Chapter One

Introduction

1.1 THE PURPOSE OF THE STUDY

Much of the work in economic theory in the past few years has been concerned with relaxing two important assumptions of classical economic theory: perfect information and the existence of tâtonnement processes to clear markets. One group of studies has followed from the work of Patinkin [43, Chapter 13] and Clower [10].[a] Some of the studies in this group have been concerned with the question of whether standard, textbook Keynesian theory is different from what Keynes [30] actually had in mind. Clower [10] and particularly Leijonhujvud [32] have argued that it is, whereas Grossman [25] has argued that it is not. Although the question of what Keynes meant is primarily of historical interest, the studies of Clower and others have made important advances in macroeconomic theory. By relaxing the assumption that markets are always in equilibrium, these studies have provided a more solid theoretical basis for the existence of the Keynesian consumption function and for the existence of unemployment. The existence of excess supply in the labor market is a justification for including income as an explanatory variable in the consumption function, and the existence of excess supply in the commodity market is a justification for the existence of unemployment.

Another group of studies concerned with relaxing the assumption of perfect information has followed from the work of Stigler [52].[b] The most prominent studies in this group are the studies in Phelps et al. [44]. Many of the studies in this group have been concerned with the mechanism by which prices or wages are determined.[c] In most cases prices or wages are postulated as being set by firms, as opposed to, say, by customers or workers. The price- or wage-setting activities of firms are usually assumed to be guided by profit-maximizing considerations. In particular, Phelps has emphasized with respect to

the studies in Phelps et al. [44] that "... [the theory] sticks doggedly to the neoclassical postulates of lifetime expected utility maximization and net worth maximization..."[45, p. 3].

Although important progress has been made in relaxing the assumptions of perfect information and tâtonnement processes, no general theoretical model has been developed with these assumptions relaxed. In the disequilibrium model of Barro and Grossman [5], for example, only output and employment are determined. All other variables, including prices and wages, are taken as given. There are no financial and investment sectors in the model. In the further study of Grossman[26], only investment is determined, and no attempt is made to integrate the investment model with the earlier output and employment model.

In the Solow and Stiglitz model [51], output, employment, prices, and wages are determined, but there are no financial and investment sectors. Also, as Barro and Grossman point out,[d] the Solow and Stiglitz model is not constructed on a choice-theoretic basis. Likewise, the Korliras model [31], which is similar to the Solow and Stiglitz model but does include financial and investment sectors, is not constructed on a choice-theoretic basis. The model of Tucker [55] is concerned with short run fluctuations in output and employment, and prices and wages are taken as given. In the group of studies concerned with price-setting behavior,[e] the price- or wage-setting activities of firms have also not been considered within the context of a general theoretical model. In the Maccini model [36], for example, which is one of the more general models in this group, only prices, output, and inventories are determined. There are no employment, investment, and financial sectors in the model.

The studies cited above, with the possible exception of the study of Korliras [31], could be characterized as "partial equilibrium" studies if they were equilibrium studies, but given that the studies are concerned with disequilibrium phenomena, they can perhaps best be characterized as "partial disequilibrium" studies. The partial nature of these studies is particularly restrictive in a disequilibrium context because of the possible effects that disequilibrium in one market may have on other markets. For example, models in which there is no financial sector rule out any effects that disequilibrium in financial markets may have on labor and goods markets. The Korliras model, while being more general in certain respects than the other models, is particularly restrictive with respect to the effects of one market on another. The model rules out any cross-market effects of disequilibrium and concentrates only on within-market disequilibrium effects. Tucker's discussion [56] of Korliras's model emphasizes this point.

In addition to the partial nature of the studies cited above, it is also the case that the price-setting behavior postulated by the second group of studies, in particular that firms set prices and/or wages to maximize profits, has not been integrated into the first group of studies. Only in the models of Solow

and Stiglitz and Korliras are prices and wages determined, and these models are not choice-theoretic. The treatment of prices and wages as exogenous or in an ad hoc manner is again particularly restrictive in a disequilibrium context because disequilibrium questions are inherently concerned with the problem that prices somehow do not get set in such a way as always to clear markets. It is thus particularly important in a disequilibrium context to determine how prices are set and why it is that prices may not always clear markets.

The purpose of this study is to develop a theoretical model of macroeconomic activity with the following characteristics.

1. The model should be general enough to incorporate most of the variables of interest in a macroeconomic context.
2. The model should be based on solid microeconomic foundations in the sense that the decisions of the main behavioral units in the model should be derived from the assumption of maximizing behavior.
3. The behavioral units in the model should not be assumed to have perfect foresight, but instead should be assumed to have to make decisions on the basis of expectations that may not always turn out to be correct.
4. Tâtonnement processes that clear markets every period should not be postulated.

Regarding point 1, the endogenous variables in the present model include sales, production, employment, investment, prices, wages, interest rates, and loans. The model also accounts for wealth effects, capital gains effects, all flow-of-funds constraints, and the government budget constraint. The general nature of the model allows cross-market disequilibrium effects to be analyzed, allows one to consider why prices, wages, and interest rates may not always be set in such a way that clears markets every period, and allows the effects of various aggregate constraints, like the flow-of-funds constraints, to be analyzed.

The rest of this chapter provides an outline of the model and discusses various methodological and computational issues. The individual behavioral units are discussed in detail in Chapters Two through Five. The dynamic properties of the overall model are discussed in Chapter Six. A static-equilibrium version of the dynamic model is presented in Chapter Seven, and this version is compared to the standard static-equilibrium model found in most macroeconomic textbooks. Chapter Eight contains a brief summary of the model and its properties, a discussion of how the model might be changed or extended, and a discussion of some of the empirical implications of the model.

1.2 AN OUTLINE OF THE MODEL

There are five basic behavioral units in the model: banks, firms, households, a

bond dealer, and the government. Banks are meant here to include all financial intermediaries, not just commercial banks. At the beginning of each period each bank, firm, and household, knowing last period's values, receiving in some cases information from others regarding certain current-period values, and forming expectations of future values, solves an optimal control problem.

The objective function of banks and firms is the present discounted value of expected future after-tax profits, and the objective function of households is the present discounted value of expected future utility. The fact that the decisions of the main behavioral units are derived by solving optimal control problems places the model on a respectable microeconomic foundation, thus meeting the requirement of point 2 above. Point 3 is also met in the sense that the decisions are based on *expectations* of future values, rather than on the actual future values. None of the behavioral units in the model has perfect foresight.

The model is recursive in the sense that information flows in one direction from the bond dealer, to banks, to firms, to households. Banks, for example, are not given an opportunity to change their decisions for the current period once firms and households have made theirs. After all decisions have been made at the beginning of the period, transactions take place throughout the rest of the period. The recursive nature of the model meets the requirement of point 4 above in the sense that recontracting is not allowed. Banks, for example, only find out what the decisions of firms and households are in the current period by the transactions that take place during the period. Likewise, firms only find out what the decisions of households are by the transactions that take place.

There is one good in the economy, which can be used either for consumption or investment purposes. There are no consumer durables: all goods that are used for consumption purposes are consumed in the current period. All labor is homogenous. Bank loans are one-period loans, government bills are one-period securities, and government bonds are consols. There is no currency in the system.

The decision variables of the government are the various tax rates in the system, the reserve requirement ratio, the number of goods to purchase, the number of worker hours to pay for, the value of bills to issue, and the number of bonds to have outstanding. The government is subject to the constraint each period that expenditures less revenues must equal the change in the value of bills plus bonds plus bank reserves (high powered money).[f] The government's decisions are treated as exogenous in the model.

Banks receive money from households in the form of savings deposits, on which interest is paid, and from households, firms, and the bond dealer in the form of demand deposits, on which no interest is paid. Banks lend money to households and firms and buy government bills and bonds. Banks are assumed not to compete for savings deposits, and the rate paid on all savings deposits is assumed to be the bill rate. Banks hold reserves in the form of deposits with the government. Banks do not hire labor and do not buy goods.

At the beginning of the period, banks receive information from the government on the tax rates and the reserve requirement ratio for the current period and from the bond dealer on the bill and bond rates for the current period. However, at this time banks do not know the values of their demand and savings deposits for the current period, and do not know the demand schedules for their loans. Banks must form expectations of these variables for the current period, as well as for the future periods, when making their decisions at the beginning of the period.

The three main decision variables of each bank are its loan rate, the value of bills and bonds to buy, and the maximum amount of money that it will lend in the period. Once a bank makes its decision on the value of bills and bonds to buy, the bank is assumed to have to buy this amount in the period. A bank needs to set a maximum on the amount of money that it will lend in the period in order to prepare for the possibility that it either overestimates the supply of funds available to it in the period or underestimates the demand for its loans at the loan rate that it set. Because of these two possibilities, a bank may end up with the actual demand for its loans at the loan rate that it set being greater than the amount that it can supply. A bank is assumed to prepare for this by setting the maximum amount of money that it will lend in the period low enough so that the bank is assured, based on its past expectation errors, that it will end up in the period with at least this much money to lend.

Firms borrow money from banks, hire labor from households, buy goods from other firms for investment purposes, and produce and sell goods to other firms, households, and the government. At the beginning of the period each firm receives information from the government on the profit tax rate for the current period, and from banks on the loan rate that it will be charged for the period and on the maximum amount of money that it will be able to borrow in the period. (Since in general each bank sets a different loan rate, it is not obvious which loan rate any particular firm faces. It also is not obvious how the loan constraints from the banks are translated into the loan constraint facing any particular firm. Problems of this sort are discussed in section 1.3.) Firms do not know at this time the demand schedules for their goods for the current period and the supply schedules of labor for the current period.

The seven main decision variables of a firm are: (1) its price, (2) its production, (3) its investment, (4) its wage rate, (5) its loans from banks, (6) the maximum number of worker hours that it will pay for in the period, and (7) the maximum number of goods that it will sell in the period. Regarding the latter two variables, firms, like banks, must prepare for the possibility that their expectations are incorrect. A firm is assumed not to want to hire more labor in the period than it plans at the beginning of the period to hire. Since a firm may underestimate the supply of labor facing it at the wage rate that it set, it prepares for this possibility by setting a maximum on the amount of labor that it will hire in the period. This maximum is assumed to be the amount that the firm plans at the beginning of the period to hire. A firm is also assumed to set a

maximum on the number of goods it will sell in the period, since it cannot sell more goods in the period than the sum of what it produces and has in inventories. The maximum is assumed to be set low enough so that the firm is assured, based on its past expectation errors, that it will end up in the period with at least this many goods to sell.

Households receive wage income from firms and the government, purchase goods from firms, and pay taxes to the government. A household either has a positive amount of savings or is in debt. It it has savings, the savings can take the form of demand deposits, savings deposits, or stocks. If it is in debt, the debt takes the form of loans from banks. A household does not both borrow from banks and have savings deposits or stocks at the same time. At the beginning of the period each household receives eight items of information for the current period: (1) the tax rates, (2) the rate it will be paid on its savings deposits (the bill rate), (3) the loan rate it will be charged, (4) the maximum amount of money it will be allowed to borrow, (5) the price it will be charged for goods, (6) the wage rate it will be paid, (7) the maximum number of hours it will be allowed to work, and (8) the maximum number of goods it will be allowed to purchase. (The question of how this information gets translated to each particular household is discussed in section 1.3.) The two main decision variables of a household are the number of hours to work and the number of goods to purchase.

The bond dealer represents in the model both the bill and bond market and the stock market. The bond dealer does not hire labor and does not buy goods. The decision variables of the bond dealer are the bill rate, the bond rate, and the average stock price. The bond dealer is not a profit maximizer; rather, it^g tries to set the bill and bond rates for the next period so as to equate the demand for bills and bonds in that period to the supply of bills and bonds in the period. The bond dealer holds an inventory of bills and bonds, and it absorbs in each period any difference between the supply of bills and bonds from the government and the demand for bills and bonds from the banks.

Households own the stock of the banks, the firms, and the bond dealer. All after-tax profits of the banks, firms, and bond dealer are paid to the households in the form of dividends. Banks, firms, and the bond dealer are assumed not to issue any new stocks. The bond dealer sets the average stock price equal to the present discounted value of expected future dividend levels, the discount rates being expected future bill rates. The expectations of the future dividend levels and bill rates are formed by households and are communicated to the bond dealer. All households are assumed to have the same expectations regarding these variables.

Because of the way the bond dealer sets the stock price, households expect the before-tax, one-period rate of return on stocks, including capital gains and losses, to be the same for a given period as the expected bill rate for that period. The bill rate is the rate paid on savings deposits. Now, capital gains and

losses are assumed to be recorded each period and to be taxed as regular income, which means that households also expect the *after-tax* rates of return on stocks and savings deposits to be the same. Households can therefore be assumed to be indifferent between holding their assets in the form of stocks or in the form of savings deposits. This assumption greatly simplifies the model.

Banks are similarly assumed to be indifferent between holding the nonloan part of their assets in the form of bills or in the form of bonds. The bond dealer sets the price of a bond, each bond yielding one dollar per period forever, equal to the present discounted value of a perpetual stream of one-dollar payments, the discount rates being the current bill rate and expected future bill rates. These expectations of the bill rates are formed by banks and are communicated to the bond dealer. All banks are assumed to have the same expectations regarding the future bill rates. The bond rate is equal to the reciprocal of the bond price.

Because of the way that the price of a bond is set, banks expect the before-tax, one-period rate of return on bonds, including capital gains and losses, to be the same for a given period as the expected bill rate for that period. Since capital gains and losses are recorded each period and taxed as regular income, banks also expect the *after-tax* rates of return on bills and bonds to be the same, which means that they can be assumed to be indifferent between the two.

The discussion in the last three paragraphs can be summarized to say that stocks and savings deposits are assumed to be perfect substitutes and that bills and bonds are assumed to be perfect substitutes. These assumptions have the effect of decreasing the number of decision variables of both households and banks by one each, and they obviously simplify the model. As will be seen in section 1.3, distributional issues are generally ignored in this study, and the above assumptions are in a sense just another example of the ignoring of distributional issues. The reason that stocks and bonds were included in the model at all was so that the effects of capital gains and losses on the economy could be analyzed.

The bond dealer is assumed to set the bond price and the stock price for the next period at the end of the current period, but before all transactions for the current period have been completed. This is assumed to be done so that capital gains and losses for the current period can be recorded during the current period. All stocks in the model are end-of-period stocks. The model is discrete, and no consideration is given to the rate of change of the stock variables during the period.

In a nontâtonnement model the order in which information flows and transactions take place is obviously quite important. In a tâtonnement model the order is not important because recontracting is allowed and no transactions take place until the equilibrium prices and quantities have been determined. One must also be concerned in a nontâtonnement model with what determines the actual quantities traded when the quantities demanded do not

necessarily equal the quantities supplied. In the present case the order of the flow of information has been specified in a way that makes it easy to determine the actual quantities traded. The important property of the model that allows this to be done is that firms make their decisions subject to the loan constraints from the banks and that households make their decisions subject to the loan constraints from the banks and the hours and goods constraints from the firms.

It will be useful for purposes of describing the determination of the actual quantities traded to define a firm's *unconstrained* demand for loans to be the firm's demand for loans if it were not subject to a loan constraint.[h] This demand can be computed by solving the optimal control problem of the firm with no loan constraint imposed. A firm's *constrained* demand for loans will be defined as the firm's demand for loans when it is subject to the loan constraint. When the loan constraint is not binding, the firm's unconstrained and constrained demands are the same. Otherwise, the constrained demand is less than the unconstrained demand. The constrained demand will sometimes be referred to as the "actual" demand, since, as discussed below, the constrained demand is always the actual value of loans taken out in the period.

It will likewise be useful to define a household's unconstrained demand for goods and supply of labor to be the household's demand and supply if it were subject to none of the three possible constraints. The constrained demand and supply are the demand and supply that result when the three constraints are imposed on the household. The constrained demand is the actual quantity of goods bought in the period, and the constrained supply is the actual quantity of labor sold in the period. Using these definitions, the determination of the actual quantities traded in the model can now be described.

Since firms and households make their decisions knowing the loan constraints from banks, the constrained-maximization processes of firms and households will always result in the constrained demand for loans being less than or equal to the maximum set by the banks. Since banks are assumed to set the maximum low enough so that they are assured of ending up with this much money to lend, the constrained demand for loans will always be the actual value of loans taken out in the period. If the actual value of loans in the period turns out to be less than the amount of money the banks end up with to lend, the difference is assumed to take the form of excess reserves.

In the case in which banks receive more money in the period to lend that they expected, they are assumed not to receive this information quickly enough in the period to be able to pass it along to firms and households in the form of less restrictive loan constraints. Banks will, of course, end up with excess reserves not only if they underestimate the supply of funds available to them in the period, but also if they overestimate the demand for loans. In other words, the loan constraints may not be binding on firms and households, and firms and households may choose, unconstrained, to borrow less money at the given loan rates than the banks had expected.

Households make their decisions knowing the hours constraints from firms and the government, thus the constrained maximization processes of households will always result in the constrained supply of labor being less than or equal to the sum of the government's demand and the maximum set by the firms. The constrained supply of labor will thus always be the actual quantity of labor sold in the period. If the hours constraints are not binding on the households, so that the unconstrained and constrained supplies of labor are the same, then the supply of labor will be less than the sum of the government's demand and the maximum set by the firms. In this case the government is assumed to get all the labor that it demanded, so that the firms are the ones who end up with less labor than they expected. (Remember that the maximum set by a firm is its expected supply.) In this case the firms may be forced to produce less output than they had planned, depending on how much excess labor they had planned for. (The concept of "excess labor" is discussed at the end of this section.)

Because households make their decisions knowing the goods constraints from firms, the constrained maximization processes of households will always result in the constrained demand for goods being less than or equal to the maximum set by the firms. The demand for goods includes the demand by households, the demand by the government, and the demand by firms (in the form of investment). Firms and the government are assumed always to get the number of goods that they want, so that households are the ones who are subject to a goods constraint.

Since firms are assumed to set the maximum low enough so that they are assured of having this many goods to sell in the period, it will always be the case that the constrained demand for goods is less than or equal to the available supply. Any difference between the number of goods produced and sold by the firms results in a change in inventories. If it happens that the actual demand for a firm's goods exceeds the demand the firm expected,[1] the firm is assumed not to receive this information quickly enough for it to be able to increase its production and employment plans for the period.

This completes the discussion of some of the main transactions in the model. It is obvious that the particular order of information flows and transactions postulated in the model is somewhat arbitrary and that other orders could be postulated. The particular order chosen here was designed to try to capture possible credit rationing effects from the financial sector to the real sector and possible employment constraints from the business sector to the household sector. This order seemed to be the most natural one, although in future work it would be of interest to see how sensitive the conclusions of this study are to the postulation of different orders.

The assumptions that firms do not retain any earnings and do not issue any bonds and new stocks are not as restrictive in the present context as

one might think. What the model is trying to capture are aggregate financial restrictions facing the firm sector, and if in practice at least some firms are constrained at times from being able to borrow as much money as they would like at the current interest rates (i.e., either constrained in their borrowing from financial intermediaries, in their issuing of bonds, or in their issuing of new stocks), the specification of the model may not be too unrealistic. In the aggregate, only so much money is available in any given period to borrow, and if interest rates do not get set in such a way as to clear the financial markets every period, then in periods of too-low interest rates some potential borrowers must go unsatisfied.

The model does account for all aggregate flow-of-funds constraints, and so the most important financial restrictions in a macroeconomic context have been taken into account. It should also be emphasized that "banks" in the model are meant to include commercial banks, savings and loan associations, mutual savings banks, life insurance companies, and other financial intermediaries, which makes it less unrealistic to assume that all borrowing takes place from the "banks." Also, many corporate bond issues are in practice privately placed—mostly to life insurance companies—and this again lessens the restrictiveness of the assumption that all borrowing in the model takes place from the banks.

Before concluding this section, it will be useful to describe the model of firm behavior in somewhat more detail. It is usually the case that the price, production, investment, and employment decisions of a firm are analyzed separately rather than within the context of a complete behavioral model. A few studies have analyzed two of the decisions at a time. Holt, Modigliani, Muth, and Simon[29], for example, have considered the joint determination of production and employment decisions within the context of a quadratic cost minimizing model. Lucas [34] has recently postulated a general stock adjustment model in which the stock of one input may influence the demand for another input, and Nadiri and Rosen [41] have used this basic model in an empirical study of employment and investment decisions. Coen and Hickman[11] have worked with a model that takes into account the interrelationship of employment and investment decisions. Mills [38], Hay [27], and Maccini [36] have considered the joint determination of price and production decisions. In the model of firm behavior in this study, all four of the decisions are determined simultaneously.[j]

The underlying technology of a firm is assumed to be of a "putty-clay" type, where at any one time there are a number of different types of machines that can be purchased. The machines differ in price, in the number of workers that must be used with each machine per unit of time, and in the amount of output that can be produced per machine per unit of time. The worker-machine ratio is assumed to be fixed for each type of machine.

One important premise of this study regarding the production, employment, and investment decisions of a firm is that there are costs involved

in changing the size of the work force and in changing the size of the capital stock. Because of these costs, a firm is likely to choose to operate some of the time below capacity and off its production function. This means that some of the time the number of worker hours paid for may be greater than the number of hours that the workers are effectively working. Similarly, some of the time the number of machine hours available for use may be greater than the number of machine hours actually used.

The evidence presented in Fair [14, Chapter 3] rather strongly indicates that firms do spend some of the time off of their production functions, and the model of employment decisions developed in [14] was based on the distinction between hours paid for and hours worked. The difference between hours paid for by a firm and hours worked will be referred to as "excess labor."[k] Similarly, the difference between the number of machines on hand and the number of machines required to produce the output will be referred to as "excess capital." Two important constraints facing a firm are that the number of worker hours paid for must be greater than or equal to the number of worker hours worked and that the number of machine hours used must be less than or equal to the number available for use.

Another important premise of this study concerns the firm's price decision. A firm is assumed to have a certain amount of monopoly power in the short run in the sense that raising its price above prices charged by other firms will not result in an immediate loss of all its customers and lowering its price below prices charged by other firms will not result in an immediate gain of everyone else's customers. There is assumed, however, to be a tendency in the system for a high price firm to lose customers over time and for a low price firm to gain customers. This assumption—that a firm's market share is a function of its price relative to the prices of other firms—is common to the studies of Mortensen [39], Phelps [46], Phelps and Winter [47], and Maccini [36]. The model developed here, however, differs from or expands on the models in these studies by postulating that a firm also expects that the future prices of other firms are in part a function of its own past prices. As will be seen in Chapters Two and Three, this postulate has an important influence on the final properties of the model.

The tendency for firms to lose or gain customers depending on whether their prices are high or low can be justified by assuming that customers search. If during each period some customers search, and if each customer who searches buys from the lowest price firm that he or she finds, then there will be a tendency for high price firms to lose customers and vice versa. Although this tendency can be justified by assuming that customers do search, in the present case the search activities of customers are not explained within the model. In the specification of the behavior of households, for example, the possible gains and costs of search are not considered, and search is not considered a decision variable of households. If search were treated as a decision variable, it would be

necessary to specify a much more complicated model than has been done. Such an undertaking is beyond the scope of the present study.

A firm's market share of labor supplied to it is treated in a manner similar to its market share of goods sold: a firm's market share of labor is assumed to be a function of its wage rate relative to the wage rates of other firms. Also, a firm is assumed to expect that the future wage rates of other firms are in part a function of its own past wage rates.

Finally, a bank's market share of loans is treated in a manner similar to a firm's market share of goods: a bank's market share of loans is assumed to be a function of its loan rate relative to the loan rates of other banks. Likewise, a bank is assumed to expect that the future loan rates of other banks are in part a function of its own past loan rates.

1.3 THE METHODOLOGY OF THE STUDY

The methodology of this study is unusual enough to require some discussion. The most important aspect of the methodology is the use of computer simulation to analyze the behavior of the banks, firms, and households and to analyze the properties of the overall model. The behavior of each bank, firm, and household was analyzed in the following way.

1. The basic equations were specified and the optimal control problem was formulated for the behavioral unit.
2. Assumptions regarding the formation of expectations were made.
3. Using the information from 1 and 2, algorithms were written to solve the optimal control problem of the behavioral unit.
4. Particular values for the parameters and initial conditions were chosen, and a "base run" was obtained by using the algorithms to solve the optimal control problem for these particular values. The parameter values and initial conditions were chosen so that the optimal paths of the decision variables for the base run would be roughly flat.
5. Various changes in the initial conditions from those used for the base run were made, and for each change the control problem was resolved to obtain the optimal paths of the decision variables corresponding to the change. These new paths were then compared to the base run paths to see how the behavioral unit modified its decisions as a result of the change. A "flat" base run was chosen in 4 to make it easier to compare the behavioral unit's modified decisions to its original decisions.

The results in 5 are analogous to partial-derivative results in analytic work in the sense that one obtains the change in one variable corresponding to a change in some other variable. In Chapters Two, Three, and Four, tables of results of carrying out the procedure in 5 are presented for banks, firms, and households, and from these tables one can get an understanding of how each unit behaves.

After the behavior of each unit was analyzed separately, the entire model was put together and solved. One solution of the overall model for one time period corresponds to the solution of an optimal control problem for each behavioral unit and to the computation of the transactions that take place after all the decisions have been made. After the transactions have all been computed, time switches to the beginning of the next period, and the behavioral units solve their control problems again, the new solutions being based on the new information that has resulted from the previous period's transactions. After the new solutions have been obtained, the new transactions based on these solutions are computed, and then time switches to the next period. This process can be repeated for as many periods as one is interested in.

One important point to keep in mind about the solution of the overall model is that although the solution of the optimal control problem for each behavioral unit corresponds to optimal *time paths* of the decision variables being computed, only the values for the current period are used in computing the transactions that take place. Each period new time paths are computed for each decision variable, and so the optimal values of the decision variables for periods other than the current period are of importance only insofar as they affect the optimal values for the current period.

The optimal control problem of each behavioral unit is stochastic, nonlinear, and subject to equality and inequality constraints. In order to simplify the problem somewhat, each behavioral unit was assumed to convert its stochastic control problem into a deterministic control problem by setting all of the values of the stochastic variables equal to their expected values before solving. This is a common procedure in the control literature (see, for example, Athans [3]). The solution values that result from such a procedure must, of course, be interpreted as being only approximations to the true solution values of the complete stochastic control problem. Only in the linear case would the decision values for the current period that result from this procedure be the same as the decision values that result from solving the complete stochastic control problem.

There is also another source of inaccuracy in this study regarding the solutions of the control problems. Cost considerations prevented the writing of highly accurate algorithms to solve the deterministic control problems, and there is no guarantee that the optima found by the algorithms are in fact the true optima of the deterministic control problems. Particular attention was concentrated, however, on searching over values of the decision variables for the first few periods of the horizon, so that some confidence could be placed on the assumption that the values chosen for the current period are close to the true solution values of the deterministic control problem for the current period. The algorithms that have been used to solve each particular control problem are discussed in the following chapters. The length of the decision horizon for each behavioral unit was always assumed to be 30 periods in the programming of the model.

Because of the assumption that the behavioral units replace stochastic variables with their expected values, the model is presented in the text using expected values directly rather than density functions. A superscript "e" on a variable is always used to denote the expected value of the variable.

Another important aspect of the methodology of this study is the treatment of the aggregation problem. There are at least two basic ways in which one might put a model of the sort developed in this study together. One way would be to specify a number of different banks, firms, and households; have each one solve its control problem; and then have them trade with each other in some way. To do this, one would have to specify mechanisms for deciding who trades with whom and would have to keep track of each individual trade in the model. Questions of search behavior invariably arise in this context, as do distributional questions. This way of putting the model together is considerably beyond the scope of the present study.

The other basic way of putting the model together is to ignore search and distributional questions. Even within this context, however, there are at least two ways in which search and distributional questions can be ignored. One way would be to postulate only one bank and one firm and treat the two as monopolists. The other way is to postulate more than one bank and one firm, but treat all banks as identical and all firms as identical. This second way is the approach taken in this study. The advantage of postulating more than one bank and one firm is that models can be specified in which the behavior of an individual bank or firm is influenced by its expectations of the behavior of other banks or firms. Models of this type, in which market share considerations can play an important role, seem more reasonable in a macroeconomic context than do models of pure monopoly behavior.

An apparent disadvantage of postulating more than one bank and firm and yet treating all banks and firms as identical is that whenever, say, a firm expects other firms to behave differently than it plans to behave, the firm is always wrong. If all firms are identical, they obviously always behave in the same way, even though they almost always *expect* that they will not all behave in the same way. Firms never learn, in other words, that they are all identical. Fortunately, this disadvantage is more apparent than real. If one is ignoring search and distributional questions anyway, there is no real difference (as far as ignoring these questions is concerned) whether one postulates only one firm or many identical firms. Both postulates are of the same order of approximation, namely the complete ignoring of search and distributional questions, and if one feels that a richer model can be specified by postulating more than one firm, one might as well do so. One will gain the added richness without losing any more regarding search and distributional issues than is already lost in the monopoly model.

The fact that distributional issues are ignored in the model makes the treatment of stock prices and shares of stock much easier than it otherwise

would be. The economy can be treated as if there were only one share of stock in existence, of which individual creditor households own certain fractions. The price of this share of stock is set by the bond dealer. The bond dealer uses expectations of future aggregate dividend levels in setting the price, where the aggregate dividend level in any period is the sum of all of the dividends from the firms, the banks, and the bond dealer. The households are, of course, the ones who form the expectations of the future aggregate dividend levels, which then get communicated to the bond dealer.

Two versions of the overall model have actually been used in this study, one called the "non-condensed" version and one called the "condensed" version. The non-condensed version postulates two identical banks, two identical firms, and two households. The two households are not identical; one is a creditor and one is a debtor. This version is solved in exactly the manner described above. Since the non-condensed version is large, costly to solve, and somewhat difficult to comprehend in its entirety, an alternative and smaller version was also specified. This "condensed" version was specified as follows.

1. The behavior of the banks, firms, and households was examined by looking at the tables of results obtained by the procedure described in 1 through 5 above (p. 12).
2. Using the results in these tables and a general knowledge of the optimal control problems of the behavioral units, the behavior of the banks, firms, and households was approximated either by equations in closed form or by simple algorithms. In the process of making these approximations, the banks were aggregated and the firms were aggregated, so that one ended up with equations or algorithms pertaining only to a "bank sector" and a "firm sector."
3. The transactions equations for the non-condensed model were then modified appropriately to correspond to the more simplified nature of the condensed model.

The advantage of the condensed version is that one can see more directly what influences the decisions of the behavioral units. In the non-condensed version the influences are buried in the optimal control problems of the behavioral units, and many times one cannot see directly what affects what. No optimal control problems have to be solved in computing the solution of the condensed version each period since the optimal control problems have in effect been approximated by equations in closed form or by simple algorithms.

For the analysis of the properties of the overall model in Chapter Six, the condensed version has been used. The analysis of the non-condensed version is relegated to the Appendix. Since the properties of the two versions are virtually the same—one merely being an approximation of the other—it seemed best to concentrate on the simpler version in the text. The Appendix contains

the results of a few runs and enough discussion to show how the non-condensed version is solved.

There is also a "static-equilibrium" version of the model, and this version should not be confused with either the condensed or non-condensed versions, which are both dynamic. The static-equilibrium version is discussed in Chapter Seven. The Gauss-Seidel algorithm is used to solve the static-equilibrium version in Chapter Seven, and again this algorithm should not be confused with either the algorithms used to solve the optimal control problems or the algorithms used in the condensed version of the dynamic model.

The advantage of using computer simulation techniques over standard analytic methods to analyze models is that one can deal with much larger and more complete models. More than merely one or two decision variables of a behavioral unit can be considered at the same time, multiperiod decision problems can be considered, and in general one can get by with making less restrictive assumptions. It should be stressed, however, that the simulation work in this study is not meant to be a "test" of the validity of the model, but only an aid to understanding its properties. The parameter values and initial conditions have all been made up and have not been estimated from any data.

It should be obvious by now that the model developed in this study is based on numerous assumptions that can in no way be verified or refuted directly. As with most economic models, the model is highly abstract. The philosophy that underlies the construction of the present model goes something as follows. The author looks on a theoretical model of the sort developed in this study as not so much true or false as useful or not useful. The model is useful if it aids in the specification of empirical relationships that one would not already have thought of from a simpler model and that are in turn confirmed by the data. It is not useful if it either does not aid in the specification of empirical relationships that one would not have thought of from a simpler model or aids in the specification of empirical relationships that are in turn refuted by the data.

As discussed in Chapter Eight, the present model does imply that macroeconometric models ought to be specified quite differently from the way they now are. The model does appear, therefore, to meet the requirement that it lead to new empirical specifications, and so it does appear to be possible, according to the above philosophy, to decide whether the model is more useful than other theoretical models. (Volume II will carry out such an analysis.)

1.4 SUGGESTIONS TO THE READER

Because of the model's size and the reliance on computer simulation to analyze its properties, the overall model is not particularly easy to comprehend. The reader should have a good understanding of the behavior of the individual units in the model from the discussion in Chapters Two through Five before proceeding to the discussion of the complete model in Chapters Six through

Eight and in the Appendix. Of particular importance in Chapters Two, Three, and Four are the tables of simulation results (Tables 2-3, 3-3, 4-3, and 4-4), where one can see how the behavioral units respond to various changes in the initial conditions. The tables presenting the equations of the condensed model for each behavioral unit (Tables 2-4, 3-4, and 4-6) should also help one to understand the behavior of each unit.

The two most important tables in the book are Table 6-2 and Table A-2, where the complete sets of equations for the condensed and non-condensed models are presented, respectively. Since the condensed model is a close approximation to the non-condensed model and is easier to comprehend, it is advisable for most purposes to study Table 6-2 rather than Table A-2. After having studied Table 6-2 carefully, the simulation results for the complete model in Table 6-6 and the related discussion should be understandable. In general, the discussion in the text relies heavily on the use of tables, and in most cases it is necessary to study the tables carefully in order to follow the discussion in the text. In order to make Chapters Two through Five a little more self-contained, some of the discussion of the behavioral units in section 1.2 in this chapter is repeated in the following chapters.

NOTES

[a]Examples of these studies are the studies of Leijonhujvud [32], [33], Tucker [53], [54], [55], Barro and Grossman [5], and Grossman [24], [25], [26]. See also the studies of Solow and Stiglitz [51] and Korliras [31].

[b]See Rothschild [50] for a survey of some of the more recent studies, and see also Nordhaus [42].

[c]See, for example, Alchian [1], Diamond [12], Fisher [18], [19], Gepts [20], Gordon and Hynes [22], Lucas and Rapping [35], Maccini [36], Mortensen [39], [40], Phelps [46], Phelps and Winter [47], and Rothschild [49]. See also an early paper by Clower [9], in which an attempt is made to provide a general theory of price determination that is applicable to all types of market structures.

[d]Barro and Grossman [5], pp. 83–84, fn. 6.

[e]See footnote c.

[f]See, for example, Christ [8] for a discussion of the government budget constraint.

[g]The bond dealer will be referred to as an it, rather than as a he or a she.

[h]Unless otherwise stated, the phrase "demand for" or "supply of" in the text is meant to refer to the quantity demanded or supplied, not to a demand or a supply schedule.

[i]Since in general a firm plans to end up with a positive level of inventories at the end of the period, the firm's expected demand for its goods is usually less than the maximum number of goods that it is willing to sell.

[j]A firm's "employment" decision in the present context corresponds to its wage-rate decision and its decision on the maximum amount of labor to hire.

[k]"Excess labor" was defined in a slightly different way in [14] as the difference between standard hours and hours worked. Under this definition excess labor can be negative if hours worked exceed standard hours. For purposes of the present study it is more convenient to refer to the difference between hours paid for and hours worked as "excess labor."