

ASPEN: A MICROSIMULATION MODEL OF THE ECONOMY

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Abstract

In this report we present ASPEN, a new agent-based microeconomic simulation model of the US economy being developed at Sandia National Laboratories (SNL). The model is notable because it allows a large number of individual economic agents to be modeled at a high level of detail and with a great degree of freedom. Some of the features of ASPEN are a) a sophisticated message-passing system which allows individual pairs of agents to communicate with one another, b) the use of genetic algorithms to simulate certain agents' learning, and c) a detailed financial sector which includes a banking system and a bond market. Results from runs of the model are also presented.

1. Introduction

In this paper we describe ASPEN, a new simulation model of the US economy that we are developing at Sandia National Laboratories (SNL).¹ It runs on SNL's massively parallel Paragon computer. ASPEN is an "agent-based" Monte-Carlo simulation, in which individuals in the model represent real-life economic decision-makers. Macroeconomic quantities of interest are generated via the aggregation of the agents' "microeconomic" actions.

The basic building blocks of ASPEN are the aforementioned agents. Household agents work a job (or collect unemployment or social security) to obtain income, which they spend on four consumer items (see below), put into a savings account, or invest in bonds. There are four different types of firm agents, producing four different types of goods -- automobile manufacturers, housing developers, producers of a nondurable necessity (like food), and producers of a nondurable whose consumption is dependent on income. Each of the firms uses capital equipment in addition to labor in order to produce its goods. Especially important (from a modelling standpoint) is the idea that firms set prices by using a genetic algorithm learning classifier system (GALCS). In this way, we simulate their learning as they develop pricing strategy.

There is also a single "government agent". In addition to collecting income, sales, and payroll tax, this agent runs a social security system, provides unemployment pay, runs a public sector, and issues government bonds whenever it runs a deficit. Finally, there is well-developed financial sector, which includes a) banks, which maintain household savings accounts, make consumer and business loans, and invest in bonds, b) the federal reserve, which may conduct expansionary or contractionary monetary policy, and c) a "financial marketplace agent", which reconciles demand and supply for bonds among the government, banks, and households.

We remark that the model still leaves out certain important elements of our economy. For example, there is no defense industry, there is no service sector, and there are no stock markets. Our response to this difficulty is twofold: first, we intend to implement these elements in a future version of the model. Second, when we tested the outcome of various fed monetary policies in the model (see section 4), the results agreed

¹ The model described here is an update of the so-called "prototype model" described in Pryor-Basu-Quint (1996). In that paper, this paper's model is referred to as the "developmental model".

qualitatively with what we know “should happen” according to economic theory and practice. This is significant, given that the simulation technique (especially the use of the genetic algorithms) is so novel. Hence, even in its current state the model has merit.

The paper is organized into four sections. In Section 2 we cover some background concerning microeconomic simulation. In the following section we describe the model. Finally, in Section 4 we go over some of the results that we have obtained using it.

2. Background

By a “microsimulation of the economy”, we mean a model in which economic decision-makers are individually modelled, and then macroeconomic quantities are generated via the aggregation of the agents’ “microeconomic” actions. It is a relatively new approach -- in fact we know of only two such models of the US economy.² Potentially it affords several advantages over more “traditional” techniques [i.e., macroeconometric or computable general equilibrium (CGE) models] of modeling the economy:

a) Since the procedure doesn’t require any particular functional form for its endogenous relationships (as macroeconometric and CGE models do), one has great freedom when modelling the behavior of individual agents, and can model them in great detail. For example, in ASPEN the “learning” of some agents is simulated via the use of genetic algorithm learning classifier systems (see section 3). In addition, one can explicitly model the effect of certain “nonlinear” legal, regulatory, and/or policy changes, such as in tax law.

b) Since the procedure is individual agent-based, one must in general build microeconomic models of the individual decision-maker rather than macroeconomic models of markets. Hence, one can utilize existing rich sources of micro-level data.

c) It is easy to model a stochastic element using a simple random number generator.

On the other hand, we feel there have been two major *disadvantages* to the use of microeconomic simulation up to now. First, because the technique is so new, there hasn’t been time to “work out modeling kinks” or estimate accepted parameter values the way there has been for other types of models. Hence there is no way at present that this type of model could give as accurate a forecast as a macroeconometric or a CGE model could. Second, keeping track of numerous agents, especially if they are modeled in great detail, can take up enormous computing capacity. However, we feel that given time and computing facilities like SNL’s Paragon (currently the USA’s largest), microeconomic simulation models will eventually “catch up” to their more classical counterparts.

3. ASPEN: The Model

3.1 The “Mechanics” of the Model

In ASPEN, we call the individual decision-makers in the economy agents. To be more specific, there are several classes (types) of agent: households, banks, government (only one agent of this type), federal reserve (only one agent of this type), and four types

² One is the Urban Institute Model, developed by Guy Orcutt. See Orcutt-Caldwell-Wertheimer 1976. The other is Robert Bennett and Barbara Bergmann’s “Transaction Model” (Bennett-Bergmann, 1986).

of firm: food producers, “other nondurables” producers, automobile makers, and housing developers. Finally, there are three other classes, each containing only one member and each with a special role defined below: a realtor, a capital goods producer, and a “financial marketplace” agent.

Each agent behaves as a real world counterpart of the same type would, and the microsimulation traces their daily actions, i.e., buying food, hiring workers, selling bonds, collecting welfare payments, conducting open market operations, etc. Agents in the same class have the same *decision rules* -- for example, if a “non-homeowning” household decides that it wants to move into a new home, it always applies for a 30-year housing loan in which its payments would be 35% of its income.³ However, same-type agents will not necessarily take the same *actions* because a) they may be in different “states” (e.g., two household agents at a particular time may have different incomes, so they would opt for different sized loans), or b) they may “draw different random numbers” from the random number generator (e.g., the decision to move in the first place is determined by the draw of a random number).

In order for its agents to accomplish actions, the model uses a system of message passing. In order to understand how this works, it is necessary to say something about time sequencing. In ASPEN, time is divided up into discrete periods, or days. In turn, each day is divided into a certain number (11) of stages. Each agent is “processed” once per stage. By this we mean that he/she a) reads any incoming messages and then acts upon them, and then b) takes “allowable” independent actions according to his/her current status.

Most actions are allowed only once (if at all) each day, during a specified stage. For instance, an automaker agent pays income tax only during “stage 1” each day. To accomplish this, not only does it debit its accounts by the requisite amounts, but it also sends a message to the government saying “I’m paying taxes of \$x”. When it is next the government agent’s turn to be processed, it reads this as an incoming message and acts accordingly (i.e., crediting its cash account by \$x).⁴

More complicated “series” of actions require a “series” of messages to be passed. For example, if a household decides to buy a new home, it first figures out its financing, and then sends a message to a bank requesting a mortgage loan. The bank then reads this message, and decides (based on the information the household has sent in its message) to accept or reject the loan. Either way, it sends a message back to the household. If the message is “accept”, the household then sends a message to a developer stating that it wants to buy a house, etc.

Last, we should note that, from a computational standpoint, implementation of the message-passing system is not a triviality. ASPEN is designed to run on the parallel processing Paragon -- hence the agents in the model are distributed among the various nodes of the computer. Each *agent* has a “message queue” containing messages waiting to be read by him, and each *node* also has its own queue. When an agent sends a message, a “toolbox routine” first determines whether the recipient is on the same node. If so, the message is immediately placed in the recipient’s queue. If not, it goes into a “holding area” of messages destined to be shipped to the *node* of the recipient. At the end of the stage, the “holding areas” are emptied, and their contents shipped to the appropriate “node queues”. At the beginning of the next stage, the messages queued at each node are distributed into

³ The parameters “30 (year)” and “35%” can be changed at the discretion of the user when he/she runs the microsimulation. See Section 3.2.

⁴ In fact every cash debit is balanced by a credit (and vice versa). Hence here is an accounting check which we have used to ensure the model is running properly.

the individual agents' queues. They are then read by the recipients when it is their turn to be "processed".

In this way, the number of "cross-node communications" is kept to a minimum, and hence ASPEN can run more efficiently.

3.2 Initialization and Parameterization

As one can tell from the above description, many of the agents' decisions in ASPEN are dependent on their current "state". For example, a household's consumption decision is dependent on its family size, its current income, its savings account balance, its bondholdings, etc. Certain of these values must be "initialized", e.g., at the start of an ASPEN run, each household is assigned a savings account balance, an initial bondholding, and an age for its head. In some cases, the assignment is done via randomization -- for instance, for initial savings levels each household draws its value from an exponential distribution with mean \$800. In this way we simulate a heterogenous population.

We remark that for almost any of these quantities the user has the ability to input his/her own values. If they choose not to exercise this option, default values are used.

All of the above discussion also applies to the model's numerous *parameters*, e.g., the frequency with which an automobile breaks down, the length of a standard mortgage, or the percentage of savings that constitutes a bank's reserve requirement.

For a list of initialization values and parameters, together with their default values (which also happen to be the values we used in the runs discussed in Section 4), see the Appendix.

3.3 The Agents

In this subsection we go over the decision rules of agents from each of the different classes. The relationships (via the decision rules) among the various classes of agents is portrayed in Figure 1.

3.3.1 The Households (Individuals)

The majority of agents in ASPEN are households (individuals). These agents generate most of their income by working a job, with their employer being one of the four types of firm, a bank, the realtor, the capital goods producer, or the government. They obtain these jobs by replying positively to a "job offer message", and collect a salary from their employer until they quit or are fired. If at any time they do not hold a job, they collect a "welfare payment" from the government, the magnitude of which is dependent on their family size. Senior citizens collect social security payments. Other revenues generated for the households include interest payments from bonds and savings accounts (see below), as well as their shares of company profits (see section 3.3.2). A flat rate income tax is paid on all income.

Using its income (plus savings), the household consumes four types of good each day: "food", "other nondurables", "transportation", and "shelter". We remark that the determination of a household's consumption for these goods is not done in the usual way -- there is no exogenous utility function that it maximizes over all feasible consumption

AGENT INTERACTIONS IN ASPEN

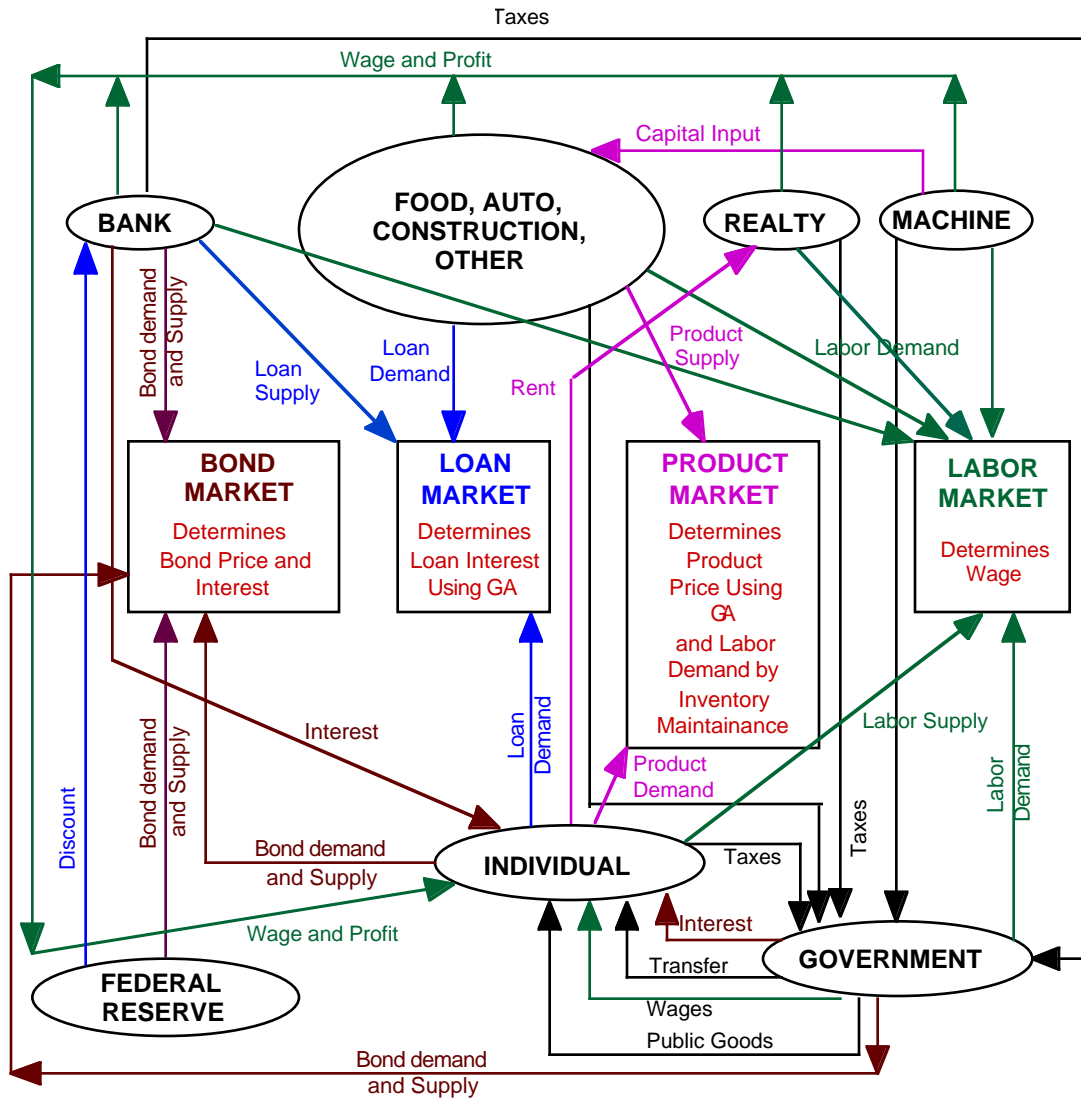


Figure 1

bundles. Rather, it uses certain “rules of thumb”. Thus we emphasize the important observation that ASPEN is a *simulation* model, not an *optimization* model.

Demand for food is deterministic each day, based on the household’s family size. Once a household has determined this demand, it determines from which food firm to make its purchase. It first consults its list of food prices (the food firms each send out “broadcast messages” of price/unit information to everyone each day). If firm f is offering food for price $p(f)$, the household buys from it with probability $k*[p(f)]^q$, where q is a given exogenous parameter and k is a normalizing constant. In words, the lower $p(f)$ is in relation to other firms’ prices, the greater chance the household has of satisfying its demand by buying from f .

A household’s consumption of “other nondurables” is done exactly the same way, except that demand is now calculated as a given percentage of (income - food expense), divided by the average industry-wide price of “other nondurables”.

Next, as long as the “family car” is running properly, a household has no transportation demand. However, with a given probability each day its car breaks down, and if that happens it must try to buy a new one. It first locates an automobile producer from which to buy, using the criterion of “price per unit of auto”, in much the same way that it determines where to buy its food. If it has enough savings to buy an “expensive” car (i.e., one selling for twice the unit price), it does so. Otherwise, it applies for an auto loan from a bank -- again, the household is more likely to apply at a bank offering a lower loan rate of interest. The amount of loan is determined as that amount for which payments are .1 of income over a five-year loan⁵, and this in turn determines the number of “auto units” bought. In conclusion, then, we see that market auto demand is a function of personal income, personal savings, and interest rates.

Demand for housing is done similarly. Each household is “initially” assigned as a renter or as a homeowner.⁶ Renters pay a given percentage of their income as rent each day, to the “realtor” agent. In addition, renters have a probability each day of wishing to buy a new home⁷, while homeowners have a (different) probability of wishing to buy a “home improvement”.⁸ Again, the decision regarding which developer to buy from, and which bank to secure the mortgage/home improvement loan from is dependent on what prices these agents are charging for their services.

Besides paying for the consumption of these four goods, a household decides how to allocate its remaining assets among “pocket cash”, saving (i.e., depositing/withdrawing money into a family savings account at one of the banks) and investment (i.e., buying/selling government bonds -- for a description of these bonds, see below). The amount of pocket cash is an exogenous constant. The split of the remainder is determined by a given increasing function, in which the independent variable is the total amount of

⁵ This is true so long as the loan amount plus “cash-on-hand” will buy no more than two “units” of auto. If it will buy more than this amount, the consumer will buy a “two unit” car, and so his payments will be *less* than .1 of his income.

⁶ This is done during the 30th day of a run, according to a) the age of the household head, and b) the employment status of the household head at that time.

⁷ This probability is dependent on interest rates for mortgages.

⁸ The parameters are set in such a way so that if interest rates were constant, total housing demand (i.e., demand for new homes plus demand for home improvements) would remain constant over time, even as renters become homeowners.

remaining assets and the dependent variable is the percentage of these assets which should be invested in bonds.⁹

In addition, once every 90 days a household has the option of moving its savings to another bank. Of course, it is more likely that they will do this if other banks are offering a higher rate of interest.

3.3.2 The Firms

In ASPEN, all four types of firm produce goods using both capital and labor. In particular they all have production functions of the form $y = c K^a L^b$, where y is the output of good during a particular day, K is the number of “machines” on hand in the factory, and L is the number of employees. The quantities a, b , and c are constants, with a and b both set to a default value of 1, and c constant across firms in the same industry.

Needless to say, a firm can vary its production by changing K or L . Once every year, a firm has the option to take out a “business loan” in order to buy a new machine (thereby increasing K by one). It makes this decision by weighing the value of increased production against the extra cost of the machine plus loan costs. In addition, a firm has the option each day of hiring or firing workers. It makes this decision by comparing recent average daily demand with the current inventory level -- if the quantity (inventory/demand) is less than a certain constant, the firm sends out job offers, while if it is greater than a certain other constant, it sends out pink slips.

Wages in this simple model are constant across all firms in all industries.

An important feature of ASPEN is how firms set prices for their product using a genetic algorithm learning classifier system (GALCS). Each day, a firm determines four “trends”: a) whether or not its price has been recently increasing or decreasing, b) whether or not sales have been recently increasing or decreasing, c) whether or not its profits have been recently increasing or decreasing, and d) whether or not its prices are higher or lower than the industry-wide average. According to the answers to a)-d), it classifies itself as being in one of sixteen “states”.

The GALCS assigns a probability vector (p^D, p^I, p^C) to each state, where p^D is the probability that the firm will decrease its price (by a certain exogenously specified amount¹⁰) the next time it enters the state, p^I is the probability it will increase its price, and p^C is the probability it will keep its price constant. When a firm enters a certain state, it first decides how to change its price by using this vector and drawing a random number. It then perturbs the vector according to how the price-change effects profits.

For instance, suppose at a particular time that for “State 2”, $(p^D, p^I, p^C) = (.1, .6, .3)$. Suppose that a firm enters this state, and draws a random number which indicates that it increases its price. Suppose further that profits then drop. The vector (p^D, p^I, p^C) is then perturbed to reflect this, say to $(.15, .5, .35)$. The idea here is that we are simulating the “learning” that the firm experiences: in the example, “raising prices in State 2” was bad

⁹ In a future version of the model, we plan to make the more realistic assumption that the savings/investment/consumption decision is also dependent on the age of the household head.

¹⁰ These amounts are given under “Price changes” in Appendix A, parts 2C, 2D, 2E, and 2F.

for the firm, and the changed probability vector reflects the fact that it will be less likely to do the same thing if it enters “State 2” again.

Finally, we remark that a firm must pay taxes on any profits, and social security taxes on its payroll. In addition, there are three options at present for the distribution of a firm’s aftertax profits. First, if a firm is “solely owned”, all of the aftertax profits go to a designated household. Next, if it is “worker owned”, this money is divided equally among all of its current employees. Finally, in the spirit of general equilibrium models (see, e.g., Varian, 1978, p. 163.), it can be disbursed equally to all households in the entire economy. This last option is the “default”, used for all of our firms in all of our current runs.

3.3.3 The Banks

Banks in ASPEN have four functions: to maintain savings accounts for households, to buy/sell government bonds, to make loans, and to hire a small workforce.

As mentioned above, households can switch savingsbanks once every 90 days. Each bank decides on its savings interest rate each day by taking “the effective yield on bonds” (i.e., the quantity “dividend/price” for bonds) and multiplying by 4/5. In the current version of the model, then, all banks will end up offering the same interest rate, so we would expect all to have roughly the same number of savings accounts.

Each day, banks must check to make sure that they have a reserve amounting to 3% of their total savings account deposits, plus another 1% “discretionary reserve”. If they exceed these requirements, they attempt to buy bonds with the excess. On the other hand, if they do not meet this requirement, not only do they attempt to sell bonds, but they also must apply for discounting from the federal reserve.

Banks also process loans. Each bank’s “loan interest rate” is the sum of two terms: the first is a function of bond prices and its observed default rate on loans, while the second is generated using a GALCS.¹¹ When it receives a loan application, it rejects the loan if either a) the payment amounts are “too high” given the applicant’s income, b) the “default rate” on recent loans has been too high, or c) the applicant has defaulted on a loan too recently. Otherwise, it accepts the application.

Finally, banks maintain a small workforce, the size of which is a function of their total assets. They too pay income and payroll taxes.

3.3.4 The Government

Each day, the government agent in ASPEN collects taxes (income, sales, and payroll taxes), pays assistance to the old and the unemployed, pays out dividends on any outstanding bonds, and employs a given percentage of the population (default: 25%). If at the end of these activities the sum of the revenues is less than the sum of the expenditures, the government issues bonds. Bonds have no maturity date, and pay out a dividend of 5 cents per unit per year. Initially they are priced at \$1/unit (meaning that the effective yield of bonds is 5%), but the prices on bonds are allowed to change (see below).

¹¹ The GALCS is similar to that described for firms’ price-setting, with “loan interest rate” playing the role of “product price”, and “total amount of loans made” playing the role of “sales”.

Finally, we remark that the user has the option to simulate an expansionary government fiscal policy in ASPEN, by specifying a payout to be given out by the government to all of the households each period.

3.3.5 The “Financial Marketplace”

Once each day, as described above, the government, households, and banks all decide how many units of bond they wish to issue/buy/sell. These “orders” are sent to a special ASPEN agent which we call “the financial marketplace”. When all of the orders have been counted, the marketplace agent determines whether there are more “buy orders” or “sell orders”. It then sends this information to the federal reserve agent, for use if the fed is conducting expansionary, contractionary, or stabilizing monetary policy (see the next subsection). This may or may not induce the fed to send its own order.

When all orders are counted (including the fed’s), the marketplace “acts”. Suppose there are more “buy” than “sell” orders, i.e., $z = (\$ \text{ value of “sell” orders} / \$ \text{ value of “buy” orders}) < 1.0$. In this case the marketplace fills all the “sell” orders, fills the same proportion (z) of each “buy” order, and raises the price of bonds. On the other hand, if there are more “sell” than “buy” orders, the marketplace fills all the “buy” orders, fills the same proportion of each “sell” order, and lowers the bond price.

3.3.6 The Federal Reserve

The federal reserve agent in ASPEN performs many of the functions of the real federal reserve. First, if a bank is unable to meet its reserve requirements, it sends a message to the federal reserve, and the fed gives it discounting at an exogenously given (by the user) discount rate. Also, if the government wishes to issue bonds but there are no buyers, the fed buys these bonds.

Finally, the fed can conduct either expansionary, contractionary, or stabilizing monetary policy. This is done once the “financial marketplace” agent reports on the relative amounts of “buy” orders and “sell” orders of bonds. If the fed is conducting expansionary policy and there is a surplus of “sell” orders, the fed sends to the marketplace a “buy” order in the amount of a certain percentage of its own bondholdings. Conversely, if the fed is conducting contractionary policy and there is a surplus of “buy” orders, it sends a similar “sell” order to the marketplace. Finally, if it is conducting a stabilizing (or “fixed interest”) policy it sends “buy” and “sell” orders in such a way so that a constant bond price is maintained.

We remark that the fed’s conducting of expansionary, contractionary, or stabilizing policy (or none of these) is an option available to the ASPEN user.

3.3.7 The Realtor and the Capital Goods Producer

Finally, we consider the specialized “realtor” and “capital goods producer” agents. The realtor agent collects rental payments from non-homeowners, and pays a staff of employees, the size of which is proportional to the number of renters. The capital goods maker produces machines, using only labor.

Neither of these are “firms”, in the sense that they do not set their own prices and that they do not vary their production via the hiring and firing of workers. However, they

do earn profits, pay taxes, and “disburse” their aftertax profits in a manner similar to other firms (see subsection 3.3.2).

4. Some Results

In Appendix B are some results using ASPEN. The results are from a model with 1000 households, 3 food producing firms, 2 “other nondurable” producers, 2 automakers, 2 housing developers, 2 banks, and 1 of all other agent types. Initializations and parameter values are set as stated in Appendix A. We first ran the model for 2000 periods (under a “stabilizing” monetary policy by the fed), in order to get the GALCS’s probability vectors [i.e., the vectors (p^D , p^I , p^C) from the discussion in subsection 3.2.2] “adjusted” to realistic values. We then ran the model 20 times (10 times under an expansionary monetary policy and 10 under a contractionary policy) for the 3000 periods after that. Thus, the results displayed are all ten-run sample averages.

The first graph charts the effects of an expansionary vs. contractionary fed policy on loan interest rates. Economic theory dictates that given a contractionary policy, the price of bonds should be lower, due to the fact that the fed is playing a “dampening” role whenever there is an overdemand for bonds. The lower price in turn implies that bonds have a higher “effective yield” as an investment. Hence the banks will invest more in bonds and less in other investments, such as the giving out of loans. This lowered supply of bank loan money implies that *we expect the loan interest rates to increase*. This is in fact exactly what we see from Graph B1.

In Graphs B2, B3, and B4 we see the secondary effects of this increase in loan rates. Basically, the increase in loan rates means that consumers can afford less expensive autos and homes -- they also in fact are less likely to purchase a home (see footnote 4). These observations are borne out in Graph B2. Also, with higher interest rates firms are less likely to make new investments in capital machinery -- hence, productivity, production, and profits suffer. In our model, the lower profits mean lower household incomes, and so again consumer demand falls. Prices then also must be lower, due to the reduced demand (Graph B3). This, combined with lower production and consumption gives lower nominal GNP (Graph B4).

Finally, we successfully reproduced on our model some of Modigliani’s (1972) experiments on the so-called FMP¹² model. Specifically, we increased government spending by \$1000 per day for three years, and observed the multiplier effects on the economy.

The resultant “government expenditure multiplier” is not properly defined unless we specify the monetary policy to be followed by the fed over the period. Hence we did the experiment under two different monetary policy scenarios, and noted the difference in the outputs of the resultant runs. The first scenario was the fed conducting a “stabilizing” monetary policy (see section 3.3.6); the second had it conducting a “fixed money supply” policy, i.e., buying a constant number of bonds each period. We remark that in the second scenario (unlike the first), the bond price was allowed to change.

In Graph B5 we display (a ten run average of) nominal GNP for our model in the “stabilizing” case, both with and without the \$1000/day fiscal expansion described above. In Graph B6 we do the same for the “constant money supply” case. Comparing these two

¹² “FMP” stands for “Federal Reserve -- MIT -- University of Pennsylvania”.

graphs, we see a much larger effect on nominal GNP in the “stabilizing” case than in the “fixed money supply” case. This intuitive result was also obtained by Modigliani.

In Graphs B7 and B8, we show the same effect occurring on real (i.e., inflation-corrected) GNP.

In Graphs B9 and B10, we have quantified these effects in terms of government expenditure multipliers. These quantifications almost duplicate Modigliani’s findings. The multiplier on nominal GNP reaches a value of close to 4 by the fifth quarter under “stabilization”, but is much smaller under the “fixed money supply” rule. In the latter case, the increase in bond interest rate dampens the increase in income. This “crowding out” effect is quite pronounced in both the nominal GNP and real GNP numbers.

Next, we present the effect on bond and loan interest rates of the change in government spending. Increased government expenditure implies more deficit, and therefore an increase in the supply of bonds. Hence (in the “fixed money supply” case), this should lead to an increase in the interest rate for bonds. This is exactly what we see in Graph B11. Regarding loan interest, since the banking industry is highly oligopolistic, all banks look at a common signal (the bond price) to determine their rates. As bond prices go down, the banks’ loan interest rates go up. Hence (in the “fixed money supply” case), the fiscal expansion should lead to an increase in loan interest rates. On the other hand, in the “stabilization” case, since the bond price is being held constant, we would expect loan interest rates to stay relatively constant. See Graph B12.

Finally, we present some further results from our runs in the “stabilization” case. Graph B13 shows the effect of increased government expenditure on nondurable consumption, average price level, home sales, and unemployment rate. Since the effect on unemployment rate seemed quite substantial, we decided to check if the *initial* rate of unemployment had any effect on the multiplier for nominal GNP. Our results (Graph B14) indicate that the multiplier is higher if the initial unemployment level is set at 10% than it is at 5% -- again, this duplicates a Modigliani test result on the FMP model.

5. Conclusion

At its present level of development, ASPEN is not yet ready to be used for quantitative forecasting. We freely admit that certain sectors need to be added/improved in the model, and that many parameters need to be estimated accurately. However, we also believe that the results in Section 4 show that our approach is valid, and this is the message we wish to get across. Indeed, we feel strongly that simulation models like ASPEN will eventually grow to complement the existing macroeconomic and CGE models, perhaps with superior analytic and forecasting power.

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APPENDIX A:

INITIALIZATION AND PARAMETERIZATION

1. Initializations

We define an "initialization" as the assignment of an initial value to a variable *which will change over the course of a run*.

1A: Households

Age of Household Head: Uniformly distributed between 21.0 and 76.0 years
Employment Status of Household Head: unemployed
Savings: Exponentially distributed with mean \$800
Bond holdings: none

1B: Food Firms

Cash Assets: Uniformly distributed between \$10000 and \$50000
Number of Machines Owned: 100
Number of Employees: 0
Price of food: \$10 per unit
Inventory: 1200 units of food

1C: "Other Nondurables" Firms

Cash Assets: Uniformly distributed between \$10000 and \$50000
Number of Machines Owned: 100
Number of Employees: 0
Price of "Other Nondurables": \$20 per unit
Inventory: 10000 units of "other nondurables"

1D: Automakers

Cash Assets: Uniformly distributed between \$100000 and \$500000
Number of Machines Owned: 100
Number of Employees: 0
Price of Automobiles: \$15000 per "car unit"
Inventory: no cars

1E: Housing Developers

Cash Assets: Uniformly distributed between \$100000 and \$500000
Number of Machines Owned: 100
Number of Employees: 0
Home Price: \$100000 per “housing unit”
Inventory: 10.0 units of housing

1F: Banks

Loan Interest Rate (consumers): 9.0%
Loan Interest Rate (businesses): 7.0%
Savings Interest Rate: 4.0%
Cash Assets: Uniformly distributed between \$100 and \$500
Number of Employees: 0

1G: Government

Bond Price: \$1.00 per unit
Number of Employees: 0

1H: Federal Reserve

Cash Assets: \$50000

1I: Realtor

Cash Assets: \$10000
Number of Employees: 0

1J: Capital Goods Producer

Cash Assets: \$10000
Number of Employees: 0

2. Parameterizations

We define a “parameterization” as the assignment of a value to a variable *which cannot change over the course of a run.*

2A: General Variables

Number of Households: 1000
Number of Food Firms: 3
Number of “Other Nondurables” Firms: 2
Number of Automakers: 2
Number of Housing Developers: 2
Number of Banks: 2
Number of Governments: 1

Number of Federal Reserves: 1
Number of Realty Companies: 1
Number of Capital Goods Producers: 1

2B: Households

Family Size: Uniformly distributed between 1.0 and 4.0
Income Tax Rate: 20% on income
Sales Tax Rate: 6% on purchases of automobiles and “other nondurables”;
0% on purchases of food and housing
“Demand” Exponents (i.e., the parameters “q” described in Subsection 3.2.1):
Food: 5.0
Other Nondurables: 5.0
Automobile: 5.0
Home: 5.0
Loan Interest Rates: 8.0
Savings Account Interest Rates: -8.0
Units of Food Demanded per day: $1.0 * \text{family size}$
Units of “Other Nondurables” Demanded per day:
 $0.4 * (\text{income} - \text{food expense}) / \text{avg. “other nondurable” price}$
Auto Failure Rate: probability of .00018 per day
Public Transportation Cost (paid to government whenever household does not own a
working automobile): \$2 per day
Rent for Non-homeowners: 20% of income
Daily Probability that Renter Desires New Home: $.00006 + .001 * (1.0 - \text{bond price})$
Daily Probability that Homeowner Desires Home Improvement:
 $.00036 + .001 * (1.0 - \text{bond price}),$
Length of Auto Loan: 5 years
Payments on Auto Loan (see subsection 3.2.1): .1 of income
Length of Home Loan: 30 years
Payments on Home Loan: .35 of income
Length of Home Improvement Loan: 30 years
Payments on Home Improvement Loan: .058 of income
“Pocket Cash” not put in savings at the end of each day: \$100
“Pocket Savings” not touched when buying autos or houses: \$300
Frequency of Changing Savingsbank: every 90 days
Unemployment Assistance: $\$50 + \$5 * \text{family size}$, per day

2C: Food Firms

Wage rate: \$100 per day
Income Tax Rate: 30% on profits
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy
“Demand” Exponent (i.e., the parameter “q” described in Subsection 3.2.1):
Business Loan Interest Rate: 8.0
Productivity Parameters (for the production function $y = c K^a L^b$):
c = .12
a = 1.0
b = 1.0
Length of Capital Improvements Business Loan: 1 year

Amount of Capital Improvements Business Loan: \$1000
Inventory/Demand Ratio under which firm Hires New Workers: 2.5 to 1
[It then hires workers until production is 1.2 times average demand.]
Inventory/Demand Ratio over which firm Fires Workers: 5 to 1
[It then fires workers until production is 0.8 times average demand.]
Price changes (movements allowed each time GALCS iterates): +\$.50, \$0, or -\$.50

2D: "Other Nondurables" Firms

Wage rate: \$100 per day
Income Tax Rate: 30% on profits
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy
"Demand" Exponent (i.e., the parameter "q" described in Subsection 3.2.1):
Business Loan Interest Rate: 8.0

Productivity Parameters (for the production function $y = c K^a L^b$):

$$c = .06$$

$$a = 1.0$$

$$b = 1.0$$

Length of Capital Improvements Business Loan: 1 year
Amount of Capital Improvements Business Loan: \$1000
Inventory/Demand Ratio under which firm Hires New Workers: 2.5 to 1
[It then hires workers until production is 1.2 times average demand.]
Inventory/Demand Ratio over which firm Fires Workers: 5 to 1
[It then fires workers until production is 0.8 times average demand.]
Price changes (movements allowed each time GALCS iterates): +\$.50, \$0, or -\$.50

2E: Automakers

Wage rate: \$100 per day
Income Tax Rate: 30% on profits
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy
"Demand" Exponent (i.e., the parameter "q" described in Subsection 3.2.1):
Business Loan Interest Rate: 8.0

Productivity Parameters (for the production function $y = c K^a L^b$):

$$c = .00008$$

$$a = 1.0$$

$$b = 1.0$$

Length of Capital Improvements Business Loan: 1 year
Amount of Capital Improvements Business Loan: \$1000
Inventory/Demand Ratio under which firm Hires New Workers: 3 to 1
[It then hires workers until production is 1.2 times average demand.]
Inventory/Demand Ratio over which firm Fires Workers: 5 to 1
[It then fires workers until production is 0.8 times average demand.]
Price changes (movements allowed each time GALCS iterates): +\$200, \$0, or -\$200

2F: Housing Developers

Wage rate: \$100 per day

Income Tax Rate: 30% on profits
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy
“Demand” Exponent (i.e., the parameter “q” described in Subsection 3.2.1):
Business Loan Interest Rate: 8.0
Productivity Parameters (for the production function $y = c K^a L^b$):
c = .000012
a = 1.0
b = 1.0
Length of Capital Improvements Business Loan: 1 year
Amount of Capital Improvements Business Loan: \$1000
Inventory/Demand Ratio under which firm Hires New Workers: 2 to 1
[It then hires workers until production is 1.2 times average demand.]
Inventory/Demand Ratio over which firm Fires Workers: 5 to 1
[It then fires workers until production is 0.8 times average demand.]
Price changes (movements allowed each time GALCS iterates): +\$500, \$0, or -\$500

2G: Banks

Wage rate: \$100 per day
Income Tax Rate: 30% on profits
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy
Discount Rate (for borrowing from fed): 5.5%
Required Reserve Ratio: 3% of total savings deposits
Desired Extra Reserve Ratio: 1% of total savings deposits
Consumer Loan Interest Rate: 8.0% / (bond price * (1.0 - default rate))
Additional Consumer Loan Interest Rate changes (movements allowed each time GALCS iterates): +.02%, 0%, or -.02%
Business Loan Interest Rate: 7.0% / bond price
Savings Interest Rate: 4.0% / bond price

2H: Government

Wage rate: \$100 per day
Number of Job Openings: 250 (or 25% of the number of households)
Dividend payment per unit of Bond: 5 cents per year

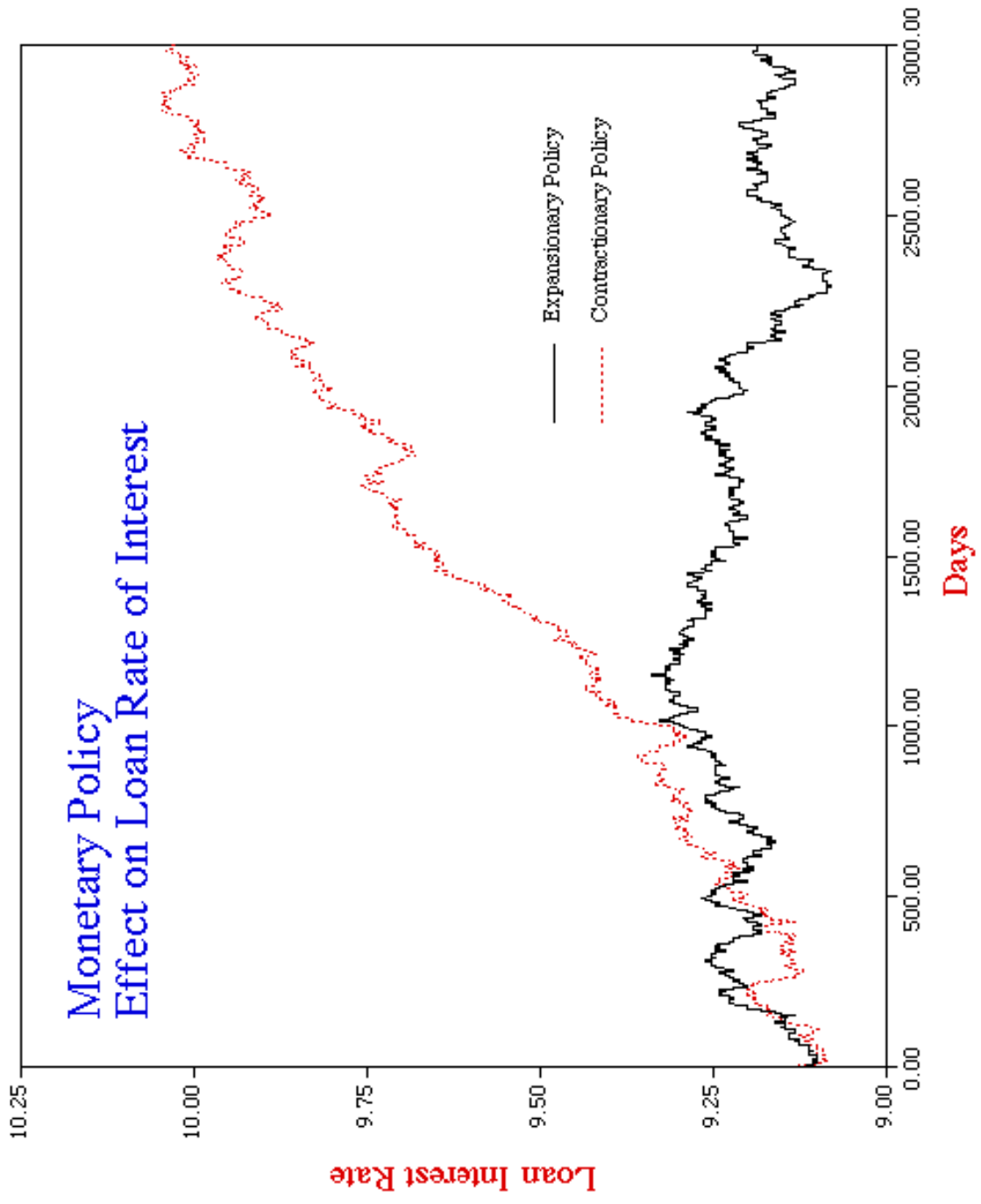
2I: Realtor

Wage rate: \$100 per day
Income Tax Rate: 30% on profits
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy

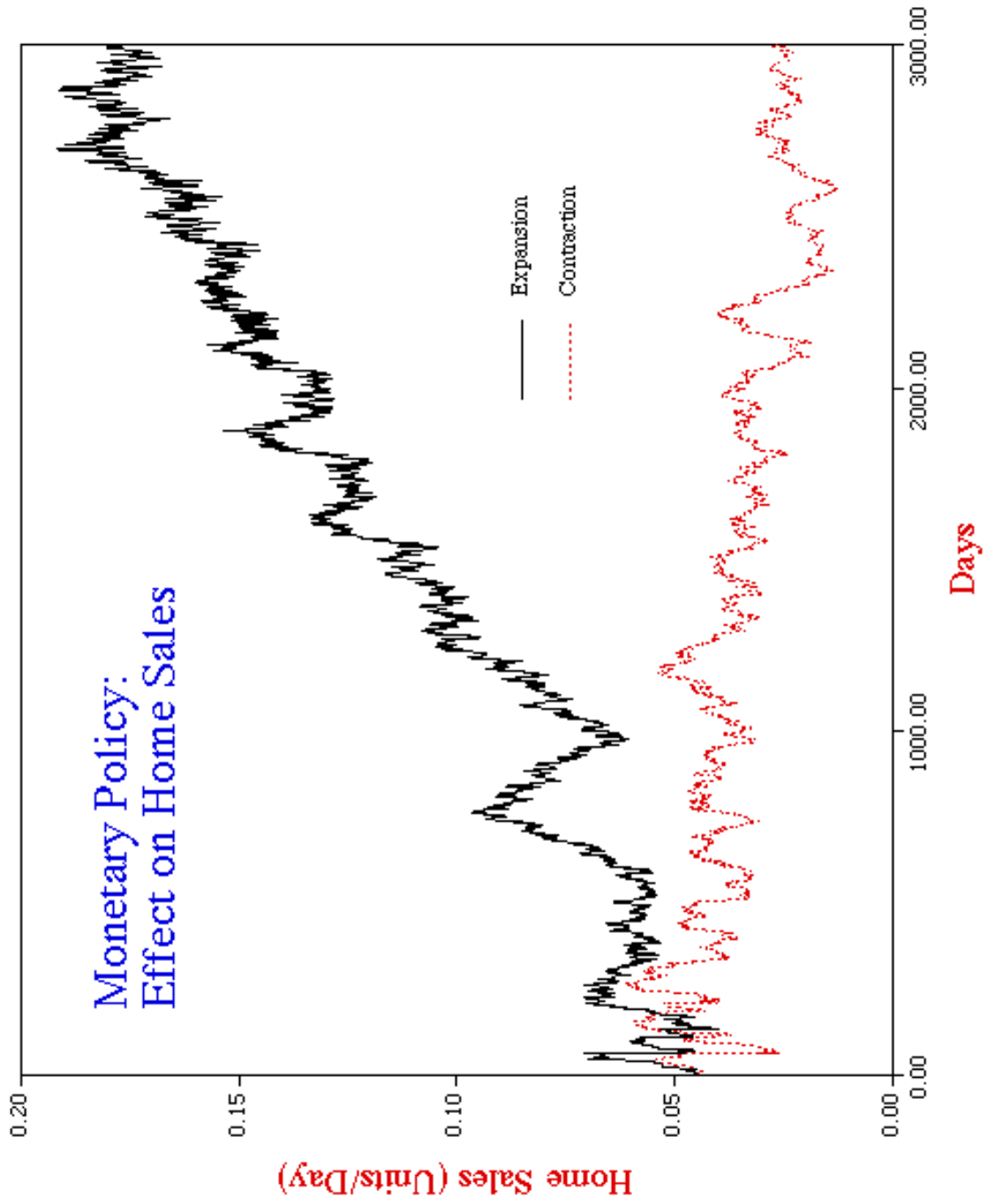
2J: Capital Goods Producer

Wage rate: \$100 per day
Income Tax Rate: 30% on profits

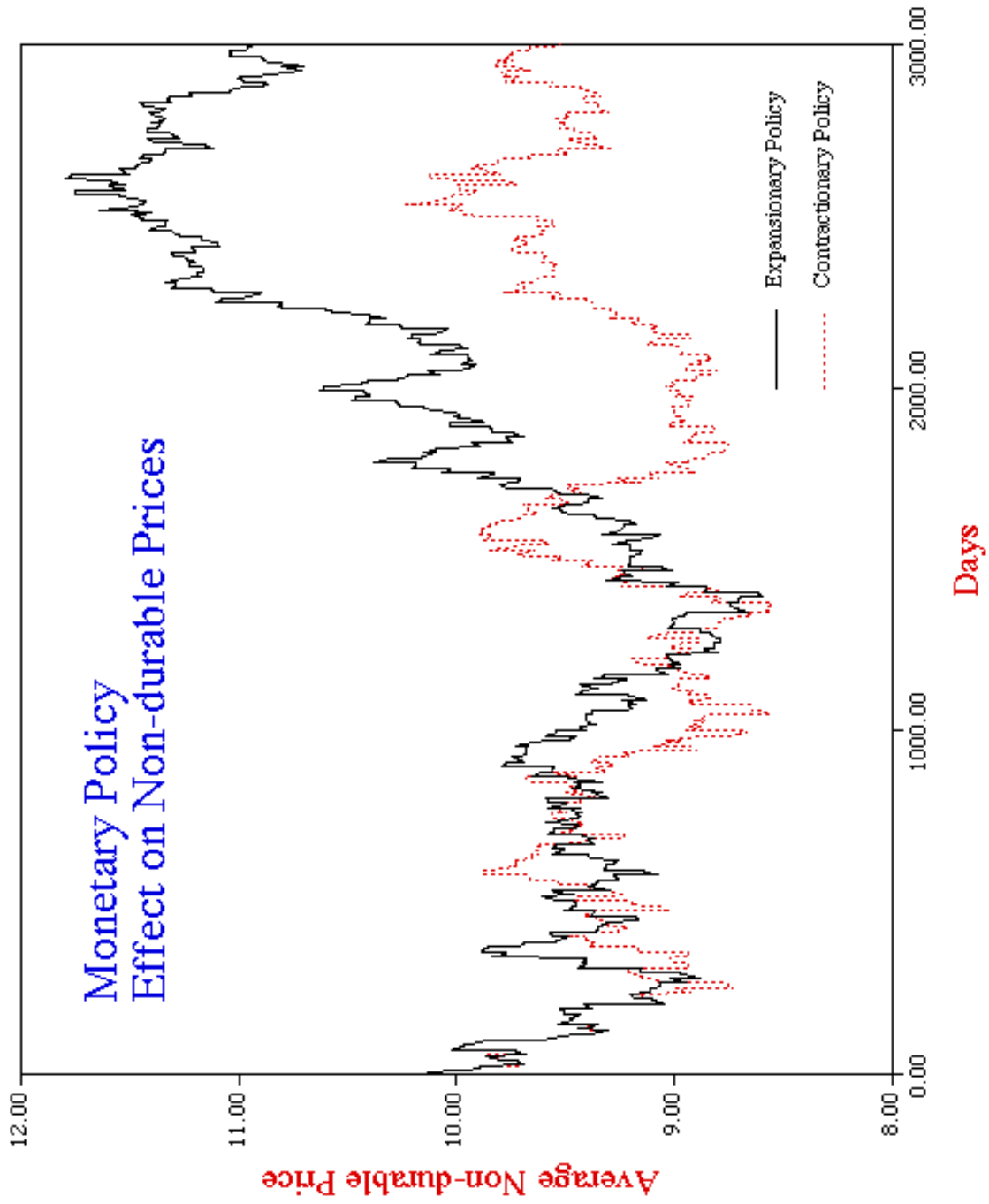
Payroll Tax Rate: 6% on wages
Disbursal of Aftertax Profit: Equally to all households in economy
Employee Productivity: .1 machine per worker-day



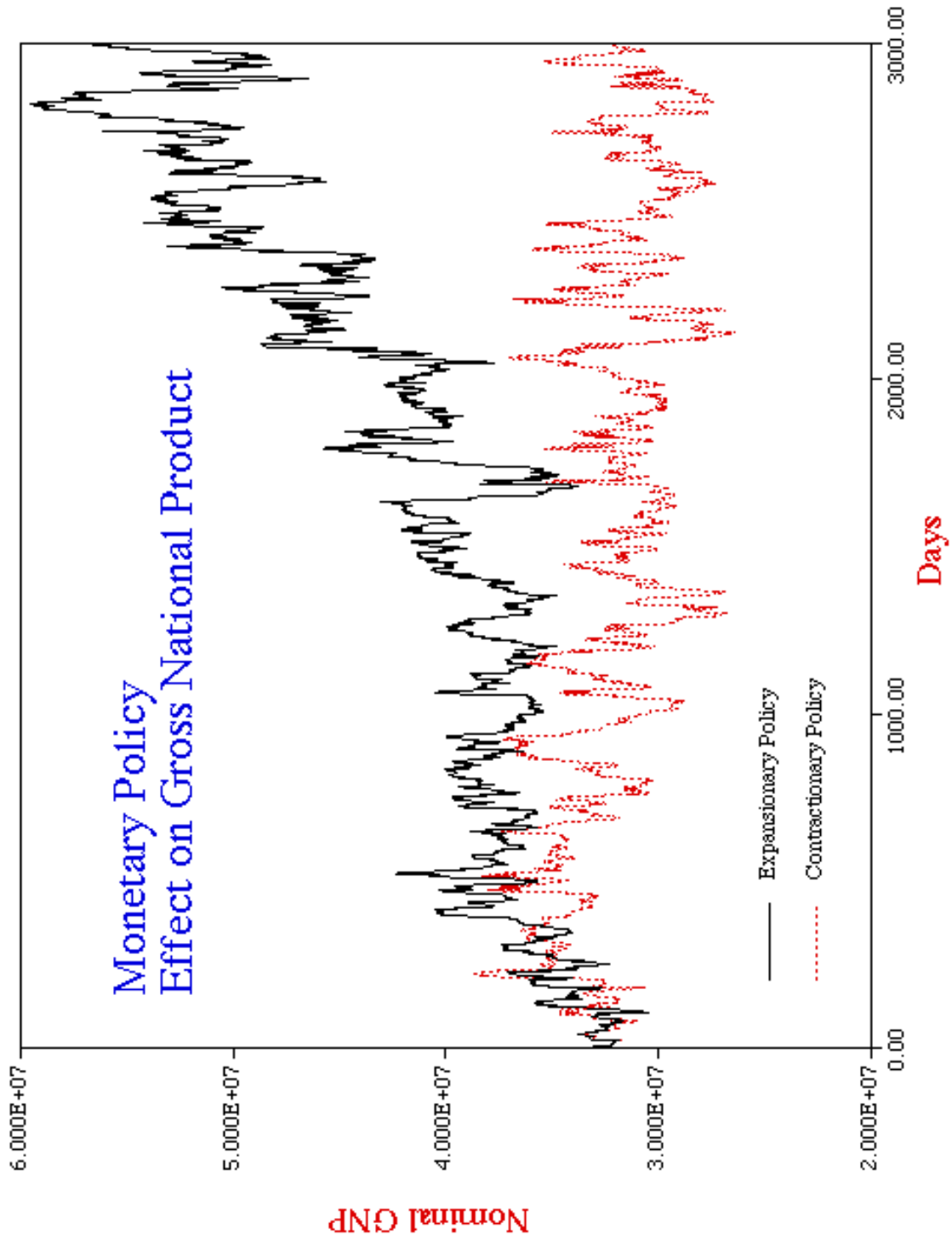
Appendix B: Graph B1



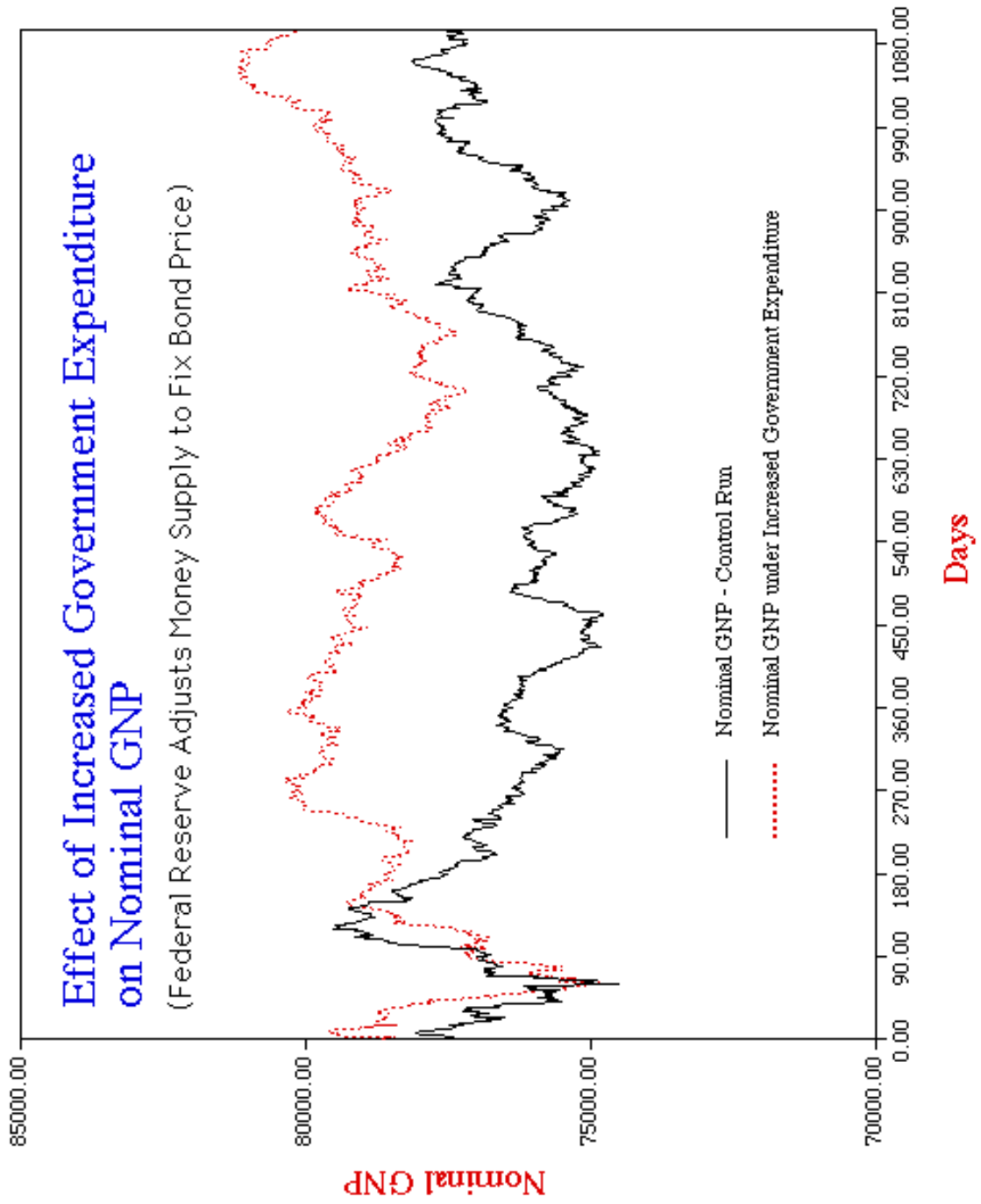
Appendix B: Graph B2



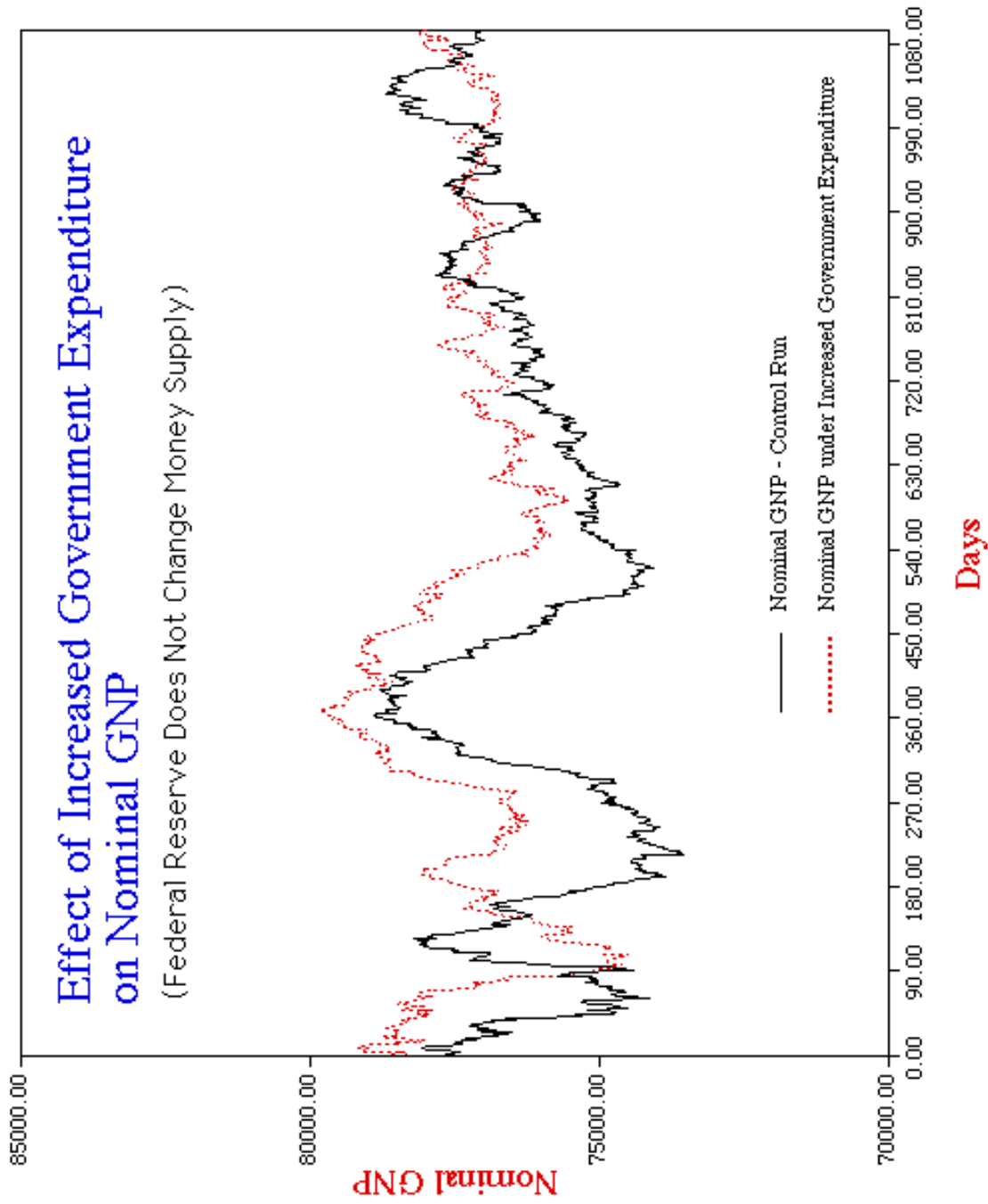
Appendix B: Graph B3



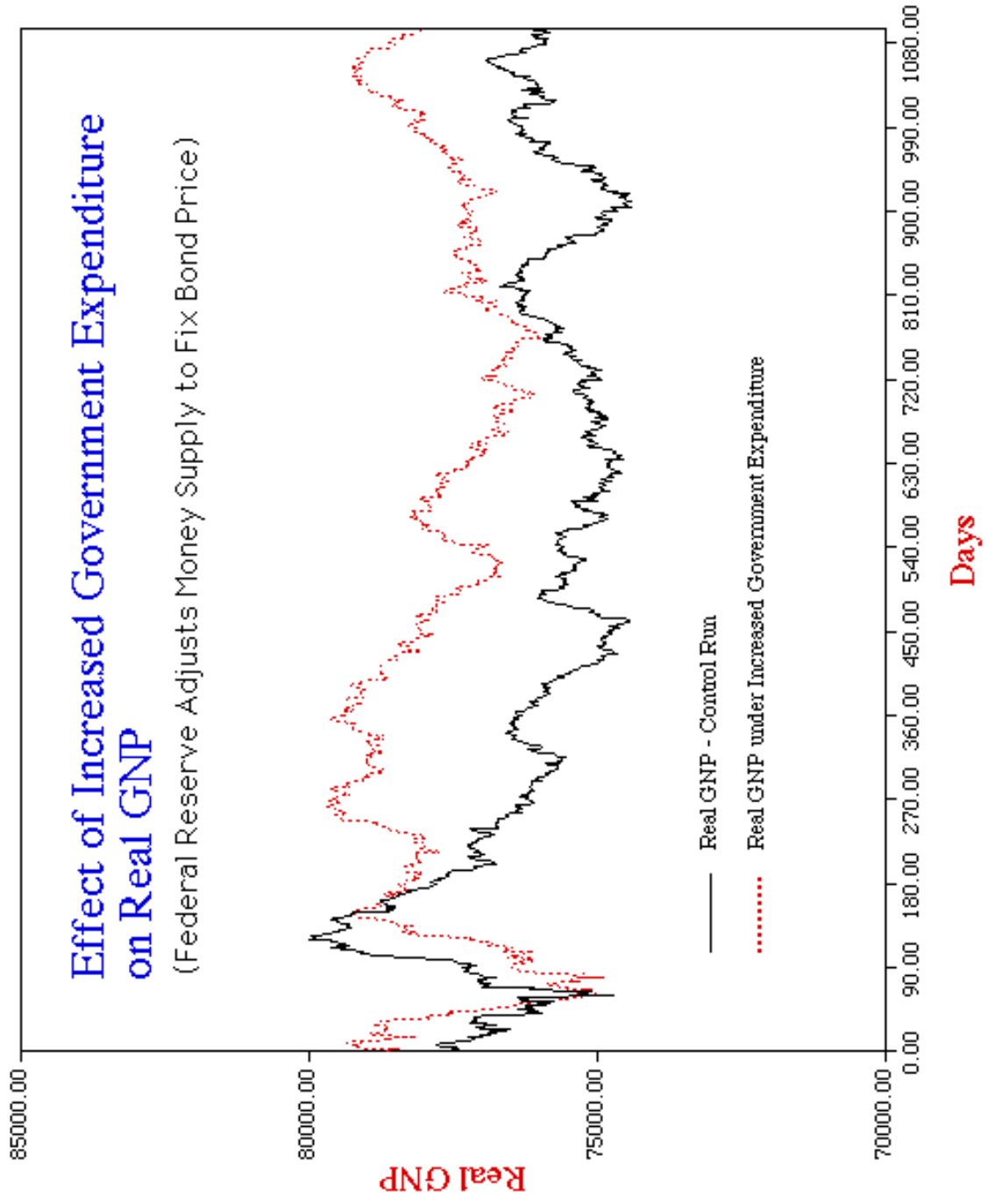
Appendix B: Graph B4



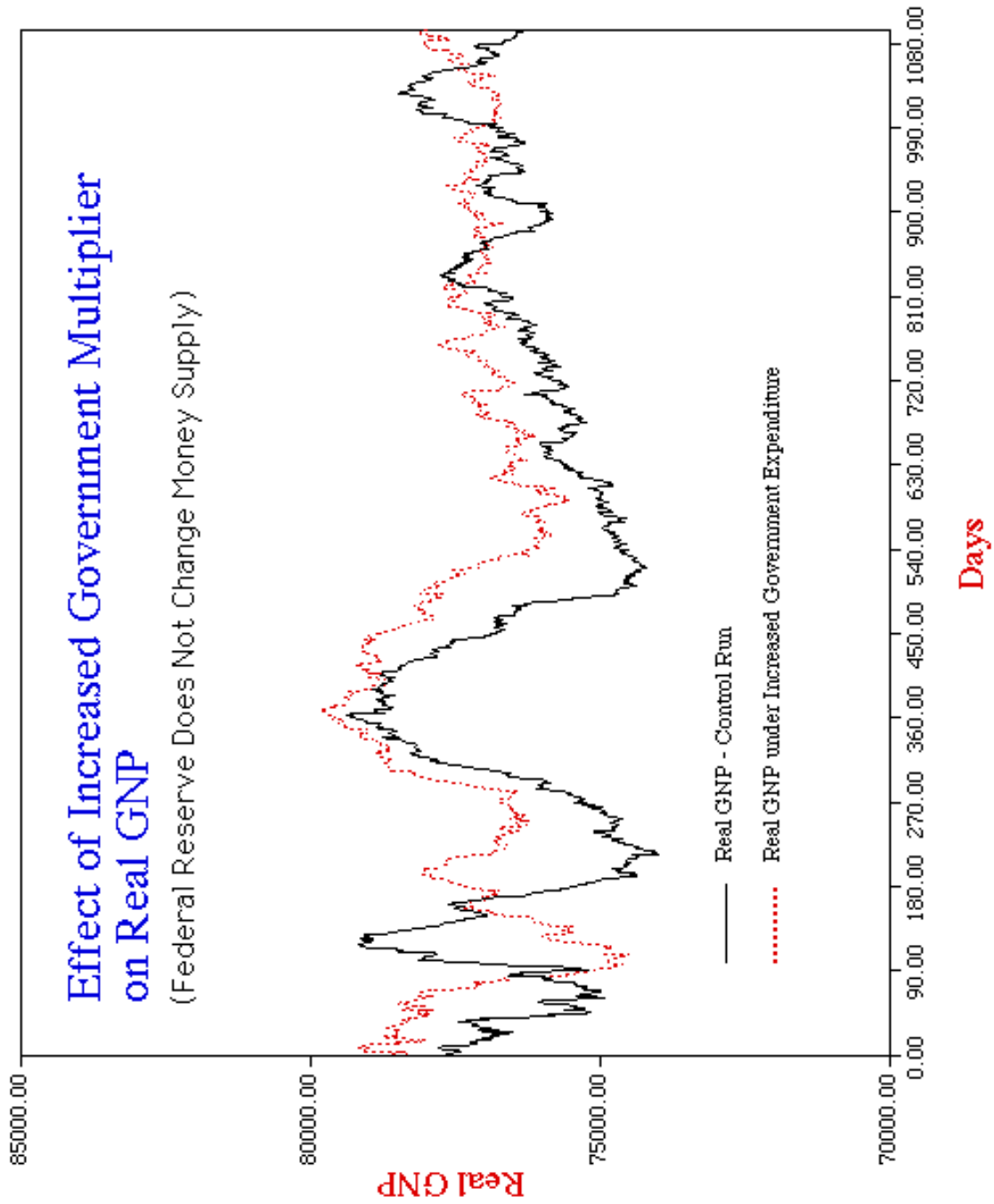
Appendix B: Graph B5



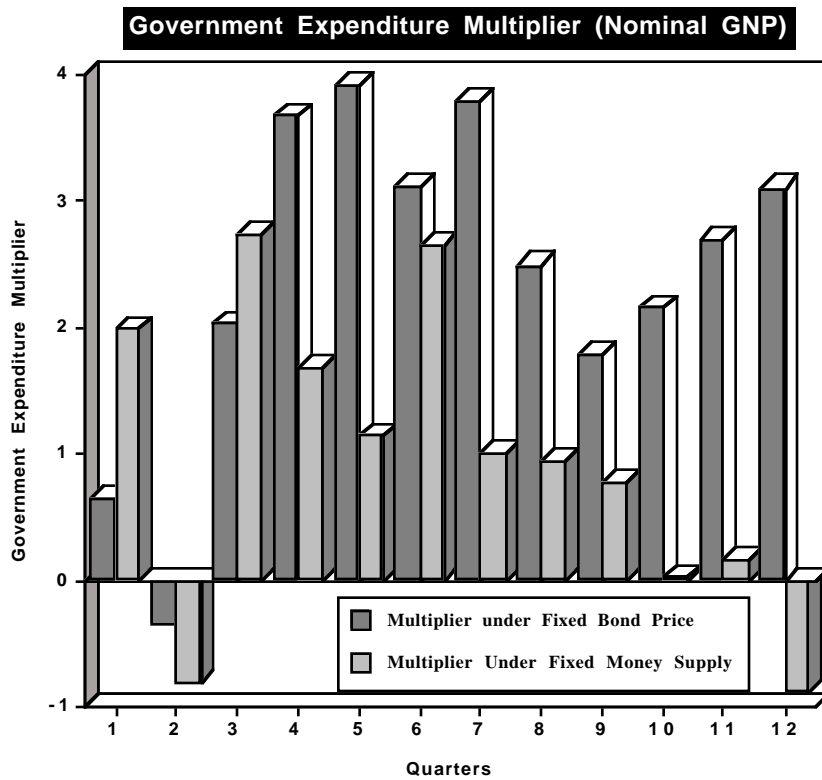
Appendix B: Graph B6



Appendix B: Graph B7

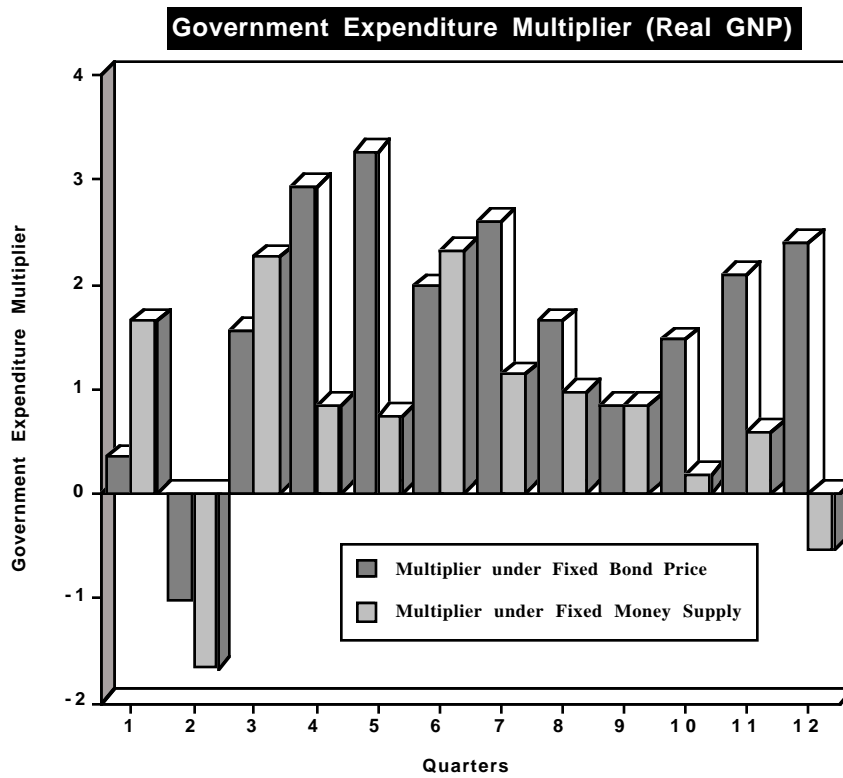


Appendix B: Graph B8



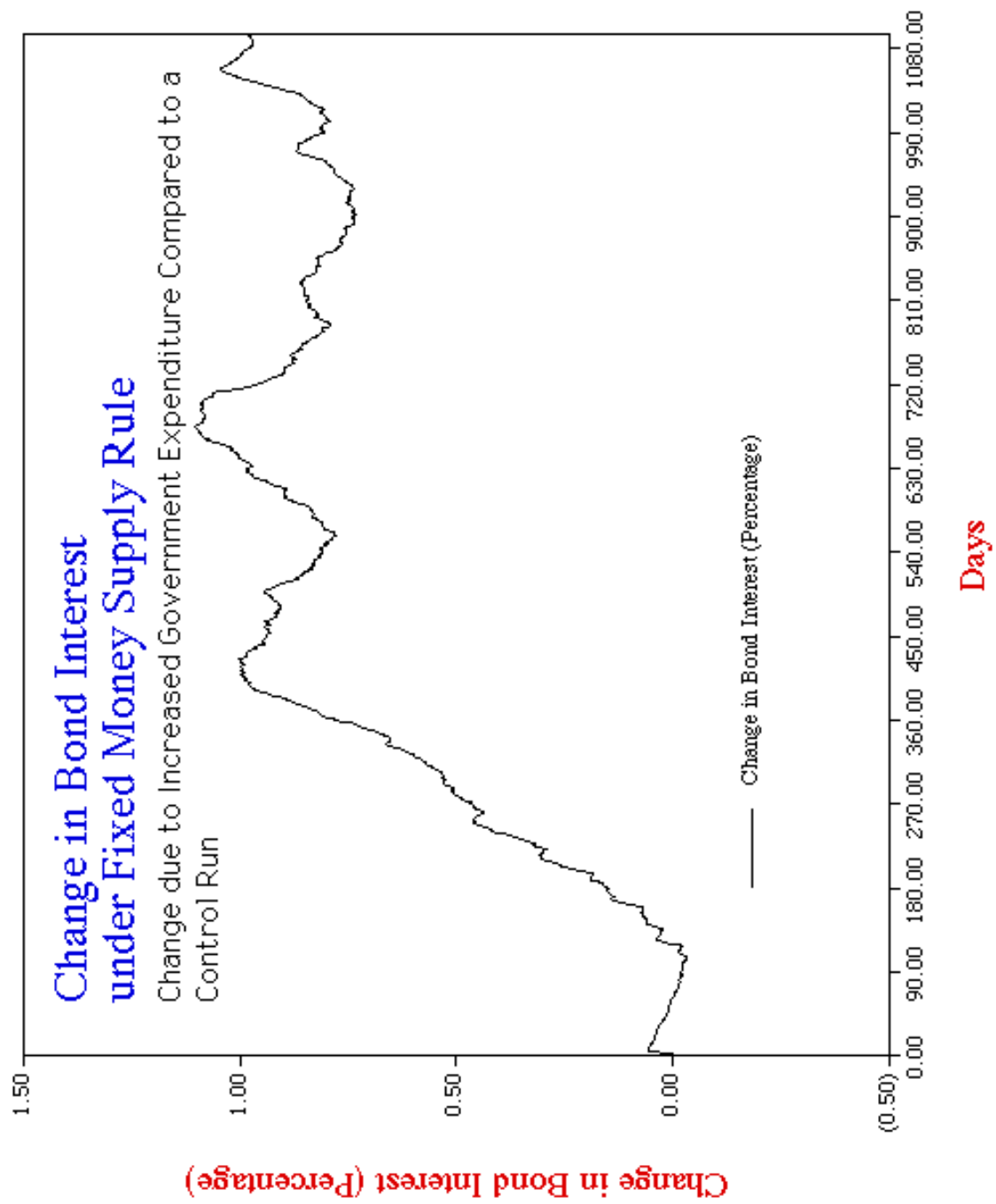
Graph shows effect of "Crowding Out" as the Government Expenditure Multiplier is smaller under Fixed Money Supply rule.

Appendix B: Graph B9

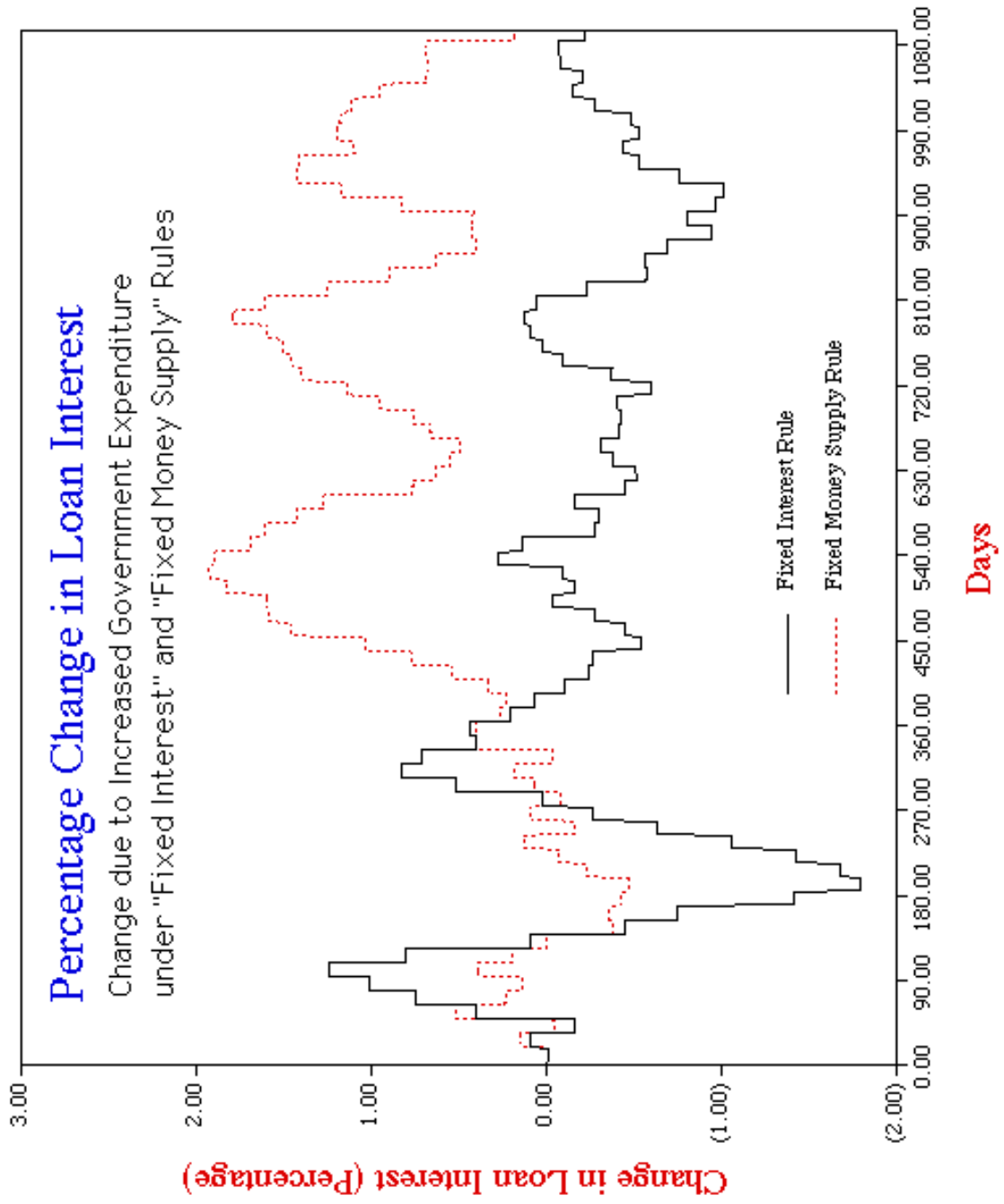


Graph shows effect of "Crowding Out" as the Government Expenditure Multiplier is smaller under Fixed Money Supply rule.

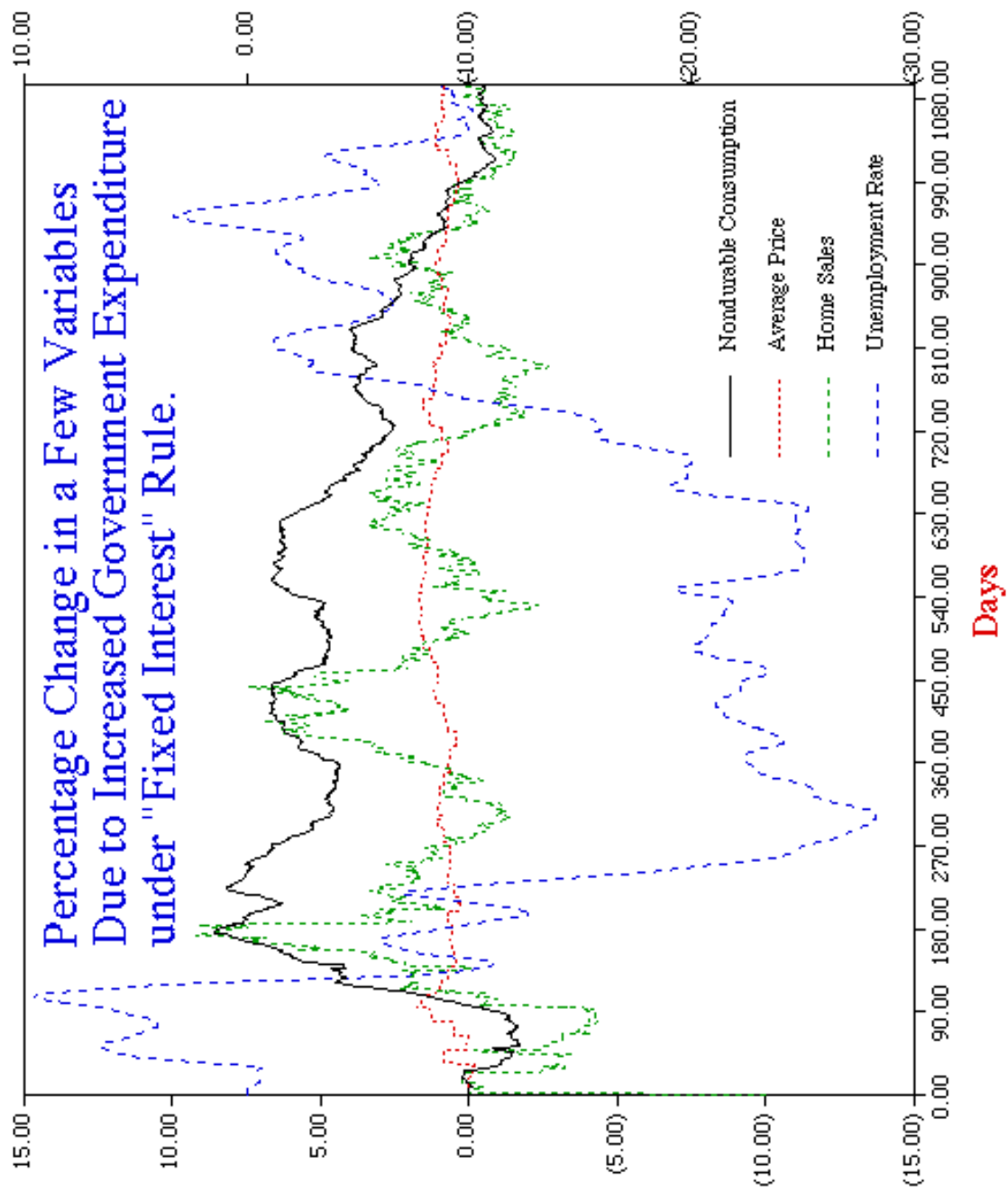
Appendix B: Graph B10



Appendix B: Graph B11

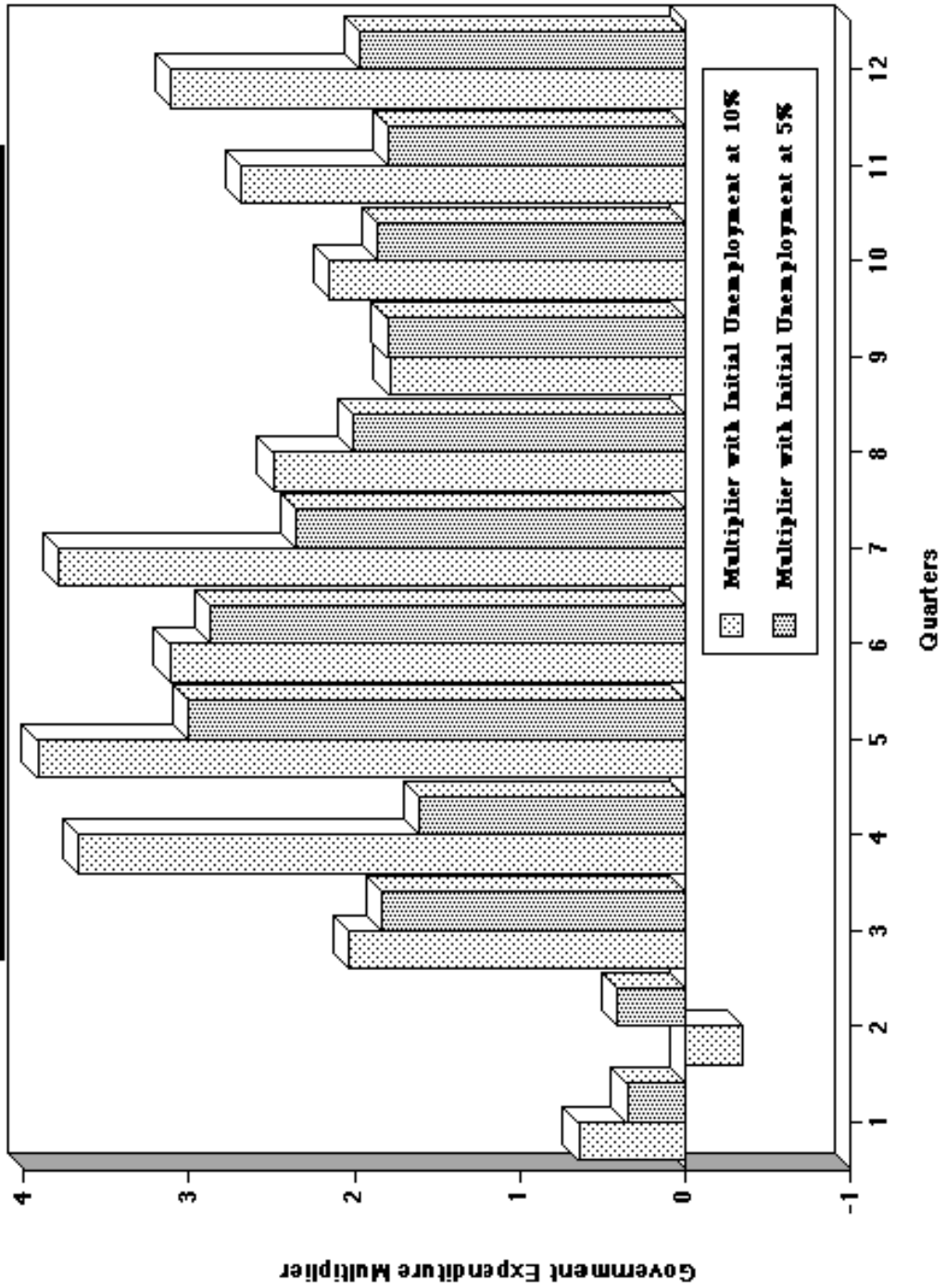


Appendix B: Graph B12



Appendix B: Graph B13

**Government Expenditure Multiplier (Nominal GNP)
Effect of Initial Unemployment Rate**



Appendix B: Graph B14