MacroLab Documentation

MacroLab: The Model

This project has addressed a research question motivated by an overarching goal of improving undergraduates' learning of macroeconomics. Various adaptations of the *feedback method* have been tested in controlled experiments, and the results described in papers 2-5 are promising, measured in terms of student preference and performance. Each simple feedback model used in the experiments had a specific pedagogical purpose, and together they can be considered a sample from the full model the author uses when teaching macroeconomics. This chapter describes and explains the structure and behavior of that full model.

Model validation is the process of building justifiable confidence in a model (Forrester and Senge, 1980). What justifies confidence—and, therefore, the validation techniques—depends on the purpose for which the model is built (Forrester and Senge 1980, Sterman 2000, Barlas 1996). The purpose of the *MacroLab* model in its current form is strictly pedagogical. The intent of this chapter, therefore, is to provide the reader with an understanding of the model that is sufficient for deciding whether it is a suitable representation of the market economy in the United States. Suitable, in this context, means that the real-world counterparts to the components of the model—and their general relationships—should resemble the U.S. economy described in standard textbooks, whether in words or models. Suitable also means that the behavior generated endogenously by the model's structure is more or less consistent with the behavior described by standard undergraduate macroeconomics textbook models—whether in narrative, diagrammatic, graphical, or mathematical form. Even mainstream textbooks have more or less subtle differences in their description of how a market economy performs, but mostly they reach similar conclusions, and a suitable *MacroLab* model should do the same when its purpose is to convey the consensus view of macroeconomic principles to undergraduates. In addition, a very large variety of *structure-behavior* tests and *extreme condition* tests have been performed, and some will be illustrated in the submodel section. Suitable also means that the model's behavior should more or less resemble the historical behavior of the real-world system on which it is based; in this case, the US economy over the past quarter century.

What distinguishes *MacroLab* from conventional methods, however, is how the story of economic structure and behavior is told. The first difference is the emphasis on *dynamics* rather than static equilibrium conditions. How the economy changes over time in different contexts is the behavioral question that students repeatedly encounter, and the time series graph is the workhorse tool for studying both historical trends and simulated behavior. Secondly, the structure of the economy is explained in terms of reinforcing and counteracting *feedback loops*. Students are encouraged to "think in time" and envision patterns that unfold and interact in reinforcing or counteracting ways with earlier trends, instead of focusing on isolated cause-and-effect events. The feedback loop is the unit of analysis, and student understanding of the source of dynamic economic behavior requires seeking, identifying, and explaining relevant feedback structure in an economic system. Another distinction, as the next chapter explains, is the *interactive* method of engaging students in vicarious construction of the model and "test driving" the *MacroLab* simulator. The simulation experiences reinforce the insights gained from studying feedback loops. In addition, small-scale student participation in model-building seems to facilitate understanding of a larger model; moreover, such participation may build respect for the scientific method and an appreciation for theory building by economists.

In short, *MacroLab* provides students with a different conceptual lens through which to view the structure and behavior of the economy. Students see an economy in motion that more or less regulates itself through a web of feedback loops that are accessible to student inspection. Also, students get to experiment with alternative market structures—including those that emerge from various fiscal and monetary policy efforts aimed at improving market performance. This chapter presents the system dynamics model that is the foundation for that learning experience. The first two sections briefly illustrate the central concepts in system dynamics modeling and provide an overview of *MacroLab's* stock-and-flow structure. Section 3 compares the model's behavior with reference behavior patterns commonly found in mainstream textbooks and uses feedback loop diagrams for the structural explanations. The fourth section compares the model's behavior with historical reference behavior patterns to see if forecasts of some actual U.S. economic patterns are reasonable. The lengthy final section provides details on the structure of the *MacroLab's* submodels, including a complete listing of equations.

1. System Dynamics Modeling Concepts

System dynamics models are used for studying and managing problems in complex feedback systems. Standard works include Forrester (1961), Richardson & Pugh (1989), Ford (1999) and Sterman (2000). The conceptual building blocks for such models are *stocks*, *flows*, and *feedback loops*, generically illustrated in Figure 1. A *stock* is an accumulation of material or information. A net *flow* is the rate of change in a stock. The *feedback loop* transmits information about the state of the system from the stocks to the decision rules—the equations— that govern the flow, which then updates the stock and closes the loop. System dynamics models are systems of differential equations. Typically non-linear and without analytic solutions, they rely on numerical integration to generate simulated behavior. See Sterman (2000, chapter. 6 and 7 and Appendix A) and Ford (1999, chapter 3). Thus, the initial value of the stock changes as the stock integrates the net flow.

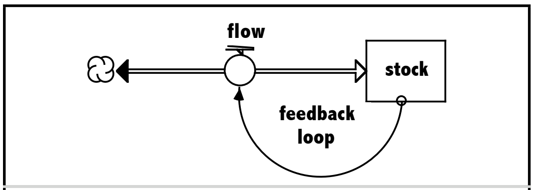


Figure 1. Stock, Flow, & Feedback Central Concepts in System Dynamics

Figure 2 presents a more general version of a generic feedback system based on system dynamics concepts. Complex systems such as an economy contain many stocks that interact endogenously; that is, they have feedback effects on each other. All models have boundaries (defined by the model's purpose, level of aggregation, and time horizon) beyond which exogenous influences originate, but those influences do not receive any feedback effects from the model during the time horizon under study. In addition to the rectangles, pipelines, and arrows that represent stocks, flows, and information links, the generic diagram also includes small circles that represent endogenous auxiliary variables (with values determined by equations) and exogenous parameters (with fixed estimates of values).

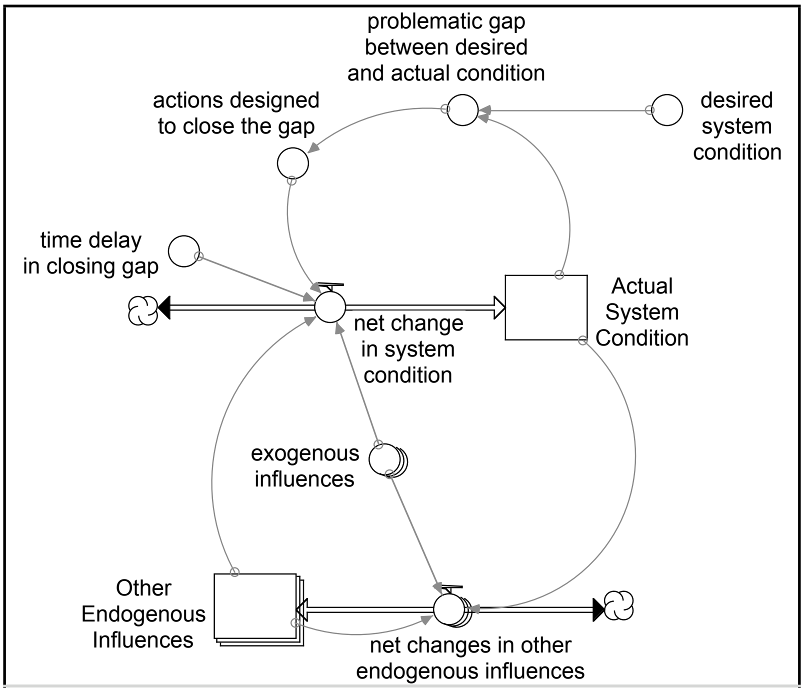


Figure 2. Generic Feedback System

The conditions of some stocks are managed (with varying degrees of success) by agents in the system. In those cases, some desired conditions for the stocks are periodically compared with actual conditions and, if problematic discrepancies ("gaps") exist, corrective actions are taken. Forming human perceptions of such gaps, making decisions on how to close them, and then taking action are all time-consuming processes. The time required by the feedback loop process—from stock to flow and back to stock—is an important determinant of the system's behavior.

2. Overview of the Model

The *MacroLab* system dynamics model consists of dozens of stocks and hundreds of equations. Figure 3, however, displays a simplified version of the structure of the main model. For purposes of clarity, the diagram shows only those information links that connect the model's *real* sector (bottom) with its *nominal* sector (top), also referred to as the "supply side" and "demand side," respectively. Nominal dollars flow through the demand sector, while the real quantities flow through the supply side. In the middle of the diagram, part of the nominal income generated by the supply side is divided among households, governments, and businesses on the demand side. On the far right, the nominal aggregate demand is the sum of demand-side spending by households, governments, and businesses, plus net exports, and that nominal quantity is converted to real aggregate demand on the supply side. Unless indicated otherwise, all variable values are determined endogenously by feedback within the system. The diamond-shaped icons are linked to submodels, described in detail in section 5.

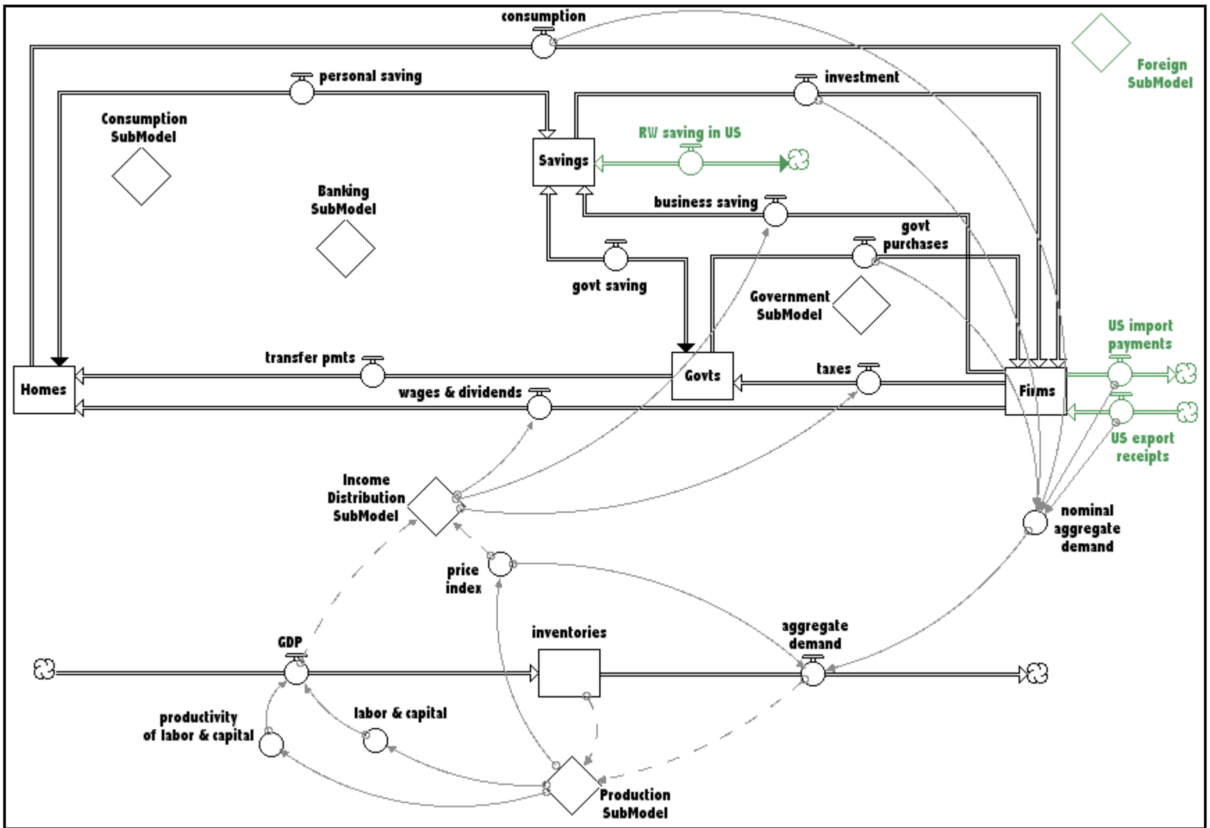


Figure 3. Simplified High-Level View of *MacroLab* Stock-and-Flow Structure

The production submodel determines the stocks of labor and capital to be employed and acquired. A link not shown in Figure 3 connects capital acquisition decisions in the production submodel to investment spending on the demand side. Changes in total factor productivity ("productivity of labor and capital") are based on exogenous growth rate assumptions. The GDP equation is a Cobb-Douglas production function. The average price level—the price index—is also determined within the production submodel, based on the expected demand for goods and services and expected costs of production. The income distribution submodel divides the nominal national income among households ("wages & dividends"), government ("taxes"), and business (retained earnings, or "business saving").

The consumption submodel determines household spending ("consumption"), which is equal to most of disposable income ("wages & dividends" plus "transfer payments") received by households; the remainder is defined as saving ("personal saving"). Investment spending, as noted above, is determined by capital acquisition decisions in the production submodel. Note, however, that the source of funds for investment is the stock of savings, which accumulates personal saving, business saving, government saving (usually a negative value in the US, when government is usually borrowing rather than saving), and saving from the rest of the world (usually positive in the US).

The government submodel receives taxes, makes transfer payments to households, and makes purchases of goods and services from business firms. When government spending exceeds tax revenue, government "saving" is a negative flow; i.e., government borrows from the stock of savings. The government submodel also accounts for government debt, and interest payments are included in transfer payments.

The banking submodel accounts for monetary flows between stocks of bank deposits and currency held by the public, as well as flows to and from bank reserves. The reserves are managed within the submodel according to the fractional reserve requirements established by the central bank, the Federal Reserve System. Interest rates are also determined within the banking submodel, based on the supply and demand for loanable funds and the monetary policy established by the Federal Reserve. A single market interest rate (not shown in Figure 3) is an output of the banking submodel, and the interest rate is an input to both the consumption submodel and the production submodel, where it affects consumer spending and capital spending (investment).

The foreign submodel—called the "rest of the world" or just RW—is literally a clone of the domestic main model and all of its submodels. The purpose of the RW sector is to enable demonstration of some interactive effects between two economies that trade with each other. As a clone, its default parameter settings are identical to the domestic sector, but parameters in both sectors are easily modified with the simulator controls in the interactive learning environment (described in chapter 8). The two economies are linked by the flows of trade (green inflow and outflow to the business firm stock of money) and flows of financial capital ("RW saving in the US"—the green *net* inflow to the US savings stock). There is also an exchange rate submodel that is accessible from the main model of the foreign sector, and conversions can be made between US dollars ($) and RW rollers (®) for purposes of international trade and capital flows.

More details about the submodels, including stock-and-flow structure and a complete listing of equations, are provided in section 5. Before examining more structure, however, the next step in building understanding of the *MacroLab* model is to compare its behavior with reference behavior patterns drawn from mainstream macroeconomics textbooks.

3. Model Behavior Compared with Textbook Reference Behavior Patterns

In this section, the behavior of the *MacroLab* system dynamics model is compared with reference behavior patterns illustrated or asserted in standard macroeconomics textbooks. When teaching, the author uses both Mankiw (2007) and McConnell/Brue (2005)—apparently the two best-selling economics textbooks in the United States (Beam 2005)—and the reference behavior patterns have been selected from those two texts. For each behavioral comparison, the structure of the *MacroLab* model is also presented, and the relationship between model structure and behavior is explained.

Six of Mankiw's (2007) "ten principles of economics" guided selection of the reference behavior patterns.[1] The list includes behavioral predictions based on Mankiw's view of how a market economy works. The principles are mainstream and are probably shared by most economics textbook authors and a majority of other economists. In this section, therefore, we use those principles to organize the discussion of *MacroLab* in the context of standard textbook reference behavior patterns. Unless otherwise cited, all references pertaining to those principles are taken from Mankiw (2007, chapter 1).

[1] The other four are decision-making principles involving trade-offs, opportunity cost, marginal thinking, and incentives that illustrate economic system structure rather than economic system behavior.

3.1 Productivity and Factors of Production. The first reference behavior pattern to be examined is suggested by Mankiw's assertion that "a country's standard of living depends on its ability to produce goods and services." He associates standard of living with average real income, and he emphasizes that productivity "is the primary determinant of living standards." He mentions that, historically, real per capita income in the United States has grown about 2 percent per year, and he emphasizes that maintaining that rate doubles the average income every 35 years. In chapter 7, Mankiw mentions the *production function* in general terms, noting that output depends on the quantity and quality of the factors of production and the prevailing technology. McConnell/Brue (2005, chapter 17) provides a similar discussion of historical trends in productivity but does so in the context of an aggregate supply and demand model, and then presents a specific simple production function in which GDP equals the number of hours worked multiplied by the productivity of each hour.

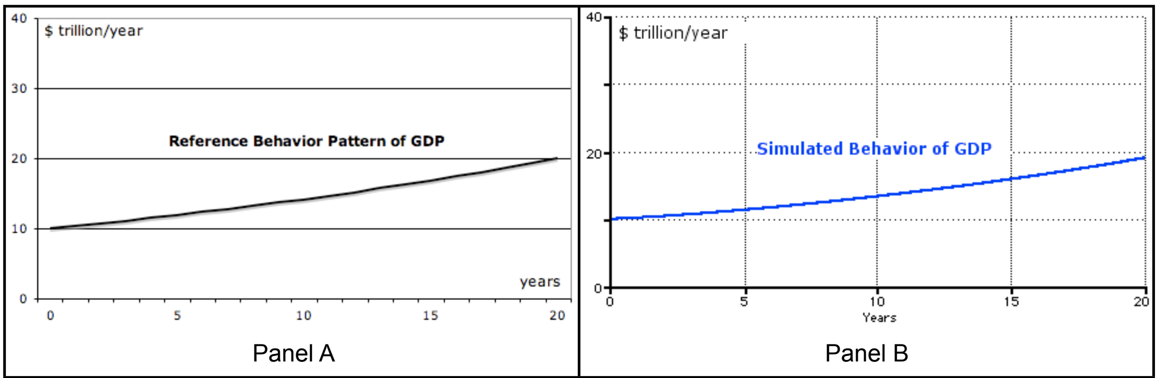


Figure 4. GDP Pattern due to Growth in Productivity and Factors of Production
Textbook Reference Behavior Pattern (A) and *MacroLab* Model Behavior (B)

Although neither textbook provides a times series graph that depicts output associated with a specific production function, panel A of Figure 4 illustrates the behavior generated by a generic adaptation of the McConnell/Brue production function. Generated by a spreadsheet, the graph in panel A assumes 100 million workers at an initial productivity of $100,000 worth of goods and services per year per worker. The overall growth rate was set at 3.5 percent, with productivity accounting for 2.1 percent and workforce growth accounting for 1.4 percent. GDP doubled during the 20-year period, rising from $10 to $20.01 trillion per year. Panel B shows the simulated behavior generated by *MacroLab* after adapting the growth rate assumptions to the model. Simulated GDP at the end of 20 years was $19.39 trillion. The estimates are quite close, but exploring the reason for the difference is instructive.

In standard textbook illustrations of the production function implicit in the spreadsheet model (based on the McConnell/Brue production function), the growth rates are the assumed *ex post* values. *If* the number of people working grew annually at a 1.4 percent rate and their productivity grew by 2.1 percent, then total output would approximately double in 20 years (since, by the rule of 70, 70/(1.4+2.1) = 20).

The initial condition assumptions were the same for both *MacroLab* and the spreadsheet model (e.g., initial workforce size and productivity). The slight difference in 20-year GDP estimates (20.01 and 19.39 for the spreadsheet and *MacroLab*, respectively) is due differences in the implementation of the growth rate assumptions. In *MacroLab*, the assumption of a 1.4 percent exogenous growth rate for the "workforce" is applied to the "working-age population." As the population grows, 70 percent of the new working-age adults are assumed to be seeking employment. Thus, the spreadsheet assumption of 1.4 percent growth rate in employment is implemented indirectly in the model, via the growth in the working-age population, the labor force participation rate, and, ultimately, the number of workers who actually get hired (based on the demand for labor). How long it takes for a 1.4 percent growth rate in the working-age population to translate into a 1.4 percent growth rate in employment depends on the structure of the model, just as it would depend on the structure of a real economy. By the end of the 20-year simulation, employment had risen to 124.9 million. A 24.9 percent increase over 20 years reflects an annual growth rate of about 1.1 percent.

The spreadsheet model assumes the annual 2.1 percent growth in productivity is output per worker. In MacroLab, the exogenous productivity growth rate refers to total factor productivity, and is interpreted as a "technology" influence on the productivity of the factors of production (labor and capital), rather than an assumption of the output per worker. The capital-to-labor ratio is determined endogenously in the model, with the resulting mix of the two factors influencing production via the Cobb-Douglas production. Thus, annual output per worker rose from $100,000 to $155,242. A total percentage increase of 55.242 percent over 20 years implies an annual growth rate in output per worker of 2.2 percent. Thus, the *ex post* values of the growth rate in workforce were 1.1 percent and 2.2 percent for workforce and workforce productivity, which would imply doubling the GDP in about 21 years instead of 20 years, which is what *MacroLab* did.

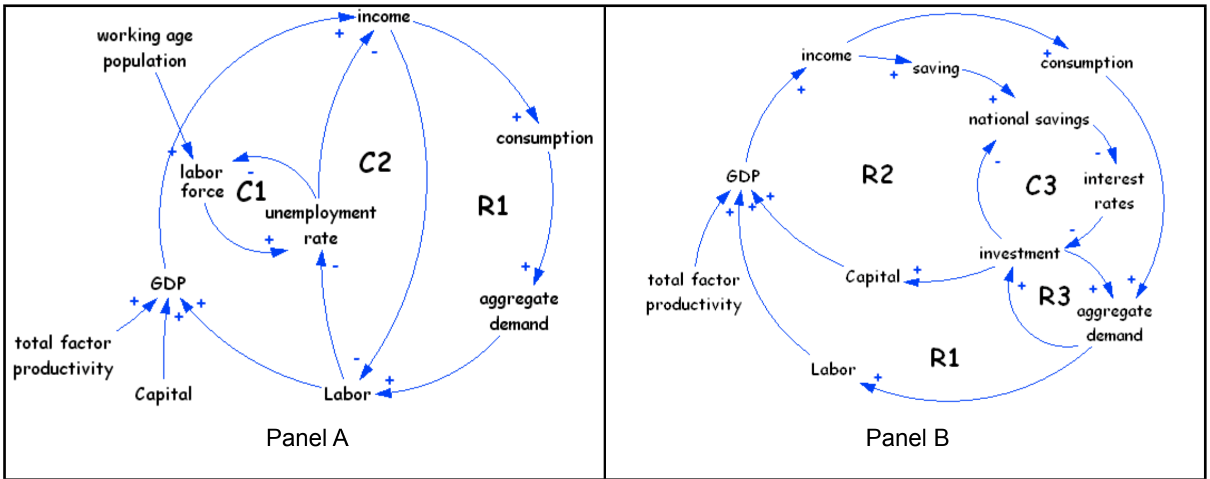


Figure 5. Combination of Feedback Loops that Increase Labor and Capital Endogenously after Stimulation by Exogenous Growth in Population & Productivity

The feedback loop diagrams in Figure 5 can be used to illustrate how the model's structure generated changes in the employed labor stock from two directions. First, multifactor productivity growth increases GDP immediately. As GDP grows, wages increase, giving a boost to both consumption and personal saving. The growth in consumption (part of aggregate demand) encourages more employment. The second effect on labor follows a path through wages. The growth in wages due to rising GDP constrains somewhat the growth in employment. However, the labor force is initially growing faster than the number of new jobs, and the pressure of initially rising unemployment keeps wages from rising as much as they would have otherwise. Thus, employment and the unemployment rate are both rising at first. After labor demand grows to fully reflect the new product demand conditions, the unemployment rate stabilizes. As Figure 5 shows, capital grows endogenously after investment is stimulated by rising aggregate demand and falling interest rates. The Cobb-Douglas production function (GDP equation) transforms the growth in productivity, capital, and labor into an average annual GDP growth of slightly more then 3.3 percent, causing it to double in the twenty-one years.

3.2. Market Economy Better Than Command Economy. The second Mankiw principle is that a market economy usually produces better results than a command economy. He emphasizes that the price mechanism is the instrument used by Adam Smith's "invisible hand" to direct economic decision-making by consumers and producers, and that when "government prevents prices from adjusting naturally to supply and demand, it impedes the invisible hand's ability to coordinate the millions of households and firms that make up the economy." To test *MacroLab's* conformance with this principle, a hypothetical reference behavior pattern was generated under the assumption that government price controls are in place, contrary to a key principle of a market economy. We might assume that the government policy is premised on the belief that *any* price changes that occur quickly are harmful and should be avoided. Thus, the government's price control policy goal will be assumed to apply to both price increases and decreases. Price *increases* might be controlled to protect consumers, while price *decreases* might be controlled to protect small businesses from predatory pricing by large-volume competitors. Specifically, in this fictional price controls program, assume that (a) all price changes in the economy require advance government approval, (b) businesses must provide one year's worth of data to justify changes, and (c) permissible changes must be implemented gradually over a one-year period. In other words, price changes would occur very slowly and only after government approval.

The behavior of an economy under such controls can be simulated in *MacroLab* and compared with a market economy in which prices respond "naturally" to changing demand and supply conditions. Blinder's (1997) survey suggests that price managers wait, on the average, about three months before changing prices after observing changes in market conditions. Even such "sticky" prices would respond more quickly than prices controlled under the government program outlined above. For purposes of the simulation experiment, we assume the three-month delay is "natural" and that the economy is in equilibrium until an exogenous shock permanently reduces consumption spending by about 2 percent (i.e., the average propensity to consume declines to a lower percentage permanently).

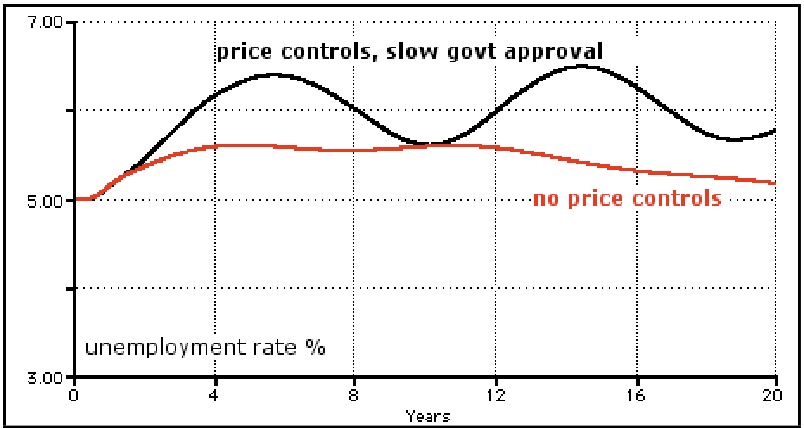


Figure 6. Unemployment Rate Response to Permanent Decline in Average Propensity to Consume, with and without the "delayed" price controls

Figure 6 compares the consumption shock effect on the unemployment rate under the government price controls program (black) and in a free market (red). Clearly, given this shock to the model economy, more stability is provided by the market than by the government. The feedback loop diagram in Figure 7 is based on the *MacroLab* stock-and-flow structure responsible for these simulation results. Loop R1, the main reinforcing loop in the economy, amplifies the effect of falling aggregate demand triggered by the consumption shock. Less production (GDP) reduces wages, which reduce consumption, thus pushing aggregate demand even lower. Declining demand contributes to an undesired inventory increase, which should put downward pressure on prices. When prices are slow to respond (in this case, due to government's price control program), the counteracting effect of loop C1 is weak, and aggregate demand continues to fall under the reinforcing pressure of loop R1. Meanwhile, labor demand continues to fall and unemployment rises, due to the reduction in product demand and the inventory surplus (loop C2). The rise in the unemployment rate should put downward pressure on nominal wages and prices. If there is a sluggish response of prices to falling wages, however, it takes longer for prices to drop and encourage a recovery in demand (loop C4). In general, then, the slower that prices respond to changes in demand and supply conditions, the longer the unemployment trend will continue after it is set in motion (in either direction). The simulated price controls program illustrates the unintended consequences of government-mandated sluggish prices.

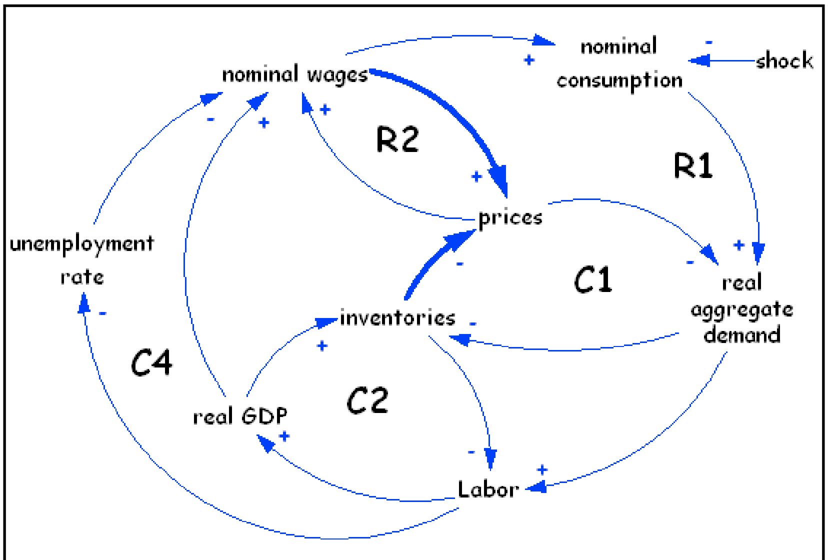


Figure 7. Feedback Loops that Influence Price Response to a Consumption Shock

3.3 Government Improvement of Market Outcomes. Mankiw also emphasizes that "the invisible hand can work its magic only if government … maintains the institutions that are key to a market economy." His discussion focuses on protecting property rights, promoting competition, and correcting market failures due to externalities. Implicit in this third principle, however, is that government has a responsibility to continuously review its own policies and avoid undermining widely-held economic policy goals such as economic growth, price stability, and high employment. In short, economic policy criteria should be part of any assessment of government policy, and government policies should be modified if doing so would improve market outcomes, *ceteris paribus*. Even if other things were not equal, potential economic policy benefits of government policy changes should be weighed against potential costs. Government budget policy provides an example. When Mankiw (2007, ch. 18) considers the pros and cons of balanced budgets, he cites the following common rationale for a budget deficit during a recession:

> *It is reasonable to allow a budget deficit during a temporary downturn in economic activity. When the economy goes into a recession, tax revenue falls automatically, because the income tax and the payroll tax are levied on measures of income. If the government tried to balance its budget during a recession, it would have to raise taxes or cut spending at a time of high unemployment. Such a policy would tend to depress aggregate demand at precisely the time it needed to be stimulated and, therefore, would tend to increase the magnitude of economic fluctuations.*

A quick illustration of Mankiw's example is provided by extending the previous simulation experiment. In the previous experiment, one structural assumption was not mentioned; namely, that government balanced its budget. The curves in Figure 6 were generated with a *MacroLab* assumption that government followed this **balanced budget decision rule**: *When national income changes, tax revenue changes immediately, and government spending gradually adjusts up or down to the new inflow of tax revenue*. There would be very brief cyclical surpluses or deficits, lasting only until the government balanced the next year's budget. An alternative policy is a so-called **unbalanced budget decision rule**: *When national income rises, tax revenue rises immediately, and government spending gradually adjusts upward to match the higher flow of tax revenue. When tax revenue falls, government spending does not change.* Under such a policy, there would be brief budget surpluses when tax revenue rose, lasting only until government could find a way to spend the money. Cyclical deficits, however, would last longer, since deficit spending would continue until tax revenue regained an inflow rate that matched the "frozen" spending outflow rate. The shortfall would be covered by deficit spending, which would raise the government debt.

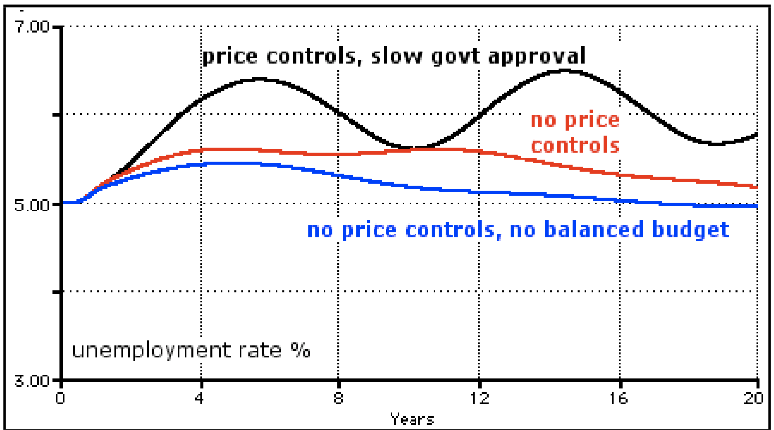


Figure 8. Deliberate Deficit Spending Results in a Quicker Economic Recovery

In Figure 8, the blue curve illustrates the effects of an *un*balanced budget policy on the unemployment rate. The marginal benefit of deficit spending is smaller than the impact of ending the price controls program. Yet, a somewhat quicker recovery does occur when the balanced budget policy is abandoned. Whether the benefits of deficit spending outweigh the costs is an empirical question, and the answer will vary case by case. Searching for the source of potential costs, however, is facilitated by the feedback loop "map" in Figure 9 (which omits business taxes and business saving from the picture, without affecting the point of the example).

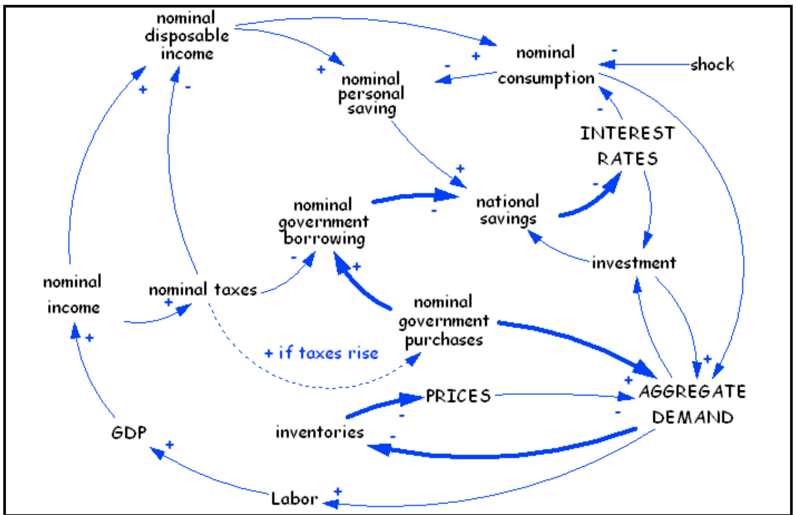


Figure 9. Additional Upward Pressure on Demand, Prices, and Interest Rates due to Government Deficit Spending

In Figure 9, focus on the heavy blue links that map three effects of deficit spending—on aggregate demand, prices, and interest rates. When nominal taxes fall in the aftermath of the exogenous investment shock, government spending continues at its previous rate. Initially, additional aggregate demand (that brings the unemployment rate down more quickly in Figure 8) comes from consumption, since the fall in taxes means that disposable income does not fall as much as total income. Eventually, that encourages more investment. The additional aggregate demand, however, puts upward pressure on prices. Thus, prices are expected to be higher when deficit spending occurs. The higher prices, in turn, negate some of the real aggregate demand growth expected from the deficit spending policy. Finally, since government spending exceeds tax revenue, financing the deficit reduces the stock of national savings and puts upward pressure on interest rates. When interest rates rise, that constrains the growth in both consumption and investment that could have been expected from the deficit spending policy.

The net effect of the deficit spending policy in this *MacroLab* simulation exercise was expansionary. Real aggregate demand grew a little faster, and the unemployment rate fell a little faster, compared to the behavior under the balanced budget policy (Figure 8). The simulation results revealed that, compared to the situation when a balanced budget policy was in effect (red curve in Figure 8), deficit spending pushed prices about 10 percent higher and interest rates almost a full percentage point higher by the end of the simulation period. Government debt and interest payments grew substantially. Interest payments on the government debt grew from 12 percent of total government spending to 18 percent. With total spending flat, the extra debt service spending went to transfer payments and government spending on goods and services was reduced. Comparing a policy benefit (e.g., lower unemployment) with a policy cost (e.g., higher prices) raises an issue that is central to the next Mankiw principle.

3.4 Inflation vs. Unemployment. Mankiw (2007) and McConnell/Brue (2005) agree that there tends to be a "short-run" trade-off between inflation and unemployment. According to Mankiw (p. 13), "Over a period of a year or two, many economic policies push inflation and unemployment in opposite directions." Writing more precisely, McConnell/Brue, (p. 197) define the *short run* as "a period in which nominal wages (and other resource prices) do not respond to price-level changes" and emphasize that the short run is "not a set length of time such a one month, one year, or three years." The point that both textbooks make, however, is the consensus view among economists that opposite-direction movements between inflation and the unemployment rate are not sustainable, and that the so-called Phillips curve is downward sloping in the short run and vertical in the long run as Friedman (1968) argued forty years ago (Mankiw, 2007, ch. 17). Mankiw (2007, ch. 17) documents how the graphical aggregate supply and demand (AS/AD) model accounts for the short-run phenomenon when the AS curve is upward sloping and how the long-term disappearance of the trade-off follows from assuming a vertical AS curve. Earlier (p. 13), he describes the short-term scenario in simple terms, given the assumption of higher aggregate demand for goods and services:

> *Higher demand may over time cause firms to raise their prices, but in the meantime, it also encourages them to increase the quantity of goods and services they produce and to hire more workers to produce those goods and services. More hiring means lower unemployment.*

To test *MacroLab's* consistency with this principle, the model economy was subjected to a step increase in bank reserves amounting to $40 billion, which then "multiplied" to a number almost ten times that amount. The trade-off between inflation and unemployment after the increase in the money supply is displayed several ways in Figure 10. The top-left panel shows the standard time series graph, where inflation (red) moves (with a lag) in a direction that is generally opposite to the direction of the unemployment rate (blue), thus illustrating the trade-off expressed in Mankiw's principle.

To explore this issue further, consider the bottom-left panel, where inflation is plotted on the vertical axis, the unemployment rate is on the x-axis, and the overall pattern of the black line (drawn over time during the simulation) suggests a downward sloping "Phillips curve." The panel on the bottom-right of Figure 10 tells a quite different story about the Phillips curve, based on a considerably different time series graph in the top-right panel. The difference in the two simulation runs is the assumption about how quickly wages adjust to changes in employment conditions. The nominal wage equation in *MacroLab* is influenced by changes in the unemployment rate but not immediately, and variation in the adjustment time is responsible for the variation in the trade-off between inflation and unemployment in Figure 10. On the left, the adjustment time is very quick—one month. On the right, the adjustment time is two years. The default assumption in MacroLab is three months, but the two extreme values were used to reveal a striking contrast in behavior. Similar variations in behavior result from variations in the average adjustment time for prices, and also for the average time taken to adjust wages when prices change.

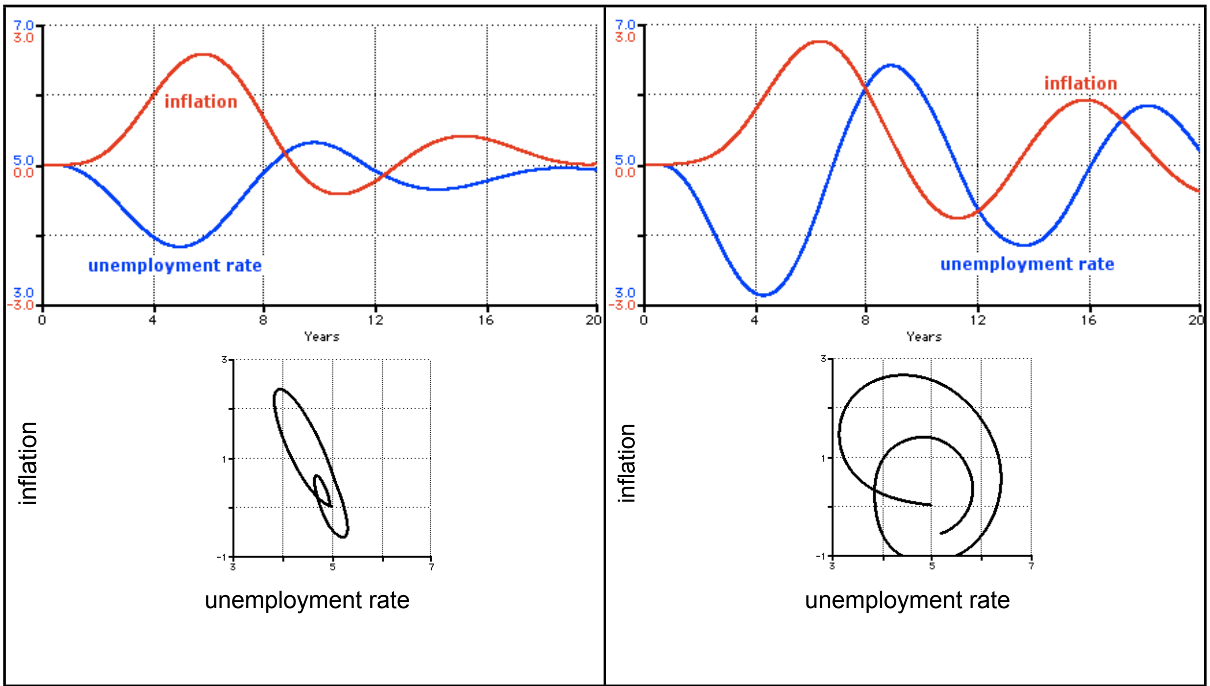
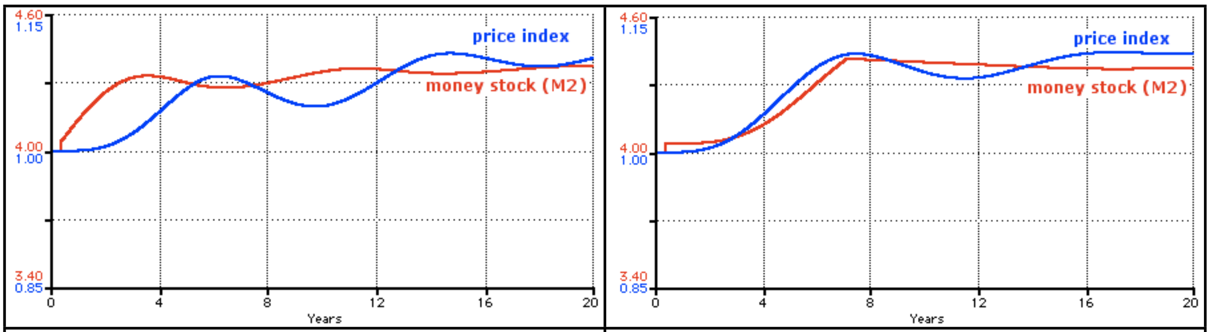


Figure 10. Variations in Trade-Off Between Inflation and Unemployment Rate
Time to Adjust Wages to Unemployment Rate: (left) One Month (right) Two Years

The pattern of real-world, empirically observed data on inflation and the unemployment rate could be due to delays inherent in the price/wage/unemployment adjustment processes, and not due to fundamental changes in those relationships. In the bottom-right panel of Figure 10, for example, the equation (the mathematical structure of the relationship) did not change. The adjustment time did not change; it was a constant two years. Yet, depending on when an observation was made, inflation and unemployment might appear to be inversely related, positively related, or not related at all! A so-called "long run" vertical Phillips curve would be consistent with the same empirical data, but that concept implies that there is some future period when equilibrium reigns and inflation and unemployment are no longer in a process of adjustment. The dynamic behavior in Figure 10 seems more consistent with a world in which the "long run" is nothing more than a series of short runs.

3.5 Money and Inflation. Mankiw's fifth principle is that "prices rise when government prints too much money." Concurring, McConnell/Brue (2005, ch. 19) note that "mainstream economists agree...that excessive growth of the money supply is the major cause of long-lasting, rapid inflation." This principle has its origin in the quantity theory of money (Fisher 1911), but owes it modern consensus status to the work of Milton Friedman, whose best known (1963) summary is, "Inflation is always and everywhere a monetary phenomenon." To test *MacroLab's* conformance with the behavior implicit in Mankiw's fifth principle, the money stock (M2) received a simulated injection of $40 billion, on top of an initial equilibrium value of $4.0 trillion. The results are shown in Figure 11, and it is clear that prices rise at about the same rate as the money supply, which is consistent with the quantity theory of money (Mankiw, ch. 12). The different patterns in the two panels in Figure 11, however, deserve close attention.



Implicit textbook assumption: Money Supply Grows Quickly after Increase in Reserves	MacroLab assumption: Money Supply Grows Only as Fast as the Growth in Loan Demand

Figure 11. Prices Will be Higher After Money Supply Rises, but the transition pattern depends on whether (left) banks can lend most of their reserves soon after the shock or (right) they must wait on demand for loans to grow.

The standard textbook explanation of the response of the banking system to an injection of reserves by the central bank is implicit in the behavior on the left panel in Figure 10. All of the initial supply of excess reserves would be converted to loans quickly, and the new deposits resulting from the loans would create additional reserves for lending as the "money multiplier" process gained steam. In that case, there would be a quick rise in the money supply and a gradual adjustment to the new goal that is implicit in the parameters of the model (reserve ratio, currency-to-deposit ratio, etc.). The red pattern on the left resembles a simple first-order delay adjustment to a goal (because it is). The default assumption in the banking submodel of *MacroLab*, however, is that bankers cannot lend a sudden glut of new reserves as quickly as they might desire. Borrowers have to be interested in taking out new loans. To promote that interest, banks can lower interest rates. Those are the steps in the process followed by the model, reflected in the red curve in the right panel of Figure 11. When interest rates start falling, both consumers and businesses respond gradually, but the full money supply expansion eventually occurs (in this simulation experiment where nothing else happens that might derail the expansion).

3.6. Gains from Trade. The last Mankiw principle we consider for model testing is that "trade between two countries can make each country better off." The point is made somewhat differently by McConnell/Brue (2005, ch. 6): "Specialization and international trade increase the productivity of a nation's resources and allow for greater total output than would otherwise be possible." The foundation for textbook explanations of the incentive for trade is the principle of comparative advantage (Mankiw 2007, ch. 13, and McConnell/Brue 2005, ch. 20). As explained in section 2, however, the current version of *MacroLab's* foreign submodel (RW) is a clone of the domestic model. As such, there are no explicit "specialties" produced by the respective US and RW sectors. The current version of the model contains no mechanism for productivity growth due to specialization; thus, simulations will not show the two economies emerging over time as a result of the comparative advantage principle. We should not expect the kind of "gains from trade" explained by textbook illustrations of country A and country B—previously engaged in inefficient attempts at self-sufficiency—suddenly finding that each has an unexploited comparative advantage that trade can exploit. The lack of such structure means the lack of such behavior. In short, the US and RW have no structural *incentive* to trade with each other. That is a weakness in the current open economy version of *MacroLab* that will be addressed in future versions. Nevertheless, *if trade occurs* (triggered by an exogenous flipping of a switch in the model) then the resultant endogenous behavior of *MacroLab* is consistent with a broad range of textbook behavioral descriptions of open economy macroeconomics. This section compares the behavior and structural explanations of both, in an effort to provide the reader with confidence that similar behavior occurs for similar reasons. In contrast with previous sections, however, the explanation of structure precedes the view of behavior.

To begin, review Figure 3 (in section 2) for a review of *MacroLab's* main model for the US sector. Note, on the nominal side, the green two-way flows connecting the US sector with the RW sector. Payment flows for trade (imports and exports) connect with business firms, and financial capital flows link with the national savings stock. The RW main model is structurally identical. Figure 12 shows the relevant excerpts from the two main models. Adjusted by the exchange rate (not shown), the outflow of US import payments equals the inflow of RW export receipts, and the inflow of US export receipts equals the outflow of RW import payments. The nominal net exports are converted to real quantities when added to real aggregate demand. The financial capital flow is a net rate, and the net saving by the RW in the US is equal to the negative value of net saving by the US in the RW (again, adjusted by the exchange rate). These are structural representations of textbook definitions of exports, imports, and financial capital flows.

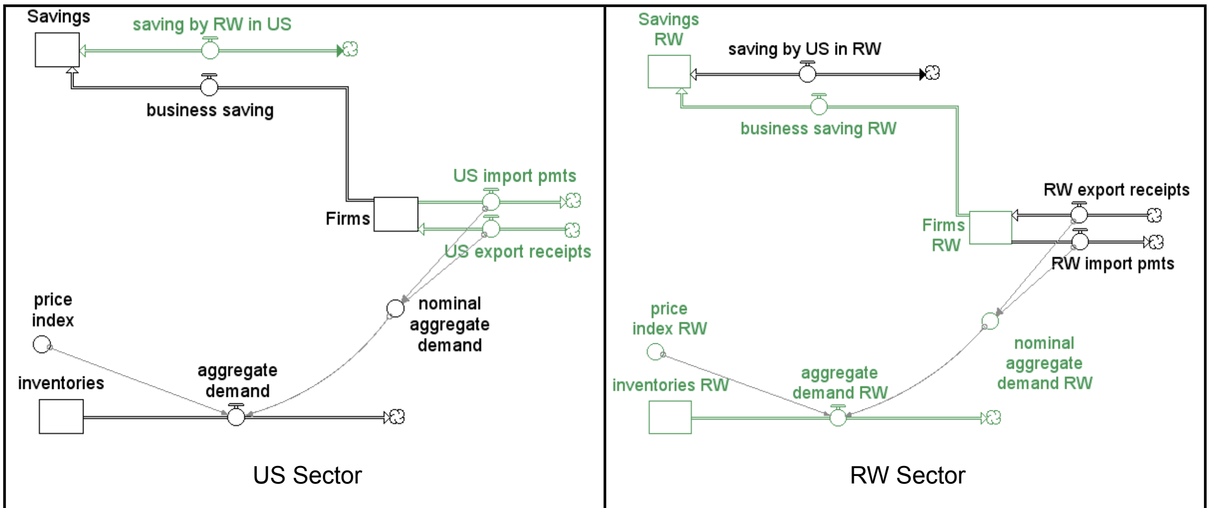


Figure 12. Nominal Inflows to US Sector are Nominal Outflows from RW Sector and Nominal Net Exports are Converted and Added to Real Aggregate Demand

With the textbook consensus as guidelines for structuring open economy relationships, examine the diagram in Figure 13, which provides a high-level overview of most of the feedback structure in *MacroLab's* open economy. (Financial capital flows are added later, and a fourth influence—speculation by traders in international currency markets—is not part of the model's structure.) The two sides of the diagram are mirror images of each other—with the US sector on the left and the RW sector on the right. The open economy diagram illustrates for students how the fortunes of trading nations rise and fall together. The heavy red curve traces a not-so-obvious reinforcing feedback loop that connects aggregate demand in the US with aggregate demand in the RW. An increase in US aggregate demand increases

US imports and raises RW aggregate demand, which then causes an increase in RW imports (US exports) and an increase in US aggregate demand.

Recall the caveat about the economies being clones. When the foreign submodel is activated, the two economies "trade" with each other, but the overall behavior should resemble the expected behavior of two trading partners that are twins. The default settings for *MacroLab* assume that the US and RW clones are identical in every way, including initial stock values, and that they follow the same decision rules. For example, both spend ten percent of nominal national income on imports when the foreign sector switch is ON. Initially, the model is in equilibrium and both sectors have zero net exports.

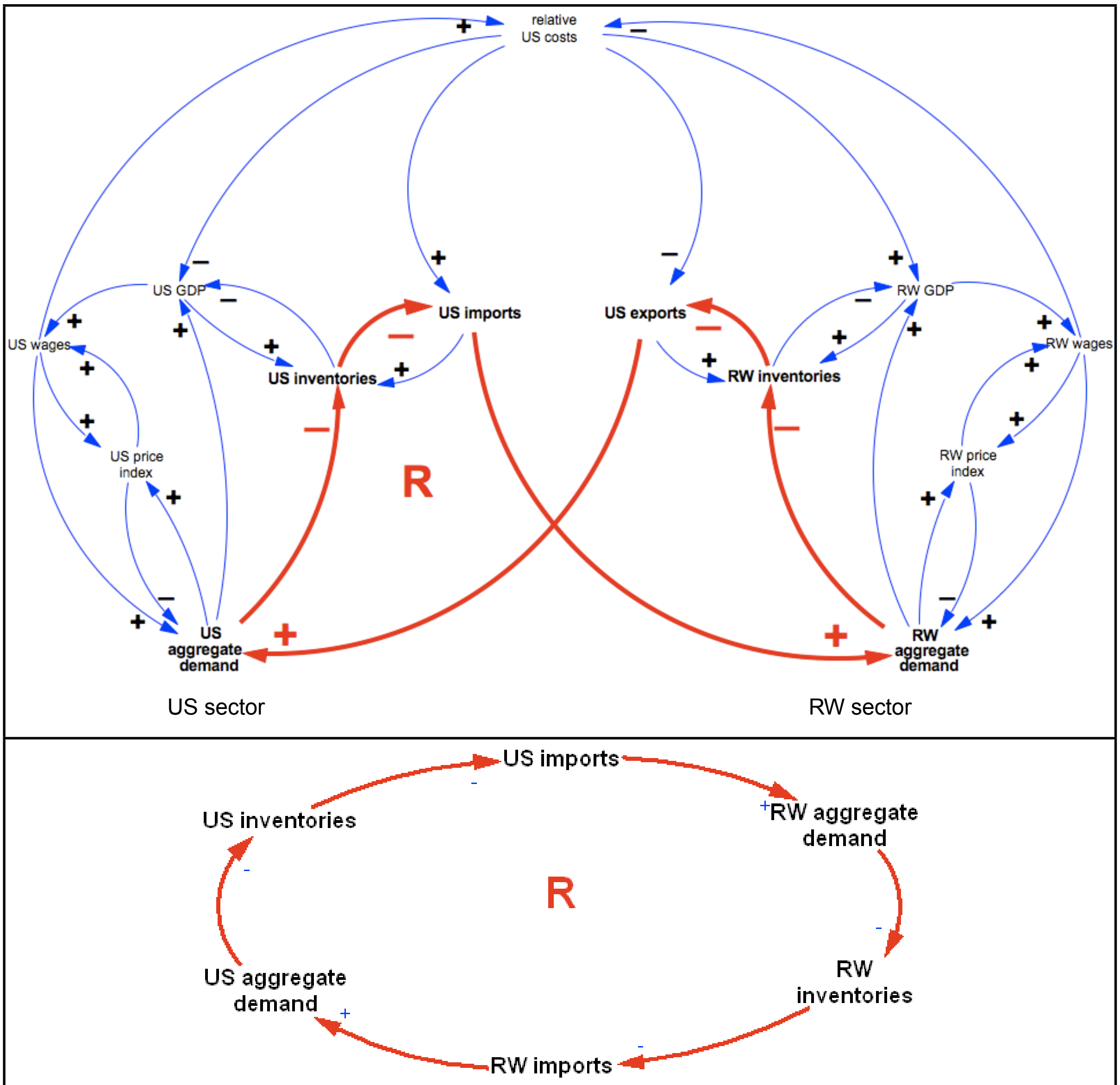


Figure 13. MacroLab Open Economy Feedback Structure
(without exchange rate sector)

To conduct the behavior test, we conducted four simulation experiments under different assumptions about productivity growth and interaction between the US and the RW.

- In the first simulation, both the US and RW began with equal productivity growth rates (1.0 percent annually), but the US technology received a positive shock (productivity increased permanently to 2.0 percent) in year five. There was no trade between the sectors, and the technological progress was confined to the US sector.

- The second simulation differed from the first only by enabling trade between the US and RW economies. The technological jump in productivity was still confined to the US sector.

- During the third simulation, the US and RW are still engaged in trade. In addition, technological progress spreads beyond borders freely at a slow rate. Thus, after the step increase in US productivity, the RW "learned and applied" the same innovations. RW productivity growth accelerated until it matched the US rate. The process was slow, however, taking almost 15 years for full adjustment.

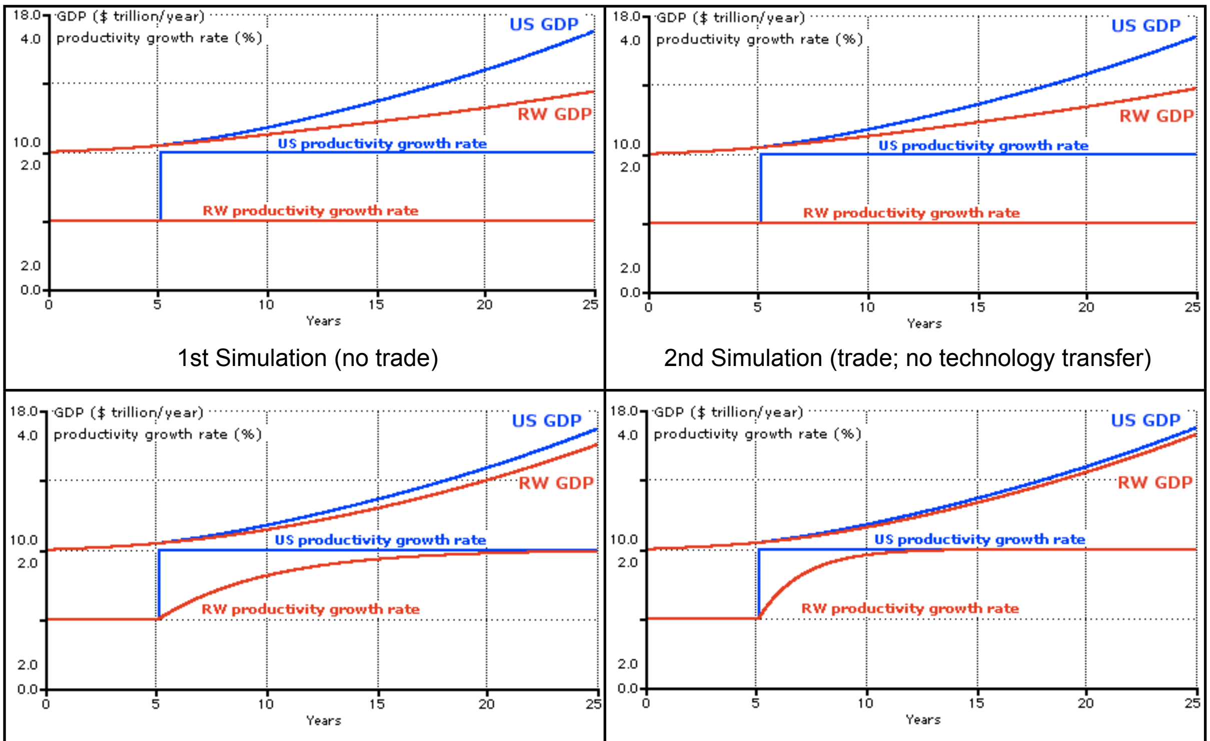
- The last simulation was identical to the third, except for a more rapid transfer of technology. Only a six-year period was needed for RW productivity to regain parity with the US.

	1st Simulation	2nd Simulation	3rd Simulation	4th Simulation
Trade	no	yes		
US productivity growth	1% in years 0-4 and 2.0% thereafter			
RW productivity growth	1% every year	1% every year	1% in years 0-4 and rises slowly to 2.0%	1% in years 0-4 and rises quickly to 2.0%
US GDP by year 25	$17.1 trillion/yr	$16.8 trillion/yr	$17.0 trillion/yr	$17.1 trillion/yr
RW GDP by year 25	$13.5 trillion/yr	$13.8 trillion/yr	$16.1 trillion/yr	$16.7 trillion/yr
Total GDP by year 25	$30.6 trillion/yr	$30.6 trillion/yr	$33.1 trillion/yr	$33.8 trillion/yr

Figure 14. Tests of the Gains-from-Trade Principle

Figure 14 summarizes the four tests, and the results are graphed in Figure 15. A comparison of the first and second simulation results suggests a mere redistribution of income rather than "gains from trade." That is not surprising since, as we have discussed, the structure of the model does not provide the US and the RW with comparative advantages in production. Merely "causing" trade by an equation that makes imports proportional to national income is not the same as building incentives for trade. Indeed, if two real-world economies were truly twins, there would be no incentive for trade. So, in a sense, simulations 1 and 2 illustrate the special case when trade *is* a zero-sum game.

However, it would be easy for students to misinterpret a comparison of the first two simulations. As a practical pedagogical experiment, it should be deferred until the model can be restructured to reflect the comparative advantage principle. At that time, a series of trade experiments "with" and "without" structural comparative advantage may have a powerful instructional impact. On the other hand, the impact of the technology transfer speed could be a useful learning exercise for students at the present time. Assume the 2nd simulation is the base case: trade occurs but the RW is stuck with its original productivity growth rate. As technological progress spreads, both economies grow, and the faster the technology transfers, the more both economies grow. That is an important manifestation of the gains-from-trade principle.



1st Simulation (no trade)

2nd Simulation (trade; no technology transfer)

3rd Simulation (trade; slow technology transfer)

4th Simulation (trade; fast technology transfer)

Figure 15. Results of Gains-from-Trade Simulation Experiments

Can *MacroLab* replicate the textbook behavior implicit in the claim that trade between two countries will make each country better off? The answer is no, because such a claim relies on the assumption that trade will not take place unless both countries have a comparative advantage in producing some good or service. For reasons previously explained, that assumption does not apply to nations that are identical twins such as the US and RW sectors in *MacroLab*. However, both the feedback structure and the simulator enable students to see and experience the reinforcing structure and behavior that tie together two market economies that trade freely with each other. If "gains from trade" is interpreted more broadly to mean the US economy benefits when its trading partners are growing strongly, then the current version of the model illustrates the principle and does so for the right reasons.

4. U.S. Economy Reference Behavior Pattern compared to *MacroLab* Behavior

Sterman (2000) cautions against using any models for unintended purposes, and the primary purpose of the *MacroLab* model is to facilitate student understanding of macroeconomics rather than forecast economic trends. Like most models, it aims for the right balance between simplification and realism. However, since *MacroLab* is a simulator and students get to "test drive" the model economy during the course, credibility of the learning experience depends somewhat on the data generated by the model. That puts a little more emphasis on realism than would be the case with most teaching models. Although *MacroLab* was not built for the purpose of tracking historical trends or forecasting future trends in the economy, its structure should generate behavior that is more or less consistent with observed behavior in a real economy. To the extent that it is capable of doing so, credibility should rise among students and also among instructors interested in the model. With Sterman's caveat in mind and the reader forewarned that "*MacroLab* is Not Designed for Forecasts," this section provides some data that may be of interest to those who use the model in an instructional setting.

Each year, the U.S. Congressional Budget Office (CBO) provides members of Congress with an updated assessment of the accuracy and precision of the five-year economic forecasts that the agency has been generating since 1976. The forecasts are, of course, compared with actual behavior in the U.S. economy. More importantly for our purpose here, the CBO forecasts are also regularly compared with forecasts originating in the Administration (the President's annual budget report to Congress, since 1976) and in the private sector (the so-called *Blue Chip* consensus forecast of about fifty economists, since 1979). Thus, the report is a rich source of historical forecasts from three prominent forecasting bodies. In this section, we compare *MacroLab's* "forecast" of gross domestic produce (GDP) since 1979 with the forecasts coming from CBO, the White House (WH), and the *Blue Chip* economists (BC).

The forecasts from CBO, WH, and BC are not released simultaneously, but they are all released during the first quarter of the first year of the five-year forecast period (e.g., during January, February, or March of 1979 for the five-year period from January 1979 to December 1983). The CBO, WH, and BC forecasts were actually GDP growth rate forecasts, which have been transformed to GDP values by applying those growth rates to the GDP at the beginning of each forecast period. The trend line for actual GDP (black) in Figure 16 is based on fourth quarter data for the year indicated, and the forecasts at that same point were made during the first quarter five years earlier.

The *MacroLab* "forecasts" were simulation runs over successive 5-year horizons, beginning with the first quarter of 1979, and actual historical data initialized the material stocks at the beginning of each run. The annual working age population growth rate was set at a constant 1.2 percent. For simulations starting in 1979-1985, 1986-1999, and 2000-2001, the multifactor productivity growth rate was set to 0.8, 1.1, and 1.5 percent, respectively. Those average productivity growth rates would have been observed over the five-year period preceding the respective forecasts and represent an assumed continuation for the next five years. In addition to the productivity growth rate, there were two other variable exogenous inputs—desired inventories and net foreign flows of payments and capital. Since 1980, inventory-to-final sales ratios have been declining at about a 2 percent annual rate, but that would have been unknown future data to any of the forecasters (and to *MacroLab*). However, anticipation of such declines over an upcoming five-year forecast period could be provided by observing past five-year trends. Thus, the estimate for desired inventories was formulated as a third-order delay with an average delay of five years. Likewise, the exact trend of net exports payments and foreign capital flows would not be knowable in advance, but could be estimated by forecasters using prior information; again, a third-order delay formulation was used with an average delay of five years. Given these settings, the equations in the model produced continuous estimates of GDP over a five-year period, with the final estimate entered as the "five-year forecast" for the end of each year in Figure 16.

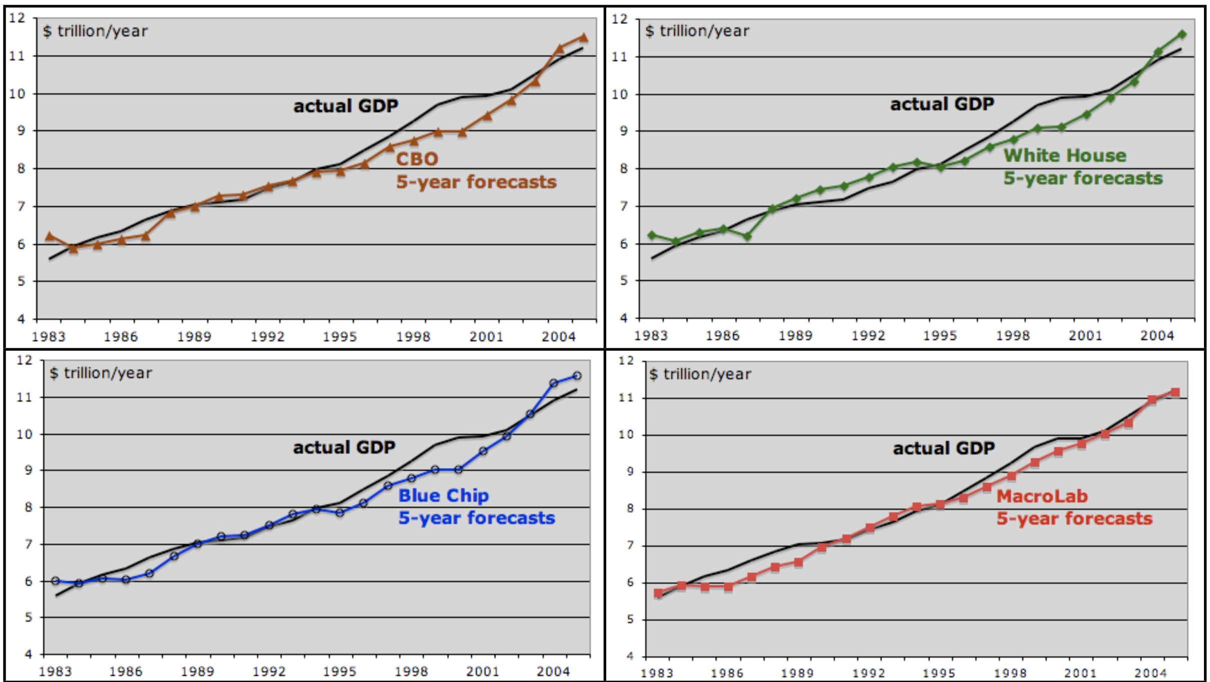


Figure 16. GDP Forecasts for Years Ending 1983-2005
Based on Forecasts made Five Years Earlier

Sources for external forecasts and data: *CBO's Economic Forecasting Record*, Congressional Budget Office (November 2006) and Bureau of Economic Analysis, NIPA Tables, Table 1.1.5, Gross Domestic Product.

Various statistical procedures could be used to estimate the "best" forecast but that is not at issue here. Visual inspection makes clear that *MacroLab* produced a series of five-year forecasts that is at least "respectable" when compared with the forecasts of three prominent forecasting bodies in the United States.

5. Detailed Model Structure

Earlier, when overall model behavior was demonstrated, feedback loop diagrams were used to provide explanatory insight into the model structure responsible for the behavior. The purpose of this section is to give readers a better grasp of the structure and behavior of each sector of *MacroLab* and to clarify the connections between sectors. In addition to providing sector-by-sector analyses, this section also aims to reinforce readers' accurate preliminary impressions or correct any misperceptions that may have formed when viewing overall model behavior in the first half of this chapter. Each subsection is devoted to a single sector and provides a stock-and-flow diagram and an annotated list of equations. There are also demonstrations and explanations of stand-alone behavior of individual submodels. Here is a section guide:

Figure 17. Subsection Guide for Section 5

Equation Structure and Parameter Estimates. About 200 equations are discussed in this section—about forty percent of the total. It is not necessary to examine nearly 500 equations to get a comprehensive view of the model structure at the equation level. For example, it would be repetitious to examine the 170 equations in the foreign sector since it is a clone of the US sector. Most of the remaining equations are in the Data Sector, consisting of initial values (e.g., initial GDP for experimental simulations), historical data (e.g., table function displaying yearly historic M2 values), and miscellaneous calculations and conversions (e.g., calculating inflation as the price index changes and converting nominal values to real values). The final category not discussed consists of equations that implement ON/OFF switch commands (e.g., to activate the foreign sector or to trigger an exogenous money supply shock). Any equation not listed is available upon request.

About three-fourths of the equations reflect hypotheses about the structure of an economy—how the pieces fit together, the incentives that give rise to decision rules, and the decision rules themselves. Less than ten percent of the equations are definitional relationships. The remainder (less than twenty percent) are exogenous parameter estimates—numerical constants that provide quantitative detail to the basic structure and are presumed to be unaffected by feedback within the model during the time horizon of a simulation run. For example, the growth rate of the working-age adult population does not change radically from year to year and is not likely to be affected by economic factors over the course of a business cycle; thus, a constant value of that growth rate can be assumed, as it has in *MacroLab*. A different formulation strategy would be necessary if the model were designed for long-term economic development planning. In that case, since the population growth rate over many decades might be influenced by economic growth rates, some structural feedback relationship should be hypothesized. In its current form, *MacroLab* is what might be called a business cycle model, appropriately used to study the economy over a period of several years rather than several decades. That is why the comparison with a reference behavior pattern of the US economy in section 4 was limited to five-year periods.

It is also important to remember that *MacroLab* was designed as a teaching model. Generating accurate behavior patterns (for the right structural reasons) is more relevant than achieving numerical precision when teaching and learning about the economy. Both qualities in a model are desirable, of course. However, economics is often described as the science of scarcity, and the allocation of time and effort when building a model is no less an optimization problem than the allocation of labor and capital in a factory assembly line. Therefore, relatively less effort in this modeling project has been devoted to parameter estimation than would be done when developing a policy model seeking to replicate actual problematic behavior and evaluate detailed policy options. Many of the parameter assumptions, therefore, should be taken with the proverbial grain of salt. Or, striking a more positive posture, *MacroLab's* interactive learning environment provides students with abundant opportunities to experiment with various plausible parameter assumptions. That said, most parameters were estimated from available historical data, from published empirical research, and from exemplary modeling work of others who followed a similar eclectic strategy.

More important than the accuracy of a particular parameter is the degree to which the performance of the model is sensitive to different values of that parameter. Sensitivity analysis, therefore, is essential to establishing confidence in the overall model even while acknowledging that some parameters are guesstimates. In the discussion of submodel equations, special attention is given to the sensitivity analyses that have been conducted, particularly those relating to estimates of time constants in delay formulations. Moreover, the results of sensitivity analyses provide a prioritized research agenda for improving parameter estimates.

Initial Values. The model can run in two modes: experimental and historic. Primarily, the two modes differ in the way the stocks are initialized. In experimental mode, the stocks always have the same initial values, the selection of which was guided by three criteria. First, an effort was made to make their relative magnitudes historically realistic. Second, the values had to initialize the model in equilibrium so that simulation results would be easier to interpret. Constrained by the first two criteria for initial values, the third was to use round numbers that students would find relatively easy to remember and manipulate (e.g., GDP = $10 trillion/year, M2 = $4 trillion, and the price index = 1.00).

In historic mode, stocks take on the initial values that existed in the particular historical year in which the simulation begins (e.g., 1986, 1997, or 2001), and the model is simulated from that initial *dis*equilibrium state. After the simulation begins in historic mode, however, stocks change endogenously based on the same equations used in the experimental mode. Since historical stock data for the rest of the world are not included in the model, the foreign submodel does not function in historic mode. Instead, the US sector relies on historical exogenous values for U.S. imports, exports, and net capital flows.

Reading the Tables. Inspect Figure 18 before reading the various equation tables. It contains excerpts from those tables, and getting acquainted with the format will make it easier to understand the information in the tables later on. In the first column, each equation has a number, and that facilitates subsequent reference to the equation in the text. To make it easier to find the equations in the diagrams, the second column displays icons that indicate whether the equations refers to a stock (rectangle), flow (arrow), or an auxiliary variable (circle). An auxiliary variable icon containing a small square within a circle is a *smooth* function; i.e., a delayed information stock. Equation 90, for example, indicates that "nominal dividends" is calculated by multiplying "business disposable income" by the "dividends percentage," but that the calculation is smoothed over an average time period of one quarter (.25 years) since dividend payments are typically delayed beyond the end of the accounting period. The third column displays the left-hand side of the equation (the equation name), and the fourth column shows the right-hand side of the equation. The Runge-Kutta 4 integration method was utilized within the *STELLA*[1] software, with the calculation interval (dt) set to .005 years (one-fourth the length of the shortest adjustment time in the model— .02 years, or approximately one week).

An equation's details may depend on whether the model is running in historic mode or experimental mode. Sometimes, an equation includes an "IF/THEN" statement and takes one value if the historic mode switch is ON and another if it is OFF. In other cases, it was more convenient to multiply entire expressions by the value of the historic mode switch or its complement (1-historic mode), thus making the irrelevant portion of the equation equal to zero. Displaying the various conditional statements and associated nested parentheses would make reading the equation lists unnecessarily difficult. Therefore, in the tables, such equations have been simplified by separating and marking them to indicate which mode would be running. Equation 26, for example, shows that the initial value for the Employment stock is 100 (million) persons when the model is running in experimental mode. However, when in historic mode, the initial value will be the actual historical number of employees in the first year of the simulation time period. Equation 74 shows that the exogenous multifactor productivity growth rate can be set arbitrarily when in experimental mode (E), but a smoothed historical estimate can be used when in historic mode (H). Additional simplification is achieved by removing all references to switches that regulate the conditions under which the equations are calculated. For example, the equation for the "target Fed funds rate" (in the list for the Monetary Policy Sector in the Banking Submodel) does not include a reference to the "open market operations policy" switch, but that switch must be ON before the "target Fed funds rate" will have any non-zero value. Unless indicated otherwise, dollar

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[1] *STELLA* is a registered trademark of isee systems (http://www.iseesystems.com).

amounts always refer to trillions, persons are measured in millions, and time is measured in years.

The bottom row of each table lists right-hand side variables that are not defined in the current table and indicates where those equations can be found. In Figure 7.23, for illustration purposes, only one is listed—"operating surplus"—and that equation can be found in the Income Distribution Submodel table. Finally, as an aid to navigation if a table overlaps a single page, there is a descriptive label at the top and at the bottom of each table.

Equation Table Illustration

		Left Side of Equation	Right Side of Equation	units
1		GDP	labor & capital * productivity of labor & capital	$/year
26		Employment(t)	Employment(t - dt) + (net hiring) * dt INIT historical = historic employment INIT experimental = 100	persons
74	○	multifactor productivity growth rate %	H: smoothed historic productivity growth rate E: 0	1/year
90		nominal dividends	smth1(disposable business income * dividends pct,.25)	$/year
96	○	disposable business income	operating surplus - business taxes	$/year
		operating surplus	Income Distribution Submodel	

Figure 18. Illustrative Excerpts from Various Equation Tables in Section 5

5.1 Main Model

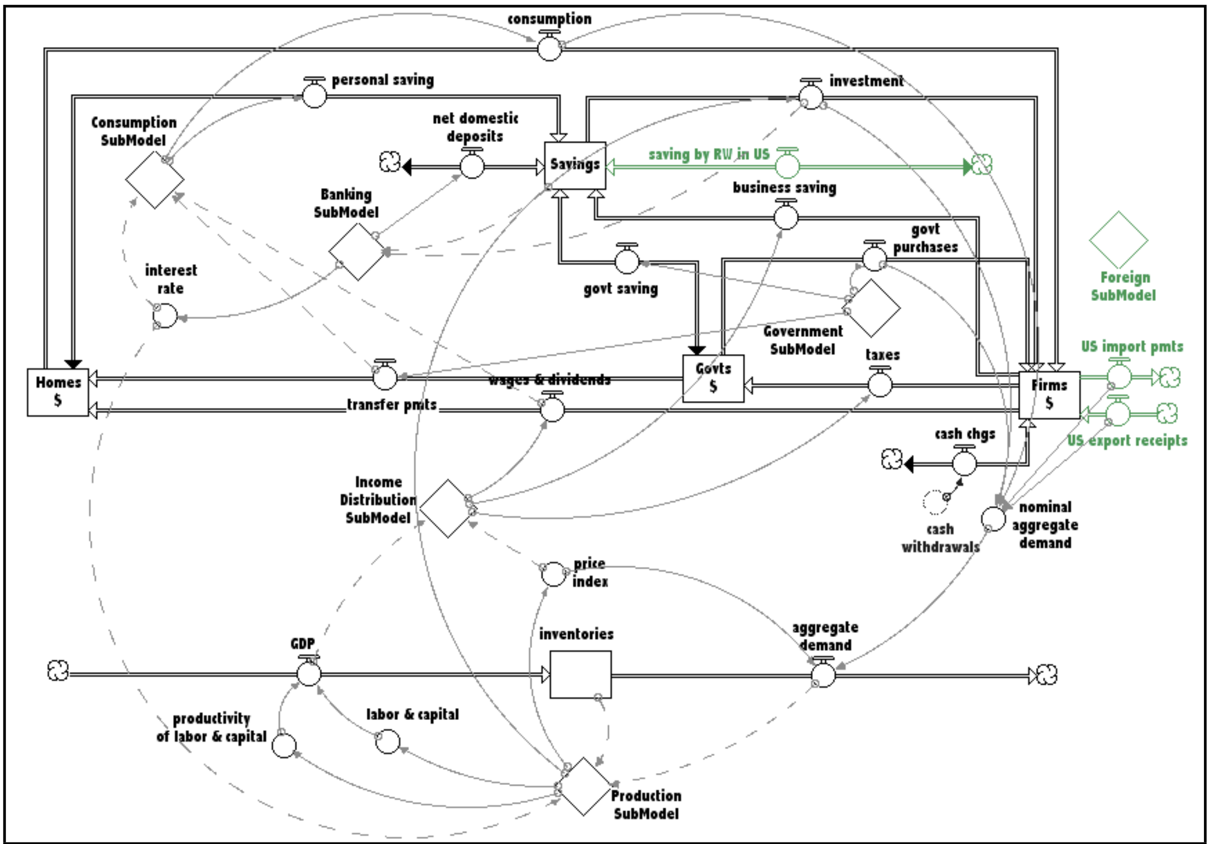


Figure 19. Main Model

Almost all of the equations at the main model level are determined at the submodel level, discussed in the pages that follow. The exceptions are nominal aggregate demand (#5 in the equation list) and (real) aggregate demand (#4). A summary of the main model was provided in section 2 and will not be repeated here. However, Figure 19 does show additional links that were omitted from Figure 3. The link from the production submodel to investment (#18) reflects the dependence of investment spending on capital acquisition decisions. The interest rate was not shown in Figure 3; here it is clear that the interest rate is formulated in the banking sector and that the interest rate affects both consumption and production submodel decisions.

Main Model Equations

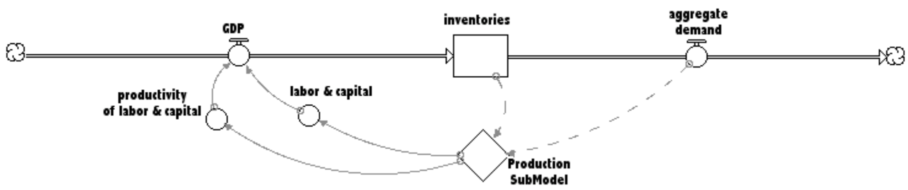
		Left Side of Equation	Right Side of Equation	units
1		GDP	labor & capital * productivity of labor & capital	$/year
2		labor & capital	factors of production	FP
3		productivity of labor & capital	multifactor productivity	$/yr/FP
4		aggregate demand	nominal aggregate demand / price index	$/year

5		nominal aggregate demand	consumption + investment + govt purchases+ US export receipts - US import pmts	$/year
6		price index	Price	1/1
7		inventories(t)	inventories(t - dt) + (GDP - aggregate demand) * dt INIT = desired inventories * (init(GDP) / init(aggregate demand))	$
8		wages & dividends	nominal disposal income	$/year
9		taxes	nominal taxes	$/year
10		business saving	nominal business saving	$/year
11		Firms $ (t)	Firms $(t - dt) + (govt purchases + investment + cash chgs + consumption + US export receipts - business saving - taxes - wages & dividends - US import pmts) * dt INIT = (consumption + investment +govt purchases + US export receipts - US import pmts)/12	$
12		Homes $ (t)	Homes $(t - dt) + (wages & dividends + transfer pmts - consumption - personal saving) * dt INIT = (transfer pmts + wages & dividends) / 12	$
13		Govts $ (t)	Govts $ (t - dt) + (taxes - govt purchases - govt saving - transfer pmts) * dt INIT = taxes / 12	$
14		Savings(t)	Savings(t - dt) + (business saving + net domestic deposits + govt saving + personal saving + saving by RW in US - investment) * dt INIT = initial M2 - Firms - Govts - Homes	$
15		transfer pmts	nominal transfer payments	$/year
16		consumption	nominal consumption	$/year
17		personal saving	nominal personal saving	$/year
18		investment	nominal investment	$/year
19		govt purchases	nominal govt purchases	$/year
20		govt saving	- government deficit	$/year
21		US export receipts	H: smth3(historical nom exports,5) E: nominal US receipts for exports $	$/year
22		US import pmts	H: smth3(historical nom imports,5) E: nominal US pmts for imports $	$/year
23		saving by RW in US	H: smth3(historic net capital inflow,5) E: US net capital inflow $	$/year
24		net domestic deposits	net domestic deposit chg	$/year
25		cash chgs	cash withdrawals	$/year

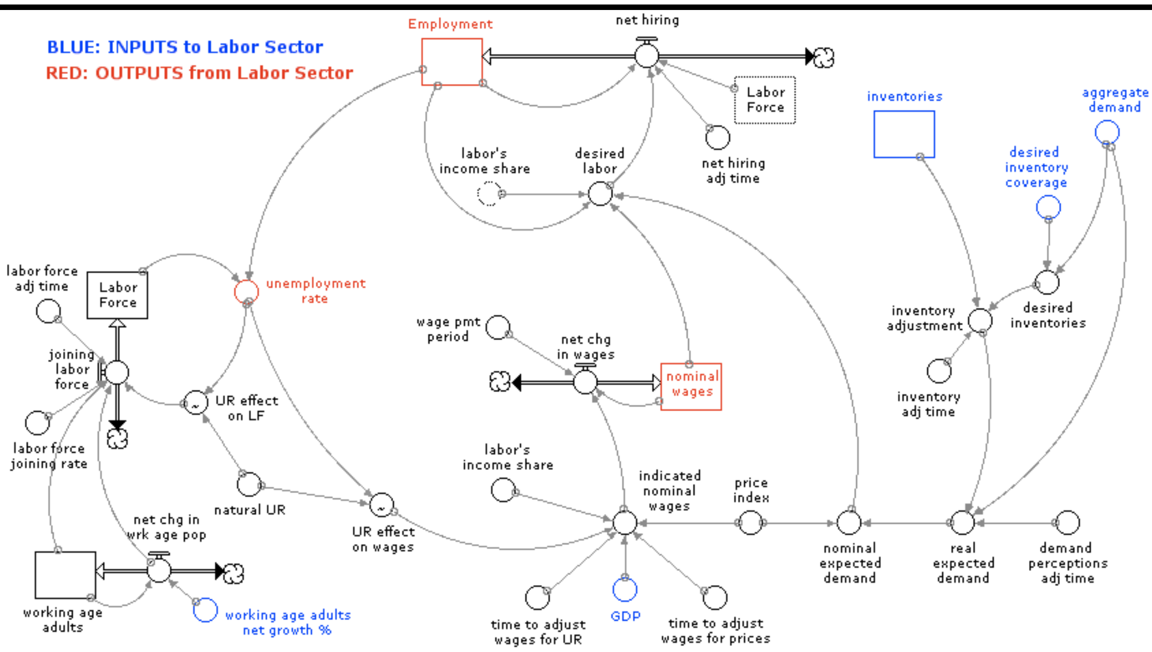
factors of production	Productivity Submodel
multifactor productivity	Productivity Submodel
Price	Price Submodel
desired inventories	Labor Submodel
nominal disposal income	Income Distribution Submodel
nominal taxes	Income Distribution Submodel
nominal business saving	Income Distribution Submodel
initial M2	Data Sector
nominal transfer payments	Government Submodel
nominal consumption	Consumption Submodel
nominal personal saving	Consumption Submodel
nominal investment	Capital Submodel
nominal govt purchases	Government Submodel
government deficit	Government Submodel
historical nom exports	Data Sector
nominal US receipts for exports $	Exchange Rate Submodel
historical nom imports	Data Sector
nominal US pmts for imports $	Exchange Rate Submodel
historic net capital inflow	Data Sector
US net capital inflow $	Exchange Rate Submodel
net domestic deposit chg	Banking Submodel
cash withdrawals	Banking Submodel

Figure 20. Main Model Equations

5.2 Labor Sector within the Production Submodel



Labor's Location within the Main Model



Labor Sector within the Production Submodel

Figure 21

The labor sector stock-and-flow structure is displayed in Figure 21, and Figure 22 contains a corresponding feedback loop diagram. Textbooks emphasize that the level of employment depends on both the supply and demand for labor (Mankiw ch. 10; McConnell/Brue, ch. 8). In the labor sector, the demand for labor is called "desired labor," and it depends positively on expected demand for goods and services and negatively on average wages—total wages divided by Employment.

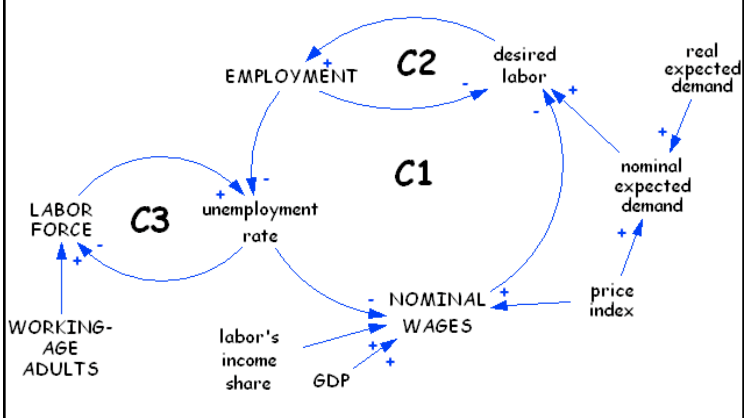
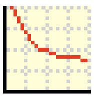
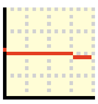


Figure 22. Feedback Loop Structure of the Labor Sector

Labor Sector Equations within the Production Submodel

		Left Side of Equation	Right Side of Equation	units
26		Employment(t)	Employment(t - dt) + (net hiring) * dt INIT historical = historic employment INIT experimental = 100	persons
27		net hiring	if(Labor Force>Employment)then(((desired labor-Employment)/net hiring adj time))else(0)	persons /year
28		desired labor	(nominal expected demand*labor's income share) / (nominal wages / Employment)	persons
29		net hiring adj time	.5	years
30		nominal expected demand	price index * real expected demand	$/year
31		nominal wages(t)	nominal wages(t - dt)+(net chg in wages)*dt INIT = indicated nominal wages	$/year
32		net chg in wages	(indicated nomimal wages-nominal wages)/wage pmt period	$/yr/yr
33		wage pmt period	.08	years
34		indicated nominal wages	GDP*labor's income share*smth1(price index, time to adjust wages for prices)*smth1(unemployment effect on wages, time to adjust wages for UR)	$/year
35		time to adjust wages for prices	1	years
36		time to adjust wages for UR	.25	years
37		UR effect on wages 	GRAPH(unemployment rate/natural UR) (0.00, 1.50), (0.2, 1.25), (0.4, 1.14), (0.6, 1.08), (0.8, 1.04), (1.00, 1.00), (1.20, 0.97), (1.40, 0.935), (1.60, 0.92), (1.80, 0.91), (2.00, 0.9)	1/1
38		unemployment rate	100 * (1 - (Employment / Labor Force))	1/1
39		natural UR	5	1/1
40		UR effect on LF 	UR effect on LF = GRAPH(unemployment rate/natural UR) (0.00, 1.005), (0.2, 1.004), (0.4, 1.003), (0.6, 1.002), (0.8, 1.001), (1.00, 1.00), (1.20, 0.999), (1.40, 0.998), (1.60, 0.997), (1.80, 0.996), (2.00, 0.995)	1/1
41		Labor Force(t)	Labor Force(t - dt) + (joining labor force) * dt INIT historical = Employment / (1-(historic employment / 100))INIT experimental = Employment / ((1-initial unemployment rate / 100))	persons
42		joining labor force	(net chg in wrk age pop*labor force joining rate)+(if(working age population>Labor Force)then((UR effect on LF*Labor Force-Labor Force)/labor force adj time)else(0))	persons /year
43		labor force joining rate	.70	1/1
44		labor force adj time	.5	years

45		working age population(t)	working age population(t - dt) + (net chg in wrk age pop) * dt INIT historical = historic working age population INIT experimental = Labor Force /.65	persons
46		net chg in wrk age pop	working age population*smth3(working age pop net growth fraction,5)	persons /year
47		real expected demand	smth1(aggregate demand,demand perceptions adj time,aggregate demand-inventory adjustment)+inventory adjustment	$/year
48		demand perceptions adj time	.5	years
49		inventory adjustment	(desired inventories-inventories) / inventory adj time	$/year
50		inventory adj time	.5	years
51		desired inventories	desired inventory coverage * aggregate demand	$
		historic employment	Calculations Sector	
		labor's income share	Productivity Sector of the Production Submodel	
		GDP	Main Model	
		price index	Price Sector of the Production Submodel	
		initial unemployment rate	Calculations Sector	
		historic working age population	Calculations Sector	
		working age pop net growth fraction	Calculations Sector	
		aggregate demand	Main Model	
		inventories	Main Model	
		desired inventory coverage	Data Sector	

Figure 23. Labor Sector Equations

More precisely, desired labor (#28 in the equations table) depends on the *nominal* expected demand (#30) and *nominal* wages (#31). Above-average profit opportunities exist when product prices are rising faster than the price of labor. An increase in the perceived demand for goods and services causes an increase in the demand for the labor required to produce those goods and services, *ceteris paribus*. Nominal expected demand depends on real expected demand (#48) and the price level. Real expected demand is a smoothed function of aggregate demand plus an adjustment for inventories (#50). The time for producers to adjust their perceptions of demand (#49) is estimated to be .5 years, as is the average inventory adjustment time (#51).[2]

An increase in the average nominal wage reduces the demand for labor, *ceteris paribus*. In equilibrium, total wages are defined as labor's normal share of national income (equal to GDP in equilibrium). Labor's income share is assumed to be .75.[3] Disequilibrium conditions —reflected in changing levels of prices and unemployment—will push wages above or below the norm. Indicated nominal wages (#34) is, therefore, a function of GDP, labor's share of income, the price index, and the unemployment rate. Wages are assumed to be paid monthly (#33).

The unemployment rate (#38) reflects both the supply (labor force, #39) and demand (employment, #26) for labor. A rise in unemployment puts downward pressure on starting

[2] Unless indicated otherwise, all delay structures are modeled as first-order delays. N. Forrester (1982) used .5 and .4 years for the perceived demand and inventory adjustment time constants, respectively.

[3] N. Forrester (1982) made the same assumption, based on national income accounts data.

wages, thus keeping total and average wages lower than they would be otherwise. The nonlinear function describing the negative effect of unemployment on wages (#37) is based on Blanchflower and Oswald (1994), who suggest a wage elasticity of unemployment equal to about - 1/10. The effect is not immediate, however, and the average adjustment time (#36) is assumed to be .25 years.

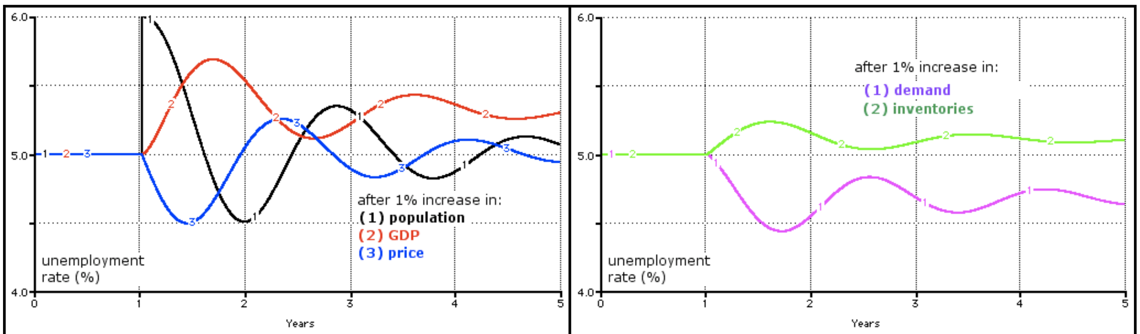
In Figure 22, loop C1 is a counteracting feedback loop connecting employment, the unemployment rate, nominal wages, and desired labor. Assume desired labor increased suddenly, due to an increase in aggregate demand. That would set in motion a hiring process that would eventually raise employment and *lower* the unemployment rate. Gradually, rising wages would constrain the growth in desired labor and employment, and that would put *upward* pressure on the unemployment rate, even if there had been no changes in the labor force (defined as those persons with a job or seeking a job).

It is likely, however, that another counteracting loop—C3—would have been expanding the labor force ever so slightly. When the unemployment rate fell initially (and wages rose), the employment outlook would have improved and the opportunity cost of remaining unemployed would have risen. That would have caused a few more working-age adults to join the job search, and the rise in the number of people seeking jobs would have put upward pressure on the unemployment rate. Thus, the initial drop in unemployment would set in motion forces that would eventually constrain the demand for labor and—at the same time—boost the labor supply. Unemployment would not keep falling.

Prices also influence wages. Changes in workers' cost-of-living will eventually affect average periodic wage adjustments—assumed here to occur annually (#35). The submodel behavior demonstration at the end of this subsection focuses on the effects of a change in prices.

Input Response Tests. To confirm that the labor sector submodel does perform as expected—a validation procedure Ford (1999) calls *verification*—a series of input response tests was conducted. Step or pulse shocks were administered to five exogenous inputs. Based on the links from the parameters to the unemployment rate in the feedback diagram in Figure 22 above, the unemployment rate should rise, *ceteris paribus*, when permanent increases occur in GDP or inventories, since the former raises the cost of labor and the latter lowers the demand for labor. The unemployment rate should decline when aggregate demand increases because demand for labor permanently increases. When prices increase, the unemployment could rise or fall—or both—depending on the timing of wages increases. The step increase in the working-age population (and, therefore, the labor force) should push the unemployment rate up immediately, but that will put extreme downward pressure on starting wages, which will bring the unemployment rate down to lower levels almost as sharply. After that, the unemployment rate should return to its initial value if wages adjust fully to the changing labor market.

When interpreting these hypotheses and the simulation results in Figure 24 below, it is necessary to keep in mind that, while all five inputs are exogenous in the labor sector, only the working-age population is exogenous in the full model. Thus, in four cases, the behavior in the labor sector will *not* necessarily be the same as would occur when the full model is running. Within the labor sector, for example, when the inventory shock is ON and a permanent 1 percent increase in the inventory occurs, the unemployment rate rises permanently. If such an inventory shock occurred in the full model, the reduction in employment would reduce production and inventories would go back down to normal levels. As that occurred, the unemployment rate would also go back down to its "natural" rate. Nevertheless, these input shock tests in the submodel are useful for confirming that what *should* happen *within* this sector *does* happen (e.g., an increase in inventories should raise the unemployment rate). The results of the input shock tests are displayed in Figure 24, and each behavior is consistent with the expected behavior. (The tendency for oscillations to occur is discussed later in this subsection.)



A: Shocks to Population, GDP, and Price

B: Shocks to Aggregate Demand & Inventories

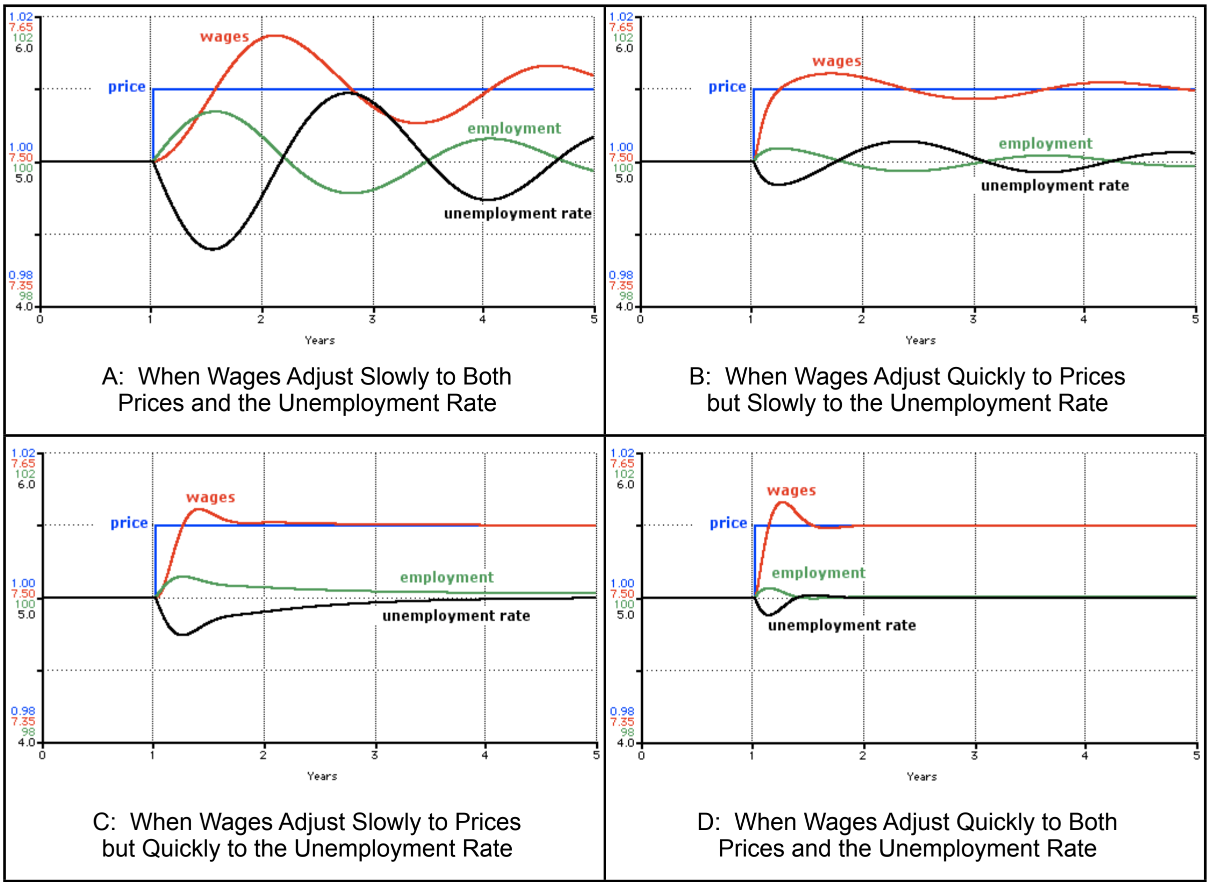
Figure 24. Unemployment Rate Response to Exogenous Input Shocks in Labor Sector

Parameter Sensitivity Analysis. The labor sector contains two graph functions (#38 and #41) and eight time constants: net hiring adjustment time (#30), wage payment period (#34), time to adjust wages for prices (#36), time to adjust wages for the unemployment rate (#37), labor force joining rate (#43), labor force adjustment time (#44), demand perceptions adjustment time (#48), and inventory adjustment time (#50). Thirty sensitivity tests were conducted—three for each parameter at values equal to, below, or above the parameter's default value in the model—and the behavior of the unemployment rate was examined when there was an exogenous shock to the model. The particular adjustments selected for each parameter test depended on the range of uncertainty in the default estimate. For example, the net hiring adjustment time—assumed to be .5 years—was adjusted down to .25 years and up to 1 year. Three simulations were also run for each graph function, with the slopes varied above and below the default assumptions. For example, the slope of the unemployment rate effect on wages was varied from -.05 to -.10 (default assumption) to -.15, based on the ranges reported in Blanchflower and Oswald (1994).

Based on the individual tests, the labor sector model was most sensitive to variations in the net hiring adjustment time, the time to adjust wages to changes in the unemployment rate, and the elasticity of wages with respect to the unemployment rate. In future refinements of *MacroLab*, reducing the uncertainty in estimates of these parameters will be a priority research task. The model's relative lack of sensitivity to the demand perception adjustment time and the inventory adjustment time could be misleading, however, since aggregate demand and inventories received no feedback effects within the labor sector in these sensitivity tests.

Extreme Conditions Tests. An additional validation test involves subjecting the model to extreme conditions and judging the realism of its response. In the labor sector, a serious error to avoid is hiring people who do not exist. Therefore, the net hiring rate (#28) can be greater than zero only when the labor force is greater than employment. In a similar fashion, the inflow (#43) to the labor force stock can be greater than zero only when the number of working-age adults is greater than the size of the labor force.

Illustration of Labor Sector Behavior. The input shock tests above revealed strong oscillatory behavior in the labor sector, which we now examine by subjecting the labor sector to another exogenous one percent price increase. Given the structural relationships described above, producers would initially respond to the nominal increase in product demand by hiring more labor. Eventually, the general rise in prices would translate into wage adjustments. Meanwhile, the rise in employment would lower the unemployment rate, and the relative scarcity of labor would also gradually increase pressure to raise wages. For purposes of this experiment, average delay times were set at one year ("slow"), one week ("quick"), or a combination of slow and quick.



A: When Wages Adjust Slowly to Both Prices and the Unemployment Rate

B: When Wages Adjust Quickly to Prices but Slowly to the Unemployment Rate

C: When Wages Adjust Slowly to Prices but Quickly to the Unemployment Rate

D: When Wages Adjust Quickly to Both Prices and the Unemployment Rate

Figure 25. Price Shock Experiment with the Labor Sector Model

Four scenarios were simulated, with the various combinations of slow and quick wage responses to changes in the price index and the unemployment rate. The results are displayed graphically in panels A-D of Figure 25. (The vertical axis scales in Figure 25 are such that the changes in price, wages, and employment are comparable in percentage terms. The scale for the unemployment rate is necessarily larger.) With varying delays in each scenario, the step-up in price was followed—and eventually matched in percentage terms—by wages. Employment and the unemployment rate naturally moved in opposite directions but eventually stabilized at their initial levels. Ultimately, therefore, the same number of people were working and their average real wage was unchanged. That is usually the point—and the end—of the textbook version of the story. The transition patterns were quite different in each scenario, however, and analyzing the differences in this simulation experiment can shed light on the origin of the dynamics.

When the wage response was *slow* to *both* price and unemployment rate changes (panel A), strong fluctuating patterns emerged and instability continued for more than four years. When the wage response was *quick* to *both* price and unemployment (panel D), the submodel system stabilized in six months. In panel B, a quick wage response to price, even when responding slowly to unemployment, reduced the amplitude of the fluctuations, but the oscillatory tendency remained. In panel C, a quick wage response to unemployment (coupled with a slow response to prices) eliminated the fluctuations, but more than two years passed before the system regained equilibrium.

The source of the interesting dynamics in this example is found in the counteracting feedback loop C1 in Figure 26 (where each pair of vertical bars indicates a location of significant delays along the loop). With two stocks—the material stock *employment* and the information stock *nominal wages*—in the counteracting loop, there exists the necessary condition for oscillations. Sufficiency is provided by the significant delays that affect changes in nominal wages (Sterman 2000). When those delays are virtually eliminated in panel D, the fluctuations disappear. This example illustrates the behavior of the labor sector, and it also demonstrates a method for isolating the structure responsible for that behavior.

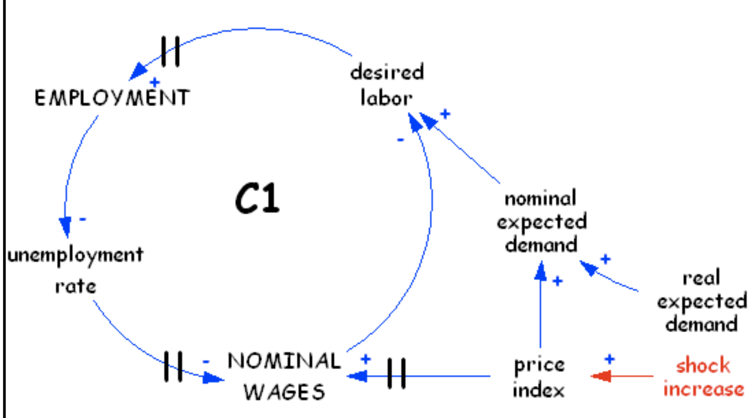
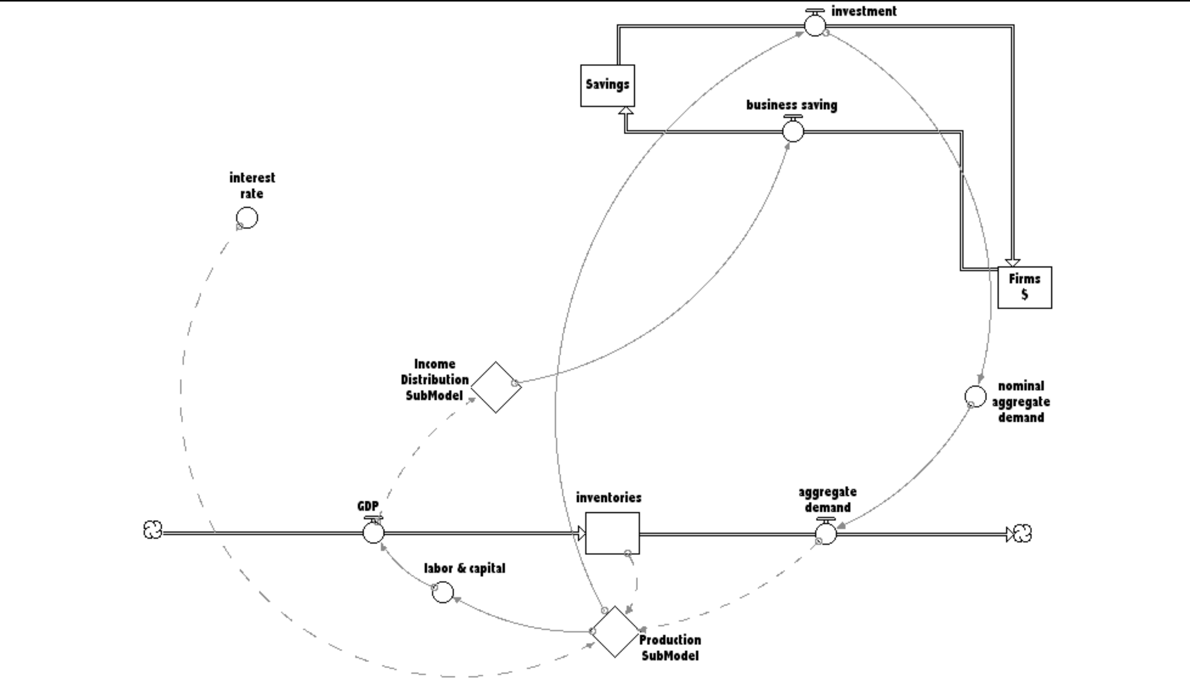


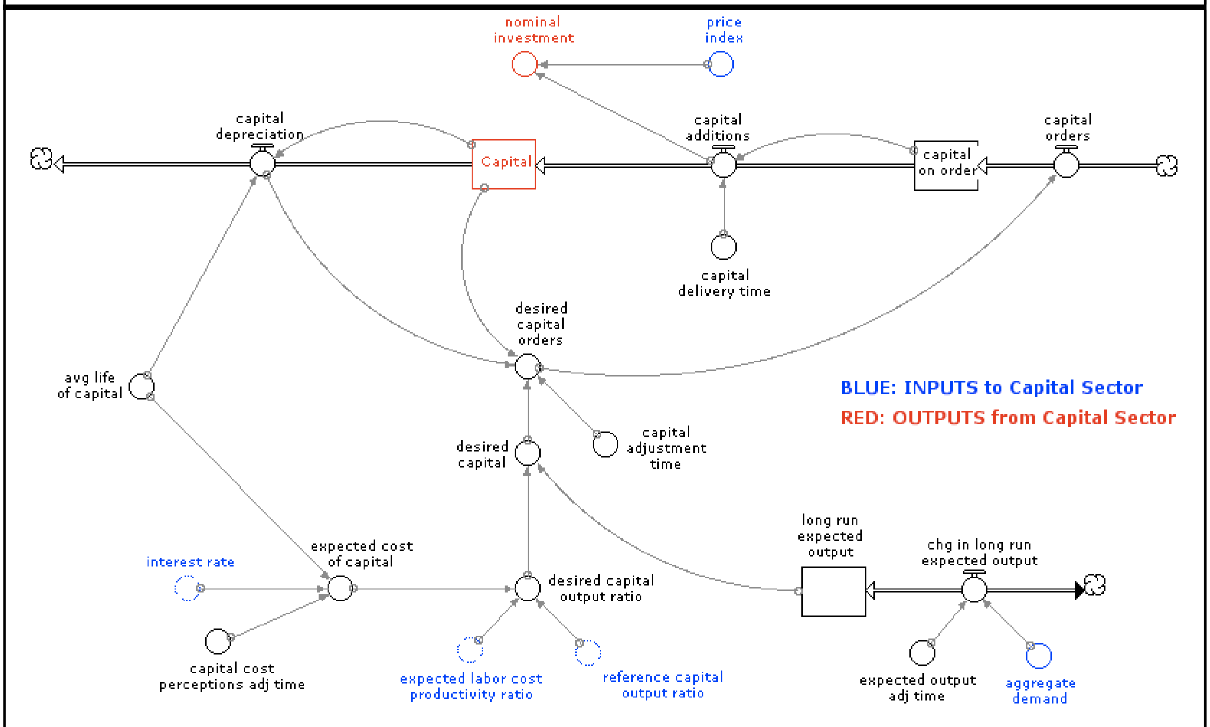
Figure 26. Oscillations Result from Delays in the Counteracting Feedback Loop C1

5.3 Capital Sector within the Production Submodel

Figures 27-29 provide four perspectives of the capital sector. The top panel of Figure 27 is a reminder of capital's position within the main model, while the bottom panel provides a detailed view of its stock-and-flow structure inside the production submodel. The equations underlying that structure are listed in Figure 28 and, finally, a feedback loop diagram in Figure 29 highlights key relationships.



Capital's Location within the Main Model



Capital Sector within the Production Submodel

Figure 27

Capital Sector Equations within the Production Submodel				
		Left Side of Equation	Right Side of Equation	units
52	○	nominal investment	capital additions * price index	$/year
53	▭	Capital(t)	Capital(t - dt) + (capital additions - capital depreciation) * dt INIT historical = private fixed assets INIT experimental=(capital's income share*initial production) / ((initial interest rate/100)+1/(avg life of capital))	$
54		capital additions	capital on order / capital delivery time	$/year
55		capital depreciation	Capital / avg life of capital	$/year
56	○	avg life of capital	14	years
57	○	capital delivery time	1.5	years
58	▭	capital on order(t)	capital on order(t - dt)+(capital orders - capital additions)* dt INIT = capital delivery time * desired capital orders	$
59		capital orders	desired capital orders	$/year
60	○	desired capital orders	capital depreciation + ((desired capital -Capital) / capital adj time)	$/year
61	○	capital adj time	3	years
62	○	desired capital	long run expected output*desired capital output ratio	$
63	○	desired capital output ratio	reference capital output ratio *expected labor cost productivity ratio /(expected cost of capital/init(expected cost of capital))	years
64	○	expected labor cost productivity ratio	smth3((avg real wage/init(avg real wage)) /(output per worker/init(output per worker)),1)	1/1
65	○	expected cost of capital	(smth1(interest rate,capital cost perceptions adj time)/100) +(1/avg life of capital)	1/year
66	○	capital cost perceptions adj time	3	years
67	▭	long run expected output(t)	long run expected output(t - dt) + (chg in long run expected output) * dt INIT = GDP	$/year
68		chg in long run expected output	(aggregate demand-long run expected output)/expected output adj time	$/year/ yr
69	○	expected output adj time	3	years
		price index private fixed assets capital's income share initial production initial interest rate interest rate GDP aggregate demand reference capital output ratio avg real wage output per worker	Price Sector of Production Submodel Data Sector Productivity Sector of Production Submodel Data Sector Interest Rate Sector of Banking Submodel Interest Rate Sector of Banking Submodel Main Model Main Model Data Sector Data Sector Data Sector	

Figure 28. Capital Sector Equations

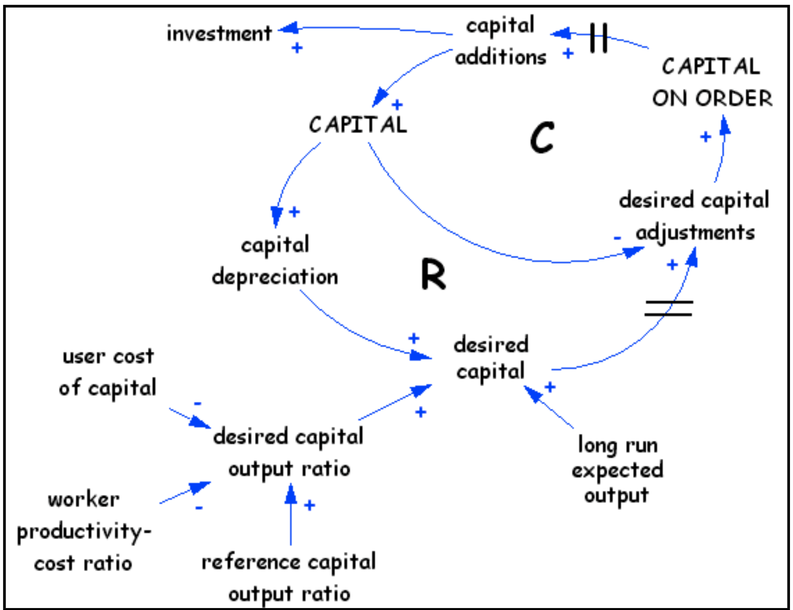


Figure 29. Feedback Loop Structure of the Capital Sector

Textbooks emphasize that the rate of investment in capital equipment and structures is a function of the expected financial return on such investments. When the revenue expectations rise or capital cost expectations fall—or some combination thereof resulting in higher expected profits—investments will be made (Mankiw, ch. 8 and McConnell/Brue, ch. 9). As the diagrams in Figures 27 and 29 illustrate, and the equations in Figure 28 specify, the investment decisions within the capital sector of *MacroLab* reflect those same considerations.

Business spending on capital equipment and structures is presumed to occur as capital orders are transformed into real additions to the capital stock. Certainly, some advance payments may accompany orders but, for modeling purposes, the assumption was made that the payment schedule would roughly correlate with actual deliveries. The role of "investment" in these diagrams, therefore, may puzzle readers who think in terms of investment "causing" capital to be added; they may have expected the causal link arrow to point *from* investment *to* capital additions. The motivation for the current formulation is the conceptualization of investment as the outcome of a capital decision-making process that generates "orders" for capital, along with a plan to pay for those orders. The investment *intention* certainly precedes the orders, but the investment *spending* is assumed to coincide with fulfillment of the plan. No claim is made that this is the best way to formulate the relationship between capital decision-making and actual spending for new equipment and structures. However, it does facilitate the integration of the real and nominal sides of the *MacroLab* economy, and it does so while maintaining consistency with the consensus textbook explanation of the capital acquisition process.

To describe the steps in that process within the capital sector of *MacroLab*, the feedback loop diagram (Figure 29) will be used, but references to variables will include equation numbers from the table (Figure 28). As noted above, nominal investment (#52) is the nominal payment for the real capital additions (#54), which result from capital orders (#59). Desired capital orders (#60) flow from a decision rule that starts with capital depreciation (#55) and then adds the difference between desired capital (#62) and current capital (#53). Desired capital rises when long run expected output (#67) rises, following an extended period (#69) of reviewing trends and updating perceptions of aggregate demand trends.

On the cost side, there is assumed to be a "normal" expectation of the capital requirements to support a planned rate of output within every industry. That figure is aggregated here and called the "reference" capital-output ratio. Historically, that ratio has been about 2/1 in the US, meaning that a $10 trillion economy—in GDP terms—would depend on a capital stock worth about $20 trillion. When a simulation begins, an initial reference capital-output ratio is calculated, based on the initial value of the capital stock and the initial production rate (GDP). (The same initial equation is used in historic mode, but the reference ratio is based on historical data.)

The reference capital-output ratio is adjusted to a "desired" ratio (#63). There would be an upward adjustment when capital costs were expected to be relatively low, and a downward adjustment when expected to be relatively high. In equilibrium, the desired and reference capital-output ratios would be equal. The cost adjustment has two components: the expected cost of capital (#65) and the expected labor cost-productivity ratio (#64). When interest rates rise and/or the average life of capital (#56) declines, the cost of capital rises and a lower capital-output ratio is desired. When real wages rise faster than output per worker, relatively less labor is desired, and a higher capital-output ratio is desired. These impacts on the desired capital-output ratio are formulated as linear relationships in the current version of the model; nonlinear effects are probably more likely.

Parameter Sensitivity Analysis. The capital sector contains six time-related parameter assumptions: average life of capital (#56), capital adjustment time (#61), capital delivery time (#57), time to smooth labor cost productivity ratio (in #64), capital cost perception time (#66), and expected output adjustment time (#69). Estimates for average life of capital (14 years) and expected output adjustment time (3 years) are based on N. Forrester (1982). The source for estimates of capital adjustment time (3 years) and capital delivery time (1.5 years) is Sterman (2000). The time to smooth the labor-cost productivity ratio (1 year) is based on the assumption of annual reviews of costs and productivity. The capital cost perception time (3 years) is based on the assumption that the delay in responding to changes in interest rates would be about the same as the delayed response to changes in demand. Following the procedure outlined in the labor sector subsection, each parameter was tested separately to determine the capital sector's sensitivity to variations. Then, the more critical parameters were tested in combinations. Variations in three parameters had significant implications for the behavior of the capital sector: average life of capital, capital adjustment time, and capital delivery time.

In experimental mode (which is used in testing the submodel), the initial value of the capital stock depends, in part, on the average life of capital. Thus, a change in the assumption for the average life of capital affects more than just the model's response to the demand shock; it also affects the initial investment necessary to maintain the initial equilibrium condition. Thus, the starting point changes—a longer life of capital means less initial investment is needed to replace discards. Therefore, when the sensitivity tests reveal vastly different investment rates, given variations in the average life of capital, that is somewhat misleading as an indicator of model sensitivity. A good estimate for average life of capital is important, however, because of its impact on the user cost of capital. When running in historic mode with a consensus empirical estimate of the capital stock, one way to gauge the accuracy of the average life of capital assumption is to compare the initial simulated investment rate with the initial historical investment rate, under the assumption that actual historical investment rates would be close to desired historical rates.

Also important for the characteristic performance of the capital sector model were the assumptions about capital adjustment time and capital delivery time. Investment showed signs of oscillation when the capital adjustment time was reduced. When delivery times lengthened, investment diverged from its trend for a much longer time. These two time constants were particularly worth investigating because they influence a major counteracting feedback loop. Loop C in Figure 29 links desired capital orders (#60), capital orders, capital on order (#58), capital additions, and capital. Sterman (2000) provides an in-depth discussion of the oscillatory tendencies in the capital adjustment process when capital adjustment time (the speed at which producers attempt to close capital gaps) is too short, relative to the delivery time (the speed with which capital can actually be installed). A combination sensitivity test was conducted, and the model was shocked with a 10 percent demand increase. In Figure 30, the blue investment curve reflects a situation in which the capital adjustment time (1.5 years) is actually shorter than the delivery time (2.25 years), and the oscillatory tendency is evident. The red curve reflects the combination of default assumptions in *MacroLab*.

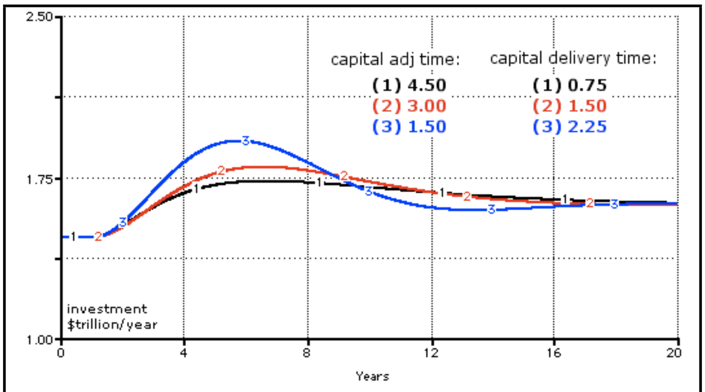


Figure 30. Investment Sensitivity To Time Constants
(shock: 10% increase in demand)

Illustration of Capital Sector Behavior. Figure 31 displays the response of investment and capital when interest rates drop from 5 to 4 percent—a 20 percent decline. There is a gradual rise in desired capital (red), due to the delay in updating capital cost expectations. As desired capital is translated into orders, investment (black) rises and additional capital (blue) begins to accumulate. As the capital gap closes, investment decreases from its peak but stabilizes at a new higher rate, reflective of the new higher rate of depreciation associated with the larger stock of capital.

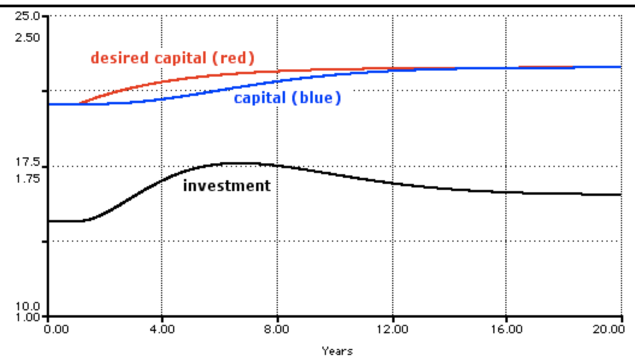
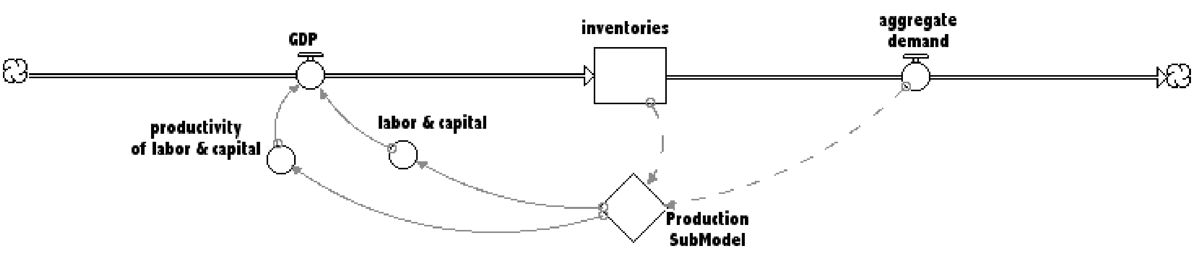


Figure 31. Capital Sector Submodel Behavior
(shock: 20% decrease in interest rates, from 5% to 4%)

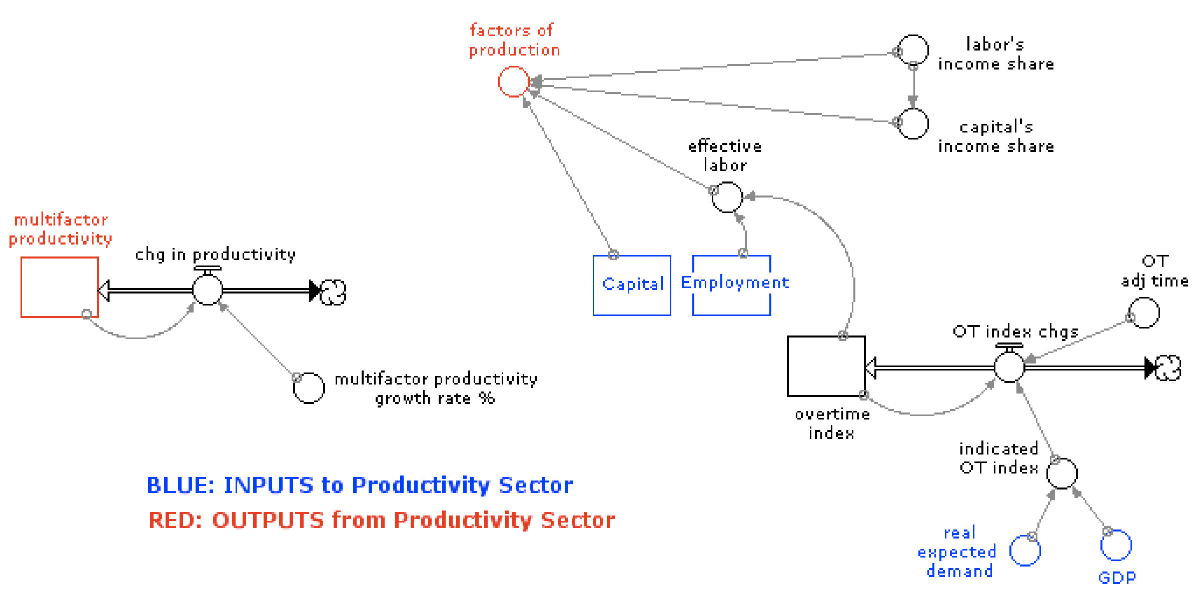
5.4 Productivity Sector within the Production Submodel

At the beginning of this chapter, the first Mankiw principle concerned the concepts of productivity and factors of production. In this brief subsection, MacroLab's formulation of those concepts is presented. Figure 32 provides both an overview and a detailed view of the productivity sector within the production submodel. In the top panel, "productivity of labor & capital" at the main model level equals "multifactor productivity" at the sector level. Likewise, "labor & capital" in the main model equals "factors of production" inside the productivity sector. GDP is the product of the two.

GDP	=	productivity of labor & capital * labor & capital
	=	multifactor productivity * factors of production
	=	(($ trillion/year) / FP) * FP
	=	$ trillion/year



Location of Productivity in the Main Model



Productivity Sector within the Production Submodel

Figure 32

Productivity Sector Equations within the Production Submodel				
		Left Side of Equation	**Right Side of Equation**	**Units**
70		multifactor productivity(t)	multifactor productivity(t - dt) + (chg in productivity) * dt INIT = initial GDP / ((capital^capital's income share)* (effective labor^labor's income share))	$/yr/FP
71		chg in productivity	multifactor productivity*(multifactor productivity growth rate %/100)	($/yr/FP) /year
72	○	labor's income share	.75	1/1
73	○	capital's income share	1-labor's income share	1/1
74	○	multifactor productivity growth rate %	H: smoothed historic productivity growth rate E: 0	1/year
75	○	factors of production	(Capital^capital's income share) * (effective labor^labor's income share)	FP
76	○	effective labor	overtime index*Employment	persons
77		overtime index(t)	overtime index(t - dt) + (OT index chgs) * dt INIT = 1	1/1
78		OT index chgs	(indicated overtime index - overtime index) / OT adj time	1/year
79	○	indicated overtime index	real expected demand / GDP	1/1
80	○	OT adj time	.25	years
		initial GDP capital Employment real expected demand GDP	Calculations Sector Capital Submodel Labor Submodel Labor Submodel Main Model	

Figure 33. Productivity Sector Equations

The Cobb-Douglas production function is formulated as follows:

K = capital
MPK = marginal productivity of capital
L = labor
MPL = marginal productivity of labor
A = multifactor productivity

then GDP = A * (K^MPK) * (L^MPL)

If the model is running in experimental mode, GDP is $10 trillion/year initially. In historic model, GDP is the actual historical value for the year beginning the simulation. Thus, initially, multifactor productivity (#71 in the equation list) is:

A = initial GDP / ((K^MPK) * (L^MPL))

and the initial value for the factors of production (#75) is (K^MPK) * (L^MPL).

Using the standard textbook assumption of constant returns to scale, the relative productivities of labor and capital sum to one. The standard method of imputing those productivities is to use historical data on the national income shares going to labor (#72) and capital (#73), under the assumption that shares of real income correspond to relative contributions to multifactor productivity. Accordingly, labor's contribution is assumed to be .75, with capital's contribution being .25.

In experimental mode, it is useful to initialize the model in equilibrium and, in that case, the growth rate of productivity is set to zero. The interface controls permit assigning a non-zero growth rate, however, whether in experimental or historic mode. In historic mode, the choice of growth rate depends on the time period under study and the purpose of the simulation exercise. If the purpose is to track historical trends, the average growth rate is used for periods sharing approximately the same rate. If the purpose is to forecast, as in the five-year forecast exercise in section 4, the smoothed average growth rate for the five years preceding each forecast was used, so that the model would use only information that would have been available in real time.

The "overtime index" (#77) could have been placed in the labor sector. However, it was placed in the productivity sector because it relates to the issue of management of the labor stock during the early periods of recession and expansion—an issue that manifests itself in productivity data during those periods. The conventional wisdom and frequent textbook explanation is that the first reaction to a demand decline is not layoffs but work slowdowns, or "undertime." Labor is reassigned to nonproductive activities, and measured output per worker declines. If the situation deteriorates further, layoffs occur and employment actually declines. When signs of recovery appear, the first reaction is to use "overtime" rather than immediately hire new workers (or call back laid-off workers), which results in an increase in measured labor productivity. Employment eventually increases when overtime costs become excessive, at which point producers conclude that the recovery is really underway.

The overtime index, therefore, adjusts employment and creates a variable called "effective labor" (#76), which is used in the production function. When aggregate demand is less than GDP, the overtime index is less than one, and effective labor is less than employment. When demand exceeds production, the overtime index is greater than one, and effective labor is greater than one. In equilibrium, the overtime index equals one, and effective labor equals employment. Producers are assumed to adjust overtime more quickly than they adjust the actual labor stock, and the average adjustment time is assumed to be .25 years (#80). Figure 34 illustrates the overtime index in action. The behavior in the graph was triggered by a ten percent step

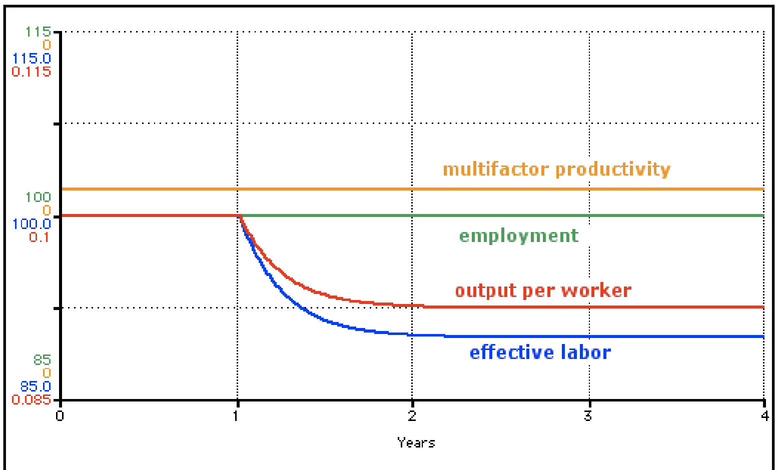


Figure 34 Productivity Submodel Test

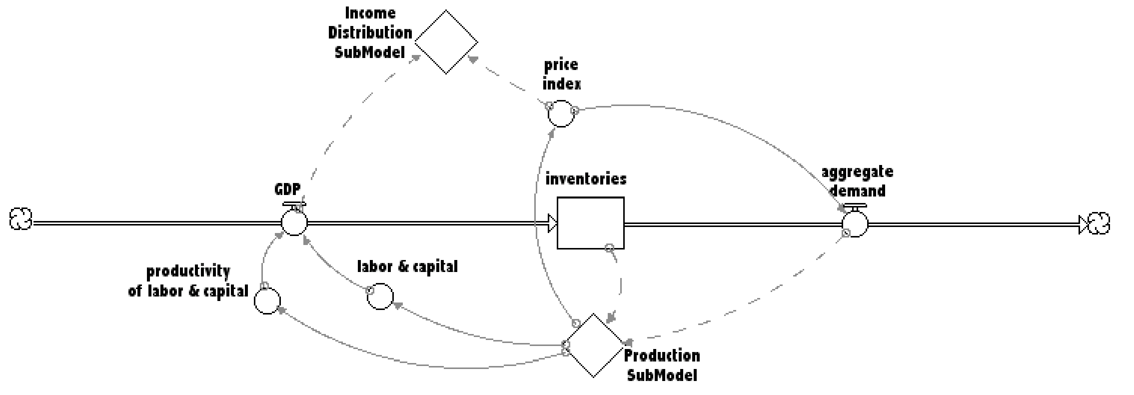
reduction in demand—simulating the onset of a recession. While employment remains constant, effective labor falls as some workers are re-assigned to nonproductive tasks. Output per worker = (multifactor productivity*factors of production)/employment; thus, output per worker falls since "factors of production" declines when effective labor declines.

Again, it is important to remember that the exogenous inputs to this sector are endogenous when the full model is running. Thus, for a given shock, the behavior in the productivity sector will not be the same as would occur when the full model is running. For example, when the demand shock is ON and a permanent 10 percent decrease occurs, labor productivity (output per worker) falls permanently. If such a demand shock occurred in the full model, the reduction in demand would eventually reduce employment and output per worker would rise since nothing has changed the skill level of the workers or the technology in the production process.

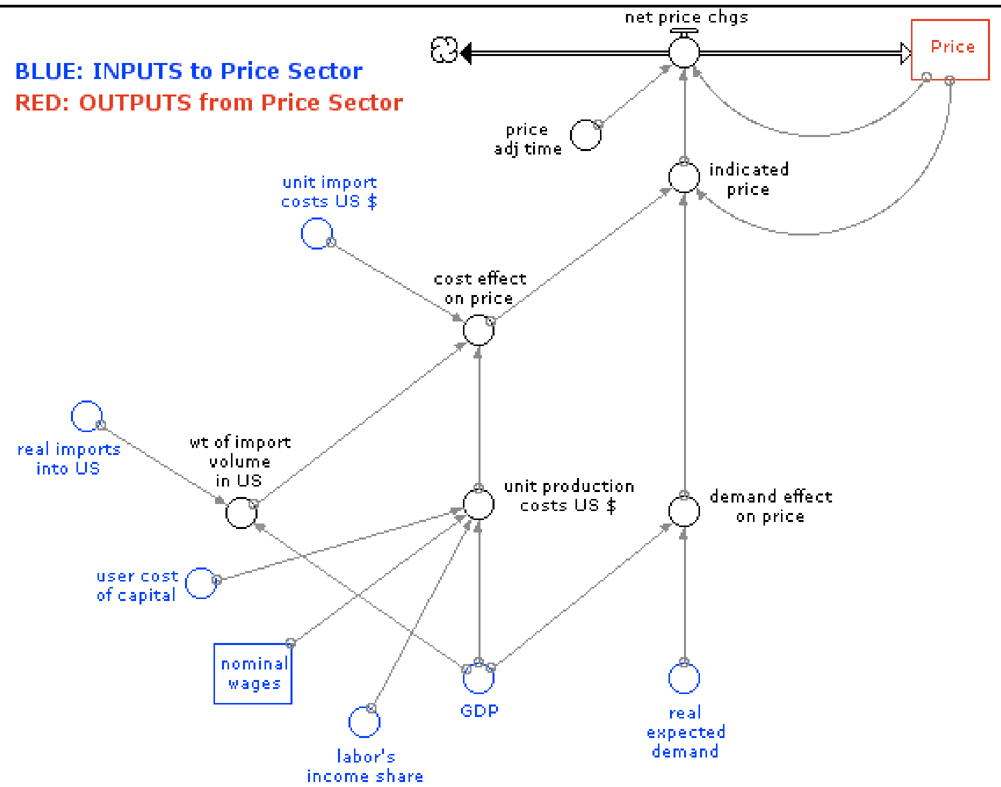
The most important validation test in this sector is to subject the submodel to extreme conditions relating to the factors of production. The Cobb-Douglas production function requires both labor and capital to interact. If labor had no tools (i.e., capital = 0), there should be no production. If tools lay idle because there were no workers (i.e., employment = 0), there should be no production. This test was implemented with a pulse outflow function in each of the two factor stocks. In year 1, all capital was drained from the stock, and the factors of production immediately dropped to zero, as expected. The same result was achieved with the employment stock.

5.5 Price Sector within the Production Submodel

The "price index" at the main model level (top panel of Figure 35) is equal to the information stock "price" within the price sector of the production submodel (bottom panel). As both theory and textbooks (Mankiw, ch. 4; McConnell/Brue, ch. 3) would recommend, price in the model is determined by demand and (the cost of) supply. The "cost effect on price" is a weighted average of the domestic and import unit costs. The "demand effect on price" is equal to 1.00 when GDP and real expected demand are equal, but is greater (less) than 1.00 when expected demand is greater (less) than GDP. The average adjustment time for price is estimated at .25 years, based on Blinder (1997).



Location of Price in the Main Model



Price Sector within the Production Submodel

Figure 35

Price Sector Equations within the Production Submodel				
		Left Side of Equation	Right Side of Equation	units
81		Price(t)	Price(t - dt) + (net price chgs) * dt INIT = 1.00	1/1
82		net price chgs	(indicated price - Price) / price adj time	1/year
83		price adj time	.25	years
84		indicated price	init(Price)*cost effect on price * demand effect on price	1/1
85		cost effect on price	(wt of import costs in US*unit import costs US $)+((1-wt of import costs in US)*unit production costs US $)	1/1
86		unit production costs US $	labor's income share*((nominal wages/GDP)/(init(nominal wages)/init(GDP))) +(1-labor's income share)*((nominal wages/GDP)/(init (nominal wages)/init(GDP))) *(smth1(user cost of capital,5)/ init(user cost of capital))	1/1
87		wt of import volume in US	1 - (GDP / (GDP + real imports into US))	1/1
88		demand effect on price	real expected demand / GDP	1/1
		nominal wages unit import costs US $ GDP real imports into US real expected demand labor’s share of income user cost of capital	Labor Sector of Production Submodel Exchange Rate Submodel Main Model Exchange Rate Submodel Labor Sector of Production Submodel Productivity Sector of Production Submodel Capital Sector of Production Submodel	

Figure 36. Price Sector Equations

Domestic unit production costs are roughly weighted according to labor costs and capital costs. In principle, capital costs should reflect a weighted average of the cost for each unit of capital in use, which could be formulated as a co-flow similar to the determination of average interest cost for servicing debt in the government submodel. However, an additional complex equation structure for that purpose seemed unwarranted, given that most of the production costs are due to labor.

Unit production costs (#86) in the equation list is an attempt to give some appropriate weight to capital costs in a simplified fashion. The relative change in capital costs is computed with the current “user cost of capital” divided by its initial value at the beginning of the simulation and then smoothed over five years so that changes in current interest rates do not radically alter the estimate of accumulated interest charges that span several years. The relative change in capital cost is then added to the relative change in unit labor production costs, with each weighted according to shares of income (i.e., shares of costs).

To illustrate, assume that over the course of a simulation, unit labor costs rose 30 percent and interest rates rose by an amount that caused user cost of capital to rise by 10 percent when calculated after smoothing. The domestic unit production costs would then be calculated by (.75*1.30 + .25*1.10), which would be 1.25—a weighted average increase of 25 percent. A simulation run using these assumptions in the price sector submodel and generating the same result is displayed in Figure 37.

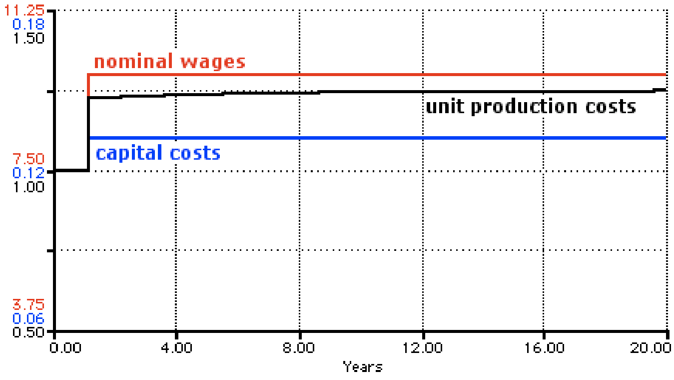


Figure 37. Price Submodel Test of Weighting Labor and Capital Costs

Figure 38 illustrates the weighting process involving import costs. The foreign sector is activated, and for one year the weight of imports (black curve) is 10 percent of the total domestic and import volume. The initial unit import cost is the same as initial US production costs, both equal to 1.00. For the first six months, therefore, US prices (blue) do not change.

The green curve shows the domestic demand price effect when a 5 percent increase in aggregate demand occurs at the six-month point, followed by rising prices (blue curve). If nothing else happened, prices would rise 5 percent (since there is no feedback effect on either demand or wages within the price sector). At the one-year point, however, an exogenous 20 percent increase in imports occurs, which raises the import weight to 12 percent (holding GDP constant in this sector). In addition, the average price of all imports (red curve) rises exogenously by 25 percent, which bumps the blue price curve to a higher trajectory. At the end of the simulation, the price level has risen by 8 percent—5 percent due to domestic demand growth and 3 percent because 12 percent of the total volume costs 25 percent more.

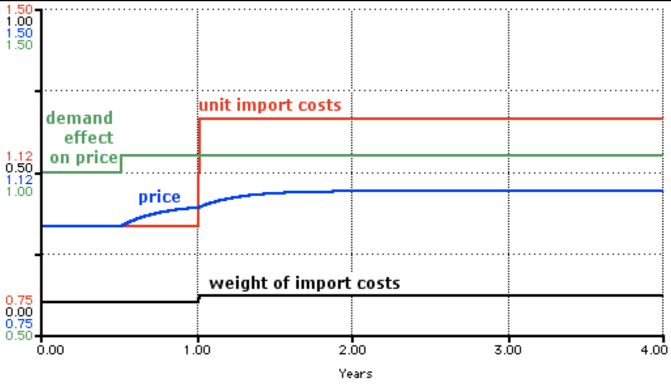
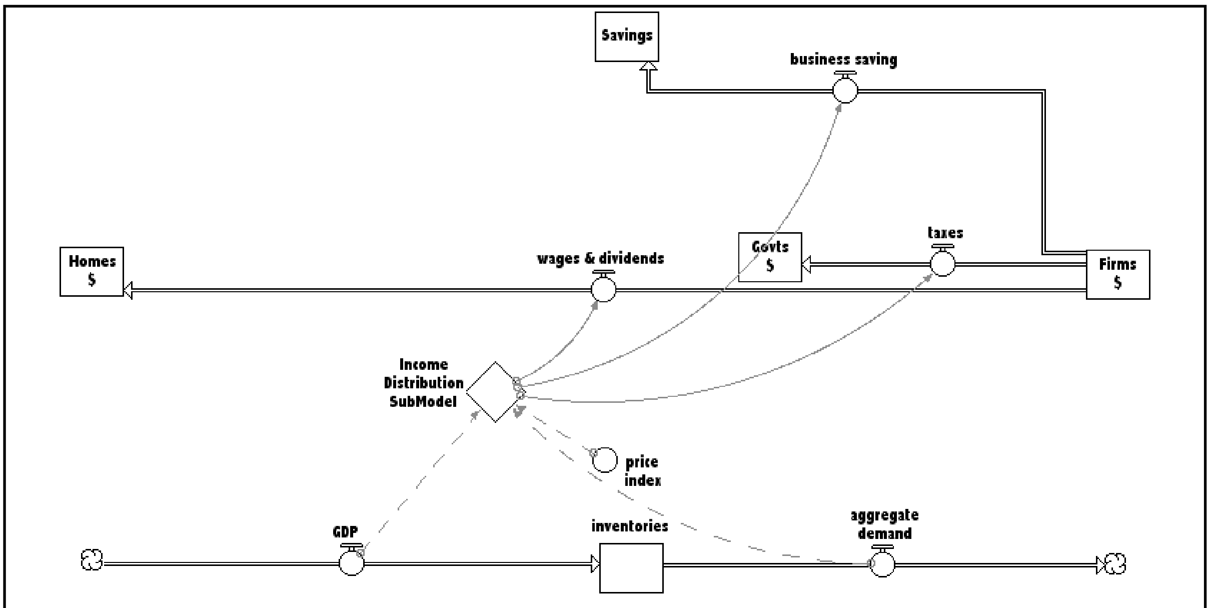


Figure 38. Price Submodel Test of Weighting Domestic and Import Costs

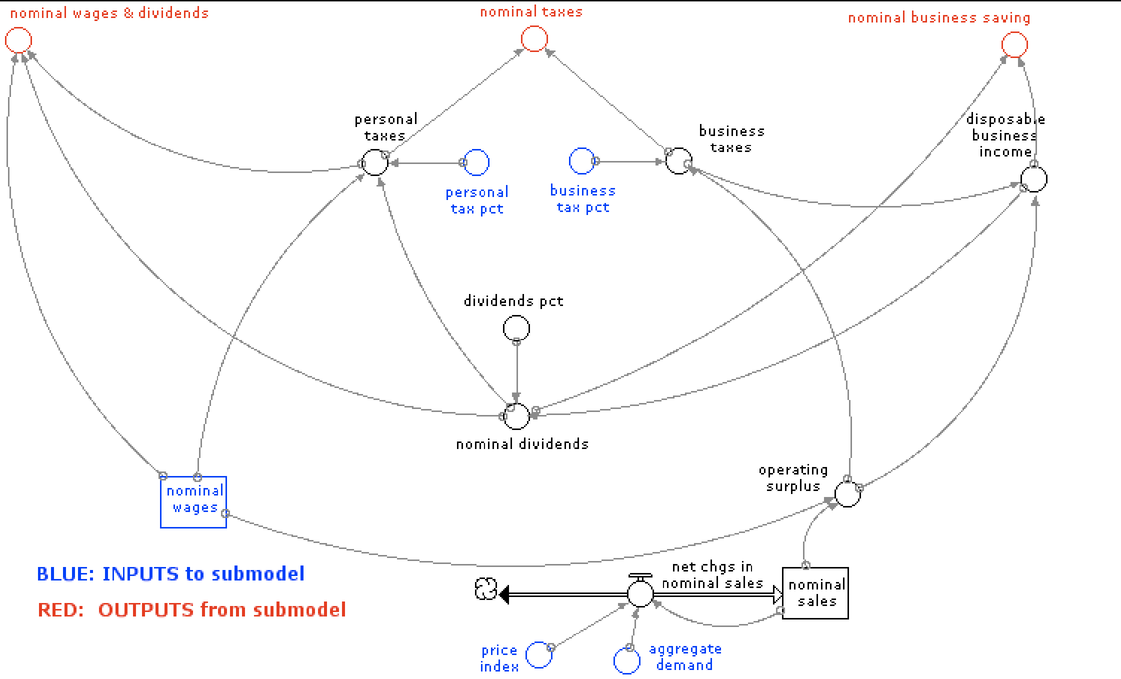
***Price Adjustment Delay*.** Variation in the price adjustment time (#83 in the equation list) has a significant effect on the behavior of the submodel—in the obvious way of shortening or lengthening the phase-in of price changes. Moreover, when the full model is running, price plays a key role in several feedback loops, and variations in price adjustment time have both amplification and oscillatory impacts on the behavior of the full model. The source for the .25 year adjustment period assumption is Blinder's (1997) survey of 186 companies that represented about 85 percent of the private, non-farm GDP. The survey led Blinder to conclude that "the typical lag of a price change behind a shock to either demand or cost is about three months."

5.6 Income Distribution Submodel

The submodel for distributing national income is very simple. Income originates on the real side of the economy—where production occurs. Adjusted to current dollars by the price index, it is distributed in three directions. After taxes (but before transfer payments), about two-thirds goes to households (called "Homes" in the main model). Governments get about one-fourth by taxing individuals and businesses. After paying wages, dividends and taxes, businesses retains less than one-tenth of national income for reinvestment in capital equipment and structures. Figure 39 displays an overview and a detailed structure. The equations are in Figure 40.



Location of Income Distribution Submodel within the Main Model



Income Distribution Submodel

Figure 39

Income Distribution Submodel Equations				
		Left Side of Equation	**Right Side of Equation**	**units**
89	○	nominal wages & dividends	nominal wages + nominal dividends - personal taxes	$/year
90	○	nominal dividends	smth1(disposable business income * dividends pct,.25)	$/year
91	○	dividends pct	.55	1/1
92	○	nominal taxes	personal taxes+business taxes	$/year
93	○	personal taxes	(nominal wages + nominal dividends) * personal tax pct	$/year
94	○	business taxes	max(0,(business tax pct) * operating surplus)	$/year
95	○	operating surplus	nominal sales - nominal wages	$/year
96	○	disposable business income	operating surplus - business taxes	$/year
97	○	nominal business saving	disposable business income - nominal dividends	$/year
		nominal wages personal tax pct business tax pct price index GDP	Labor Submodel Calculations Sector Calculations Sector Price Sector of Production Submodel Main Model	

Figure 40. Income Distribution Submodel Equations

Several simplifying assumptions were made with regard to taxes. There is a single personal tax rate and a single business tax rate. The tax base for business is assumed to be the operating surplus (#95); thus, no taxes are levied on production or sales. Even if the total business tax revenue (#94) is approximately correct, the tax structure in the model does not capture tax incentive effects that arise from different types of taxes levied at different points in the economy. Another simplifying assumption is that the personal tax rate is the same for wages and dividends (#89). A mildly progressive aggregate tax structure is achieved by making the personal tax rate vary inversely with the unemployment rate, a correlation observable in the US economy.

The functionality of this submodel is easily imagined, but Figure 41 provides an illustration. The shock in this case is a 30 percent reduction in the personal tax rate (from 20 to 14 percent). After-tax wages and dividends increase by 7.5 percent, while tax revenue (#92) decreases by almost 20 percent. There is no multiplier effect within the submodel because the reinforcing feedback loop from income to spending is outside this submodel.

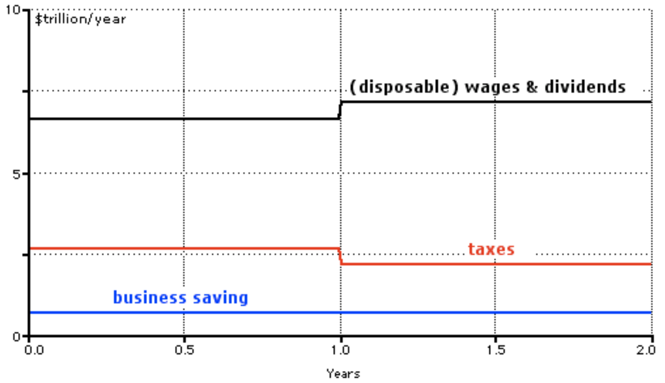


Figure 41. Income Distribution Submodel Test
shock: 30 percent cut in personal tax rate

5.7 Consumption Submodel

The focus now shifts to the nominal, demand side of the model economy. As both the overview and detailed structure in Figure 42 indicate, the inputs to the consumption submodel are *disposable income* (after-tax wages and dividends plus transfer payments) and *interest rates*. Mankiw (ch.15) acknowledges and McConnell/Brue (ch. 9) emphasizes that personal consumption is largely determined by personal disposable income, and both note that a decrease in interest rates has a positive impact on consumption. Changes in wealth, particularly reflected in changes in the value of homes and financial investment portfolios, also affect consumption, but that influence is not included in the current version of *MacroLab*.

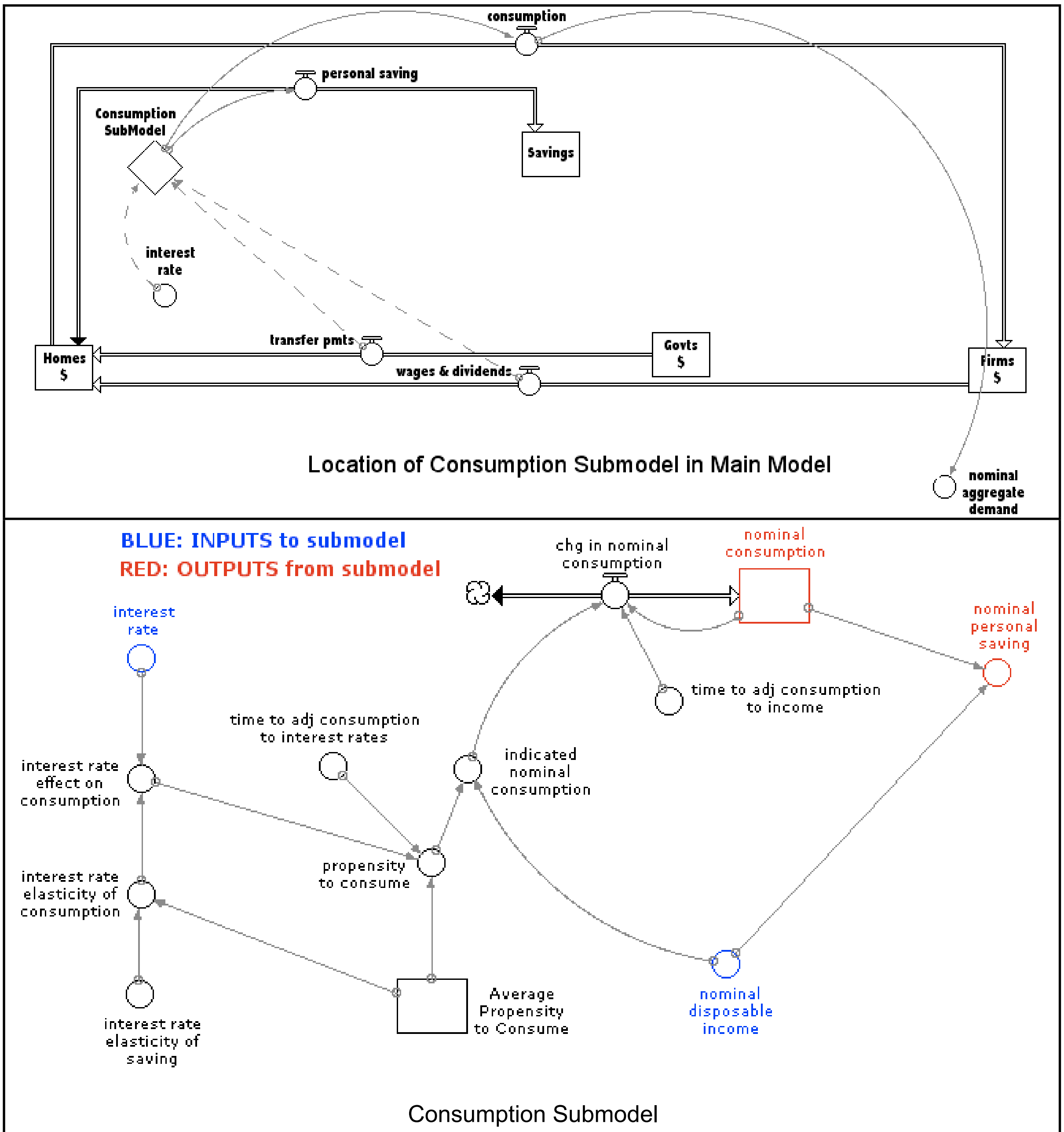


Figure 42

Consumption Submodel Equations				
		Left Side of Equation	**Right Side of Equation**	**units**
98	□	nominal consumption(t)	nominal consumption(t - dt) + (chgs in nominal consumption) * dt INIT historical = historic real C INIT experimental = indicated nominal consumption	$/year
99		chgs in nominal consumption	(indicated nominal consumption - nominal consumption) / consumption adj time	$/yr/yr
100	○	indicated nominal consumption	disposable income * propensity to consume	$/year
101	○	time to adjust consumption to income	2.5	years
102	⊚	propensity to consume	average propensity to consume * smth1(interest rate effect on consumption,time to adjust consumption to interest rates)	1/1
103	□	average propensity to consume(t)	average Propensity to Consume(t - dt) INIT experimental = (wages & dividends+business saving + taxes -investment -govt purchases) / (disposable income)	1/1
104	⊚	interest rate effect on consumption	1+((interest rate - init(interest rate)) / init(interest rate) *interest rate elasticity of consumption)	1/1
105	○	interest rate elasticity of consumption	-interest elasticity of saving / (average propensity to consume / (1-average propensity to consume))	1/1
106	○	interest rate elasticity of saving	.2	1/1
107	○	time to adjust consumption to interest rates	.5	years
108	○	nominal personal saving	disposable income - nominal consumption	$/year
		historic real C	Data Sector	
		interest rate	Interest Rate Sector of Banking Submodel	
		historic nom consumption	Data Sector	
		historic disposable income billions	Data Sector	
		wages & dividends	Income Distribution Submodel	
		business saving	Income Distribution Submodel	
		taxes	Income Distribution Submodel	
		investment	Capital Submodel	
		govt purchases	Government Submodel	
		disposable income	Income Distribution Submodel	

Figure 43. Consumption Submodel Equations

A key feature of this submodel is its incorporation of the well-documented phenomenon of consumption smoothing (Fisher, 2001). Consumer spending in one period is not determined solely by income in that period. Instead, as Friedman's "permanent income hypothesis" suggested fifty years ago, consumers appear to adapt their spending gradually to changes in income. *MacroLab's* default assumption for the average time to adjust consumption to income (#101) is based on Friedman's (1957, p. 229) conclusion that

> *Permanent income for the community as a whole can be regarded as a weighted average of current and past incomes, adjusted upwards by a steady secular trend and with weights declining as one goes farther back in time. The average time span between measured incomes averaged and current permanent income is about 2.5 years.*[4]

Of course, such an assumption does not mean that consumers wait 2.5 years to change their spending after a change in income. Indeed, the first-order delay function (used throughout *MacroLab*) generates the greatest rate of change in the output variable (e.g., nominal consumption, #98) immediately after a change in the input variable (e.g., indicated nominal consumption, #101). The rate of change slows after the initial response, however, as the exponential averaging process used here—equivalent to Friedman's geometric weight averaging process (Glahe 1973)—puts less weight on previous inputs "as one goes farther back in time." As is the case with all key parameters, the consumption adjustment time can be varied by the user at the interface level of *MacroLab* and different income smoothing times can be tested.[5]

The propensity to consume (#102) is based on a reference value (average propensity to consume, #103) and the interest rate effect on consumption (#104). When the model is in historic mode, the average propensity to consume is based on historical data. In experimental mode, the value is established so that the model is initialized in equilibrium, a condition in which investment equals personal saving plus business saving and government spending equals tax revenue. In the stand-alone consumption submodel, the average propensity to consume is set at .90, but a pull-down menu permits variations in that assumption. The *marginal* propensity to consume is not a parameter in the model; rather, it is determined endogenously by the propensity to consume and the consumption adjustment time. Thus, the marginal propensity to consume varies and its value depends on when the measurement is taken. When measured over the period following an income shock, it will be smaller immediately after a change in income but will approach the average propensity to consume as the model approaches equilibrium.

The other key influence on consumption in this submodel is the change in interest rates. Wright (1969) estimated the interest rate elasticity of saving (IRES, #106) to be .20. Given the IRES and the average propensity to consume (APC, #103), the interest rate elasticity of consumption (IREC, #105) can be calculated as follows:

$$\text{IREC} = -\ \text{IRES} / (\text{APC}/(1-\text{APC}))$$

which yields, for example, a default value of -.022 for the interest rate elasticity of consumption in *MacroLab* when average propensity to consume is .90 and the interest rate elasticity of saving is .20. With these parameter values, consumption would increase by about 1 percent (0.0089) if interest rates fell by 40 percent (e.g., from 5 to 3 percent). The effect is small compared to the effect of income, but it is does cause consumption to decrease

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[4] The same assumption was made by N. Forrester (1982) and N. Mass (1975).

[5] Although *MacroLab* is not designed as a forecasting model, one test of the validity of its default parameter assumptions is the extent to which its behavior matches historical data. Over five-year historical periods, the model's behavior correlates much better with US historical patterns when the 2.5 year consumption smoothing time is used, compared to shorter time constants.

—and personal saving (#108) to increase—when interest rates rise, and conversely.

The results of a test of this effect are displayed in Figure 7.49. With an average propensity to consume of .90, the impact would be difficult to discern if the graph were drawn to scale for all variables. Therefore, the test uses .80 for the average propensity to consume, and disposable income is constant at $5 trillion/year. Given the assumption of .20 for the interest rate elasticity of saving, the interest rate elasticity of consumption would be -.05. When interest rates drop from 5 to 3 percent, the propensity to consume rises from .80 to .816, and the propensity to save drops from .20 to .184. Thus, in the graph, nominal consumption rises from $4.00 to $4.08 trillion/year, and nominal saving falls from $1.00 to $0.92 trillion/year. In this example, the interest rate decline shifts $80 billion/year from saving to consumption. (There is no multiplier effect because the feedback loop from spending to income is outside the consumption submodel.[6]) When the more historically accurate propensity to consume of .90 is used, the effect is reduced by more than half—nominal consumption rises by about $40 billion/year.

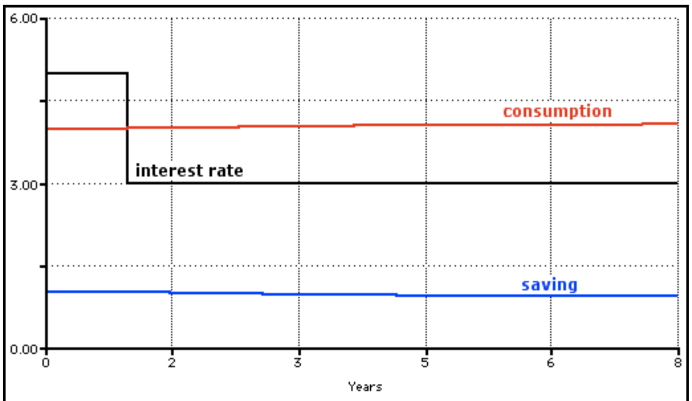

Figure 44. Consumption Submodel Test
shock: interest rate decline from 5 to 3 percent

The submodel is clearly sensitive to the assumption about average propensity to consume, but that parameter is comparatively easy to estimate from historical data. The time to adjust consumption to interest rates (#107) is highly uncertain, but the model is not very sensitive to variations in that parameter. Also uncertain are the estimates of the interest rate elasticity of saving and the adjustment time for smoothing consumption, and the model is sensitive to changes in both parameters. Future refinements of *MacroLab* will include either better estimates of both parameters or additional justification for the continued use of current estimates.

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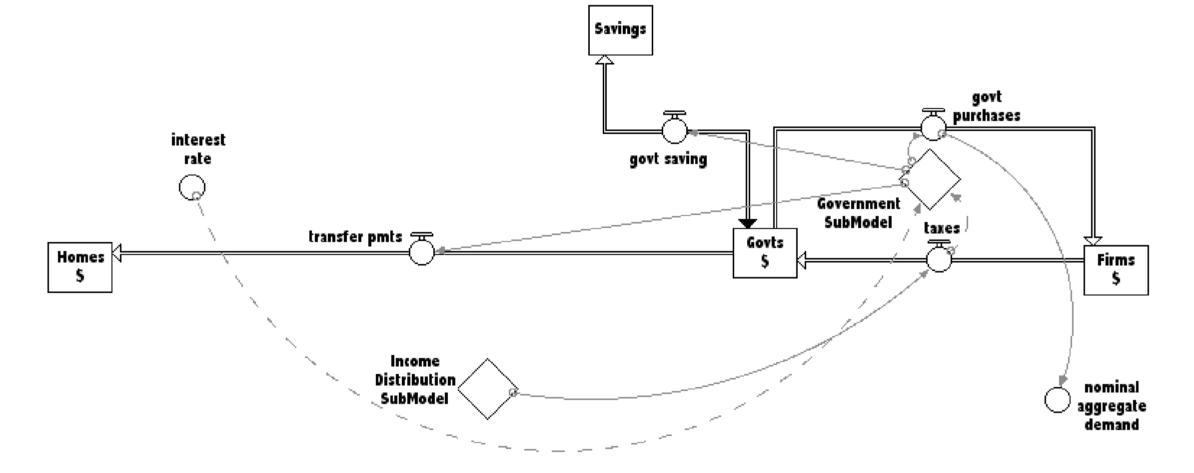
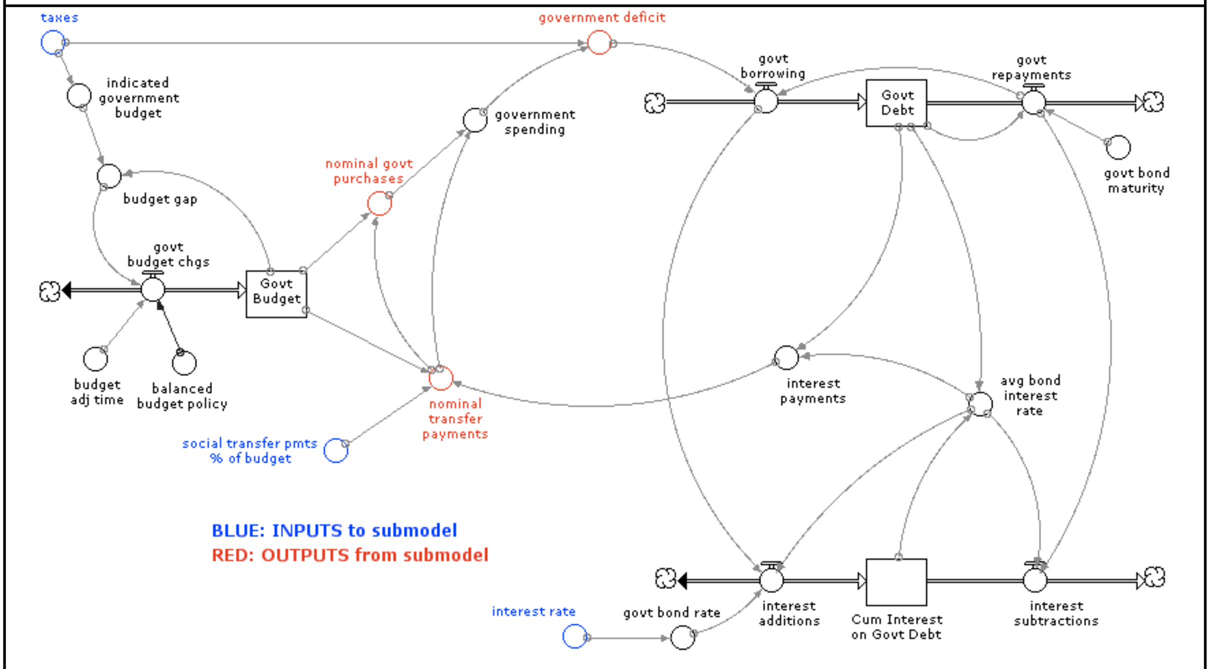
[6] If Wright's (1969) estimate of the interest rate elasticity of saving included multiplier effects, then the .20 estimate is too high for use in the stand-alone submodel. However, it would still be appropriate when the full model was running.

5.8 Government Submodel

Inclusion of a detailed government structure in the current version of *MacroLab* is part of a long-range goal to endogenous many of government's fiscal effects on the overall economy. The most significant endogenous feature is the government budget, which *grows* in proportion to tax revenue growth. The default assumption is that political leaders will spend every dollar that comes in, and that spending will *never decrease* even when tax revenue falls during a simulated recession. While clearly an oversimplification—after all, tax cuts do happen—it appears to be the norm in the US. (It is possible to change that assumption so that government must follow a balanced budget policy.) Another key endogenous feature is the feedback effect of rising debt service payments on the division between purchases and transfer payments. Government purchases—the residual spending after social transfer payments and interest payments—tend to shrink as a portion of total spending during periods of deficit financing, which is consistent with US historical trends.



Location of Government Submodel within the Main Model



Government Submodel

Figure 45

Government Submodel Equations				
		Left Side of Equation	**Right Side of Equation**	
109		government spending	nominal govt purchases + nominal transfer pmts	$/year
110		nominal govt purchases	Govt Budget - nominal transfer pmts	$/year
111		nominal transfer payments	Govt Budget * social transfer pmts % of budget + interest payments	$/year
112		Govt Budget(t)	Govt Budget(t - dt) + (govt budget chgs) * dt INIT historical = historic real govt outlays INIT experimental = indicated govt budget	$/year
113		govt budget chgs	If(balanced budget policy=0)then(max(0,budget gap/budget adj time)) else(if(budget gap>0)then(budget gap/budget adj time)else (budget gap/(budget adj time/3)))	$/year/ year
114		balanced budget policy	0	1/1
115		budget adj time	1	years
116		budget gap	indicated govt budget - Govt Budget	$/year
117		indicated government budget	taxes	$/year
118		Govt Debt(t)	Govt Debt(t - dt) + (govt borrowing - govt repayments) * dt INIT historical = historic govt debt INIT experimental = 5	$
119		govt borrowing	government deficit + smth1(govt repayments,.08)	$/year
120		govt repayments	Govt Debt / avg govt bond maturity	$/year
121		avg govt bond maturity	5	years
122		government deficit	government spending - taxes	$/year
123		interest payments	Govt Switch*(Govt Debt*avg bond interest rate/100)	$/year
124		avg bond interest rate	if(Govt Debt>0)then(100*Cum Interest on Govt Debt/Govt Debt)else(0)	1/year
125		govt bond rate	interest rate*.9	1/year
126		Cum Interest on Govt Debt (t)	Cum Interest on Govt Debt(t - dt) + (interest additions - interest subtractions) * dt INIT = (interest rate/100) * Govt Debt	$
127		interest additions	if(govt borrowing>0)then((govt bond rate/100)*govt borrowing)else(govt borrowing*(avg bond interest rate/100))	$/year
128		interest subtractions	govt repayments*(avg bond interest rate/100)	$/year
		historic real govt outlays	Calculations Sector	
		taxes	Income Distribution Submodel	
		interest rate	Interest Rate Sector of Banking Submodel	
		social transfer pmts % of budget	Calculations Sector	
		historic govt debt	Calculations Sector	

Figure 46. Government Submodel Equations

Still exogenous, however, is the reference budget division between purchases and transfer payments, and also the highly simplified tax rates (in the data sector of the model).

Two principal inputs to the government submodel—taxes and interest rates—are indicated in both panels of Figure 45. Government's indicated budget (#117 in the equation list) is equal to taxes, and the budget gap (#116) is the difference between the indicated budget and the current budget (#112). When government is *not* following a balanced budget policy (#114 = 0), then government budget changes (#113) can never become a negative value; the net flow into the budget information stock will be zero (if taxes remain level or decline) or a positive value. When the balanced budget policy *is* in effect, then the net change in the budget can be positive or negative—the budget could shrink.

The exogenously influenced estimate of social transfer payments' share of the budget is added to the interest payments (#123) to determine nominal government transfer payments (#111). The remainder of the budget goes to all other government purchases (#110) of goods, services, and infrastructure. If total government spending (#109) exceeds taxes, then a deficit (#122) exists and government borrows (#119) to finance the difference, and the debt (#118) increases. The rate of repayments of principal (#120) depends on the average maturity (#121) of government bonds. The debt is assumed to function on a rollover basis—government borrows from Peter to pay Paul. The only way that the government debt can be reduced is by running budget surpluses rather than deficits.

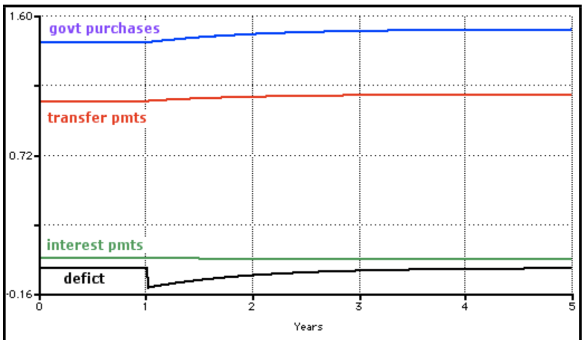
The interest payments (#123) are based on current debt and average interest rates (#124) on that debt. A co-flow structure (Sterman 2000, ch. 12) is used to keep track of the average interest rate. As government borrows, the interest obligations at that time are accumulated (#127 and #126). When government pays off a bond holder, the average interest rate is attached to that payoff in the interest subtractions outflow (#128). The significance of this structure is that the average interest rate changes more slowly than the current rate (#125).

To illustrate the behavior of the government submodel, Figure 47 displays three simulation experiments in which the submodel is shocked by a five percent change in tax revenue. In panel A, taxes *increase* by five percent, which causes a five percent increase in the government budget (under both balanced and unbalanced budget policies). With an average budget adjustment time of one year, the complete adjustment takes a little more than three years and a budget surplus exists during the transition period. During the budget surplus period, the debt is reduced and interest payments fall slightly. The fall in interest payments keeps transfer payments from rising quite as much as otherwise would have been the case. Thus, government purchases grow by slightly more than five percent and transfer payments grow by slightly less than five percent.

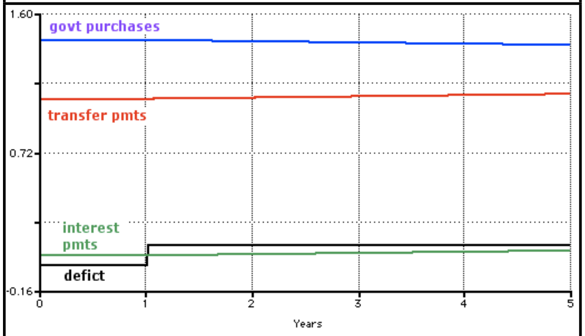
Panels B and C illustrate the dynamics when tax revenue *falls* by five percent.

In panel B, government is *not* following a balanced budget policy, and the budget does not decline when taxes fall. Instead, a continuous deficit occurs, and there is an increase in the debt and interest payments. The rise in interest payments causes transfer payments to rise. However, since the government budget is flat, government purchases decline by an amount equal to the transfer payments increase.

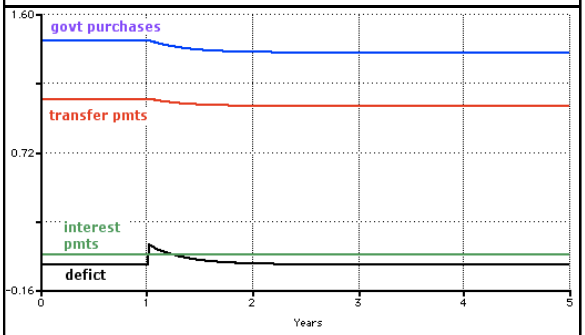
In panel C, government follows a balanced budget policy. The five percent reduction in taxes causes a five percent reduction in the government budget, with the adjustment time accelerated to complete the adjustment within one year. Both government purchases and transfer payments decline by almost the same amount. Due to the brief deficit during the transition to a balanced budget, however, the debt and interest payments rise slightly, which causes transfer payments to decline somewhat less than government purchases.



Panel A: Taxes Increase by 5 Percent



Panel C: Taxes *Decrease* by 5 Percent, with UNbalanced Budget Policy

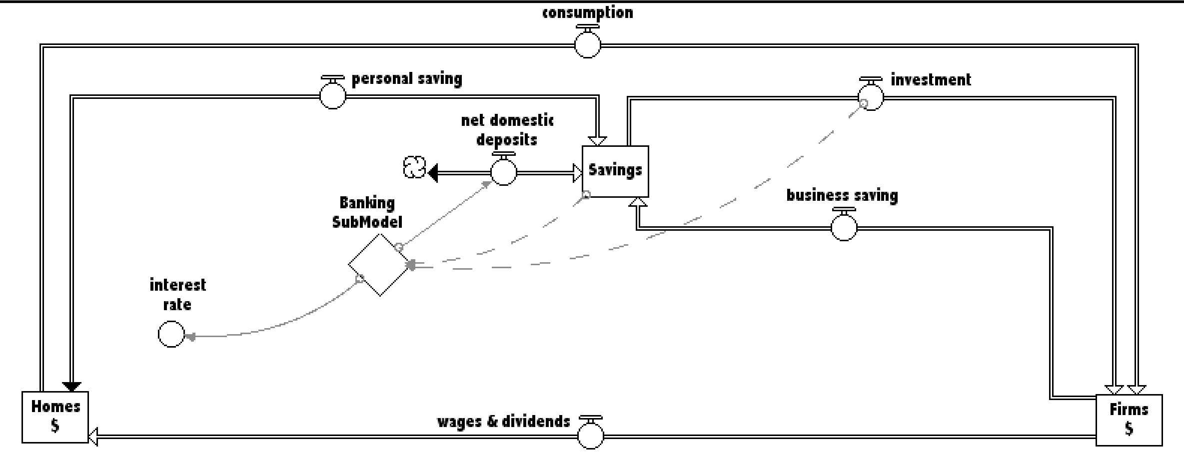


Panel C: Taxes *Decrease* by 5 Percent, with Balanced Budget Policy

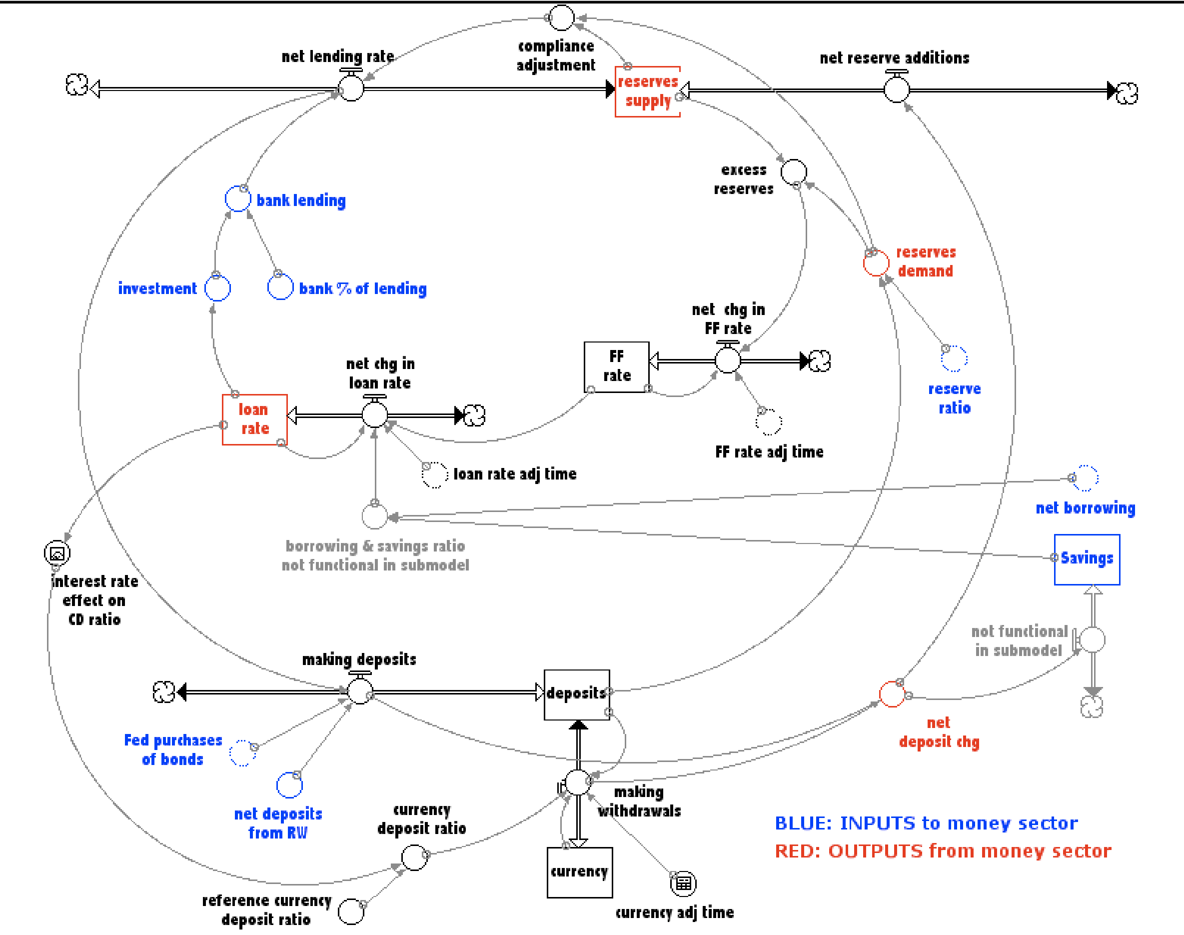
Figure 47. Government Submodel Effects of Change in Tax Revenue

5.9 Money Sector within the Banking Submodel

The banking submodel has two sectors, one for money and interest rates and the other for monetary policy. Here, the focus is on the structure of the model's banking system and how it affects the money supply and interest rates. The next section describes the influence of monetary policy on the banking system.

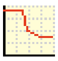


Location of Banking Submodel within Main Model



Money Sector of Banking Submodel

Figure 48

Money Sector Equations in Banking Submodel				
		Left Side of Equation	**Right Side of Equation**	**units**
129		deposits(t)	deposits(t - dt) + (making deposits + net deposits from RW - making withdrawals) * dt INIT historical = historic M2-historic currency INIT experimental = initial M2*(1-initial currency to m2 ratio)	$
130		making deposits	Fed purchases of bonds+net lending rate+net deposits from RW	$/year
132		making withdrawals	((deposits * currency deposit ratio)-currency) / currency adj time	$/year
133		currency(t)	currency(t - dt) + (making withdrawals) * dt INIT historical = historic currency INIT experimental = initial M2*initial currency to m2 ratio	$
134		currency deposit ratio	smth1((1+interest rate effect on CD ratio)* reference currency deposit ratio,.5)	1/1
135		currency adj time	2.5	years
137		interest rate effect on CD ratio 	GRAPH(smth1(loan rate / init(loan rate),3)) (0.00, 0.125), (0.2, 0.124), (0.4, 0.123), (0.6, 0.12), (0.8, 0.114), (1.00, 0.00), (1.20, -0.0165), (1.40, -0.027), (1.60, -0.0315), (1.80, -0.0345), (2.00, -0.0375)	1/1
138		reserves supply(t)	reserves supply(t - dt) + (net reserve additions)*dt INIT historical = historic bank reserves INIT experimental = reserves demand	$
139		net reserve additions	net deposit chg	$/year
140		net lending rate	if(compliance adjustment<0)then(compliance adjustment) else(bank lending - init(bank lending))	$/year
141		bank lending	(bank % of lending/100)*investment	$/year
142		bank % of lending	15	1/1
144		reserves demand	reserve ratio * deposits	$
145		reserve ratio	M2 required reserve ratio+excess reserve ratio	1/1
146		net deposit chg	making deposits - making withdrawals	$/year
147		excess reserves	reserves supply / reserves demand	1/1
147b		compliance adjustment	(reserves supply-reserves demand)/.04	$/year
148		FF rate(t)	reserves supply(t - dt) + (net chg in FF rate)*dt INIT historical = historic FF rate INIT experimental = 4	1/yr
149		net chg in FF rate	((init(FF rate)/excess reserves)-FF rate)/FF rate adj time	1/yr/yr
150		FF rate adj time	.04	years

151		loan rate(t)	loan rate(t - dt) + (net chg in loan rate) * dt INIT historical: historic prime rate INIT experimental: FF rate+3	1/yr
152		net chg in loan rate	(((borrowing & savings ratio/init(borrowing & savings_ratio)) *(FF rate+3))-loan rate)/loan rate adj time	1/yr/yr
153		loan rate adj time	.08	years
154		borrowing & savings ratio	(net borrowing / init(net borrowing))/(Savings / init(Savings))	1/1
		historic M2	Data Sector	
		historic currency	Data Sector	
		initial M2	Data Sector	
		initial currency to m2 ratio	Data Sector	
		historic bank reserves	Data Sector	
		historic bank% of investment loans	Data Sector	
		Fed purchases of bonds	Policy Sector of Banking Submodel	
		historic FF rate	Data Sector	
		historic prime rate	Data Sector	
		net borrowing	Data Sector	
		Savings	Main Model	
		M2 required reserve ratio	Policy Sector of Banking Submodel	
		excess reserve ratio	Data Sector	
		net deposits from RW	Data Sector	
		investment	Main Model	
		reference currency deposit ratio	Data Sector	

Figure 49. Money Sector Equations within the Banking Submodel

In their chapters on money and banking, Mankiw (ch. 11) and McConnell/Brue (ch. 14) emphasize the process by which the banking system creates multiple expansions or contractions of the money supply and affects the supply and price of credit for both households and business firms. When only the Simple Private Sector of *MacroLab* is functioning, the money supply is fixed, and interest rates are determined simply by the relative supply of loanable funds (the Savings stock at the main model level) and the demand for those funds (the investment outflow from savings). When the Banking Sector is activated, however, the money supply can grow (and decline) as banks make loans, and interest rates receive an additional influence—banks' incentives to make loans.

Before describing the way the money sector works, some unusual aspects of Figure 48 should be explained. As previously mentioned, most of the exogenous inputs to these submodels would be endogenous connections if the full model were running. Examples are "net borrowing" and "Savings." The Savings stock receives the net deposit change from the money sector, and Savings is the loanable funds influence on interest rates in the money sector. Thus, a loop exists. Likewise, net borrowing—which includes investment—affects interest rates in the money sector, but the interest rates affect the borrowing; another loop exists. Moreover, as we saw in the main model, investment is an outflow from the stock of Savings; without an inflow (e.g., from personal and business saving), Savings would be drained in the monetary sector. Where to draw the line between endogenizing relationships and maintaining stand-alone submodels is a difficult choice. In this case, investment was needed as a response variable in the monetary sector; otherwise, the change in interest rates would not affect lending rates. Since Savings could not be properly used to represent a supply influence on loan rates, net borrowing could not be used as the corresponding demand influence. However, both variables are displayed on the diagram in Figure 48 as a reminder that they do influence interest rates when the full model is running. Let us now focus on some essential structure in the money sector of the banking submodel.

Near the bottom of the diagram in Figure 48, the deposits and currency stocks (#129 and #133 in the equation list) comprise the money supply, M2. Leaving currency aside for later discussion, consider the simple feedback loop structure in Figure 50. When customers make deposits (#130), that creates both liabilities and assets for a bank. The liability is the total value of customer accounts, while the assets are the bank's reserves. A certain fraction of reserves (#145) is required by law and by prudent banking practice to be set aside, unavailable for lending. The set-aside amount is called reserves demand (#144). When the total supply of bank reserves (#138) exceeds reserves demand, an excess (#147) exists. Idle excess reserves earn no interest, so banks have an incentive to reduce the reserves supply to the level of reserves demand. When excess reserves increase, competitive banks will offer incentives to attract loan customers. One incentive, of course, is the interest rate on the loans. When excess reserves increase, that puts downward pressure on interest rates, *ceteris paribus*.

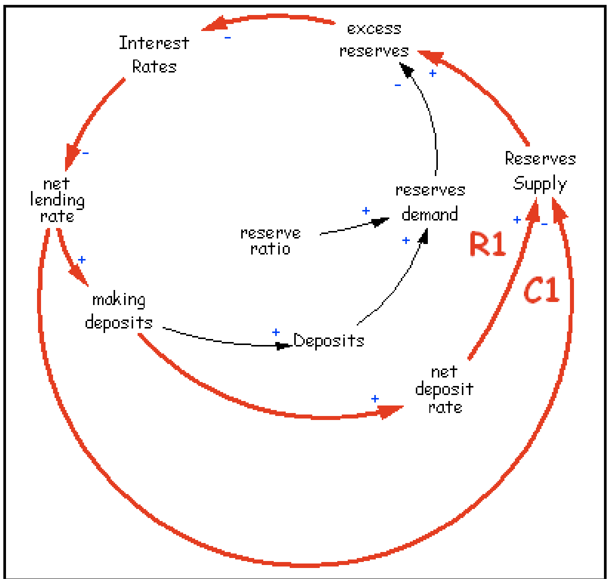


Figure 50

The feedback diagram uses the single term "interest rates." In Figure 48, *two* interest rates are represented—the Fed Funds rate (#148) and the loan rate (#151). The Fed Funds rate is most immediately affected by discrepancies between reserves supply and demand. The Fed Funds market is the interbank loan market for commercial banks that have either a surplus or deficit of reserves. If excess reserves exist for the banking system as a whole, individual banks with excess reserves will tend to lower their asking price for short-term loans; otherwise, banks in need of reserves will turn to other short-term loan markets. Reserves that are abundant and that are losing potential as interest-bearing assets in the Fed Funds market will also be offered to the bank's personal and commercial loan customers at lower-than-normal loan rates. Also, the "other short-term loan markets" will be moving in the same direction as the Fed Funds market, as attempts are made to compete for borrowers needing reserves.

The lower interest rates will attract more loan customers and net lending (#140) will increase. Assuming for a moment that the loans are not taken out of the banking system in the form of cash, each new loan gets placed in an existing or new customer account, and the banking system's liabilities grow. The reserves loaned out simultaneously add and subtract to the banking systems' supply of reserves, as suggested by the R1 and C1 loops in Figure 50. The reserves *supply remains unchanged* but the reserves *demand grows* as the reserve ratio is applied to a larger stock of deposits. Whatever excess reserves existed before, it is somewhat smaller now. As the process continues and the demand for reserves rises to meet the supply, the excess disappears and upward pressure on interest rates appears—first, on the Fed Funds rate and eventually on all other loan rates. Counteracting loop C2 in Figure 51 illustrates the process. With each round of new deposits, the reserves demand grows, the excess reserves shrinks, interest rates rise, new lending slows down, and fewer new deposits are made.

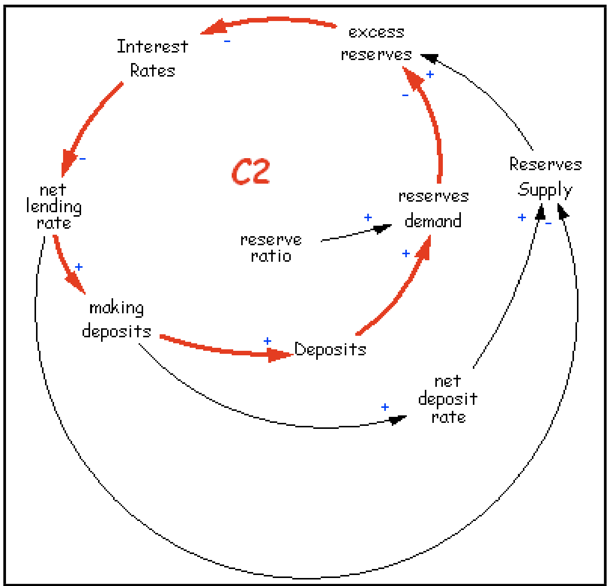


Figure 51

In the meantime, however, the initial quantity of excess reserves has generated an increase in the money supply, defined as "deposits" in Figures 50 and 51 since we have been assuming zero currency. If we drop that assumption, we can see in Figure 52 that the potential for money supply growth described above is limited by loops set in motion by the public's demand for cash.

About ten cents of every dollar deposited in M2 accounts is eventually withdrawn in the form of cash. As loop C3 in Figure 52 suggests, for a given currency-to-deposit ratio, more deposits means more withdrawals (132), and more withdrawals means a lower level of deposits. Follow loop R2, and a reinforcing process can be seen. The lower deposit level reduces reserves demand, which increases excess reserves and lowers interest rates. Lower interest rates provides less incentive to put extra cash in bank accounts and more incentive to hold cash for convenience; thus, the currency-to-deposit ratio rises (#137 and #134) and leads to an even greater rate of cash withdrawals from the banking system.

The withdrawals also reduce the net deposit rate (#146) and the net additions to the supply of reserves (#139). Thus, the cash withdrawals reduce both the demand for reserves (R2 loop) and the supply of reserves (C4 loop). What is the net effect? Every dollar of cash withdrawn is a dollar of reserves supply removed from the system. Each of those dollars "lost," however, reduces the reserves demand by only a fraction. Thus, the net effect is to reduce the supply of reserves much more than the demand, and that reduces the potential for excess reserves to be loaned and new deposits created. The currency withdrawal process, then, limits the potential growth in the money supply. But

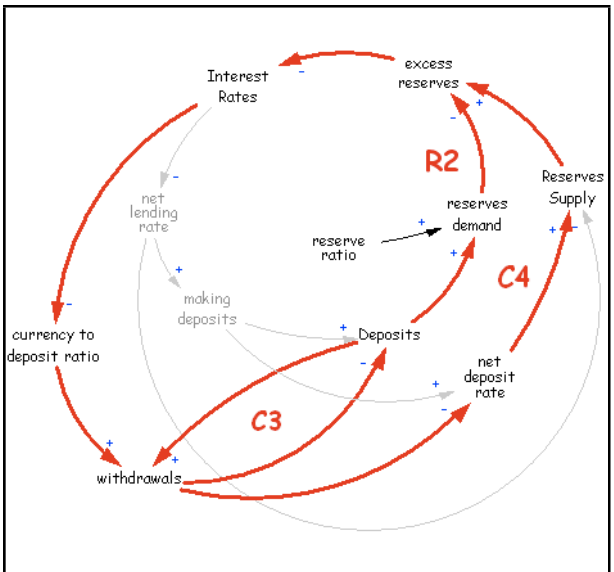


Figure 52

there is a limit to the limit. The C4 loop eventually raises interest rates and encourages more deposits and a lower currency-to-deposit ratio.

To test whether the structure described above produces such behavior, *MacroLab's* money sector was shocked with an injection of $100 billion, and the results are displayed in Figure 53. In the top panel, the feedback loop connecting interest rates and the currency-to-deposit ratio has been cut, and the currency-to-deposit ratio remains constant. The loan interest rate falls immediately after the shock, and then rises steadily.

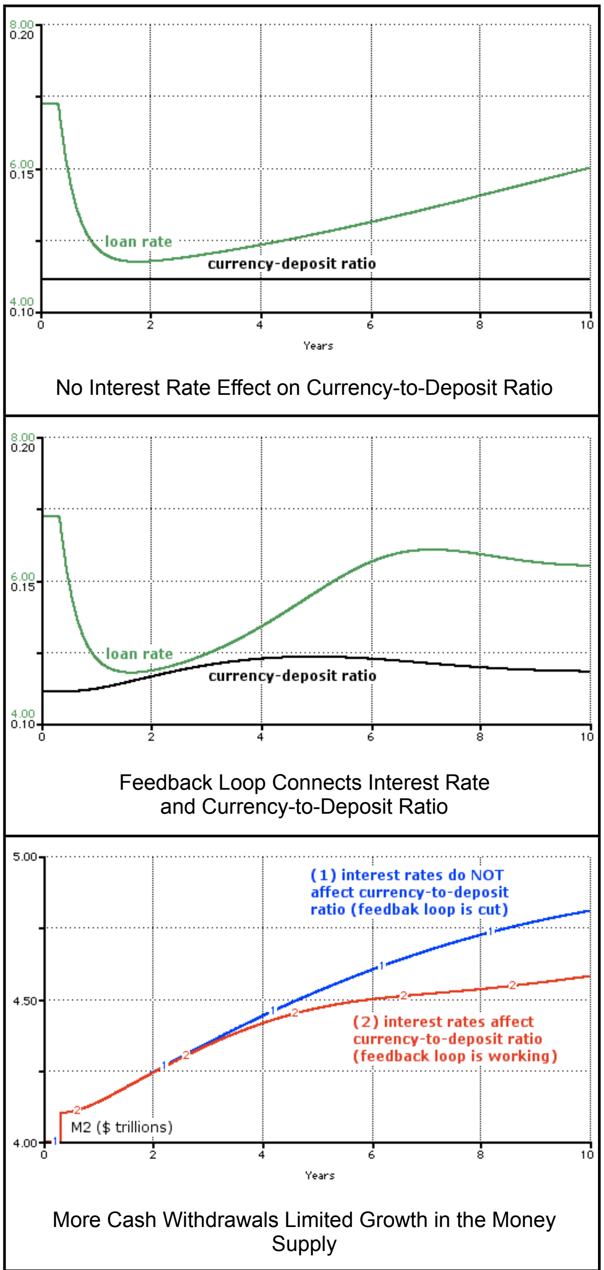


Figure 53

In the middle panel, the same shock is administered, but the feedback loop is reactivated. When the interest rate falls, the currency-to-deposit ratio rises. Moreover, the additional cash withdrawals accelerate the interest rate rebound, but that eventually encourages more saving and the currency-to-deposit ratio comes back down. In addition, the feedback effect stabilizes interest rates.

The bottom panel in Figure 53 shows the effects on the money supply. The blue curve corresponds to the top panel—when the currency-to-deposit ratio remains low because there is no feedback effect from the interest rates. The red curve corresponds to the middle panel, when the currency-to-deposit ratio rises. As expected in the latter case, the growth in the money supply is limited by the additional cash withdrawals.

In this discussion of the structure and behavior of the money sector submodel, no explanation was given for what might have precipitated such shocks to the system. In the next subsection, a simple monetary policy model will illustrate one source of such shocks.

5.10 Monetary Policy Sector within the Banking Submodel

In this subsection, a very simple model of monetary policy is presented, as part of a long-range plan to endogenize much of government economic policy making. The model follows the textbook approach to open market operations by the Federal Reserve System (the "Fed"). As explained in Mankiw (ch. 11) and McConnell/Brue (ch. 15), the goals of the Federal Open Market Committee (FOMC) include economic growth, low unemployment, and stable prices. When economic conditions warrant action with respect to these goals, the FOMC authorizes the staff of the New York Federal Reserve Bank to engage in open market buying and/or selling of US government bonds with the objective of adjusting interest rates to desired levels and influencing aggregate demand accordingly. Figure 54 displays the stock-and-flow structure responsible for such decision-making and action within *MacroLab*.

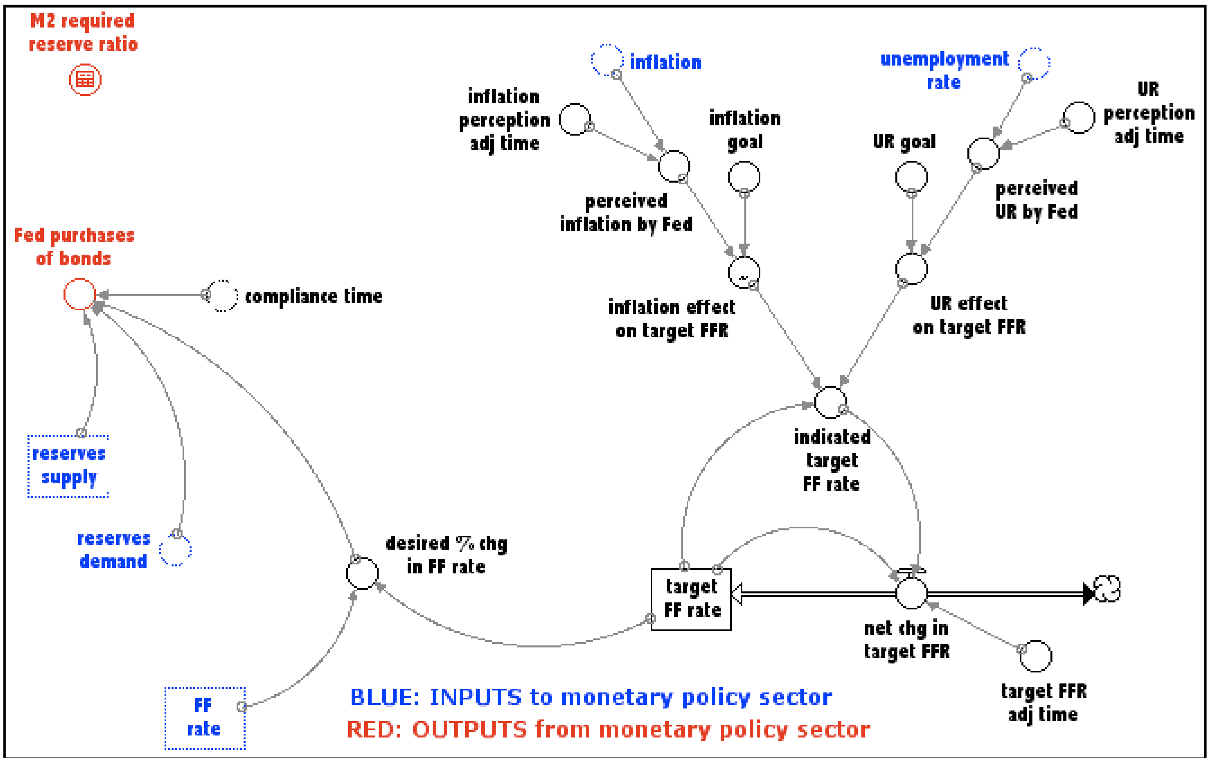


Figure 54. Monetary Policy Sector within the Banking Submodel

Two of the inputs to this sector—inflation and the unemployment rate—are among the economic indicators monitored by the FOMC in its deliberations. The outputs are two policy instruments available to the Fed: (1) the required reserve ratio and (2) open market operations. Finally, at left, note the three blue information inputs from the money sector. Information about the Fed Funds rate and the supply and demand for reserves provides the data needed to formulate an action plan to pursue inflation and unemployment goals. The general strategy is to decide whether interest rates should be higher or lower, and to manipulate the supply of bank reserves so as to influence the Fed Funds rate directly, the loan rate indirectly, and aggregate demand ultimately.

Policy Sector Equations within Banking Submodel

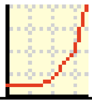
		Left Side of Equation	Right Side of Equation	
155		desired % chg in FF rate =	if(FF Rate=0)then(0) else((target FFR-FF Rate) / FF Rate)	1/1
156		target FF rate(t) =	target FFR(t - dt) +(net chg in target FFR)*dt INIT = FF Rate	1/year
157		net chg in target FFR =	(indicated target FF rate - target FF rate) / target FFR adj time	1/yr/yr
158		target FFR adj time =	0.25	years
159		indicated target FF rate =	init(target FF rate) * (inflation effect on target FFR /init(inflation effect on target FFR)) * (UR effect on target FFR /init(UR effect on target FFR))	1/year
160		inflation effect on target FFR 	GRAPH(if(inflation goal=0)then(perceived inflation by Fed/.25)else(perceived inflation by Fed/inflation goal)) (0.00, 0.54), (0.333, 0.58), (0.667, 0.62), (1.00, 0.74), (1.33, 1.28), (1.67, 1.98), (2.00, 4.00)	1/1
161		UR effect on target FFR	UR goal/perceived UR by Fed	1/1
162		inflation goal =	H: 3 E: 0	1/year
163		UR goal =	5	1/1
164		perceived inflation by Fed	smth1(inflation,inflation perception adj time)	1/yr
165		perceived UR by Fed	smth1(unemployment rate, UR perception adj time)	1/1
166		inflation perception adj time	0.25	years
167		UR perception adj time	0.25	years
168		Fed purchases of bonds	((reserves demand-(1+(desired % chg in FF rate))*reserves supply)/compliance time))	$/year
169		compliance time	2	weeks
170		M2 required reserve ratio	.01	1/1
		reserves supply reserves demand inflation unemployment rate FF rate	Money Sector of Banking Submodel Money Sector of Banking Submodel Data Sector Labor Submodel Money Sector of Banking Submodel	

Figure 55. Equations in Policy Sector of Banking Submodel

The focus in this subsection is on open market operations since that is the only policy tool that is formulated endogenously within the current version of *MacroLab*. The required reserve ratio can be varied exogenously, and its default value—.01—is the approximate average ratio of required reserves to M2 over the past twenty years in the US. For most of that time, non-checkable deposits have had no reserve requirement, and checkable deposits (those in M1) have had a weighted average requirement of slightly less than ten percent.

Below, we develop a general outline of the policy development process and then illustrate how that process is formulated in *MacroLab*. To the extent possible, we want to formulate decision rules in the model that evoke visions of real policy makers thinking and acting in real time. To that end, let us imagine what the policy makers know and how they might react to a development that calls for a change in policy. The following discussion parallels the line of reasoning in Table 15.3 of McConnell/Brue.

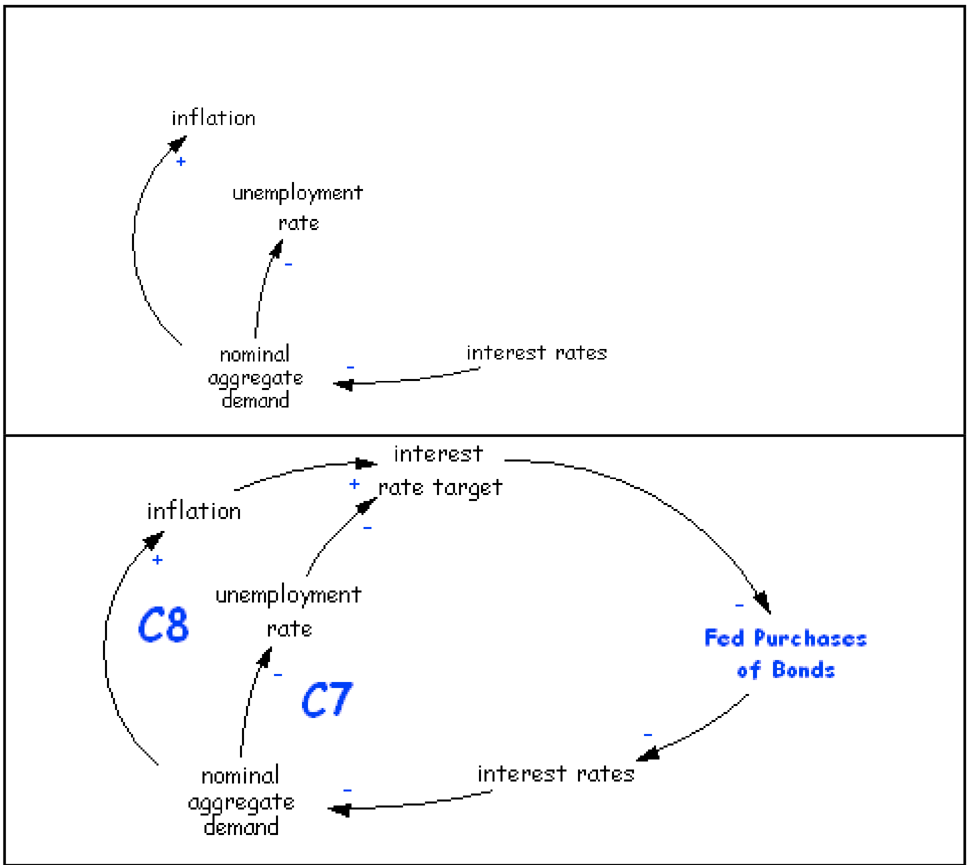


Figure 56. Structuring the Policy Problem

We begin by assuming the policy makers believe the hypotheses implicit in the links in the top panel of Figure 56. That it is to say, they believe that an increase in interest rates reduces nominal aggregate demand, *ceteris paribus*. Moreover, they are aware of the short run trade-off between inflation and unemployment resulting from sharp changes in nominal aggregate demand (Mankiw's fourth principle, discussed in section 3.4). They also know that they should adopt a target interest rate based on the links in the bottom panel, and then act accordingly. For example, a rise in inflation suggests the policy of raising interest rates and curbing demand, while a rise in unemployment suggests the opposite policy. If the implicit interest rate target falls, the policy makers know they should buy more bonds in order to depress interest rates (bringing them closer to the interest rate target) and boost demand. Finally, they are painfully aware of the feedback consequences of their actions, as suggested by the loops C7 and C8. A balanced policy approach is one that recognizes the trade-off between unemployment and inflation. Nevertheless, it is inevitable that the interest target will change in the future as a result of policy actions in the past.

The first modeling challenge, therefore, is to write equations that enable policy makers to become aware of the economic conditions of concern to them, and the next step is to write a decision rule for the conduct of open market operations. We begin with the exogenous inputs that represent conditions in the economy—the information about inflation and unemployment. Policy makers do not know the current level of unemployment or the current rate of change in prices; they only know what they see in data collected last month, and even then they are assumed to take some time to adjust their perceptions. In the model, the default assumption is that the average time delay in updating those perceptions (#165 and #166) is approximately three months. Like most time constants in *MacroLab*, these assumptions can be varied at the interface level of the model.

The policy makers in the model compare their perceptions with their goals for unemployment and inflation. The default goal for the unemployment rate (#163) is 5 percent, roughly the average in the US over the past twenty years and close to the current CBO estimate of the "natural" rate of unemployment. The default inflation goal (#162) is 3 percent unless the model is in a no-growth experimental mode, in which case the inflation goal is zero. When the unemployment rate changes, the impact on policy (#161) is assumed to be proportional to the relationship between the perceived unemployment rate and the goal. When inflation changes, the impact (#160) is presumed to be nonlinear and disproportionately greater at higher levels of inflation, as Mankiw (2002) suggests.

The impact of perceived inflation and unemployment are compared with their initial impacts at the beginning of the simulation run, and "effect" ratios are computed. The two ratios are given equal weight in equation #159, and multiplied times the initial value of the Fed Funds rate. When the ratios are both equal to one, no policy change occurs. When the product of the ratios is greater than one, the target Fed Funds (#156) rate rises, and conversely. A desired percentage change in the Fed Funds rate (#155) is used in the calculation of the volume of Fed bond purchases (#168). The formulation of equation #155 is similar in principle to the so-called "Taylor Rule" (Taylor, 1993) and adaptations such as the "Mankiw Rule" (2002). In the current version of the model, the equation is not based on econometric estimates of the Fed's policy response function, but an illustration later in this subsection makes use of such estimates and improves the "fit" between the simulation results and historical data.

This description of the model's sequential decision rules has taken us from "interest rate target" to "Fed purchases of bonds" in the bottom panel of Figure 56. To get to interest rates and, ultimately, to aggregate demand, it is necessary to overlay the Fed purchases with the money sector diagram, which is accomplished in the two panels of Figure 57.

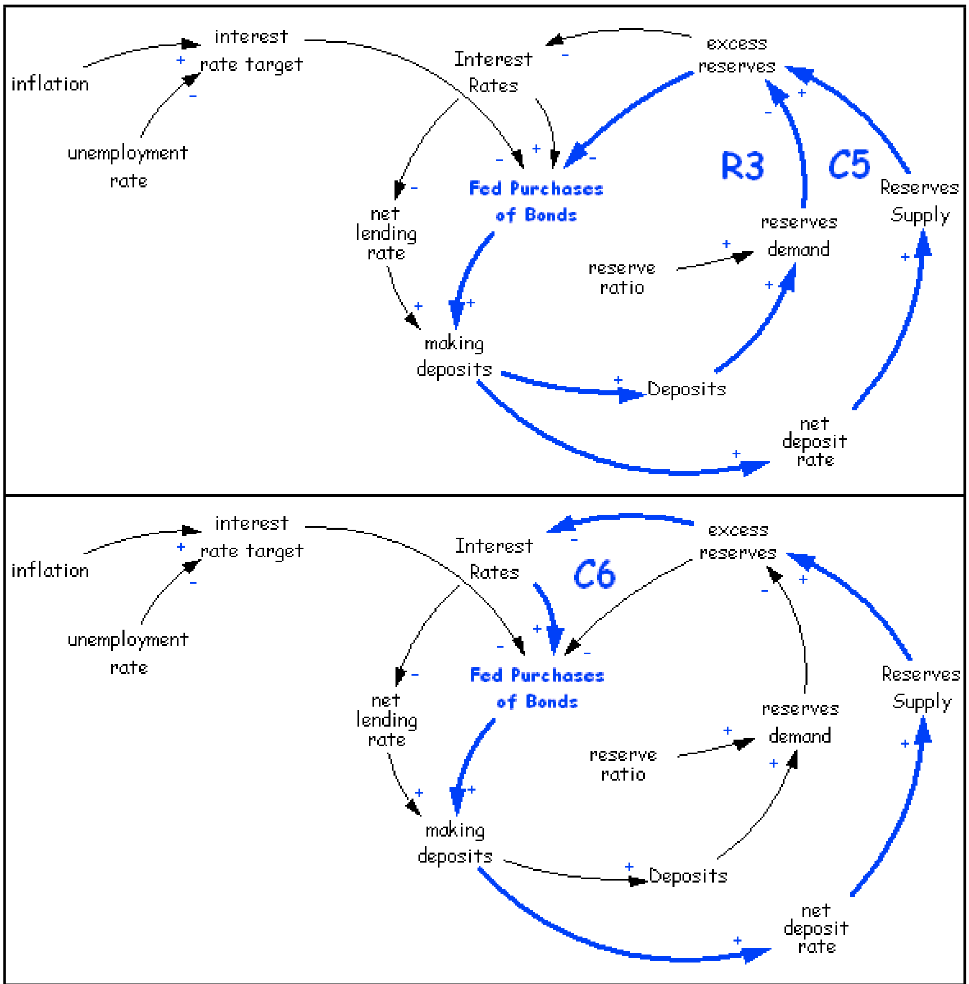


Figure 57. Feedback Loops in the Money Sector Resulting from Fed Purchases of Bonds

When the Fed buys bonds, the sellers receive an increase in their bank deposits, and their banks automatically receive a credit to their reserve account at the regional federal reserve banks. In one respect, the effects of the deposits triggered by the Fed's actions are similar to the effects examined earlier in Figures 50 and 51. The deposits increase reserves demand by an amount determined by the reserve ratio. The deposits also increase reserves supply by the full amount. The significant difference, however, is that money the bond sellers receive from the Fed does not simultaneously drain the reserves of other banks in the system. It is "new" money, and creates an immediate increase in excess reserves that will have the effects on interest rates that we examined earlier.

Once the FOMC has established a target Fed Funds rate and an initial shock to the system occurs, the effect on the Fed Funds rate is almost immediate, and other interest rates respond over a period measured in a few weeks rather than a few months. That sets in motion a series of feedback effects that could—if unchecked—counteract the initial change in the Fed Funds rate. For that reason, the FOMC authorizes Fed staff to enter the open market each week to buy or sell bonds, as necessary to offset market forces that would push the banks' reserves supply in a direction that could cause the Fed Funds rate to depart from the target rate. The policy receives constant maintenance. The formulation of that maintenance is achieved in equation #168. Even when there is no change in the desired Fed Funds rate, the reserves supply and demand ratio established by the initial intervention is maintained by that equation.

Figure 57 is not the end of the story, however. The inflation and unemployment conditions need to receive the effect of the change in interest rates, and Figure 58 illustrates the feedback effect. The top panel of Figure 58 maintains consistency with previous diagrams but is difficult to read. The bottom panel abstracts out just the feedback loops C7 and C8, and the path of influence becomes clear. The loop is closed between the Fed's perception of economic conditions, formulation of a policy to address those conditions, and the impact on those conditions (plus the updated perceptions as conditions change).

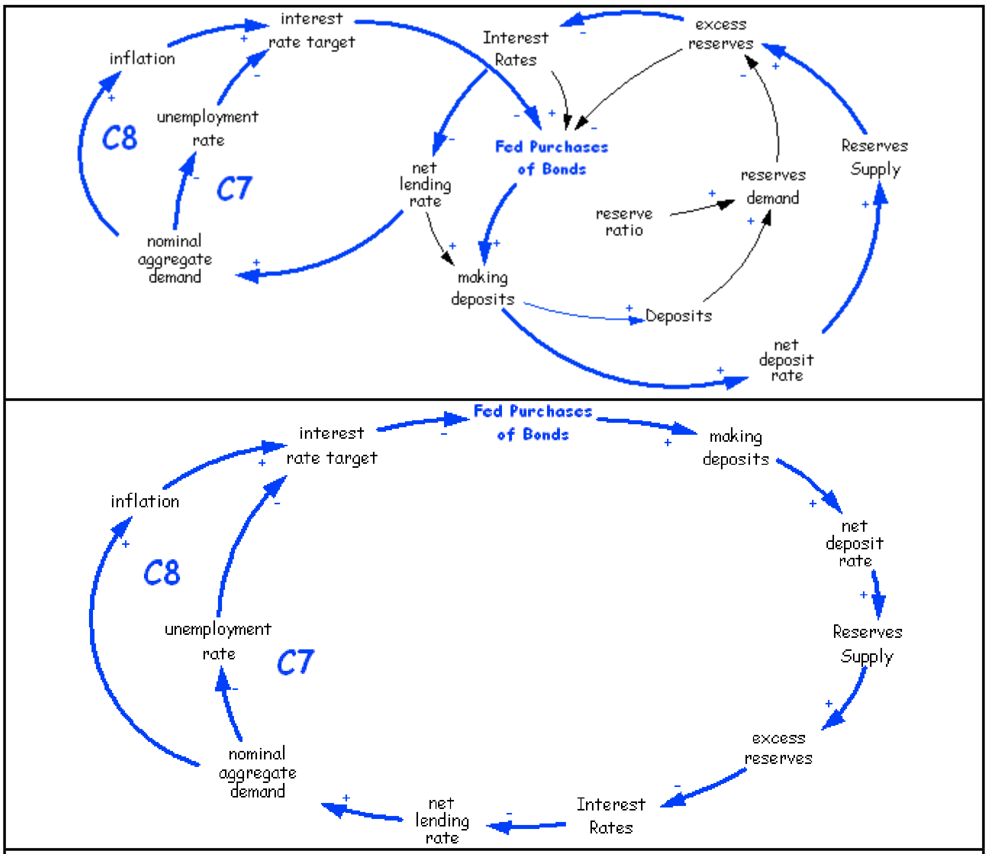


Figure 58. Closing the Loop Between Fed Policy and the Impact on Inflation and Unemployment

The first behavioral illustration of these structural explanations demonstrates the direction of the policy response to changing economic conditions. In addition, it highlights the issue of perception delay. The shock test demonstrates the policy response to inflation and unemployment. It also mimics the response of the economy to the policy. Since the economic conditions are exogenous to this submodel, there can be no actual effect from the model. However, by using a sine wave input function, it gives the policy rule a moving target, enabling observation of how continuous changes in economic conditions trigger policy changes in the model.

Panels A1 and A2 in the top row of Figure 59 illustrate the response of the Fed Funds rate to a sine wave of changing inflation. Note that the interest rise moves (with a lag) in the same direction as inflation, as the structure requires.

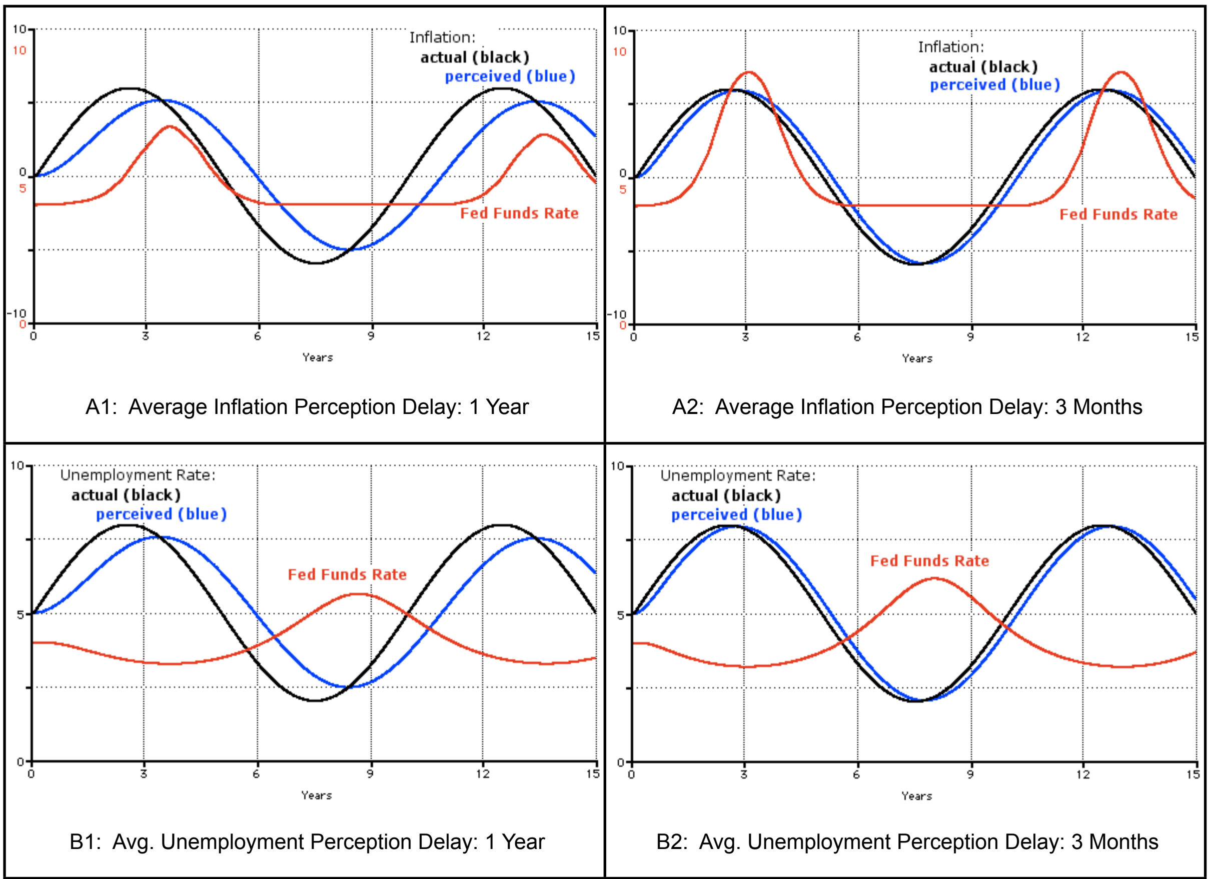


Figure 59. Delayed Perceptions of Economic Conditions Affect Fed Funds Rate Timing

The bottom row (B1 and B2) illustrates the sine-waving unemployment rate and the opposite-direction movement of the interest rate (with a lag). When the unemployment rate rises, the Fed Funds rate falls, and conversely.

The difference between the panels A1 and A2 (and also between B1 and B2) is the length of the perception time assumption. In A1 and B1, the policy makers are assumed to get their information late or update their perceptions slowly, or both—the average delay is one year. In both panels A1 and B1, note that the interest rate response tracks the *perceived* condition in the economy fairly closely, but lags the *actual* condition considerably. In panel A1, the interest rate response to rising perceived inflation occurs at a time when actual inflation has already peaked and turned down. Such an out-of-phase policy is akin to “too much, too late” and could push the economy into a recession. (A recession does not occur in panel A1 because the inflation pattern is driven by the sine wave input and not by the interest rate.) In panel A2, the submodel used the default assumption of a three-month perception delay, and the interest rates rise and fall in a more timely fashion. Panels B1 and B2 illustrate the same point with regard to the unemployment rate.

The sine wave exogenous input is one of several exogenous test inputs that could be used to shock the model. In Figure 60, actual historical data have been used. The inputs to the exogenous model variables "inflation" and "unemployment rate" are the monthly inflation and unemployment rate data from the US over the twenty-year period since 1986. Thus, it is possible to compare the behavior of interest rates in the model with the historical interest rates, when both are responding to the same economic data.

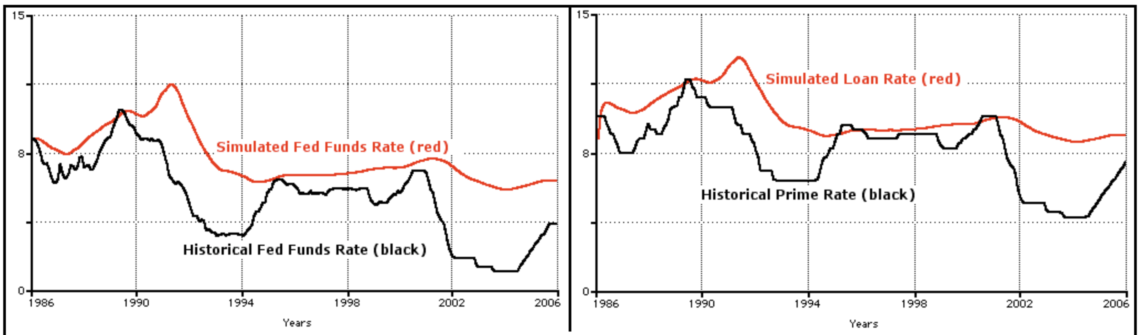


Figure 60. Interest Rate "Fit" with Historical Interest Rates When Historical Inflation and Unemployment Rate are Inputs to Banking Submodel

Whether it is a "good fit" or not is for readers to decide. There appears to be an upward bias in the *MacroLab* interest rate response, or it could be that other forces in the historical economy produced a downward bias in actual interest rates, unrelated to monetary policy. Or, it could be that the crude policy decision rule in the model is only capable of capturing general up-or-down trends. For most pedagogical purposes, that will be sufficient make the point.

The results of another test of the model's response to the same historical input data are presented in Figure 61. This time, instead of equation #157, the so-called "Mankiw Rule" was used to calculate the target Fed Funds rate. Mankiw (2002) performed a regression analysis of historical data on the Fed Funds rate, inflation, and unemployment during the 1990s. His equation

$$\text{Fed Funds Rate} = 8.5 + 1.4 * (\text{core inflation} - \text{unemployment})$$

fits the data for that period very well, with an adjusted R^2 of .85. His equation was substituted into the "net chg in target FFR," and "perceived inflation by Fed" and "perceived UR by Fed" replaced "core inflation" and "unemployment." Use of the Mankiw's equation improves the correlation between the behavior of the model's interest rates and historical interest rates.

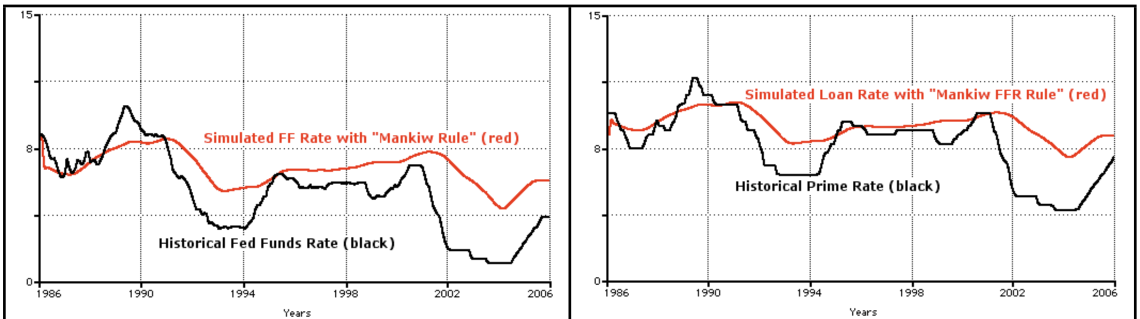


Figure 61. Use of the Modified "Mankiw Rule" in the Setting of the Target Fed Funds Rate When Historical Inflation and Unemployment Rate are Inputs to Banking Submodel

In his discussion of the equation, Mankiw (2002, p. 37) says, "this tight fit has profound implications for understanding monetary policy. … The Fed raises interest rates in response to higher inflation to cool the economy [and] responds to high unemployment by cutting interest rates to stimulate aggregate demand."

His regression model does provide empirical support for hypotheses about the *motivation* of monetary policy makers, and that is important when writing decision rule equations. However, the regression model provides no glimpse into the *process* of converting policy motivations into policy outcomes over time. For that purpose, a different model is needed. The behavior of a *dynamic process model* should reflect actual history, but it should have the added benefit of clarifying how and why such behavior developed over time. Feedback diagrams based on stock-and-flow structure, when coupled with simulation capability, enable connection of structure and behavior. *That* has profound implications for understanding policy.

5.11 Exchange Rate Submodel

In the "gains from trade" discussion in section 7.3.6, the exchange rate issue was postponed. Now we consider it. Mankiw (2007, chs. 13-14) and McConnell/Brue (2005, ch. 21) emphasize three influences on the exchange rate between two currencies: relative prices, relative aggregate demand, and relative interest rates, summarized as follows (with the obligatory *ceteris paribus* qualification for each):

1. When US prices rise more than RW prices, the value of the dollar falls.

2. When the US increases its imports from the RW more than the RW increases its imports from the US, the value of the roller rises and the value of the dollar falls.

3. When US interest rates rise more than interest rates in the RW, the value of the dollar rises.

The feedback loop diagram in Figure 62 is derived from the exchange rate stock-and-flow structure in Figure 63. Both diagrams—and the underlying equations in Figure 64—are consistent with the three basic hypotheses listed above. In the feedback diagram, an increase in US prices reduces RW demand for US goods (expressed first in foreign currency and then divided by the exchange rate to convert to US currency). That reduces US net exports, increases the relative supply of dollars in the RW, and lowers the exchange rate. To see the representation of the second hypothesis, assume US demand increases. The increase in US payments for imports would decrease US net exports, increase the relative supply of dollars in the RW, and reduce the exchange rate. The third hypothesis is evident when an increase in US interest rates is assumed. That increases the net capital flow to the US, as dollar-denominated securities appear more profitable. The resultant decrease in the relative supply of dollars in the RW raises the exchange rate.

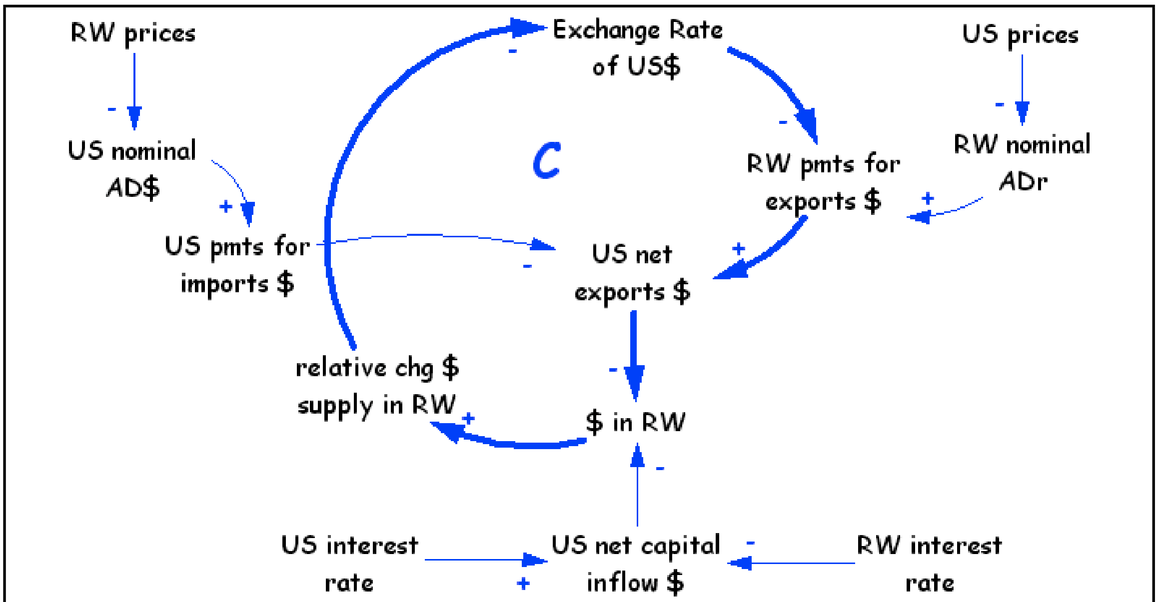


Figure 62. Exchange Rate Determined by Relative Change in Supply of Dollars in the RW (and Rollers in the US, not shown)

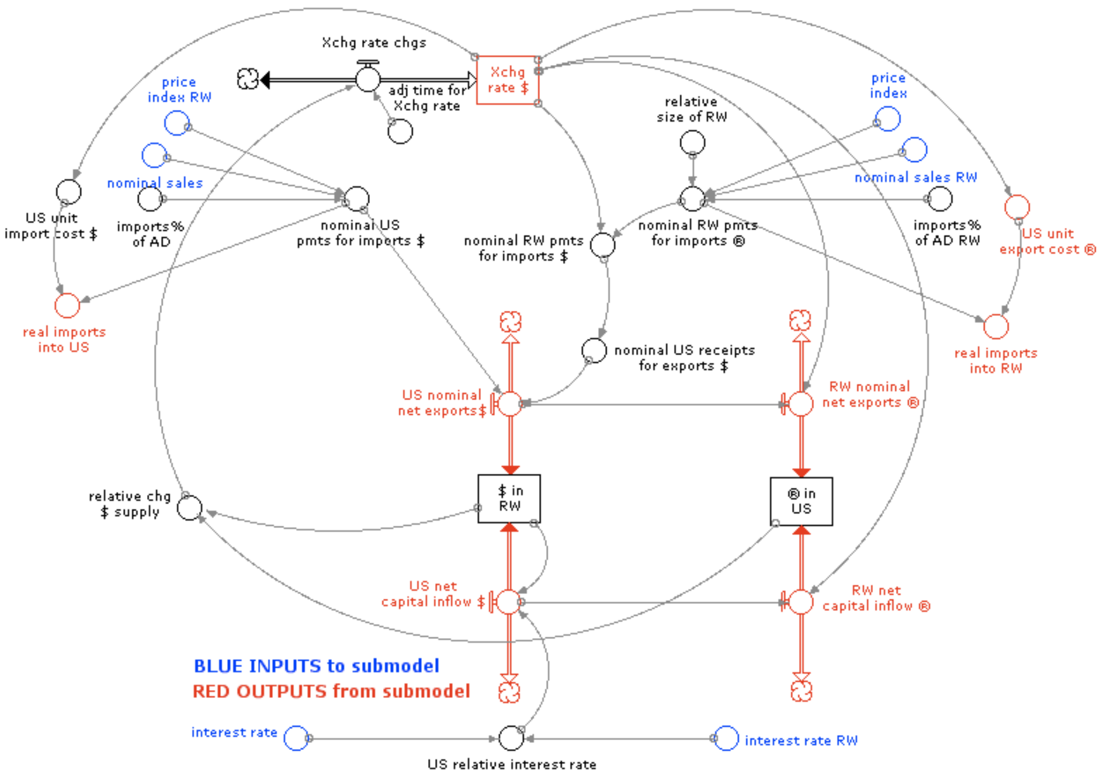


Figure 63. Exchange Rate Submodel

The feedback loop is visible in the stock-and-flow structure of the submodel. In Figure 63, follow the links from Xchg rate $ (#176 in the equation list below) to nominal RW pmts for imports $ (#187) to US nominal net exports $ (#182) to relative chg $ supply (#179) and back to the exchange rate. The stock-and-flow diagram also includes the parallel feedback loop running through the stock of foreign currency in the US (® in US, #184).

The relative supply equation (#179) compares both currency stocks to compute a *relative* change. Despite the word "supply" in the equation name, equation #179 is actually measuring *net change* in the stocks. The net change is due to inflows (net export payments by the US) and outflows (net capital inflows to the US), which are measures of supply and demand, respectively. Thus, relative supply and demand for both currencies drives changes in the exchange rate.

The logic of the three hypotheses is also visible in the stock-and-flow structure. The increases in both US prices (top right) and US demand (left) put downward pressure on the exchange rate by reducing US net exports and the demand for dollars needed for payments. The mechanism for the interest rate hypothesis is the capital inflow of dollars to the US (and out of the RW). The hypotheses are also revealed by scrutiny of the relevant equations in Figure 64, but readers who are tired of equations by now may want to skip straight to the simulation examples, where the submodel tests for the hypothesized behavior.

Exchange Rate Submodel Equations

		Left Side of Equation	Right Side of Equation	units
176	□	Xchg rate $(t)	Xchg rate $(t - dt) + (Xchg rate chgs) * dt INIT = 1	® / $
177	⇔	Xchg rate chgs	((init(Xchg rate $) * (1/relative $ supply)) -Xchg rate $) / adj time for Xchg rate	® / $ / year
178	○	adj time for Xchg rate	.02	years
179	○	relative $ supply	($ in RW / ® in US) /(init($ in RW) / init(® in US))	1/1
180	□	$ in RW(t)	$ in RW(t - dt) + (- US net capital inflow $ - US nominal net exports$) * dt INIT $ in RW = 1	$
181	⇔	US net capital inflow $	$ in RW*US relative interest rate	$/year
182	⇔	US nominal net exports$	nominal US receipts for exports $ - nominal US pmts for imports $	$/year
183	○	US relative interest rate	(interest rate-interest rate RW) / interest rate RW	1/1
184	□	® in US(t)	® in US(t - dt) + (- RW net capital inflow ® - RW nominal net exports ®) * dt INIT ® in US = 1	®
185	⇔	RW net capital inflow ®	-US net capital inflow $ * Xchg rate $	®/year
186	⇔	RW nominal net exports ®	-US nominal net exports$ * Xchg rate $	®/year
187	○	nominal RW pmts for imports $	nominal RW pmts for imports ® /Xchg rate $	$/year
188	○	nominal US pmts for imports ®	nominal US pmts for imports $ * Xchg rate $	®/year
189	○	nominal US receipts for exports $	nominal RW pmts for imports $	$/year
190	○	US unit import cost $ experimental	price index RW / Xchg rate $	1/1
191	○	US unit export cost ®	price index * Xchg rate $	1/1
192	○	real imports into US	H: historic real imports/1000 E: nominal US pmts for imports $ / US unit import cost $ experimental	$/year
193	○	real imports into RW	nominal RW pmts for imports ® / US unit export cost ®	®/year
		interest rate	Main Model	
		interest rate RW	Main Model RW	
		nominal RW pmts for imports ®	Data Sector	
		nominal US pmts for imports $	Data Sector	
		price index	Main Model	
		price index RW	Main Model RW	
		historic real imports	Data Sector	

Figure 64. Exchange Rate Submodel Equations

Figure 65 shows the results of the three *separate* simulation tests of the exchange rate hypotheses discussed above. The test results in the top panel came from the exchange rate submodel. The full model generated the results in the bottom panel. In each test for both models, there was a 10 percent step increase in one input variable. In each test of the submodel, all other exogenous input variables remained constant. In the full model, all variables were free to move after the shock.

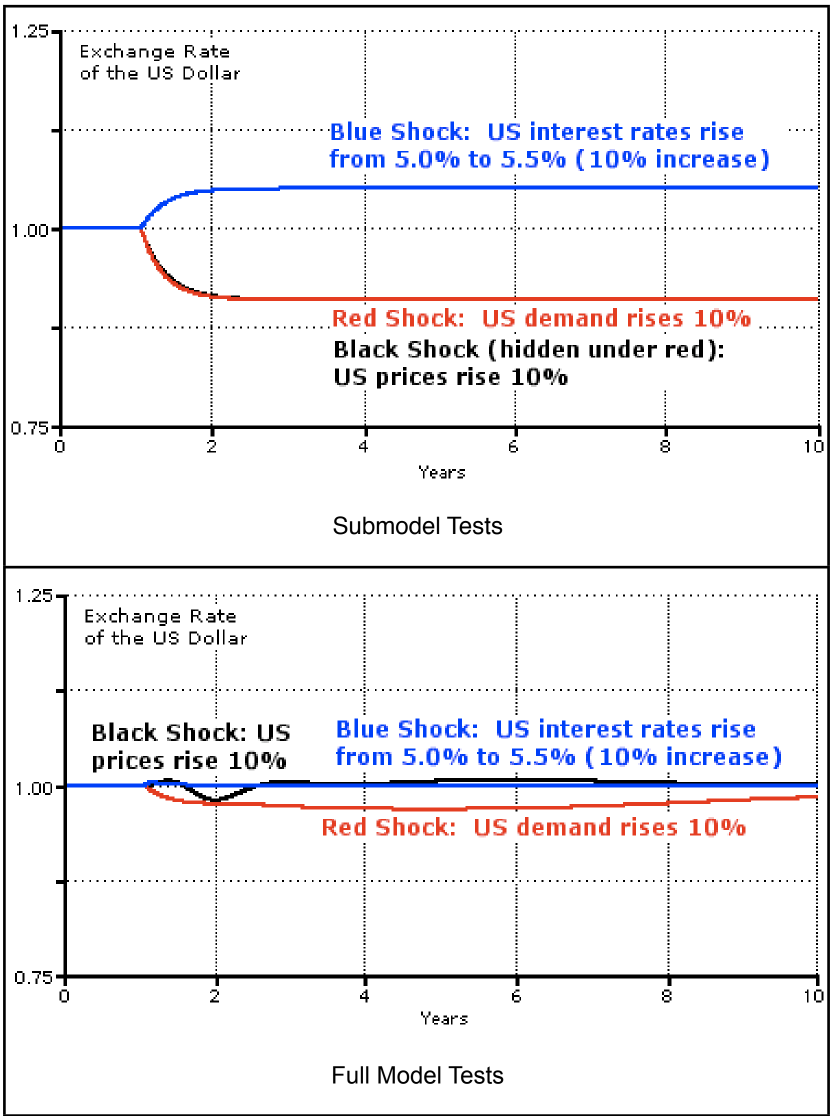


Figure 65. Separate Tests of Each Hypothesis

The isolated tests in the submodel show the expected results. The exchange rate moves unmistakably in the "right" direction during each test. The results in the full model are not inconsistent with the hypotheses, but the magnitudes are much smaller than in the submodel experiment. In one case—the interest rate shock—a microscope is needed to see the slight rise in the exchange rate, and even that effect is temporary as the interest rate (on a separate graph) soon settles down near its initial value. The price effect is sharp but temporary, as price also returns to its initial level. Only the demand shock has a sustained effect, but it also seeks a return to its original equilibrium value as the simulation ends in the tenth year.

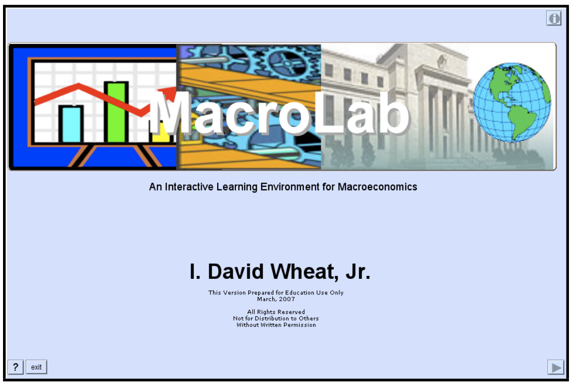
5.12 The Value of Simulation

Throughout this chapter, a caveat has been repeated: *When submodels contain exogenous inputs that are endogenous to the full model (and endogenous in real economic systems), it is likely that the behavior of the submodel, when shocked, will be somewhat different from the behavior of the full model if shocked the same way*. The significance of this point is amplified when there are several exogenous inputs that *interact with each other* when endogenized. The tests of the exchange rate hypotheses in the submodel and the full model illustrate what can happen.

The full model tests, of course, do not mean that the hypotheses are wrong. An axiom among modelers is that "all *models* are wrong, but some are useful." Both the full model and the submodel are certainly wrong in the sense of being only simplified representations of reality. The exchange rate results in the full model *might* mean the model needs structural adjustment or better parameter estimates. However, a different interpretation is possible, especially since the submodel produces the hypothesized behavior in magnitudes and patterns that are easy to see and interpret. When "everything else" is literally held constant, the hypotheses are supported, and that's all the hypotheses claim.

When the entire system is subjected to a shock, system-wide hypotheses are necessary to take into account the interaction and feedback effects. Such hypotheses are difficult to develop with words and graphs. Feedback diagrams can be helpful in the development—but not the testing—of such hypotheses. The value of a simulation model in hypotheses testing has been illustrated in the exchange rate hypotheses examples. Such a model must be accessible, however, to students and scholars from diverse backgrounds and with diverse learning styles and preferences. The next—and final—document in this thesis introduces the interactive learning environment (ILE) of *MacroLab*. The examples provided in the ILE document are intended to illustrate how the feedback diagramming approach is integrated with the simulation experiments when teaching macroeconomics.

MacroLab: The Interactive Learning Environment



This final chapter is intended as a simple guide to using the interactive learning environment (ILE) of *MacroLab*. As such, it has two purposes. First, it aims to demonstrate how students use the ILE in a macroeconomics course. The focus will be on how the ILE integrates feedback loop analysis and simulation activities. The second purpose of the chapter is to provide instructions for readers interested in exploring the ILE and experimenting with simulation options.

The ILE and its underlying system dynamics model of nearly 500 equations have been developed with system dynamics software called *STELLA* (http://www.iseesystems.com). In general, a file created with a STELLA application has three levels of information: the interface level (where the ILE is visible), the model level (where the stock-and-flow structure is constructed), and the equation level (containing a comprehensive list of equations in the model). Beginning with version 9 of *STELLA*, navigating between the levels is accomplished by simply clicking on left-hand side tabs. Earlier versions of the software have small black triangles pointing up or down to indicate options for moving to a higher level (e.g., the interface) or a lower level (e.g., the equations).

1. Layout and Navigation

Figure 66 displays a site map of the interface level of the *MacroLab* file. The site map is always available to the user who gets lost. To go to the site map, merely click on the question mark (?) button at the bottom of any page at the interface level. Each button on the site map is a link to the page indicated by the button name.

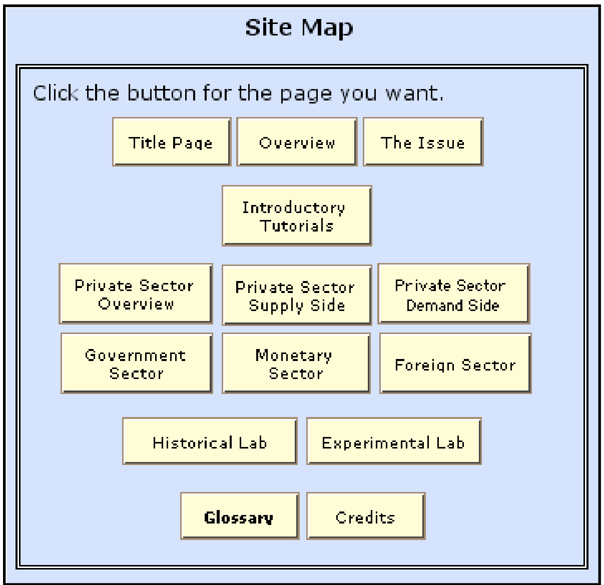


Figure 66. Site Map for *MacroLab*

From the Title Page, the user should advance to the Overview page by clicking obvious "next" buttons. Figure 67 displays the Overview page and its links to the sections of the ILE devoted to the four main sectors of the model: the simple private sector, the government sector, the banking sector, and the foreign sector. Another button is linked to the introductory tutorials on causal links and feedback loops. The two colorful buttons at the bottom are links to the "simulation labs" where control buttons, time series graphs, and various options are available for using the model. The simulation experiments

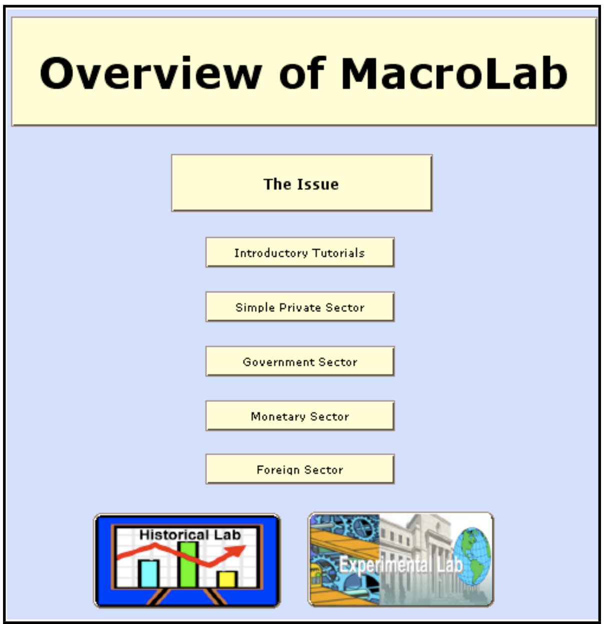


Figure 67. Overview

are conducted on the Experimental Lab page, where the time series graphs display only the behavior of the model and not historical data. The Historical Lab page is used for either viewing historical time series data for the US economy, or for comparing the historical performance of the US economy and the performance of *MacroLab*. Such a comparison makes sense only when *MacroLab* is running in historic mode.

On both simulation lab pages, the user can click a switch to make the model run in either experimental or historic mode. The default option is experimental mode, and "re-set" buttons restore all default options. The mode choice depends on whether the user's purpose is to see how the model behaves under various parameter or structural assumptions, (in which case, the experimental mode would typically be selected) or whether the purpose is to see how the model's behavior compares with actual historical behavior of the US economy.

The main functional distinction between the two modes is the way the stocks are initialized. In experimental mode, the stocks always have the same initial values. In historic mode, stocks take on the initial values that existed in the particular historical year in which the simulation begins (e.g., 1986 or 1993), and the model is simulated from that initial disequilibrium state. After the simulation begins in historic mode, stocks change endogenously based on the same equations used in the experimental mode. The foreign submodel does not function in historic mode; instead, the US sector relies on historical exogenous values for U.S. imports, exports, and net capital flows.

The large button labeled "The Issue" is a recent addition to the Overview page and, as such, it is linked to a page that is still under construction. In the spirit of the admonition to model problems and not systems, a modification-in-progress is the establishment of a "problem" that will provide focus to the study of the economic system during the macroeconomics course. Tentatively, the level of employment (or the rate of unemployment) has been selected as "the issue." Getting a job and remaining gainfully employed is an issue of relevance to most students. Moreover, studying the way that jobs are created (and destroyed) requires consideration of a host of relationships in the economy. In other words, using the issue of employment as the searchlight for exploring the economy, students will discover much about the way the entire economic system is structured. Moreover, the relationships uncovered will help construct (or renovate) students' mental models of the US economy. Finally, such a focus enables a start-small-and-build-out approach to learning. An extended study of the causes and effects of employment (and the unemployment rate) will inevitably intersect with such topics as GDP, inflation, interest rates, exchange rates, taxes, and government spending. However, the context of those topics will be more obvious when the fundamental question is always: "How does that relate to employment?" The Issue page should be fully functional by the 2007 summer semester.

2. Historical Lab

Figure 68 displays the Historical Lab page. Note that the experimental mode switch is ON ("green"). The default population growth rate is zero in experimental mode, which is why the red labor force line is flat on the graph. The pink curve, on the other hand, traces the growth of the actual US labor force stock over the twenty-year period since 1986. If the user wanted to see the model's projection of the labor force over that time period, then the historic mode switch should be ON. Note, however, that a few additional settings are necessary before the model will be ready to run in historic mode, and those settings require going to the Experimental Lab. After that, the user would return to the Historical Lab to run the simulation and view the results. Turning the pages of the graph will reveal additional historical time series data and corresponding model estimates for the same variables.

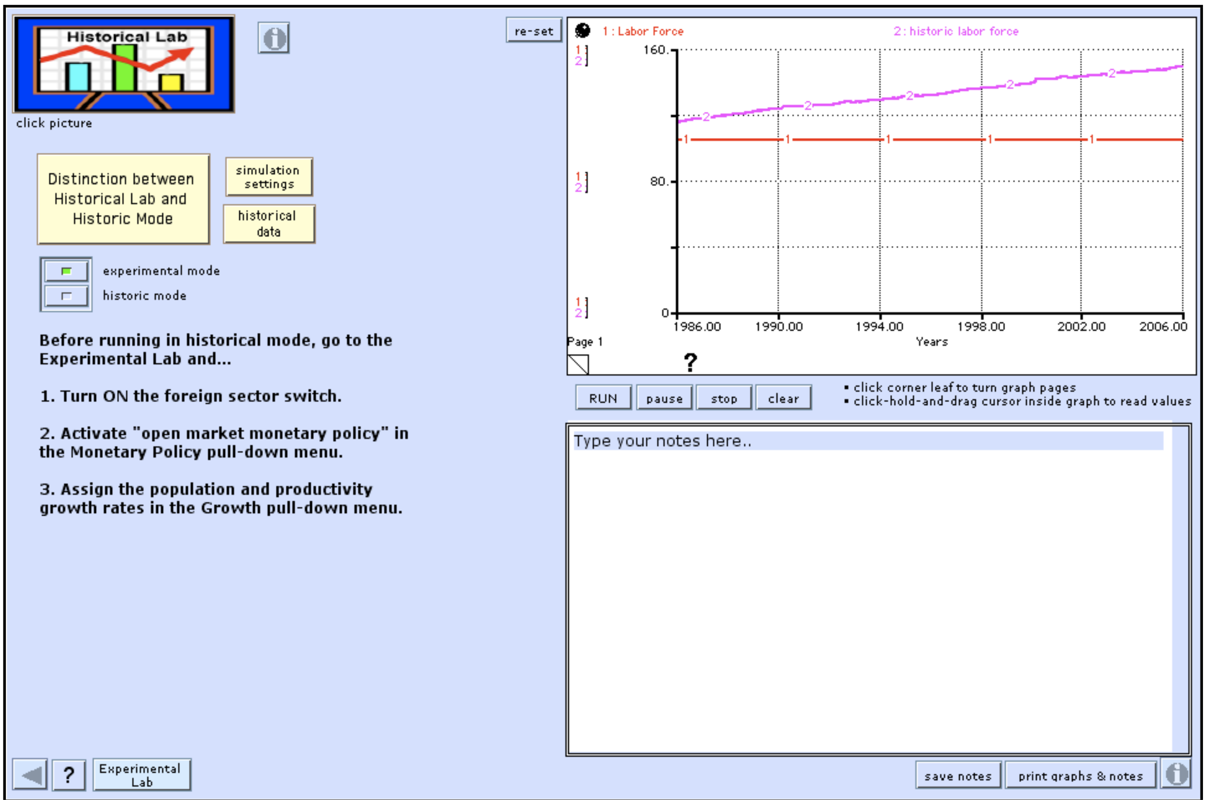


Figure 68. Historical Lab (in experimental mode)

The time period of the simulation is selected by clicking the "simulation settings" button. As Figure 69 shows, there are many other options available, but most users of the model should change only the "From" and "To" dates. When historic mode is operational, pick the desired calendar year period for the simulation length. When in experimental mode, the length of the simulation depends on the user's purpose. If the primary purpose is to view short-run changes in unemployment, for example, a simulation period "from" 0 "to" 10 years might be a good choice. That would be long enough to observe at least one and maybe two inventory cycles but not so long that the interesting variations were compressed too tightly to be discernible. On the other hand, significant changes in the stock of capital would require a longer simulation period.

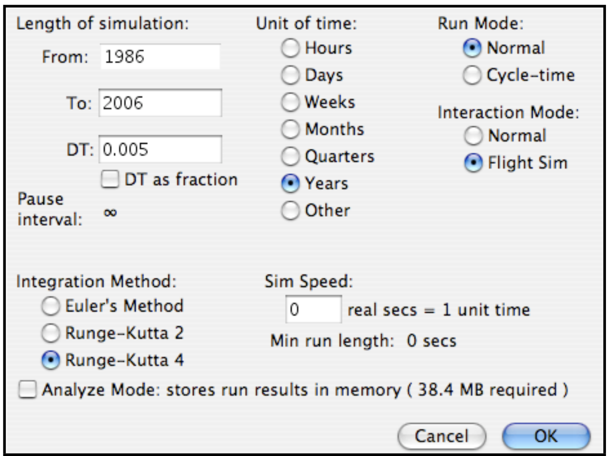


Figure 69. Simulation Settings: Users Should Change Only the Length of the Simulation

It is important, however, to remember that *MacroLab* is primarily a short-term business cycle model. When in experimental mode, a simulation length that spanned many decades or a century might be technically possible (i.e., the model would run without "exploding"), but the results would be misleading. The constant value assumptions for many exogenous parameters in the model would be incorrect over such long time periods. More importantly, some key real-world structure could be different in distant time periods, but the model's structure would remain the same. Floating exchange rates became the norm only in the mid-1970s, for example. Also, prior to the 1950s, the Federal Reserve System was part of the Treasury Department and lacked the independence of modern central banks. Moreover, when the model is running in historic mode, there could be an additional problem. It is recommended that simulation periods not begin earlier than 1980 because not all historical stocks in the model's current database contain data for years prior to that date. The model might appear to run satisfactorily from, say, 1950, but hidden from the user's view might be the fact that a certain historical stock was not initialized accurately.

Before leaving the Historical Lab page, it is worth repeating the distinction between Historical *Lab* and historic *mode*. In the Historical *Lab*, users see actual historical data on the time series graphs, regardless of which mode (experimental or historic) is operating. In historic *mode*, the model is trying to replicate the actual historic behavior of the US economy. It does so by beginning the simulation with the same conditions that existed at that "time" in US history. For example, if the simulation began in 1990, the initial values for the money supply, employment, interest rates, etc., would be the actual values that existed in 1990. After that initial beginning, however, the behavior of the model would depend on all the relationships in the model. It would not keep using actual data throughout the simulation. In experimental mode, the model depends on the same structural relationships as in historic mode, but the initial values are set by default in the model (e.g., initial employment = 100 million persons) or by the user (e.g., price adjustment time). Figure 70 illustrates an historic mode simulation, in which *MacroLab* tracks the historical unemployment rate closely until the two patterns diverge near the end of the simulation period.

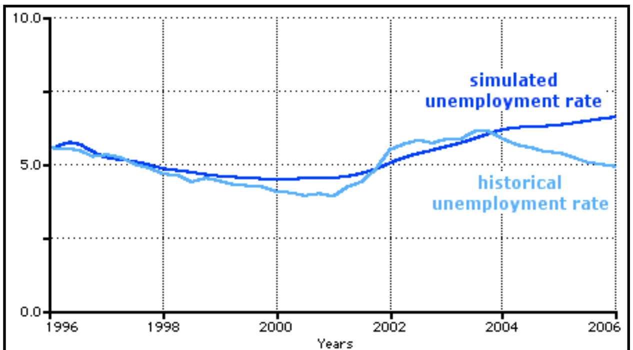


Figure 70. Historic Mode Simulation, 1996-2006 Historical (light blue) & Simulated (dark blue) Unemployment Rate

3. Experimental Lab

Figure 71 displays the Experimental Lab page, and the experimental mode is ON. The unique feature of the Experimental Lab page is the user capability to select the structure of the economy and many parameter values before (and during) a simulation. The simple Private Sector is always ON ("green") and cannot be turned OFF. By default, the Government and Banking sectors turn ON when the re-set button is clicked, but either or both may be turned OFF. The default condition of the Foreign sector is OFF. The Foreign sector should *not* be ON unless both the Government and Banking sectors are also ON. The pull-down menu on the Experimental Lab page (Figure 72) provides users with dozens of opportunities to examine the implications for behavior when parameter assumptions are changed.

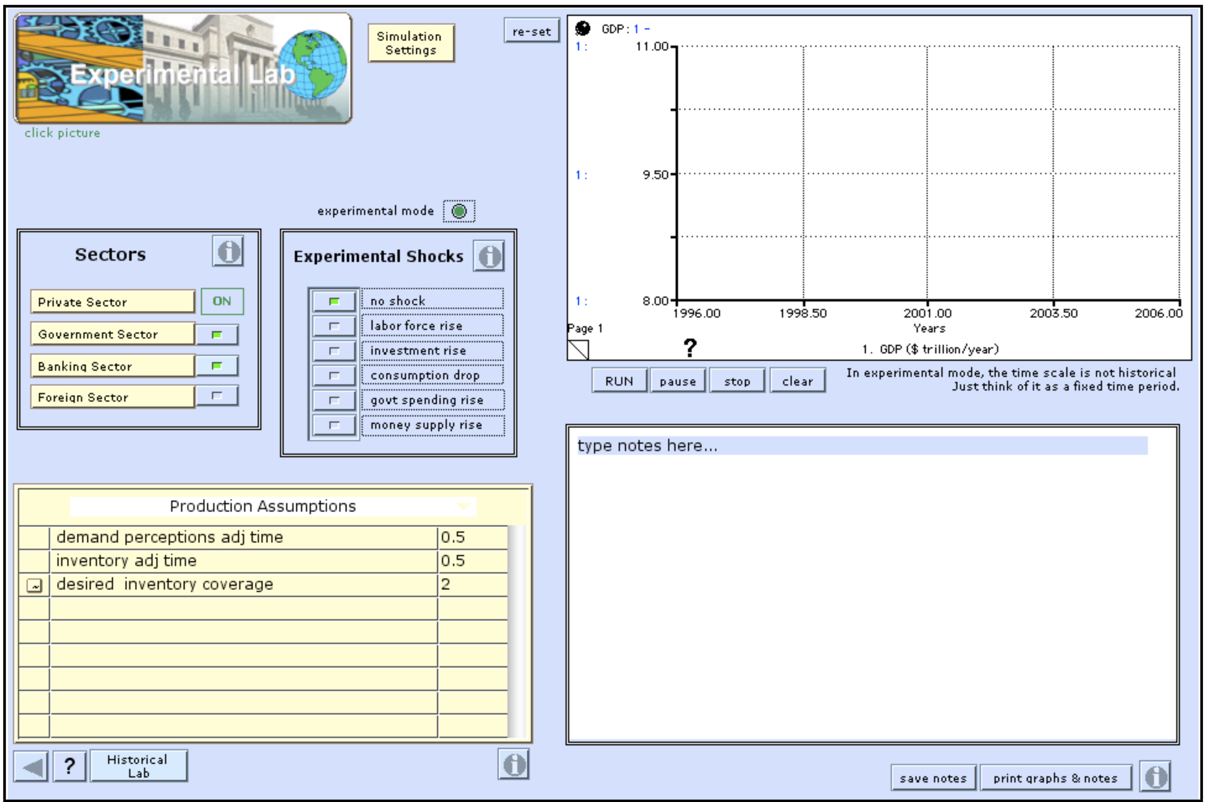


Figure 71. Experimental Lab

The user also has the exogenous power to "shock" the model and observe the behavior patterns that emerge. Clicking "money supply rise," for example, causes a sudden $40 billion injection of reserves into the commercial banking system. The "consumption drop" switch causes a sudden reduction in consumers' propensity to spend (and increases their propensity to save), amounting to about 2 percent of disposable income. These and other switches enable putting the model economy into a simulated

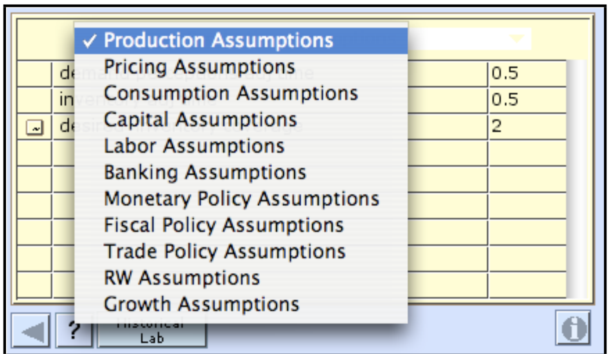


Figure 72. Pull-Down Menu Provides Options for Changing Parameter Assumptions

recession or expansion. Following the shock of a money supply increase, for example, the unemployment rate oscillates relatively more when price adjustments occur relatively slowly (Figure 73).

Before doing the simulation experiment in Figure 73, students would be required to study the feedback loop structure in Figure 74. They would do some "thought experiments" about the effect on employment if prices were "sticky"; i.e., if prices adjusted slowly to sudden changes in demand (up or down). In the threaded discussion board for the distance learning course, they would post their hypotheses for the behavior of loop C1. Then they would be assigned a simulation exercise, such as the one in Figure 73, in order to "test drive" their hypotheses.

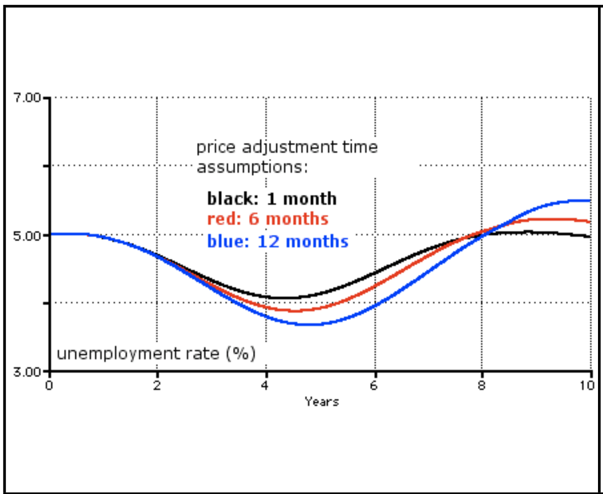


Figure 73. Experimental Mode Simulation of Unemployment after Money Supply Rises

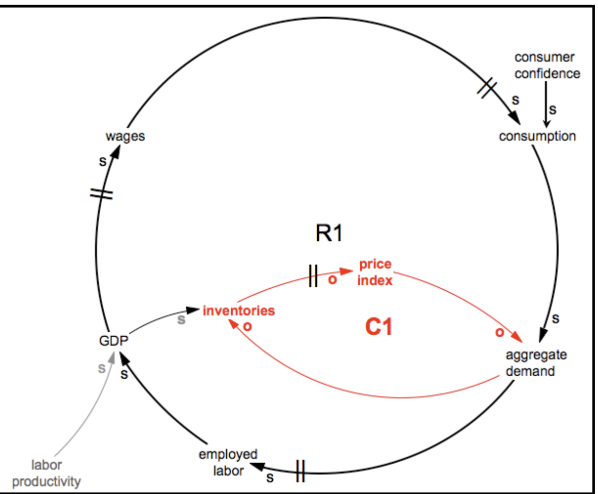


Figure 74. Possible "Sticky Price" Loop, C1

4. Sector Tutorials

From the Overview page, the user can link to sections within the ILE that correspond to the structural sectors in the model economy: simple private sector, government sector, banking sector, and foreign sector. The page for each of those sectors is similar in layout, and Figure 75 displays the page for the Demand (i.e., nominal) side of the simple private sector.

The large buttons in the top half of the page are text buttons with information for students to read. The bottom half contains buttons that can display different views of the private demand side of the model economy. The "Intro to Demand Side" button, for example, opens a slide show that illustrates a set of feedback

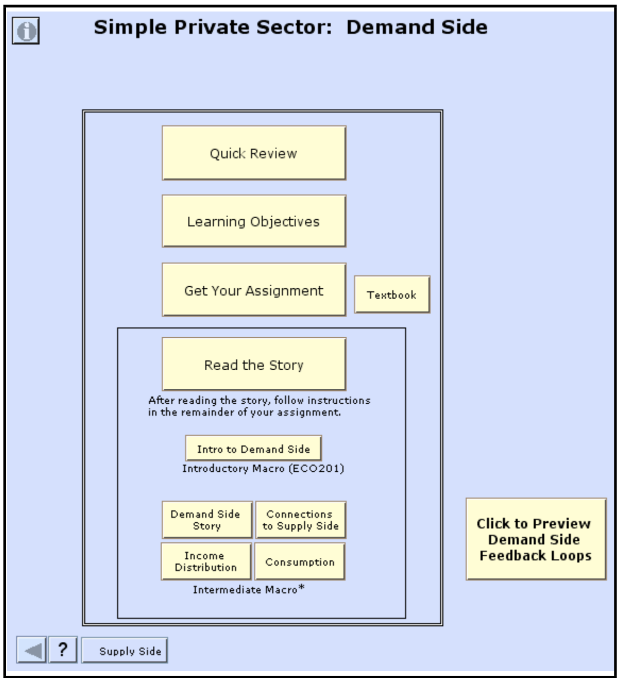


Figure 75. ILE Page for Demand Side

loops, one at a time with annotation. The "preview" button on the right provides a one-slide summary (Figure 76). The other four small buttons on the page in Figure 75 actually take the students to the model layer and display an unfolding, annotated picture of the stock-and-flow structure for different submodels on the private demand side. Each of the other sector tutorial pages is similar to this one, in terms of layout and function.

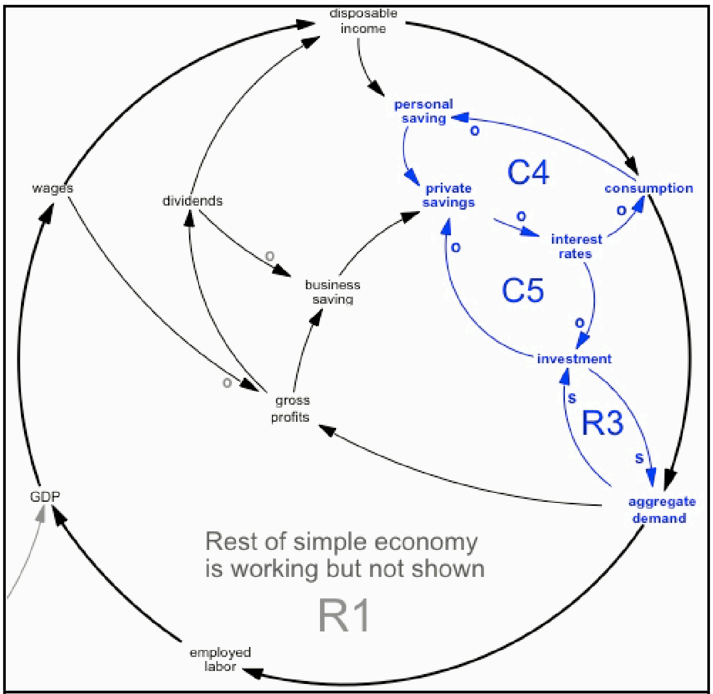


Figure 76. The Preview of the Private Demand Side

5. Final Comments

This version of the interactive learning environment will be the nucleus for a future electronic textbook version of *MacroLab* that will be accessible via the Internet. The highest priority for the next phase is interactive hypothesis development with "coaching" from the ILE. The fundamental objective will remain the same—to improve learning the dynamics of an economy by studying its feedback structure.

References in the Model Documentation Section

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review*, *12:3*, 1-28.

Beam, A. (2005). A Textbook Case of Competition. *The Boston Globe*, p. www.boston.com/ae/books/articles/2005/08/25/a_textbook_case_of_competition/.

Blanchflower, D. & Oswald, A. (1994). *The Wage Curve.* Cambridge, MA: MIT Press.

Blinder, A. S. (1997). On Sticky Prices: Academic Theories Meet the Real World. In N. G. Mankiw (Ed.), *Monetary Policy*. (pp. 117-154). Chicago: The University of Chicago Press.

Fisher, D. (2001). *Intermediate Macroeconomics: A Statistical Approach.* Singapore: World Scientific Publishing Company.

Ford, A. (1999). *Modeling the Environment* (paperback ed.). Washington, D.C.: Island Press.

Forrester, J. W. & Senge, P. M. (1980). Tests for building confidence in system dynamics models. *TIMS Studies in the Management Sciences*, *14*, 209-228.

Friedman, M. (1957). *A Theory of the Consumption Function.* Princeton, NJ: Princeton University Press for the National Bureau of Economic Research.

______ (1963). *Inflation: Causes and Consequences.* New York: Asia Publishing House.

Mankiw, N. G. (2007). *Brief Principles of Macroeconomics* (4th ed.). New York: Thomson Southwestern.

McConnell, C. R. & Brue, S. L. (2005). *Macroeconomics: Principles, Problems, and Policies* (16th ed.). New York, NY: McGraw-Hill Irwin.

Richardson, G. P. & Pugh, A. L. (1989). *Introduction to System Dynamics Modeling.* Waltham, MA: Pegasus Communications.

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World.* Boston, MA: McGraw-Hill Companies.

Wright, C. (1969). Saving and the Rate of Interest. In A. Harberger & M. Bailey (Eds.), *The Taxation of Income from Capital.* Washington: The Brookings Institution.