate states. Qualitative simulation is based on a representation of system components...
in terms of positive and negative influences between variables. Simulation proceeds according to set of well-specified transition rules, generating all possible qualitative behaviors of a system. Finally, the causal ordering approach discusses methods for automatically clustering relationships and ordering them for the simulation process.

In all of these techniques there is a focus on developing an account of causal reasoning about physical systems. Causality, while not well understood, plays an important role in our thinking about both physical and social sciences. The theory of confluences defines ("mythical") causality based on the way effects of a disturbance are propagated to other parts of a device model during the process of predicting its behavior. In qualitative process theory, knowledge of causal relations is given directly in the definitions of physical processes, which are considered to be the medium to transmit casualty. The causal ordering among a set of qualitative relations is meant to capture the sequence of a reasonable, causal account of system behavior.

**Quantitative Economics**

Although the concept of causal ordering was first developed and applied in economic reasoning and comparative statics (Simon (1952, 1953), Simon and Iwasaki (1989), the adaptation of modern qualitative modeling and simulation techniques to economic analysis encounters certain complications. Economics as an inexact science does not have correct differential and function equations to describe system behavior. Problems in economics tend to be conceptually complex and poorly (mathematically) defined. Incorporating the ideas of advocates of a particular theory with the concerns for consistency with economic reality make the implementation of qualitative reasoning in economics difficult though not impossible.

Taking advantage of recent advances in computer technology and artificial intelligence, new techniques of qualitative economic reasoning inspired from the development of qualitative physics focus on the understanding of the cognitive process of economic theory. In search of an unambiguously signed prediction for an economic system, reasoning about model components and their interactions provides a more natural and direct approach for economic problem solving. The goal of computer implementation of qualitative reasoning in economics is not only to validate model consistency with existing theory but also to offer a flexible framework for developing alternative extensions or new theories that can be simulated and compared.

Existing works on new qualitative economics are primarily theoretical (Bourgine and Raiman (1986), Farley (1986), Berndsen and Daniels (1989, 1990), Farley and Lin (1990a, 1990b), and Lin and Farley (1991)). Bourgine and Raiman (1986) discuss the use of order of magnitude information as a means for removing ambiguity from the process of qualitative macroeconomics. The contributions of Farley and Lin (1990a, 1990b) and Lin and Farley (1991) lie in the formalization of qualitative market models and of a simulation paradigm suited to market-based economic reasoning, including techniques for realization and application of the comparative statics. The works of Berndsen and Daniels (1989, 1990) are more closely related with the confluence-based simulation of qualitative physics, adding an explicit treatment of time lags in the definition of causal relations.

**Market-Based Models**

The basic element of our approach to qualitative economics is a market model specified by a set of causal relations and a tatonnement adjustment process. Demand and supply, as inversely related functions of price, represent two of the most fundamental relations in a market. Typically, qualitative demand and supply functions are written as follows:

\[ D = f(P, Y, ...) \]

\[ S = f(P, W, ...) \]

The variables D and S represent quantities of a certain commodity that are demanded and supplied, respectively, in a particular market. The market price level P is an internally determined variable, while Y and W are externally influenced parameters referring to the income of market consumers and the cost level of productive resources (e.g., wages for skilled labor), respectively. The direction of the causal relation is from the independent variables (causes) on the right-hand side of the equation to the dependent variable (effect) on the left-hand side. The sign (+ or −) under a variable or parameter on the right-hand side of the equation indicates the positive or negative effect that a positive change in the
corresponding variable or parameter has on the left-hand side dependent variable; the effects are opposite when the change is negative.

It is clear that there may be multiple casual relations affecting the same effect variable. Due to the lack of quantitative data about the strength, or sensitivity, of a causal relation, a condition of structural ambiguity may result, where the effect of a given parameter perturbation on a particular variable within a market is ambiguous. Structural ambiguity must be considered carefully when attempting to formulate a qualitative market model. In general, the simpler (i.e., less dense in causal relations) the model, the less chance there is that ambiguous predictions can be obtained.

Equilibrium of the simple one-commodity market is defined as the intersection of its demand and supply functions. That is the price at which \( D = S \). The tatonnement price adjustment process is used to explain the stability of market equilibrium. Whenever there is pressure of excess demand (i.e., \( D-S > 0 \)) in the market, the price level \( P \) will increase. As price level rises, demand becomes lower and is accompanied by increasing supply, according to the causal relations discussed above. These changes, due to the adjustment in price level, serve to restore equilibrium in the market. Similarly, price level \( P \) falls whenever there is excess supply (i.e., \( D-S < 0 \)) in the market, leading to increased demand and lower supply. The tatonnement adjustment rule can be expressed by the following qualitative function:

\[
\Delta P = f_0(D-S)
\]

The notation \( \Delta P \), representing the qualitative derivative or direction of change in price level, is positively correlated with excess demand \( D-S \), with landmark correspondence at zero. The qualitative function with landmark correspondence at zero, \( f_0 \), implies that \( \Delta P = 0 \) whenever \( D-S = 0 \) indicating the stability of market equilibrium.

The qualitative functions of causal relations and tatonnement adjustment process, together with the constraint of market equilibrium in terms of zero excess demand, is a paradigmatic example of the form taken by our models of market mechanism in economics.

The qualitative reasoning paradigm for this basic market system is to (1) perturb the initial system state by altering the value of one or more parameters in the market, (2) propagate the effects upon market variables according to the specifications of causal relations; (3) check the value of the equilibrium condition and start the required adjustment process; and if possible (4) perform comparative statics as to changes in market variables by comparing initial and final equilibrium states.

As long as there are no conflicting causal relations producing structural ambiguity, the above qualitative simulation procedure provides an operational implementation for reasoning about market behavior in economics. By maintaining an open system view in the implementation, it makes the comparative study of market behavior under different assumptions relatively easy to realize. By adding parameters, variables, and functions to a basic market model, various structural considerations of a market organization can be modeled and evaluated by qualitative simulation.

Extending from the basic structure of market-based qualitative simulation, more complex economic theories can be constructed by combining instances of this simple market model. The idea is to put forward a system model in a piecemeal fashion, a complex system seen as a set of interrelated market components. Market models are defined one at a time and linked together as a variable in one market is parameter to one or more other markets. Applying ceteris paribus assumptions as to individual market behaviors, simulation about the whole economic system consists of sequentially updating elements of component markets following active connections. An active connection is a variable that has been hanged in one market and is parameter to another market; that other market must then be visited to perform market simulation and propagate effects of the change.

Ambiguity may now arise through interactions between markets. Depending on the order that active connections are traversed and markets visited, a variable in some market may take on different values. We refer to this phenomenon as propagational ambiguity, resulting from race conditions that arise in the market-by-market simulation scheme. Rather than simulating all possible traversal orderings in a complex multi-market system, we keep track of paths visited in each partial simulation and thus avoid redundant and ambiguous updating of the market system. Non-dominant feedbacks are assumed throughout all partial simulations. Finally, by assuming stability of market equilibrium, the qualitative technique of
comparative statics can be performed to combine changes in all final circumstances of partial simulations.

**Qualitative Microeconomics**

The study of qualitative microeconomics ranges from deriving properties of purely qualitative models to the comparative statics of general equilibrium theory. The focus has been on the model solvability and its stability as the prerequisites for comparative statics. Hicks [1939] considered two qualitatively specified market systems more than 50 years ago. These are (1) the case in which all commodities are "gross substitutes", i.e., a change in the price of one commodity leads to the same directional change in demand for all other commodities; (2) the Morishima case in which all commodities obey the rules "substitutes of substitutes and complements of complements are substitutes, but substitutes of complements and complements of substitutes are complements."

Substitutability and complementarity can be specified in causal relations of demand with respect to the prices of other related commodities. Lin and Farley [1991] report a correct solution for the simulation of Hicksian "gross substitutes." The same model can be adopted to simulate and validate the Morishima cases as well. In addition to the specifications of causal relations, other requirements in general equilibrium theory such as Walras’ Law and Homogeneity can be specified as qualitative constraints to limit the directions of changes for some variables in the model (see Quirk [1981] for details).

Assuming the existence and stability of the market equilibrium, the result of comparative statics follows from combining final qualitative states of all partial simulations. Based on the comparative statics, the correctness of qualitative simulation can be easily checked for all these qualitatively determined systems. The application of our market-based qualitative simulation paradigm is not limited only to these few restrictive cases of qualitative specified models. However, for a large and complex system in which some component markets and their connections may not be well-defined, the correctness of qualitative simulation is an open question. To resolve problems of model ambiguity, sometimes we will need order of magnitude or quantitative information about the changes involved. Of course, we do not claim that techniques of qualitative reasoning and simulation can replace this quantitative requirement.

**Qualitative Macroeconomics**

Qualitative simulation plays an important role for policy analysis in a macroeconomic model. Given a particular theory or economic doctrine in mind, the study of impact multipliers due to fluctuations of economic environment has been typically qualitative, because quantitative predictions were neither readily available nor reliable in most cases.

Consider a typical Keynesian macroeconomic model, in which income-investment-saving relationships from the product market interact with income-interest rate relationships from the money market. This demand-side macroeconomic theory is known as the IS-LM model. Qualitative reasoning in terms of the IS-LM model has proven useful for explaining and predicting basic effects that government policies have upon the economy. As a special application of market-based qualitative simulation, this is simply a two market system – product and money markets – with interactions and feedbacks through income and interest rate adjustments. Berndsen and Daniels [1989, 1990] present a similar Keynesian model using technique of constraint propagation to study the time-interval transition of qualitative states. Our methods of qualitative simulation (Farley and Lin [1990a, 1990b]) focus on the change of variables with respect to parameter perturbations as comparative statics has been stressed on comparing initial and final equilibrium states to determine perturbation impacts.

Adding components of labor market and an aggregate output market to the basic IS-LM model, a textbook Keynesian macroeconomic model can be simulated qualitatively. With variations of model specifications (i.e., causal relations and adjustments), government policy can be simulated and compared for different theoretical considerations, such as classical vs Keynesian, or Keynesian vs monetarist, etc. To simulate a Keynesian macroeconomic model, we perturb a component market by introducing a policy change. For example, a tax increase in the product market. Qualitative simulation is performed by a sequence of market updates starting from the perturbed product market to money and output markets which in turn to shift the labor market. These four aggregate markets
are linked via income, interest rate, price, and wage respectively. Some degree of structural ambiguity may be inevitable due to specific model formulation (e.g., dense causal relations) and assumptions in use (e.g., real and monetary wage controversies).

Qualitative Disequilibrium Analysis

Although the price adjustment process is the driving force of market equilibrium, the inexact specification of such process does not stand up for its correctness on all grounds. First, the initial state of a market model may not be in equilibrium at all. Further, the non-equilibrium or disequilibrium may persist following market perturbation. The central feature of a disequilibrium model is its price rigidity. When a market can not be cleared promptly through price adjustment mechanism, it is subject to quantity constraints of spillovers from other imbalanced markets. This original idea of quantity rationing in economic theory can be traced back to Keynes' General Theory [1935] (See also Quandt [1988] for a survey of modern contributions of disequilibrium economics).

Disequilibrium has been considered as one main characteristic of microeconomic foundation of macroeconomics. Our implementation of market-based qualitative simulation is flexible for different model considerations. In Lin and Farley [1991], qualitative disequilibrium analysis is presented in a two-market microeconomic framework and applied to a simple consumption-labor macroeconomic disequilibrium model. First, we extend the concept of causal relations to define quantity "spillovers" which replace price adjustment process in equilibrium analysis. Next we consider four possible disequilibrium regimes: Keynesian unemployment, classical unemployment, under consumption, repressed inflation, and the classical case of Walrasian equilibrium for qualitative simulation. It turns out to be a straightforward and natural extension of our qualitative simulation paradigm to provide validation of disequilibrium theory in economics. In particular, we have correctly simulate some well-known observations concerning policy change in relation with disequilibrium regimes.

Conclusion

The technique of market-based qualitative simulation reflects the traditional approach of economic reasoning and writing, generating simulation traces of market activities which yield natural explanations of predicted effects. The techniques of qualitative simulation and comparative statics are shown to be useful for structural analysis at both micro and macro levels for both equilibrium and disequilibrium consideration. It is not limited only to validation of existing theory but also can be used to create alternative or new hypotheses to be tested and simulated.

Future works include applying qualitative reasoning to econometric modeling and to large scale structural analysis in economics. Coupled with the advancement of artificial intelligence applications in qualitative physics, the practical implementation of qualitative economics to deal with real world problems will be seen in the near future.

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