MicroWorlds and Evolutionary Economics

When I hear, I forget. When I see, I remember. When I do, I understand.[1]

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Abstract

This paper discusses the use of microworlds in evolutionary economics. A macroeconomic microworld is presented as an example.

Introduction

Since the time of Veblen, evolutionary economists have viewed the world through a dynamic and holistic lens and spoken-out against the static and atomistic theory that dominates economic thinking. In addition, they have championed the idea that economists should spend their time determining how various policy changes will most likely shape emerging socioeconomic systems and how the behavior of these systems can be altered in socially desirable ways (Gruchy 1987). Although these views are appealing and arguably correct, as a practical matter they are somewhat difficult to implement. More precisely, a large and diverse body of literature being developed in disciplines such as control theory and psychology shows that human beings find it very difficult to *accurately* trace through the evolutionary implications of proposed policy changes in complex socioeconomic systems.[2] This difficulty arises because the behavior of these systems is a direct result of their structures or patterns, which consist of stock and flow networks embedded in interacting nests of positive and negative feedback loops, that have themselves been joined by nonlinear couplings. As a consequence, the circular and cumulative behavior of these systems is often quite different from what human intuition suggests it will be.[3]

In recent years Radzicki (1988, 1990a, 1990b) has argued that system dynamics computer simulation modeling can be combined with evolutionary economic theory to construct dynamic institutionalist pattern models. The main benefits of these models would be their preciseness, explicitness, and ability to be simulated. Computer simulation, of course, would make it possible for the dynamic implications of proposed policy changes to be observed.

Recent research in the field of system dynamics has shown that turning system dynamics models into games or "microworlds" can, under certain circumstances, greatly enhance the insights received by those that play (and develop) them.[4] The purpose of this paper, therefore, is to discuss some of the issues surrounding the creation and use of system dynamics microworlds in evolutionary economics. A dynamic fiscal policy game is presented as a means of illustrating the arguments put forth.

MicroWorlds

Although gaming has essentially existed for as long as the computer has, it has only recently been integrated into microworlds or "learning laboratories" that run on microcomputers. A microworld is a computerized environment that enables *and encourages* a person to explore, and experiment with, a dynamical feedback system. The goals of a microworld are to help a person discover the ways in which a system's feedback structure or pattern relates to its behavior and how individual decisions can affect its performance (Diehl 1988; Simons 1990). Through experimentation, a person working within a microworld is able experience behaviors that take years to unfold in the real system being mimicked and/or that have not yet actually occurred because the real system has progressed down a different evolutionary path. If the microworld has been properly designed, moreover, this freedom to explore facilitates user self-discovery or "learner directed learning" (Bakken 1989; Peterson

1990; Simons 1990). In terms of evolutionary economics this means that, in principle, an evolutionary theorist or student could explore the dynamics of a theory or a pattern model within a microworld and uncover new insights into its structure and behavior.

Broadly stated, there are two types of microworlds that are based on system dynamics models: computer games and board games. Computer games can be either single player or multi-player, while board games are almost always multi-player. Multi-player computer games tend to work best on a computer network, with each player working at a separate machine. Board games are usually played with all the participants seated around a table.

Computer games use software that simulates a system dynamics model for a finite period of time (usually one period), pauses, receives and displays feedback from the model, invites a player to make a decision(s) based on the feedback, and then simulates the model for another finite period of time. A central feature of this type of microworld is that it keeps track of the decisions made by a player for later reflection and analysis. One of its main advantages is that it can usually be played many times by a player, quickly, and without coordination by a game moderator. The result is that experimentation and exploration are easily undertaken.

Depending on their design, board games based on system dynamics models can be played either entirely without the aid of a computer, or with the aid of a computer that runs off to the side and out of the players' central stream of consciousness. In the former case, the players themselves simulate the model through time with the aid of the game board and other accounting devices such as game pieces and paper and pencils. In the later case, a computer simulates the model and keeps track of the accounting calculations while a game moderator relays information between it, the players, and the game board. In this type of microworld, the game board functions primarily as a conceptualization device. Meadows (1989) argues convincingly that board games are superior to computer games when multiple players are involved because the round-table atmosphere promotes a higher level of discussion and interaction. The drawback to this type of microworld is that its format makes exploration and experimentation somewhat difficult.

Design and Implementation

Currently, a literature is emerging that describes how best to turn system dynamics models into computerized microworlds (Morecroft 1988; Graham et al. 1989; Kim 1989; Meadows 1989; Andersen et al. 1990; Peterson 1990; Saeed 1990; Simons 1990). Although there is still much to be learned, the keys to the creation of a successful microworld -- that is, one that facilitates learner directed learning -- appear to be proper design and proper implementation. The former involves the physical construction of the microworld and the determination of the rules of play and experimentation, while the latter involves the determination of the information a person will receive before, during, and after play. In each case, the overriding goal is to minimize the chance that a player will treat the microworld as a video game or toy, and maximize the chance that it will stimulate his or her curiosity and motivate him or her to think critically.

In designing a microworld, it is helpful to remember that human beings make virtually all decisions via bounded rational rules (Kleinmuntz 1985; Morecroft 1988; Sterman 1989a, 1989b). As a result, care must be taken to ensure that a player is not bombarded with information and asked to make too many decisions during a round of play. Both Andersen et al. (1990) and Peterson (1990) present guidelines involving topics such as screen design that are aimed at preventing this from occurring. It is also useful to remember that a successful microworld can only be created from a good system dynamics model *and* that not all good system dynamics models can be turned into successful microworlds. In particular, studies (and common sense) indicate that the perspective from which the underlying system dynamics model is built (e.g., the level of aggregation chosen; the selection of the particular decision processes portrayed) will have a substantial effect on the success of the microworld built around it (Andersen et al. 1990).

In terms of the proper implementation of a microworld, Bakken (1989) has accumulated evidence indicating that the ability of a person to control a system being simulated within a microworld is strongly related to their understanding of its structure (feedback loops, delays, nonlinear couplings, *et cetera* -- i.e., the very things that cause evolutionary behavior).[5]

Moreover, both system dynamics studies (Diehl 1988; Bakken 1989; Sterman 1989a, 1989b) and traditional psychological studies (e.g., Brehmer 1987) show that outcome feedback, or information on the dynamic implications of decisions made in the game and received during play, is *not* effective in helping people learn about system structure. All of this implies that a person should receive training on the relationship between a system's structure and behavior before beginning to use a microworld; should have access to information on system structure and behavior during play; and should be debriefed on the subject *vis-á-vis* their experience after play. Kim (1989) describes the improvement in employee learning that took place in a corporate setting, only after a program of briefing and debriefing was added to the gaming experience. Graham et al. (1989) provide a comprehensive overview of successful and unsuccessful strategies for using microworlds in teaching and research settings.

Fiscal Policy Game

In order to illustrate many of the concepts discussed above, an actual microworld created by the author will be described. It is an example of how gaming can be used to explore the dynamics of macroeconomic theory and fiscal policy.[6] A similar microworld, based on a case study of the rise and fall of People's Express Airlines (Sterman 1988), is an example of how gaming can be used to explore the dynamics of what is essentially an institutionalist pattern model.

The goals of the fiscal policy microworld are to: 1) provide players with an environment for exploring the dynamics of Keynesian macroeconomic theory and the multiplier and accelerator processes; 2) emphasize the interactions in the world economy; 3) reiterate the necessity of making choices in economics; and 4) drive home the point that, due to feedback effects, the decisions people make both shape their emerging world and (often) come back to haunt them.

Design

The system dynamics model that underlies the fiscal policy microworld is based on a synthesis of Keynesian macroeconomic theory, Milton Friedman's permanent income hypothesis, and the Samuelson-Hicks multiplier-accelerator model. More specifically, it follows the directions originally taken by Low (1980) and Forrester (1982) by recasting the Samuelson-Hicks multiplier-accelerator model from a system dynamics perspective and extending it with an international sector, an endogenous aggregate demand forecasting sector, an endogenous permanent income sector, and a relatively sophisticated investment sector. In addition, it has been replicated and linked to its copy via international trade so that secondary feedback effects in each economy are possible, and it corrects some of the well-known problems associated with traditional Keynesian theory.[7]

Figure 1 presents the major feedback loop structure of one of the economies in the fiscal policy microworld. Inspection of the Figure reveals that six principle feedback loops -- two positive and four negative -- govern the macroeconomic behavior of the sector. Positive feedback loops generate self-reinforcing behavior and are responsible for the exponential growth or decline of systems. The major positive loops in the sector are identified by the large plus signs placed within parentheses in Figure 1. Negative feedback loops generate counteracting or goal-seeking behavior and are responsible for stabilizing (or trying to stabilize) systems. The major negative loops in the sector are identified by the large minus signs placed within parentheses in Figure 1. The small plus (minus) signs next to the arrows that comprise the various feedback loops in the Figure indicate places where a change in the variable at the back of the arrow causes, *ceteris paribus,* a change in the variable at the front of the arrow in the same (opposite) direction.[8]

In terms of the representation of specific macroeconomic processes with feedback loops, the dynamical behavior of both the multiplier process and the accelerator process is strongly influenced by positive feedback. In particular, the Keynesian multiplier is represented in Figure 1 by a positive loop connecting Permanent Income, Consumption, National Income, and Disposable Income, and the accelerator is represented, in part, by a positive loop connecting National Income, Expected National Income, and Investment.

The four negative loops shown in Figure 1 depict either leakages from the macroeconomy or explicit goal-seeking behavior. The first negative loop captures the leakage due to spending on imports and is a causal chain linking Permanent Income, Imports, National Income, and Disposable Income.[9] The second negative loop portrays the leakage or "fiscal drag" that arises from the collection of income taxes by the government and is a causal chain linking Permanent Income, Consumption, National Income, Tax Revenue, and Disposable Income. The third negative loop represents the leakage due to the wearing-out of the economy's capital stock and is a causal chain linking Capital and Depreciation. Finally, the fourth negative feedback loop represents goal-seeking behavior within the accelerator process and is a causal chain linking Investment and the Capital stock. The goal-seeking behavior takes place when the model compares the economy's Capital stock to its Desired Capital stock and adjusts Investment spending accordingly. Macroeconomic instabilities can occur when Investment falls as the economy's Capital stock nears its desired level, and rises as it moves away from it.

Figure 2 depicts the game screen for the fiscal policy microworld. Inspection of the Figure reveals that the screen is divided into four sections: a "Decisions" section, "Reports" section, "Graphs" section, and a section reserved for the viewing of reports and graphs. The "Decisions" section is the place where a player enters his or her policy changes in response to feedback from the model. Four fiscal policy tools are available for player manipulation: Government Spending, Lump Sum (Non-Income) Taxes, the Marginal (Income) Tax Rate, and Transfer Payments. The "Reports" section is the place where a player can call-up information on the game ("Created By;" "Instructions") or its underlying feedback structure ("Major Causal Loops"; "Model Overview").[10] It is also the place where he or she can call-up the "Major Macroeconomic Flows" report shown in Figure 2. This report displays the current values of the major national income and product accounting flows in the economy and thus changes as the model is advanced through time. The "Graphs" section is the place where a player can call-up a time series graph of any of the major variables in the economy he or she is trying to control. Whereas the "Major Macroeconomic Flows" report displays only the current values of the selected variables, each of the "Graphs" records and displays the historical values of the variables produced during the game up to the current point in time. Indeed, it not only does this for the model's endogenous variables, but also for its four exogenous ones -- i.e., the policy levers from the "Decisions" section. Thus, a player can go back at any time and examine his or her policy changes *vis-á-vis* the behavior of the model.

As shown in Figure 3, a person plays the game by intervening in the economy with the fiscal policy tools available in the "Decisions" section of the microworld. The game is started in equilibrium with the trade and federal deficits equal to zero. In year three, however, the government of the second economy cuts its spending by $50 (billion). This shock unleashes an oscillation with a downward trend in *both* economies. The player, of course, is instructed to use the available fiscal policy tools to try and stop this undesirable behavior. As there are no price levels or monetary sectors in the model, the "down side" to a strategy of continuously pumping-up the economy with spending increases and tax cuts is the expansion of the twin deficits. Thus, the player is also instructed to try to keep the deficits at a "reasonable" level. One last complication to all of this is the accelerator. Even without the interactions with the second economy, the first economy will stall and decline whenever its capital stock reaches its desired level. The player, therefore, has to battle a second set of forces working to create an undesirable situation in the economy. Figure 4 presents the graph of National Income for a typical play of the game, Figure 5 the corresponding Federal Deficit plot, and Figure 6 the graph of the player's choices for Government Spending during the simulation.

Implementation

As the above description indicates, a player must keep track of many things while playing the fiscal policy game. In fact, one might even hypothesize that the microworld provides a player with so many policy options and so much feedback that the assembly of a well thought out strategy, where effects are systematically related to causes, is impeded. Experience with the microworld has shown that players do "best," in the sense of learning about the impact of various fiscal policies on multiplier-accelerator dyads, if they are first taught the underlying macroeconomic theory in a traditional manner,[11] and then with causal loop diagrams and/or a traditional system dynamics model. Moreover, learning appears to be enhanced if players have access to the model's feedback loop structure during play, and if they are debriefed with a discussion of the theory *vis-á-vis* causal loop diagrams after they play. These effects are identical to those described by Kim (1989). It should also be noted that the "Major Causal Loops" report is specifically included in the game so that players can refer to it when making decisions between rounds. A quick glance at Figure 1 will reveal that the places where the four fiscal policy levers impact the system are clearly marked for the player with rounded rectangles.

One last result that is worth noting at this time is that, generally speaking, it appears that players do a significantly better job controlling the system if they play the game more than once or twice -- a luxury actual policy makers do not have. Although this result is probably not surprising, it does point out the value of exploration and experimentation. It also implicitly illustrates the evolutionary nature of the simulations as, from play to play, the economy travels down different dynamical paths.

Future Research

At this time it appears that microworlds have two main uses in evolutionary economics: 1) to help students learn existing economic theory (traditional or otherwise) in a superior way; and 2) to aid in the process of developing new theories and pattern models. Although much of the discussion in this paper was implicitly centered around the first use, the second may ultimately be more beneficial to evolutionary economists. This is because, in principle, microworlds can enable evolutionary economists to discover more about their new theories and pattern models than would otherwise be the case. The result will be better models and theories and hence policies that are more effective in shaping emerging economic systems in socially desirable ways.

Endnotes

1. Chinese proverb suggested by Meadows (1989, p. 636) as appropriate for viewing the contribution gaming can make towards helping people understand the dynamics of complex systems.
2. See Diehl (1988), Sterman (1989a; 1989b), and Bakken (1989), for overviews of the literature relating to human errors in dynamic decision making.
3. This argument is implicitly advanced in the field of macroeconomics in the traditional debate over activist stabilization policies. Those that favor nonactivism cite the difficulty of determining the correct timing and magnitude of fiscal and monetary interventions due to the lags that exist between problem recognition and policy impact.
4. Other terms that are used more or less interchangeably with "microworld" are "learning laboratories," "learning environments," and "flight simulators."
5. To be fair, this contradicts the findings of other researchers. See for example Broadbent and Aston (1978).
6. See Sterman and Meadows (1985) for an example of a microworld used to explore a theory of the economic long wave and Saeed (1990) for an example of a microworld used to explore economic development theory.
7. For example, its incorrect specification of stocks and flows. Excellent discussions of the problems associated with traditional Keynesian theory are contained in Low (1980) and Solow (1984).
8. More precisely, a small plus sign next to an arrow indicates:

$$\frac{\partial \text{ Variable at Head of Arrow}}{\partial \text{ Variable at Tail of Arrow}} > 0$$

and a small minus sign next to an arrow indicates:

$$\frac{\partial \text{ Variable at Head of Arrow}}{\partial \text{ Variable at Tail of Arrow}} < 0$$

9. Unlike traditional Keynesian theory, imports in the fiscal policy microworld are a function of permanent income, rather than national income. This implies that, in each economy, all capital goods are produced domestically.
10. The "Major Causal Loops" report is shown in Figure 1. The "Model Overview" report is shown in Figure 3.
11. For example, by having them read the description of the interaction between the multiplier and accelerator provided by Samuelson and Nordhaus (1989, Chapter 10). Experience has also shown that having players examine the original multiplier-accelerator model is *not* at all useful in helping them to intuitively understand its structure and behavior, let alone in helping them to play the game well.

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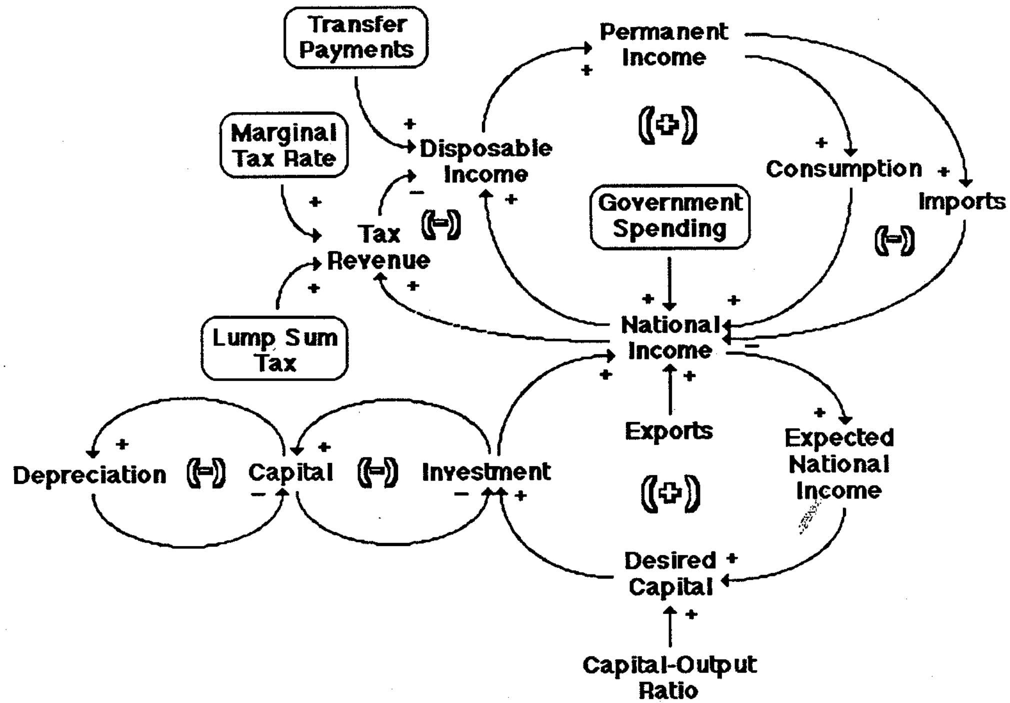

Figure 1: Major Feedback Loop Structure of One Economy in the Fiscal Policy Game

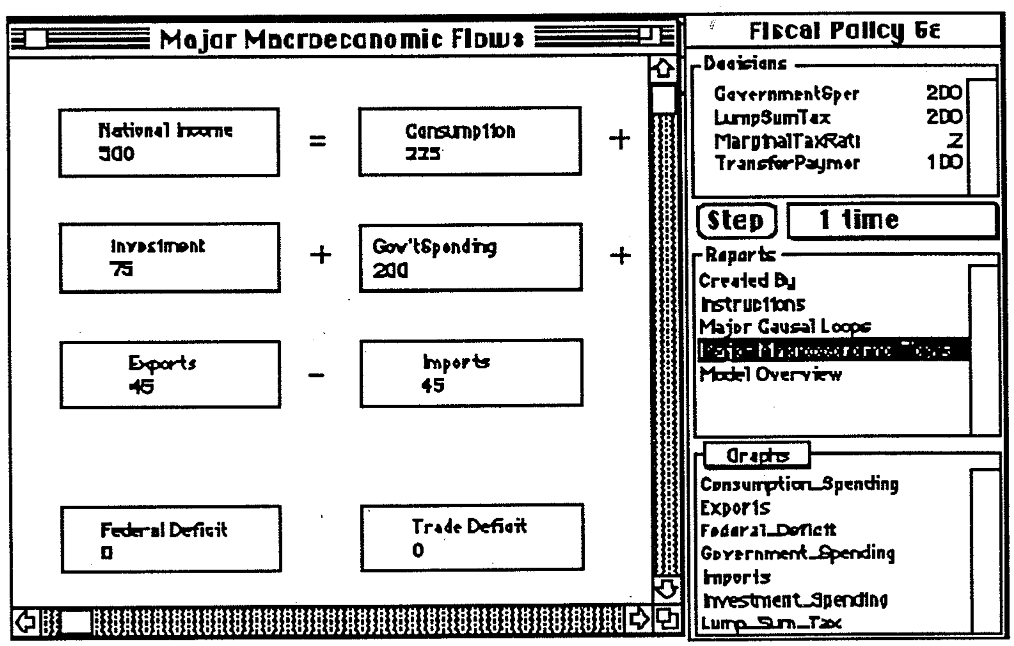

Figure 2: Game Screen and Major Macroeconomic Flows Report

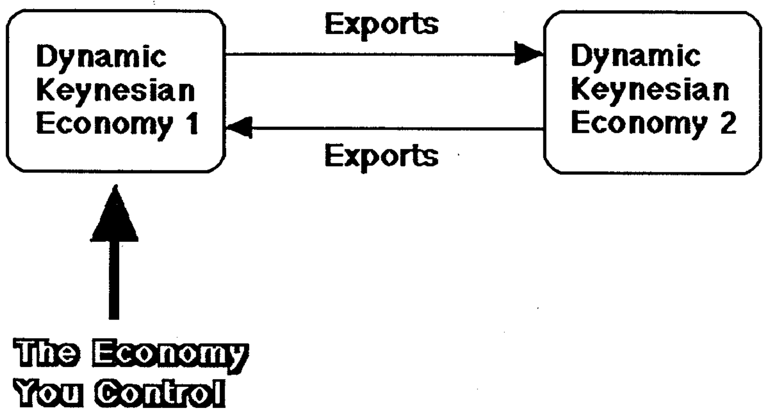

Figure 3: Overview of the Fiscal Policy Game

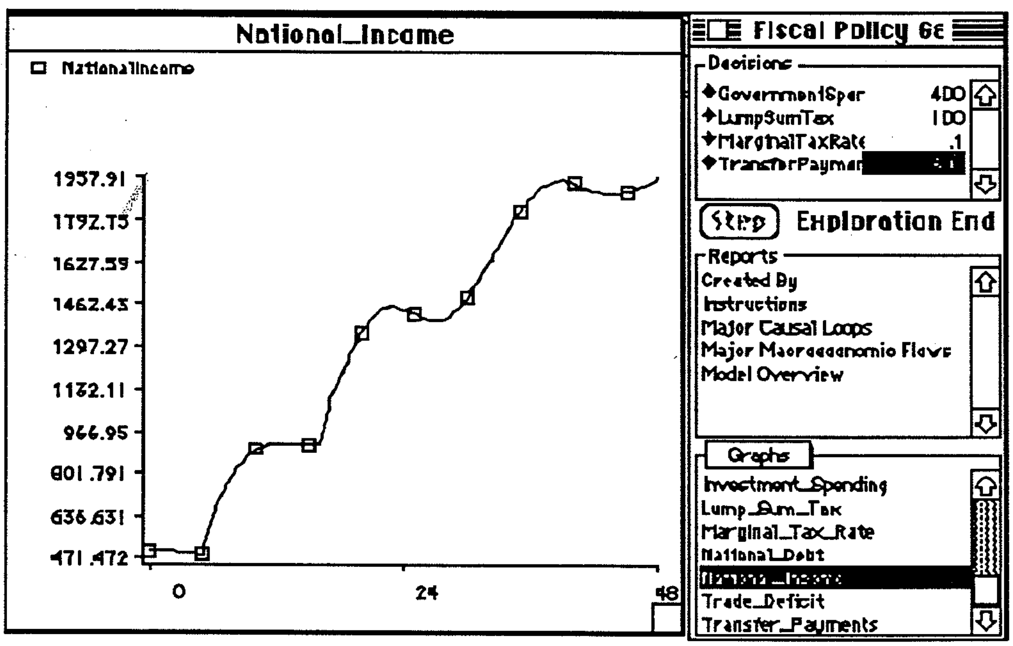

Figure 4: National Income Plot After a Typical Play of the Fiscal Policy Game

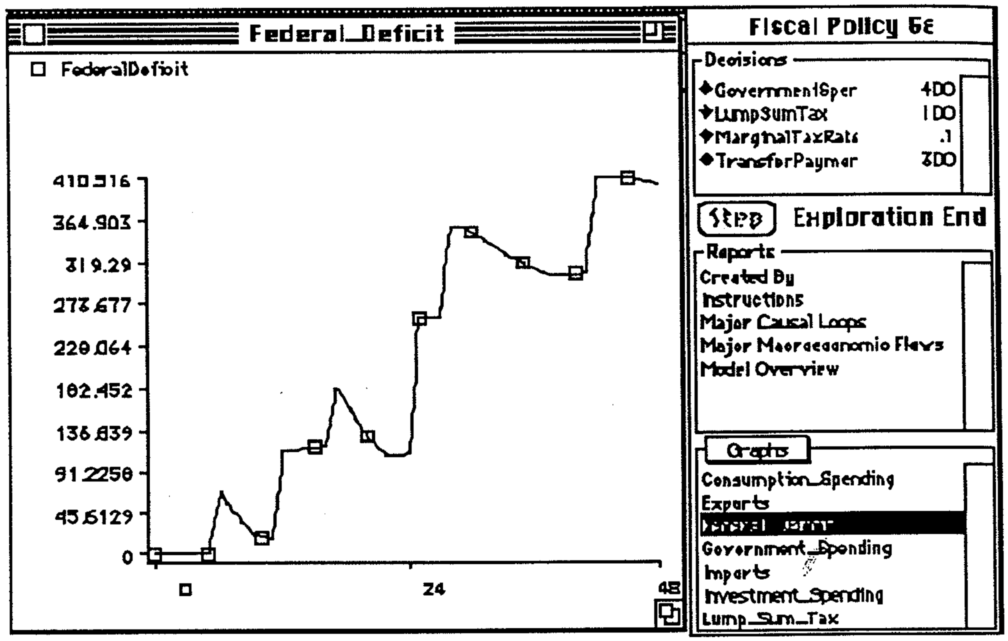

Figure 5: Federal Deficit Plot After a Typical Play of the Fiscal Policy Game

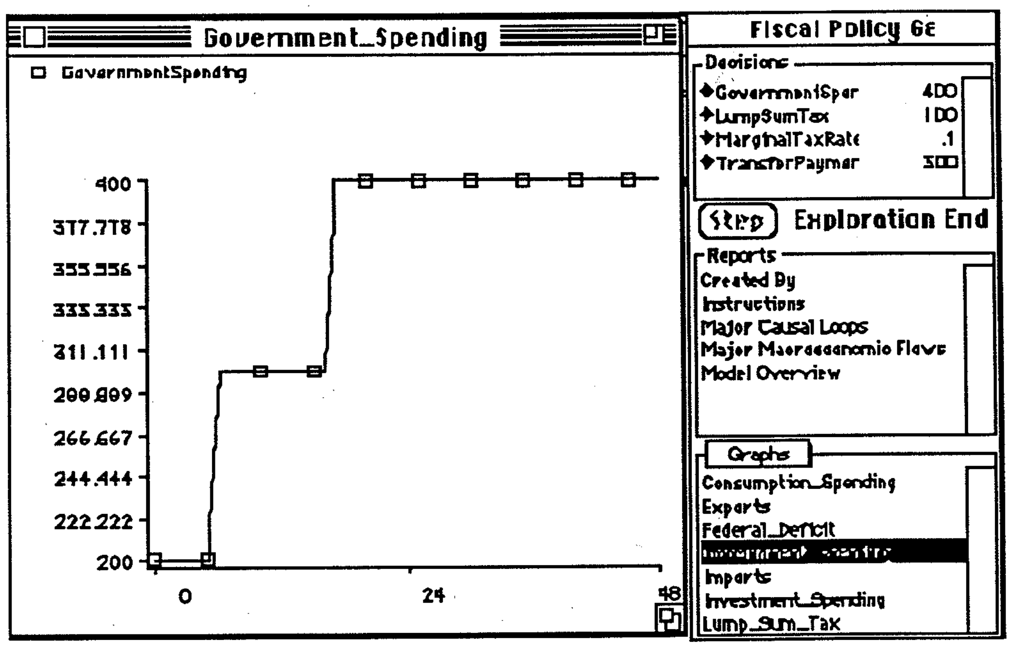

Figure 6: Government Spending Plot After a Typical Play of the Fiscal Policy Game