education, public education on smoking, etc.) there is no clear cost benefit and there may be, in fact, a cost deficit, but this may be repaid by better health or better health awareness. The campaign against smoking, for example, has not reduced *total* smoking, but has reduced smoking substantially among the older population groups [1].

## IX. Summary

We have discussed the needs and some of the advances in training needed. We must train the general consumer to use the system and to respond to it, and the consumer with special needs must be trained to satisfy those needs. Training must be provided for a wide variety of providers ranging from nurses, to paramedics, to the physicians themselves. The system as a whole must be trained so that the hospital, the clinics, or a group of doctors can use the system and be trained by it. And in each case, the training must be both general in terms of overall medicine and specific in terms of treatment of highly specific diseases or emergencies.

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# Structure and Cause and Effect Relations in Social System Simulations

JOHN W. BREWER

*Abstract*—**The physical system analyst begins his analysis with a circuit diagram; after the inputs are designated a signal flow or block diagram is drawn in order to facilitate the derivation of a mathematical model. The author illustrates that a different designation of inputs completely changes the form of the signal flow or block diagram so that the circuit diagram is the more fundamental depiction of a circuit. Socioeconomic analysts tend to begin their discussion at the equivalent of the block diagram level. A starting point more like a circuit diagram is needed. The author demonstrates that bond graphs can fill this need. The bond graphs symbols developed can be used to model social systems at a level of aggregation analogous to the microeconomic level in conventional economics.**

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## I. Introduction

Social system analysts will commonly begin their discussions with illustrations of cause and effect relations. This is true of demographic analysts [9], conventional economic analysts [1], and less conventional socioeconomic analysts [6], [15]. Figs. 1 and 2 are examples of this type of exposition.

B. R. Gaines provides some theoretical implications of the search for cause and effect as well as some amusing anecdotal observations [10]. J. W. Forrester has outlined procedures and provided standard graphical symbols for the illustration of cause and effect relations [6]. His colleague, D. Meadows, is very explicit about the importance of these graphs to social system modeling. "Preparatory to building a model of the resource-use system, the cause-and-effect linkages in the system are mapped out qualitatively" [15].

The last statement also describes the philosophy adopted by the present author in previous social system modeling efforts [17], [18]. The purposes of this correspondence are to illustrate the limitations of such a procedure and to propose an alternate modeling method. Additionally, an alternative graphical depiction of the modeler's assumptions will be described wherein *explicit assignments of cause and effect are avoided, and the structure of the system is emphasized.*

The abstract definitions of "system" and "state" provided by Zadeh and Desoer [19] and the bond graph methods of Paynter, Karnopp, and Rosenberg [12], [14] are the theoretical basis for the sequel. The reader familiar with graph theory will find the

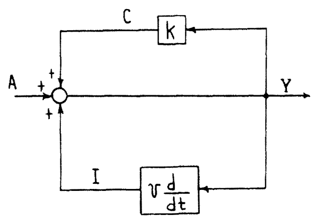


Fig. 1. Example of diagram of cause and effect in conventional economics literature [1]. The macroeconomic variables are $A$: autonomous expenditure, $C$: consumption, $I$: induced investment, $Y$: income, $v$ and $k$: constants.

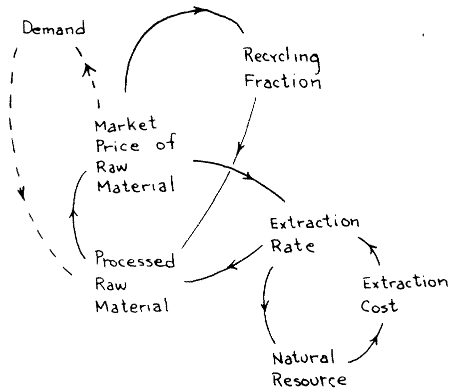


Fig. 2. Adaptation of diagram of cause and effect from systems dynamics literature [15]. The dashed lines are used here to represent a much more complex causal network represented in the original paper.

descriptions of the relationship between bond graphs and graph theory to be useful [4], [13].

The author was led to the thoughts contained in this note after an unfortunate experience. An attempt was made to modify an existing simulation model to test a newly proposed oil import tax policy. The attempt had to be abandoned because the cause and effect relationships of the model as constituted were not quite correct when the new "input" (import tax) was applied. As will be argued, this type of difficulty may occur quite commonly as simulation models are developed as policy evaluation tools.

The remainder of the correspondence is organized in the manner described below. The second section is a review of cause and effect relations in physical systems wherein it is shown that these relations change as the location and nature of inputs are changed. The third section is an argument that the "bonds" of a socioeconomic system should be represented rather than cause and effect relations. In this section, previous work of the author, which has limited accessibility, will be reviewed and extended [2]. The fourth section is an outline of the manner in which bond graph analysis can be used in large systems studies. Suggestions for research are provided in this section. Concluding remarks are provided in the final section.

## II. Systems as Nonoriented Abstract Objects

Social system analysts are using a procedure similar to that of physical scientists when they assign cause and effect relations. For this reason, it may be instructive to consider first the assignment of cause and effect in physical system analysis where the issues are clear.

An examination of the physical systems literature indicates that such assignments are quite arbitrary. In the mathematical approach taken by Zadeh and Desoer (19) an "abstract object" (or mathematical model of a system) is the designation of a set of "relevant" variables[1] and a set of relations between them. If a certain subset of these variables is designated as "inputs" and another subset designated as "outputs," the object is called *oriented*, otherwise *nonoriented*. Zadeh and Desoer quickly point out that such designations are arbitrary: "... there is considerable arbitrariness in the way (an object) is oriented and once (the object) is oriented, there is further arbitrariness in the way in which a state vector is associated with (the object)" [19]. A similar attitude is indicated by Paynter [14] and Karnopp and Rosenberg [12].

To appreciate these notions consider the electrical circuits illustrated in Figs. 3(a) and (c): the same circuit is shown with the only difference being that in the former case the voltage $e$ is designated as input while the current $f_1$ is designated as input in the latter case.

The main purpose of assigning cause and effect is to derive a mathematical model. The main purpose of a mathematical model is to predict output given the input. The additional information that one needs to predict the output is called the *state* [19]. If the mathematical model consists of a set of simultaneous ordinary differential equations in variables which can be related algebraically to the output, the state is merely the set of initial conditions on these variables. In summary, cause and effect is assigned in a model of a physical system to facilitate the derivation of a set of simultaneous differential equations (called the *state equations*).

[1] No attempt is made by Zadeh and Desoer to devise a foolproof procedure for completing the list of "relevant" variables. Of course, that task is the basic problem of science.

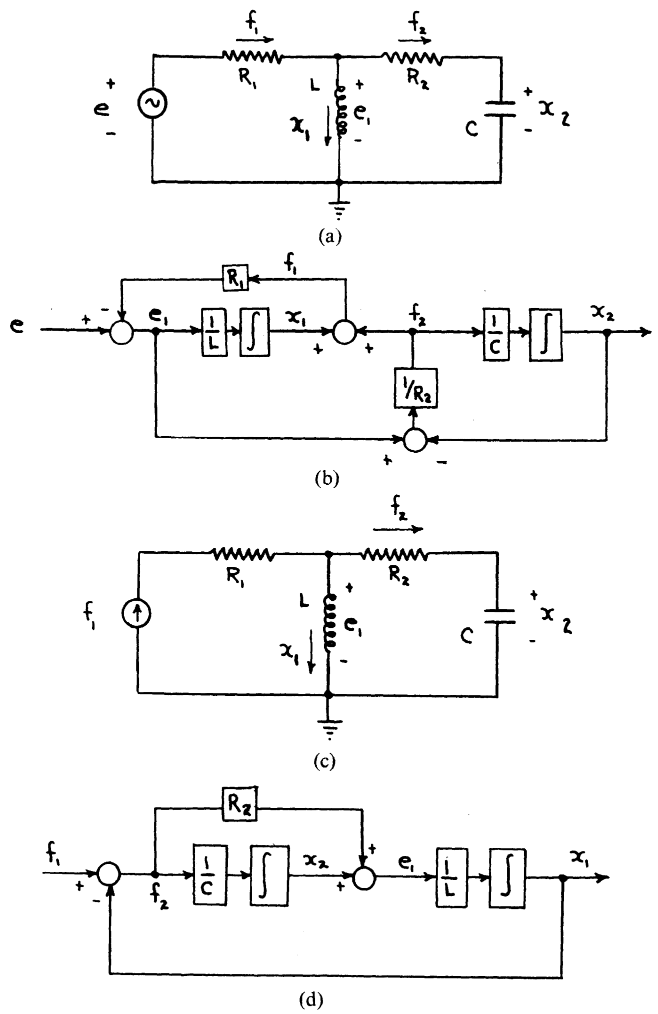


Fig. 3. Orientation, cause and effect in a physical system. (a) Network with voltage input. (b) Diagram of cause and effect which is used to derive state equations. (c) Same network with current input. (d) New "orientation" creates redesignation of cause and effect.

The assignment of cause and effect for the input designations in Fig. 3(a) and (c) are shown in Fig. 3(b) and (d), respectively. The state equations which result from analysis of Fig. 3(b) are

$$\dot{x}_1 = -\frac{R_1 R_2}{L(R_1 + R_2)} x_1 + \frac{R_1}{L(R_1 + R_2)} x_2 + \frac{R_2}{L(R_1 + R_2)} e \tag{1}$$

$$\dot{x}_2 = -\frac{R_1}{C(R_1 + R_2)} x_1 - \frac{1}{C(R_1 + R_2)} x_2 + \frac{1}{C(R_1 + R_2)} e; \tag{2}$$

while the state equations which result from an analysis of Fig. 3(d) are

$$\dot{x}_1 = -\frac{R_2}{L} x_1 + \frac{1}{L} x_2 + \frac{R_2}{L} f_1 \tag{3}$$

$$\dot{x}_2 = -\frac{1}{C} x_1 + \frac{1}{C} f_1. \tag{4}$$

Clearly, the redesignation of the input has radically changed the state equations. More to the point, the redesignation of input forced a *change in the assignment of causes and effects* required for the derivation of these equations. In particular, consider the voltage $e_1$ and the current $f_2$. In Fig. 3(d), $f_2$ is a cause of $e_1$, while in Fig. 3(b), the causations are somewhat circular.

The truly abstract nature of a circuit diagram is not always fully appreciated. The circuit diagrams of Fig. 3(a) and (b) (less the designations of input variables) are always a description of the circuit *precisely because cause and effect relations are not shown explicitly on such diagrams*. The circuit diagram less input designation, is a *nonoriented* description in the sense of Zadeh and Desoer. On the other hand, the block diagrams are valid descriptions only after particular input designations are made. Block diagrams are *oriented* descriptions in the sense of Zadeh and Desoer and are less fundamental than the circuit diagram.

A fact that makes this discussion worthwhile is that computer technology has reached the point where an analyst need only supply a *nonoriented* description of a physical system (circuit diagram or a bond graph). The process of assigning cause and effect and of deriving the state equations (for a given "orientation") is so straightforward and so unambiguous that it has been reduced to computer code [12], [16].

The thrust of this paper is to point out that, heretofore, mathematical modeling of social systems has started with diagrams analogous to block diagrams. If experience with physical systems can be extrapolated, one must conclude that block diagrams could become invalid when inputs are redesignated. Unfortunately, *since social system simulations are often used as policy evaluation tools, the changing of the identity of inputs is precisely the type of computer experiment that is called for.*

Clearly then, the field of social system simulation theory requires the development of a "nonoriented" point of view. Nonoriented graphical descriptions of social systems would be a particularly important innovation. If these descriptions can be associated with computer code that will derive (and solve) state equations, so much the better.

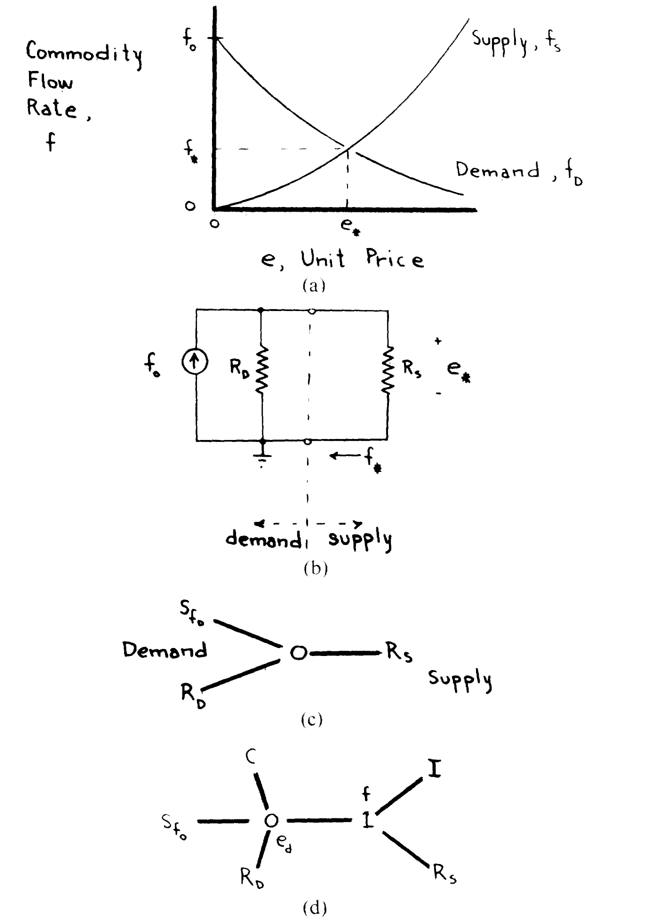


Fig. 4. Nonoriented representation of microeconomic components of socioeconomic systems. (a) Supply and demand curves. (b) Static electric circuit which is an analog of supply and demand if resistors are nonlinear. (c) Bond graph of supply and demand. (d) Dynamic compliance and inertia components in the marketplace.

## III. Bond Graphs of Microeconomic Systems

The theory of nonoriented descriptions of microeconomic systems has been investigated to some extent [2], [5], [7], [8]. The authors of these early papers have been impressed with the analogy between physical and microeconomic analyses and have not expressed the urgency evident in the previous section.

The circuit diagram analogies of Franksen [7], [8] represent a perfectly valid approach to the development of a nonoriented social system theory but we prefer the use of bond graphs [12], [14], for reasons that will become clear.

In this section we will review and extend recent attempts at microeconomic bond graph analysis. In the next section we will propose research that will extend the use of bond graphs and the use of the ENPORT computer language to the modeling of larger social systems which contain microeconomic components as subsystems.

### A. Tetrahedron of State

Define the *revenue rate* variables as

$$e = \text{unit price of a commodity} \tag{5}$$

$$f = \text{commodity flow rate.} \tag{6}$$

These variables are analogous to "power variables" in physical systems [12]. The similarity to the notation for voltages and currents in Fig. 3 is not accidental. Notice that

$$ef = \text{revenue flow rate.} \tag{7}$$

This product is analogous to power in physical systems. A surprising convention is that $f$ is taken positive in the direction of the flow of *receipts* which is always *counter* to the flow of commodity.

The *revenue variables* are defined to within an arbitrary constant as follows: the *inventory*

$$q = \int f\,dt \tag{8}$$

and the *economic impulse*

$$\lambda = \int e\,dt. \tag{9}$$

These variables are analogous to the "energy variables" of physical systems analysis [12].

### B. Supply and Demand

Supply and demand relations are illustrated in Fig. 4. Notice that the supply rate

$$f_s = \phi_{RS}^{-1}(e) \tag{10}$$

where $\phi_{RS}^{-1}(\cdot)$ denotes an inverse nonlinear resistive relationship [2], [12]. A special case is the linear equation,

$$f_s = \frac{1}{R_s}\,e. \tag{11}$$

Also note that the demand rate

$$f_D = f_0 - \phi_{RD}^{-1}(e). \tag{12}$$

The electric analog circuit which also leads to equations of the form (10) and (12) is illustrated in Fig. 4(b) and was suggested to the author by an anonymous visitor to his office.

Notice one bothersome thing about electric circuit analogies: the equilibrium "current" $f_*$ is seen to flow from supply to demand in the lower conductor; but this same current flows *from* demand *to* supply in the upper conductor!

A bond graph which will also result in (10) and (12) is illustrated in Fig. 4(c). Notice that demand is a source of revenue in microeconomics much as a current (or "*flow*") source is a source of power in physical systems.

An economic *port* is a point in a microeconomic system where commodity is exchanged for money. Supply and demand as represented in Fig. 4(c) are fundamental one ports. The *marketplace* is the *zero function* and is a fundamental *n*-port element (a two port in Fig. 4(c)) of economic bond graphs. The *one junction* of economic bond graphs will be discussed in detail in the sequel. One final comment: if the supplier is a monopoly, it is an "*effort*" (or price) source rather than a resistor.

There is one important way that an economic resistance differs from an electrical resistance. An implication of the second law of thermodynamics is that energy "dissipated" in an electrical resistance will not return to the circuit. There is no similar restriction on revenue. This fact causes no special problem.

### C. Dynamic Elements

Section III-B is a discussion of static effects while dynamic elements are discussed here. Walrus theorized about dynamic markets wherein the flows $f_s$ and $f_D$ are not equal and unit price changes are proportional to this difference [1]. The linear case is

$$\frac{de}{dt} = \frac{1}{C}(f_D - f_s) \tag{13}$$

where $C$ is a proportionality constant which we shall call *economic compliance*. The integral of $f_s - f_D$ is the inventory $q$ which must be stored by the supplier.

Equation (13) can be written in the equivalent forms

$$e = \frac{1}{C}q \tag{14}$$

or

$$\frac{d\lambda}{dt} = \frac{1}{C}q \tag{15}$$

where $\lambda$ is the economic impulse (definition (9)).

A generalization of (14) is

$$e = \phi_c^{-1}(q) \tag{16}$$

where $\phi_c^{-1}$ denotes a nonlinear inverse compliance function. Indeed, the price $e$ set by a real supplier will be more likely represented by (16) than by (14).

Marshall envisioned *two* prices in the marketplace: the supplier's price $e_s$ and the demander's price $e_d$ [1]. Marshall suggested that the rate of change of commodity flow was proportional to the difference in these prices; that is,

$$\frac{df}{dt} = \frac{1}{I}(e_d - e_s) \tag{17}$$

where $I$ is a constant which we shall call *economic inertia*.

Equation (17) can be written in the equivalent forms

$$f = \frac{1}{I}(\lambda_d - \lambda_s) \tag{18}$$

or

$$\frac{dq}{dt} = \frac{1}{I}(\lambda_d - \lambda_s). \tag{19}$$

A generalization of (18) is

$$f = \phi_I^{-1}(\lambda_d - \lambda_s). \tag{20}$$

Inertia can be associated with the lag inherent in changing production capacity or consumptive facilities. A nonoriented description of a market with both compliance and inertia is provided in Fig. 4(d).

If $I \cdot f$ is called *economic momentum*, then (18) indicates that momentum is equal to the net impulse. This interpretation may aid the reader to attach some intuitive meaning to impulse.

### D. Comment on 1-Junctions and the Analog of Kirchhoff's Voltage Law

As is well known, the 0-junction is used to represent Kirchhoff's current (node) law in the bond graphs of electrical circuits while the 1-junction is used to represent Kirchhoff's voltage (mesh) law. The 0-junction in economic bond graphs is a representation of the rule of conservation of mass of the commodity: several streams of commodity converge and/or diverge at a common price.

There have been attempts to describe abstract economic analogs of the mesh. We find the results of these efforts to be a bit contrived and, more importantly, quite unnecessary. It is not required that economic systems and physical systems be completely analogous. It is probable that no economic analog of the mesh exists; that is, a set of system components through which a *common* commodity flows in such a manner that the sum of the price changes is zero. Price change is usually associated with capital and/or labor and is described, in a nonoriented way, by the *field* bond graph symbol which is discussed in detail in the next section.

This is not to say that the 1-junction does not serve a purpose in economic bond graphs. Indeed, this bond graph symbol was used in Fig. 4(d) to provide for the proper accounting of supplier's price and demander's price and is, in that sense, a somewhat trivial example of a Kirchhoff mesh.

### E. The Explicit Economic Resistive Field: The Firm

In Section III-B the supplier was viewed as a simple 1-port bonded to demand. In the present section, the more complete nature of the supplier or "firm" is recognized. The firm is simultaneously bonded to several markets. For example, as indicated in the "word" bond graph of Fig. 5(a), it is bonded to capital, labor, and raw material (i.e., the "factor") markets as well as to the demand for its product. Actually, the real situation is far more complex than illustrated here because the firm is bonded to a larger set of factor markets; for example, managerial, skilled, unskilled, and clerical labor markets may be bonded to the real firm.

It will be shown that the efforts and flows on the bonds can be related using classical economic concepts. In the bond graph lexicon, these relations define a *resistive field* [12]. Further, since the relations cannot be resolved into a set of one and/or two port relations, the resistive field will be said to be *explicit* [12].

First it is noted that two constraints are imposed upon the analysis of the firm. The first constraint might be called the law of good bookkeeping, namely,

$$ef = e_1 f_1 + e_2 f_2 + e_3 f_3; \tag{21}$$

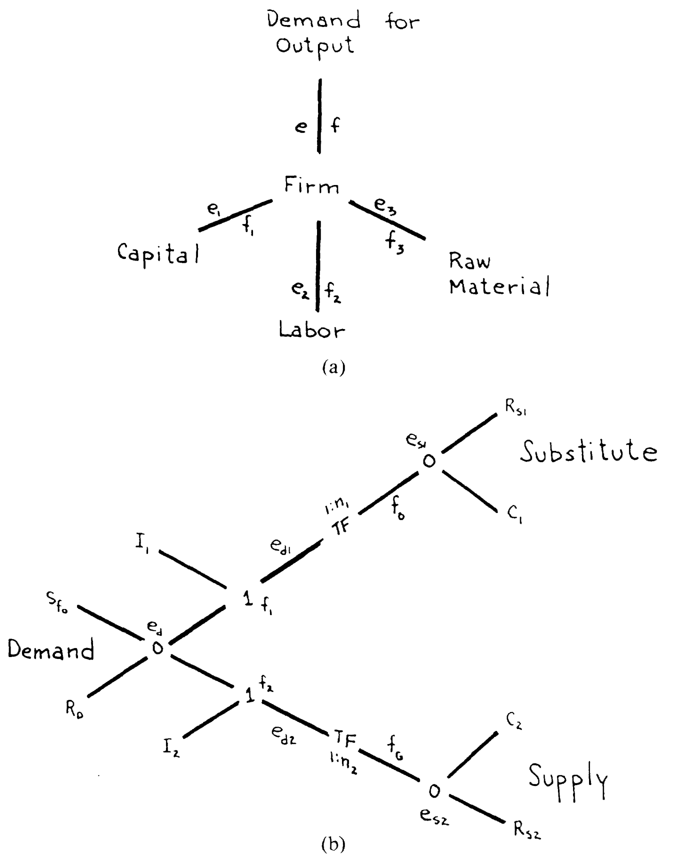


Fig. 5. Important economic multiports. (a) Firm is an explicit resistive field and, in the case of microeconomic systems, is probably more fundamental than the 1-junction. (b) "Transformers" relate units in a market in which substitution is possible.

that is, income is equal to expenditures. Notice that this relation indicates that a physical analog would have to be dissipationless! In the ideal view of the firm described in (21), no allowance for tax, savings, or deficit spending is made. All earnings accrue to the investors at rate $e_1 f_1$.

The second constraint is the *production function*

$$f = f(f_1, f_2, f_3). \tag{22}$$

A commonly used production function is the Cobb–Douglas form

$$f = k f_1^{\gamma_1} f_2^{\gamma_2} f_3^{\gamma_3} \tag{23}$$

where the constants $k$, $\gamma_1$, $\gamma_2$, and $\gamma_3$ are found by log-linear regression. Notice that according to this relation, the output ceases if the flow of any of the factors is interrupted.

The problem that faces the bond graph analyst is this: since either the $e$ or the $f$ variable (but not both) at each bond will be imposed on the firm, what will be the corresponding responses of the firm? The question is answered by solving an optimization problem (usually easier said than done). Managers will use whatever freedom they have to maximize the return to investors $e_1$. In general, the firm provides four responses (the complimentary variable at each bond); however, because of two constraints ((22) and (23)) only two of these responses can be selected independently.

Note that the identity of those variables which are imposed on the firm depends upon the manner in which the system is "oriented" (recall the terminology of Section II). Thus a *set* of optimization problems are associated with the firm!

To provide a concrete example, suppose that the system is oriented in such a way that $f, e_1, e_2, e_3$ are imposed upon the firm. In what follows, these variables may be treated as given in the analysis. Use (23) to eliminate $f_1$ from (21) and solve for the rate of return $e_1$. Impose the necessary conditions for optimality.

$$\frac{\partial e_1}{\partial f_2} = 0 = \frac{\partial e_1}{\partial f_3}. \tag{24}$$

These two conditions plus (21) and (23) are four equations in four responses $e, f_1, f_2, f_3$. After much algebra, it can be shown that

$$e = \frac{\gamma}{\gamma_1}\left(\frac{\gamma_1}{\gamma_2}\right)^{\gamma_2/\gamma}\left(\frac{\gamma_1}{\gamma_3}\right)^{\gamma_3/\gamma}\left[\frac{e_1^{\gamma_1} e_2^{\gamma_2} e_3^{\gamma_3}}{k f^{\gamma-1}}\right]^{1/\gamma} \tag{25}$$

$$f_1 = \left(\frac{\gamma_1}{\gamma_2}\right)^{\gamma_2/\gamma}\left(\frac{\gamma_1}{\gamma_3}\right)^{\gamma_3/\gamma}\left[\frac{f}{k}\,\frac{e_2^{\gamma_2} e_3^{\gamma_3}}{e_1^{\gamma_2+\gamma_3}}\right]^{1/\gamma} \tag{26}$$

$$f_2 = \left(\frac{\gamma_1}{\gamma_2}\right)^{(\gamma_2/\gamma)-1}\left(\frac{\gamma_1}{\gamma_3}\right)^{\gamma_3/\gamma}\left[\frac{f}{k}\,\frac{e_1^{\gamma_1} e_3^{\gamma_3}}{e_2^{\gamma_1+\gamma_3}}\right]^{1/\gamma} \tag{27}$$

$$f_3 = \left(\frac{\gamma_1}{\gamma_2}\right)^{\gamma_2/\gamma}\left(\frac{\gamma_1}{\gamma_3}\right)^{(\gamma_3/\gamma)-1}\left[\frac{f}{k}\,\frac{e_1^{\gamma_1} e_2^{\gamma_2}}{e_3^{\gamma_1+\gamma_2}}\right]^{1/\gamma} \tag{28}$$

where

$$\gamma = \gamma_1 + \gamma_2 + \gamma_3, \tag{29}$$

so that the firm is indeed a resistive field.

We conclude this section with a reiteration of a very important point: commodity flows through elements of an economic network with a resulting change in price but not in the same sense that current causes voltage drops in an electric circuit. The price changes are usually associated with capital and labor, and this is true of mining, transportation, production, distribution, and waste disposal firms. In short, *the firm is a more fundamental junction structure than the 1-junction in economic systems bond graphs.*

### F. Substitution Effects and a Revenue Rate Preserving Two Port

One of the important phenomena associated with the exploitation of a resource is that of substitution. In this section the bond graph symbols which describe substitution are determined. In the course of the discussion the economic *transformer* will be introduced.

The discussion is facilitated by focusing on a particular example. Consider the demand for home heating fuels. The consumer can use natural gas or fuel oil. Obviously, the commodity flows have different units. The consumer, in a sense, is in the Btu market.

Denote

| | | |
|---|---|---|
| $n_1$ | gallons of fuel oil per Btu, | (30) |
| $n_2$ | cu ft natural gas per Btu, | (31) |
| $f_1$ | Btu rate to demand from fuel oil, | (32) |
| $f_0$ | flow rate from fuel oil supplier, | (33) |
| $f_2$ | Btu rate to demand from natural gas, | (34) |
| $f_G$ | flow rate from natural gas supplier. | (35) |

Clearly

$$f_1 = \frac{1}{n_1} f_0 \tag{36}$$

and

$$f_2 = \frac{1}{n_2} f_G. \tag{37}$$

Notice also that the Btu price paid for oil by demand is

$$e_{d1} = n_1 e_{s_1} \tag{38}$$

where $e_{s_1}$ is the price of fuel oil and

$$e_{d2} = n_2 e_{s_2} \tag{39}$$

where $e_{d2}$ is the Btu price paid by demand for gas and $e_{s_2}$ is the gas supplier's price. The equation pair (36) and (38) defines a *transformer* [3], [12] as does the pair (37) and (39).

The bond graph for this situation is illustrated in Fig. 5(b). Notice that dynamics have been associated with substitution in this graph. The demand must invest in home heaters in order to use one fuel or the other. These heaters cannot be easily and quickly changed in order to take advantage of relative changes in supplier's price. Thus inertia elements are shown on the bonds to the demand.

It follows from (36) and (38) and from (37) and (39) that

$$e_{d1} f_1 = f_0 e_{s_1} \tag{40}$$

$$e_{d2} f_2 = f_G e_{s_2}. \tag{41}$$

These equations show that economic transformers are revenue rate preserving (as they should be).

The transformer moduli $n_1, n_2$ can change with time for technical and geological reasons so that the economic transformers of substitution are *modulated transformers* [12].

The view of substitution taken here is remotely related to that taken by Franksen [7].

## IV. Active Bonds, Policy and Bond Graphs of Socioeconomic Systems

Anyone who has studied the matter knows that the Forrester, or "Systems Dynamics," methodology [6] finds little favor among conventional economists (find a list of criticism compiled by Young *et al.* [18]). The relatively naïve mathematical basis of System Dynamics (as compared to conventional economics) and the unwillingness of many devotees of System Dynamics to engage the conventional economic literature do much to encourage a crankish reputation.

This author, however, is persuaded by Forrester's provocative judgement:

> Mathematical economics and management science have often been more closely allied to formal mathematics than to economics and management . . . in many professional journal articles, the attitude is that of an exercise in formal logic rather than that of a search for useful solutions of real problems. In such an article, assumptions having doubtful validity are stated . . . and adopted without justification [6].

In short, in order to make a problem tractable mathematically, unrealistic assumptions are accepted. Assumptions of perfect competition or perfect monopoly and tacit assumptions of complete lack of planning and foresight are a partial list. Of course, this criticism can only be leveled at *mathematical* economics. Galbraith, for example, has the conventional credentials but does not seem bounded by the aforementioned constraints [11] perhaps because he is not a mathematical economist. In fact, it seems that a *descriptive* economist, such as Galbraith, is a more thorough critic of conventional economic thinking than Forrester.

The bond graph methods described in Section IV are based, in part, upon the concepts of conventional mathematical economics. In this section, an attempt is made to describe the type of research that will extend these methods so that they will be useful to those who would build simulation models based upon a more complete set of assumptions and would then test proposed policy.

The *active* bond, in physical system analysis, refers to a bond where information (for example, in the form of an $e$ or an $f$ variable) is exchanged but not energy [3], [12]. This type of bond is useful in economic systems analysis also: one need only substitute the word "revenue" for "energy." An example of an economic active bond is the government control of price. The government is bonded to the market and imposes the value of the $e$ variable on that 0-junction; however, no commodity or revenue flows to government. Still other examples are an oil import quota and a soy export quota. In both cases, government supplies the value of the $f$ variable to the 1-junction bonding supplier to demand but no commodity or revenue flows to government. Thus two important types of policy are quite nicely described by a standard bond graph symbol: the active bond to an effort source and the active bond to a flow source.

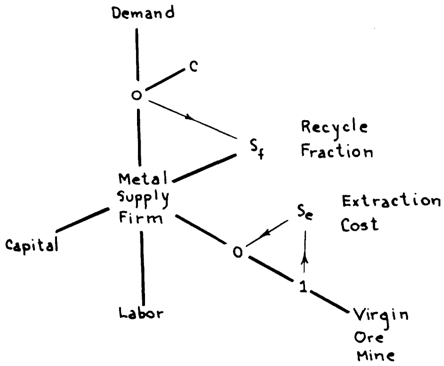


Fig. 6. Nonoriented (bond graph) representation of socioeconomic system shown in an oriented way in Fig. 2. Active bonds are indicated with a full arrow. The flow controlled effort source is equivalent to a resistance.

It is amusing to note that an active bond precisely defines an economic situation, whereas a true physical bond cannot be exactly active because at least some small amount of energy must always be dissipated with information transfer.

Active bonds, that is, the transfer of information without transfer of commodity or revenue, may also be the symbol required to describe many of the dynamic effects studied by Forrester [6]. More specifically, the flow of cash and orders and inventory may be described by active bonds. The details of this type of graphical description are yet to be worked out, but one can imagine a bond graph with a superstructure of the elements described in Section III overlaid with an information transfer network described by active bonds.

Another use of active bonds is to describe the time dependence (*modulation*) of passive element parameters (e.g., resistance values, transformer moduli, compliances, etc.) [12]. It may well be that many of the effects studied by Galbraith [11] can be described by modulations with active bonds. For example, the corporate control of demand might be designated as an active bond modulation of $f_0$ or some parameter of $\phi_{RD}^{-1}(\cdot)$ in (12).

In order to illustrate the above discussion, Fig. 6 was constructed. This is a nonoriented bond graph of the same phenomenon shown in an oriented fashion in Fig. 2. Active bonds are designated by full arrows on the bond. Three such bonds appear in this graph. The firm produces a metal from virgin ore and recycled solid waste. The compliance is added to conform with the discussion of Randers and Meadows [15]. Notice that extraction rate is shown to influence extraction cost. The recycle fraction is shown as a flow source modulated by the metal product price. These bondings were purposely selected to conform to the discussions of Randers and Meadows [15] although the bonds to capital and labor were not explicitly accounted for by these System Dynamicists.

The active bond to recycle flow represents the possible tendency of local solid waste decisionmakers to take into account the price of a metal and not merely the price offered for scrap. Once a decision to recycle is made, the flow is maintained for the lifetime of the plant (perhaps an inertia should be included in the model.) Whether this phenomena is real or completely described is not the point: the point is that, with the active bond, the analyst is able to depict influences other than purely objective and mechanical market forces.

The nonoriented view in Fig. 6 is an alternative starting point for policy testing. There is a subtle advantage to the use of bond graphs not mentioned previously: the assumptions of the modeler are more explicitly and more clearly stated. A physical systems analyst with no economics background but with a knowledge of bond graph notation could quickly and accurately describe the model communicated in Fig. 6. Much text must be supplied with Fig. 2 in order to explain that graph.

We conclude this section with one suggestion for future work. After a modeler has decided upon a policy (orientation) for testing, the state equations can be derived by hand (and then rederived for an alternative policy) [12]. A computer code, such as ENPORT [16], which would derive the equations would be a valuable assist to policy testing. At the present time, nonlinear fields and modulated elements cannot be dealt with by ENPORT. Such extensions would be an important contribution to the social system simulation discipline.

## V. Concluding Remarks

Policy testing seems a useful and important application of socioeconomic simulation. A state variable model is required in order to simulate response to an input (policy). In order to derive a state variable model, the distribution of cause and effect must be assigned. However, as has been shown, cause and effect distributes differently for different inputs (orientations).

A point which is not made above is that adding complexity to a model can also cause a change in some cause and effect relations. Thus the use of an oriented description can be an impediment to the improvement of a model.

A new nonoriented approach to socioeconomic modeling and simulation is proposed here. The basis is the bond graph symbolism which is gaining favor among physical systems analysts. A side benefit of adopting this procedure is that many valuable concepts of microeconomics will be introduced into the formalism of a systems dynamicist.

The free use of the active bond will differentiate the socioeconomic analyst from the conventional mathematical economist. Its proper use will encourage, among other things, the study of the descriptive economics literature, a nontrivial contribution to the evolving paradigms of social system simulation.

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# Hierarchical Regionalization by Iterative Proportional Fitting Procedures: A Comment

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***Abstract*—Slater's use of the iterative proportional fitting procedure (IPFP) for identifying hierarchical regions can be questioned on two grounds: the IPFP scores can provide unreliable indicators of regional linkage; and, in any case, the IPFP matrix cannot satisfactorily be assigned the properties of transitivity and assymetry which are necessary conditions for a hierarchical system.**

A correspondence by Slater, published in the April 1976 issue of this Transactions [11], prompts two questions. Firstly, is the iterative proportional fitting procedure (IPFP) or "biproportional" method a valid procedure for transforming an interaction matrix into an adjacency matrix for the purpose of identifying functional regions? Secondly, is it logical to describe the partitioned binary matrix of significant IPFP scores as a hierarchical system when this matrix does not satisfy the conditions of transitivity and assymetry required in modeling such systems?

The use of IPFP is first considered. Slater states that "confounding effects of varying sizes of total in-migration and total out-migration present in the original table are removed by the IPFP" [11, p. 322]. This sentence may be questioned in one crucial respect: in carrying out any exercise in functional regionalization, particularly when the exercise assumes the existence of hierarchical relations, any differences in the sizes of two interacting entities can never be dismissed as a "confounding" effect, but is of fundamental importance in attaching significance to the strength and directionality of the interaction. The importance of size differences can be demonstrated by applying the IPFP method to an interaction table characterized by marked differences in the size of entities as indicated by the row-sums and column-sums, which in turn lead to a high degree of hierarchical structuring, as will be shown later. Following the example set by Slater, the interaction table is derived from a data set of real-world interactions.

Table I is a segment from a $20 \times 20$ origin-destination study of long-distance telephone traffic between urban centers in Tasmania [14]. The data are presented as mean hourly call rates over a surveyed period of 12 busy hours, comprising two hours on each of six surveyed days, so that a score of 0.08 indicates that

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