Chapter 2
Get Started with Macro Modeling

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2.1 Introduction

In this chapter, we demonstrate a way to get started with system dynamics (SD) modeling of a national economy. The essence of our approach is a modular framework that can be customized to reflect a modeler's hypotheses about how a particular economy works. We call it the *MacroLab* Template *(*the 'Template'*)*.

As a tool for macro modeling, the Template evolved from twenty years' experience teaching macroeconomics with an SD-based model called *MacroLab*, initially a very simple model designed to demonstrate and explain feedback dynamics in an introductory course. A more comprehensive version was published in Wheat (2007).[1] The current version, *MacroLab20,* retains some of the original features, particularly the integration of demand-side and supply-side theories through an organizing framework of stocks, flows, and feedback loops. Now, however, *MacroLab* is fully customizable, thanks to the Template—a 'plug and play' modular framework that motivates exploring, comparing, and combining various hypotheses about key sectors of a macroeconomic system. Given our perpetual motivation to learn more about how economies work, we value this framework because it facilitates comparison and consideration of alternative theories in the context of empirical realities.

Our message here is that the Template is useful not only for customizing *MacroLab*; it can be used as a framework for *any* macro model. It can even be used as a learning tool by those who are curious about the various ways that SD-based economic modeling is done. The belief that such curiosity exists was a prime motivation for this book, and we hope this chapter meets the expectations of our readers—both conventionally trained economists as well as those who learned economics as a second language.

[1] Two published SD-based macro models (Mass 1975 and N. Forrester 1982) pre-dated *MacroLab* and inspired its development. Yet, both were closed economy models, and Forrester's self-described "rudimentary financial system" (p. 73) was an IS-LM structure while the Mass model had no financial sector. The lectures notes of Radzicki (1993) following his visit to the University of Bergen were also useful. Published narratives of J.W. Forrester's 'National Model' (e.g., Forrester, Mass, and Ryan, 1980) were inspirational as well, although his model was never published and was still under development when he died in 2016. Eberlein (2020) plans to complete and publish Forrester's long-awaited model.

After describing the Template in section 2.2, we devote two sections to a simple demonstration model. Section 2.3 provides an overview of its structure and behavior, and section 2.4 provides step-by-step guidance for building it. The final section includes some thoughts on using the Template for comparing alternative macro theories.

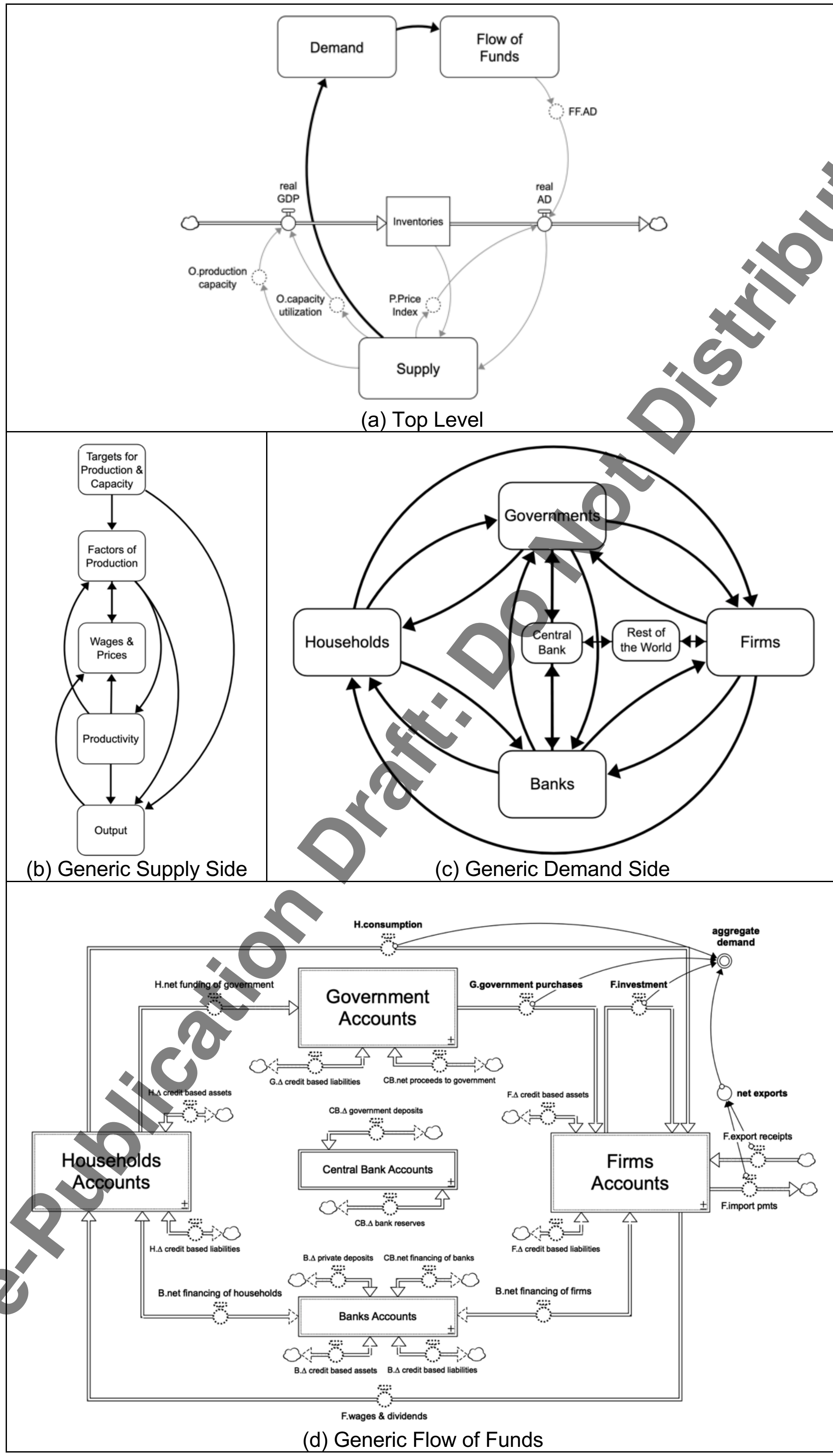
2.2 *MacroLab* Template

The Template is a software framework that facilitates the theory-building task of combining macroeconomic identities and behavioral hypotheses into a coherent dynamic macro model. Of course, the burden remains on the modeler to justify confidence in the hypotheses. The framework motivates constructive thinking about theory and how it could be organized in a simulation model, but it does neither the thinking nor the organizing; that's the modeler's job.

Although it is a theory-neutral tool, the Template puts two stakes in the ground before the modeler takes over. First, it makes room for both supply and demand 'sides' of an economy. The modeler retains control over where to put the emphasis, but the Template discourages thinking that a modern macro model can ignore one side or the other. In addition, the Template connects the two with a pivotal stock-flow-feedback process involving gross domestic product (GDP), inventories, and aggregate demand (AD). It makes a clear operational distinction between GDP and AD—two separate activities (producing and purchasing) involving different institutions that respond to different incentives. Unifying the supply- and demand-side perspectives with this stock-flow-feedback process is what defines the *MacroLab* Template.

The Template has three levels, with most equations at the third level. Panel (a) in Figure 2.1 depicts the top level we have mentioned: aggregate Demand and Supply sub-models plus a stock-flow-feedback process governed by three identities.[2] By definition, real GDP is the product of production capacity and capacity utilization; and real AD is the quotient of (nominal) AD and the price index. A numerical difference between a stock's inflow and outflow is reflected in a change in the level of that stock. Thus, real GDP $\equiv$ real AD + change in inventories.

[2] In Figure 2.1, note the difference between icons for stocks and those for sub-models. Stock icons are rectangular while sub-models are oval-shaped. The flow icon resembles a pipeline with a valve on top that controls the rate of the flow. Metaphorically, flow equations open and close the valves. We used *Stella Architect* software (https://www.iseesystems.com/store/products/stella-architect.aspx), to develop the *MacroLab* Template.



(a) Top Level

(b) Generic Supply Side

(c) Generic Demand Side

(d) Generic Flow of Funds

Fig. 2.1 Generic Sub-Models in *MacroLab* Template

Panels (b) and (c) display the second level containing generic sub-models on the supply side and demand side, respectively. When modelers use the Template, they start with an empty theoretical shell; i.e., it contains no behavioral equations. Each sub-model contains a few parameters that are temporary placeholders for variables that will be formulated during the modeling process. The Template is a *tabula rasa* that awaits the modeler's hypotheses.

The supply side is designed for an integrated set of small models that represent hypotheses about steps in the aggregate process of producing and pricing goods and services. Those steps include decisions about utilizing current production capacity and developing future capacity, and the implication of those decisions for aggregate price trends and utilization of productive resources. The impetus for these decisions is current and projected AD, and the primary output from the supply side is real GDP.

The demand side is about buying goods and services and the factors that influence aggregate spending. The sub-models represent institutional sectors—households, business firms (managers of the supply side), government, and foreign trading partners—that make purchasing decisions; plus institutions that influence those decisions, such as commercial banks, the central bank, and government. The agnostic sub-models await behavioral hypotheses that postulate decisions *within* the institutions and the relevant systemic interactions *among* them.

The sub-models displayed in the generic Template are intended to suggest a range of possibilities for components in a macro model. When the Template is used to guide model-building, the number of sub-models, their names and contents, and their connections with the others will be determined by the modeler. The boundary choices about breadth (endogenous/exogenous/excluded variables) and depth (aggregation level) will reflect the purpose of the model. The links among sub-models can also be modified to reflect the modeler's behavioral hypotheses about how the equations in one affect the equations in others.

Modelers whose primary interest is demand-side modeling could reduce the supply side in panel (b) to a few equations that encapsulate the conversion of perceived demand into output. Such a 'demand creates its own supply' perspective effectively stands Say's Law on its head. Others will think the supply side needs *more* specification than suggested in the diagram; e.g., separate sub-models for employment (labor and hours), capital, and natural resources.

In like manner, the demand side could be less or more detailed than suggested by panel (c). It is certainly possible to sharply curtail the demand side, as if Say's Law rules. On the other hand, it is possible to disaggregate further; e.g., to create multiple household sectors based on demographic or worker/capitalist distinctions, or divide business firms into goods producers and service providers. There could be two government sectors: national and regional. Similarly, the Banks and Central Bank sub-models could contain detailed institutional structure (as in *MacroLab20*), or they could be compressed into a single Banks sub-model containing a few equations that determine the central bank's policy interest rate and commercial banks' loan rate. The Rest-of-the-World sub-model (RW) could contain a simple exogenous net exports function, a complete model of aggregated trading partners; or something in between; and, of course, it would be omitted entirely from closed economy models. Except for the simplest structure, the RW would also require an exchange rate sector.

The sectoral spending decisions on the demand side are received by a Flow of Funds sub-model (FF) such as the one displayed in panel (d) of Figure 2.1. At the top, for example, consumption spending is flowing from households to firms. At the bottom is a return flow of wages and dividends. At the top right of the diagram is the output of this sub-model—aggregate demand—the sum of household consumption, business firm investment (excluding so-called inventory investment), government purchases, and net exports.

All flows are driven by demand-side decisions already made in other sub-models, as indicated by the prefix on each flow variable. With arrayed Accounts stocks partitioned into assets and liabilities, inflows and outflows are channeled to and from the appropriate accounts. For simplicity in this diagram, multiple net flows are bundled. For example, 'net funding of government' is the sum of taxes minus transfers, net government borrowing, and net government interest receipts (typically negative).[3]

The use of credit is a consequential feature of modern economic systems (Guttman 1994, Godley and Lavoie 2007) and the flows to/from the Bank assets in panel (d) are suggestive of the transactions that would be modeled in a Banks sector on the demand side. The banking system, still neglected in most macro models, is an integral part of *MacroLa*b20. However, like the rest of the Template, the FF is adaptable to the modeler's experience and purpose. Credit transactions are not a pre-requisite for a simple macro

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[3] Again for simplicity, all private sector taxes are paid by households after receiving wages and dividends from firms and banks. Primary bond market activity is limited to transactions between government and households, but secondary market transactions involve households, firms, commercial banks, and the central bank. Cash proceeds of credit transactions are represented as flows between asset accounts of sectors. Other flows update the counterpart liability and asset accounts of the debtor and creditor sectors, respectively. For example, when a bank lends to a household, the household incurs a credit-based liability due to the credit transaction, while the bank gains a credit-based asset. For more details on the modeling techniques using arrays, see the online version of *MacroLab20* at https://exchange.iseesystems.com/public/david-wheat/macrolab20.

model to be useful. Indeed, given the purpose of this chapter, we use a highly simplified FF structure in our demonstration model.

The take-away message of the FF diagram is that each spending flow has a destination and a source. Even when exogenous financial shocks are triggered in a model, the resulting flow that goes somewhere must come from somewhere. Every inflow is, simultaneously, an outflow from somewhere.[4] Likewise, every financial asset in the economy has its liability counterpart somewhere else; e.g., household deposits are assets for households and liabilities for commercial banks. These accounting principles are used within the Template to calculate balance sheets for each sector and a composite balance sheet for the entire model economy. Indeed, arrayed Accounts stocks actually accumulate and partition assets and liabilities and, therefore, maintain balance sheet data for each sector.

Since every financial asset has a matching financial liability, the net financial assets for the economy sum to zero, and that is observed in the balance sheet of a stock consistent model. Likewise, each transaction has a net value of zero (e.g., taxes received by governments minus taxes paid by households, firms, and banks must equal zero). Flow consistency can be verified with a transaction matrix for the entire economy. Together, the balance sheet and transaction matrix are used to confirm stock-flow consistency within the Template. When a macro model lacks stock-flow consistency, that would be apparent in the balance sheet and/or transaction matrix, and the model should be evaluated in that context.[5]

In summary, the *MacroLab* Template suggests ways to organize a macro model, yet is flexible enough to accommodate a range of theoretical perspectives and modeling purposes. The next two sections illustrate these complementary features with a simple model.

2.3 Structure and Behavior of SIMM

In this section, we introduce our demonstration model—a highly simplified macroeconomic model called SIMM—and describe its structure and behavior. SIMM is simple enough for beginners to build and understand.

[4] This is true even for central bank transactions, although in panel (d) they appear to come from the clouds. The central bank records credits and debits to the government accounts and the reserve accounts of commercial banks, and those entries constitute the sources. Other flows seemingly from the clouds are adjustments to counterparties' liability and assets accounts during credit transactions.

[5] Details of the balance sheet accounting in the Flow of Funds sub-model in *MacroLab20* can be found in the online version at https://exchange.iseesystems.com/public/david-wheat/macrolab20. The literature on macro financial accounting and stock-flow consistency can be traced to Brainard and Tobin (1968), Turnovsky (1977), Backus, Brainard, Smith and Tobin (1980), and Godley and Cripps (1983). A modern authoritative reference is Godley and Lavoie (2007). Also in this volume, see chapter 4 (Yamaguchi and Yamaguchi) and chapter 18 (Keen) for stock-flow-consistent approaches using different SD software.

And it is transparent; the source of dynamic behavior emerging from this model is easy to find (with a little practice). Moreover, building SIMM reveals a modeling method that can be used by macro specialists wanting to enrich, extend, or replace this model with their own hypotheses.

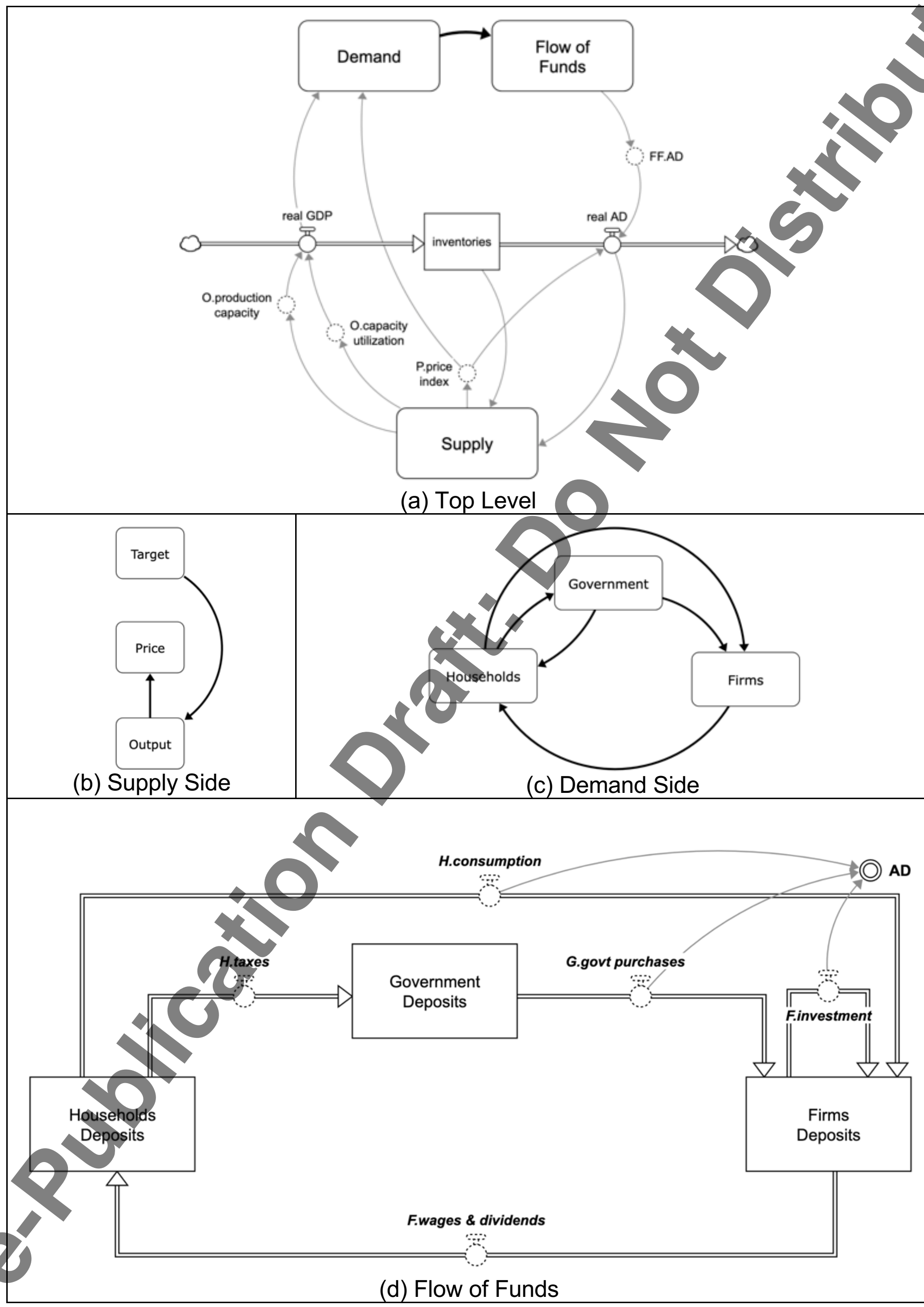


Fig. 2.2 Sub-Model Structure of SIMM

2.3.1. Sub-Model Structure. Figure 2.2 displays the sub-model structure of SIMM. In panel (a), close inspection of the top level reveals a small departure from the generic Template. In SIMM, the only supply-side variables that influence the demand-side are real GDP and the price index. In addition, panels (b) and (c) have fewer sub-models. For example, it's a closed economy with no foreign trade, and the financial sector is not engaged in credit transactions with other sectors.

The flow-of-funds structure in panel (d) is also simpler, due to SIMM's closed economy and the absence of an active financial sector. Foreign trade flows and the stocks and flows for banks and the commercial bank have been omitted from the diagram. The commercial banks in this simple model merely serve as a digital repository for private sector deposits. Likewise, the central bank merely holds the government accounts and the reserves of the commercial banks. In SIMM, these financial institutions do nothing with the funds entrusted to them. They merely record the flows in and out of their depositors' accounts. Although the passive financial sector does not contribute to the dynamics of the model, it is still important for accurate accounting, and SIMM has accounting equations where changes in the three deposits stocks are mirrored in the liabilities of the financial sector. This enables SIMM to generate a separate balance sheet for each sector and a consolidated one for the model economy.

Two stocks—Households Deposits and Firms Deposits—constitute the money supply in the model economy. Taxation drains money from the aggregate circular financial flow, while government purchases inject money into that flow. The numerical difference between government taxation and purchasing is reflected in changes to Government Deposits, and that has a simultaneous effect on changes in deposits at households and/or firms; i.e., the broad money supply. In SIMM—with no commercial bank credit, no central bank transactions, and no international financial flows—a change in the level of Government Deposits is the only influence on the money supply.[6] Whether a change in the money supply has any dynamic consequences for the model economy's performance depends on the behavioral equations that govern the demand-side sub-models.

2.3.2 Feedback Structure. Examining the equations within each sub-model necessarily requires a close-up, ground-level view (of the 'trees'). This permits ignoring the surrounding complexity of relationships with the rest of the model. However, such a focused view risks forgetting that the elements within the sub-models are part of a larger feedback structure (the 'forest'). The purpose of Figure 2.3, therefore, is to provide a high-level view of key feedback relationships within SIMM, including those that link together the demand and supply sides of the model economy. Readers are

[6] In this respect, SIMM differs sharply from *MacroLab20* where the money creation and destruction process is dominated by commercial bank loans that create deposits and repayments that drain deposits, as emphasized by Bank of England economists McLeay, Radia, and Thomas (2014).

encouraged to refer to this diagram whenever the larger context of a sub-model equation is not obvious.

The qualitative structure of this diagram corresponds to the quantitative structure of SIMM. Note the location of real GDP, Inventories, and real AD. That's the dividing line between the demand side at the top and the supply side at the bottom. The feedback diagram is a communications tool; it translates a complex quantitative model into a relatively simple picture that emphasizes the systemic structure of an economy.

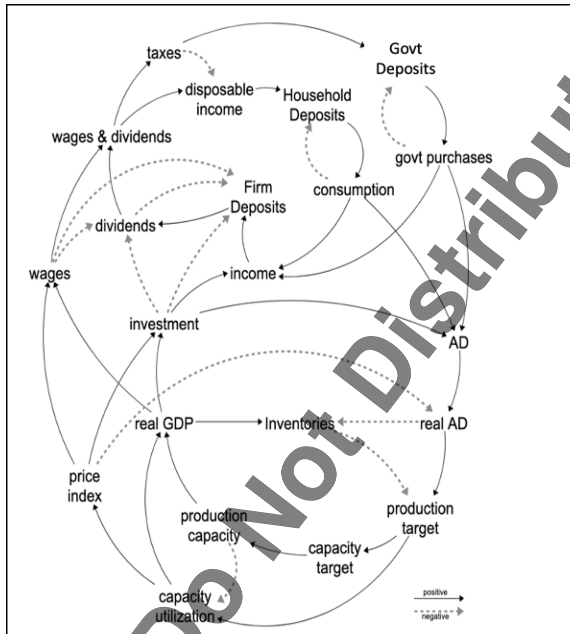


Fig. 2.3 Feedback Structure of SIMM

As in a translation of phrases from one language to another, a feedback diagram contains both literal and figurative elements. For identity equations such as AD, real AD, income, wages & dividends, etc., Figure 2.3 displays all components, exactly as defined in the quantitative model. However, behavioral relationships are displayed in a simpler reduced form that does not necessarily reflect proximate causation in the model. For example, the diagram shows real AD and inventories influencing the production target, but the model's actual set of smoothed causal connections is not visible. To fully grasp the underlying behavioral hypotheses, it is necessary to examine the equations in the stock-and-flow structure.

Nonetheless, the diagram provides useful information about the model. It reveals, for example, that all taxes are paid by households. It also indicates the polarity of relationships: e.g., the solid link from Real AD to production target is a positive relationship: when real AD changes, the production target changes in the same direction, *ceteris paribus*. However, the dashed link from inventories to production target is a negative relationship; e.g., if inventories rise, then (*ceteris paribus*) the production target falls. During a simulation run (*sans ceteris paribus*), the net change of the production target depends on the direction and magnitude of these two causal influences.

Of course, the diagram also displays the feedback loops. The number of negative links in a loop determines its polarity. Positive loops—those responsible for behavior that reinforces itself—contain an *even* number of negative links (including none). Negative loops—those responsible for self-correcting behavior—contain an *odd* number of negative links. In Figure 2.4, the loops in panels (a) and (b) are negative and positive, respectively.

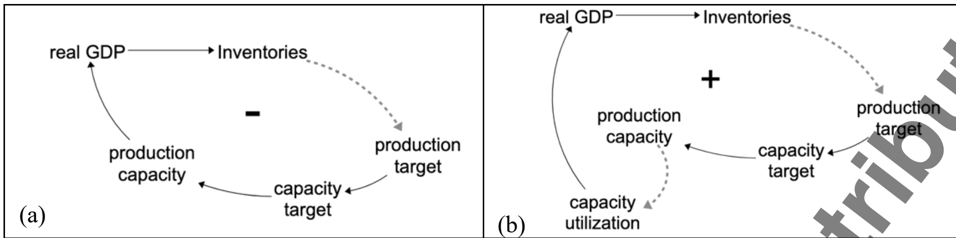


Fig. 2.4 Examples of Negative and Positive Feedback Loops in SIMM

Figure 2.4 displays just two of several feedback loops on the supply side of SIMM, and there are even more on the demand side. When the two sides interact, the total number of loops is more than the sum on each side. As simple as it is, even SIMM is a complex system. The feedback diagram provides a useful summary view of the structure of the model, but there is little chance of correctly inferring the model's behavior merely from the diagram. Moreover, there are nonlinear relationships at work, making an analytical solution unlikely. In this context, numerical simulation provides the only practical method for exploring the behavior of complex systems.

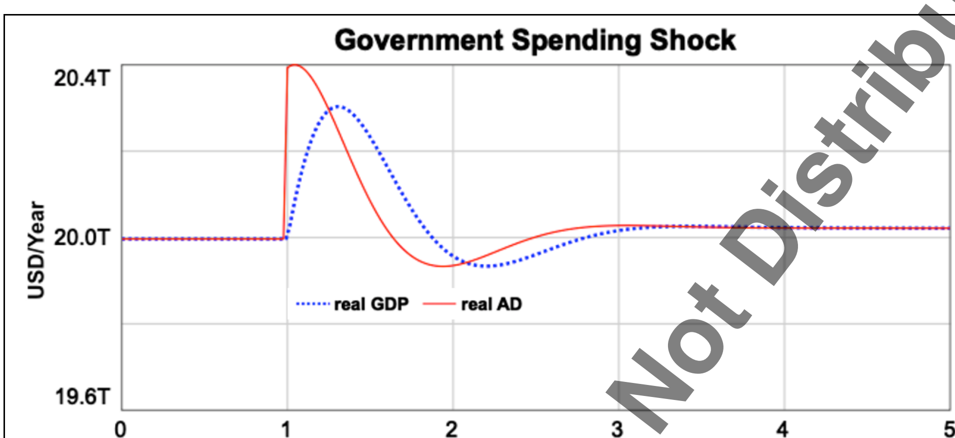
2.3.3 Behavior. A full battery of simulation behavior experiments with SIMM is beyond the scope of this chapter, but we illustrate model behavior with an exogenous demand shock equivalent to two percent of GDP. In year 1, government purchases increase by $400 billion/year. In Figure 2.5, the results are displayed in two ways: graphically for AD and GDP, and in excerpts from a consolidated balance sheet generated by SIMM.

The graph shows the response of real AD to the sudden $400 billion increase in nominal AD, followed by a gradual decline due to a slight rise in prices and a substantial *drop* in government spending due to a minimum deposits constraint and a no-debt policy (discussed in the next section). Real GDP gradually responds to changes in real AD and peaks after about three months, mostly with adjustments to capacity utilization, and continues to follow the pattern of demand with about a one-quarter lag. There is a brief, mild recession a year after the boom. The short-lived stimulus raises production capacity by $25 billion/year, only one-tenth of one percent above its initial value. The price level (not shown) increases only slightly over a two-year period and stabilizes at 1.005.

The balance sheet excerpts compare deposits before the shock and at the end of the simulation period, with plus and negative signs indicating assets and liabilities, respectively.[7] Initially, private sector deposits totaled $15.2

[7] The consolidated balance sheet is displayed on SIMM's user interface; it is the summation of the sectoral balance sheets calculated within the Flow of Funds sub-model.

trillion, but they rose by $95 billion as a result of the brief period of government deficit spending financed by drawing on deposits. The rise in private sector financial assets was matched by a corresponding increase in commercial bank liabilities. Moreover, it is easy to see the source of the $95 billion increase in the money supply: government's account at the central bank declined by the same amount.



Partial Balance Sheet in Year 0 and Year 5

	Households	Firms	Banks	Government	Central Bank	sum
year 0						
Bank Deposits	10.200T	5.000T	-15.200T			0.000T
Central Bank Deposits			15.200T	0.850T	-16.050T	0.000T
year 5						
Bank Deposits	10.264T	5.031T	-15.295T			0.000T
Central Bank Deposits			15.295T	0.755T	-16.050T	0.000T

Fig. 2.5 GDP, AD, and Balance Sheet Effects of Government Shock

We also tested what would happen if the same shock occurred *without* the government's deposits constraint and no-debt policy; i.e., a different hypothesis about fiscal policy. In summary, government spending would remain $400 billion/year above its initial value, and the stimulus effect would be much greater: real AD and real GDP would stabilize at $20.4 trillion/year (revealing a multiplier of 1.0). By year 5, the money supply would increase by $991 billion, with Government Deposits $141 billion in the red as if the central bank had monetized the debt. Inflation would be about 1 percent each year after the shock.[8]

Now that readers have sampled the structure and behavior of SIMM, we will present the detailed structure of the model. The next section is the 'how to' guide we promised—for purely reflective readers who may be curious about some aspects of the model, and for active readers who want to build this dynamic simulation model and play with it.

[8] The alternative test results are not shown here. However, readers who play with SIMM will be able to conduct both tests, with the minor modifications of equation 2.53 described in the next section.

2.4 Detailed Structure of SIMM

In this section, our focus is on telling readers how to build SIMM. But we know most will soon forget what they read here. Plus, it may not be obvious how our general instructions are implemented with the software. What's more, a narrative alone may not provide the stepping stone to SD macro modeling for some readers. Therefore, guided by an ancient proverb, we provide parallel activities for showing how to get started and for involving those readers who want a hands-on experience.[9] Supplemental materials for this chapter include access to a video-recorded demonstration of the process described in this section plus a downloadable version of SIMM. An online version at https://exchange.iseesystems.com/public/david-wheat/simm can be simulated without SD software; only an internet browser is needed.

2.4.1 SIMM Shell. The SIMM shell model—adapted from the Template but still without behavioral equations—is also included with the supplemental materials. To add equations to SIMM, it is advisable to download the shell version to your computer and work with it (using, if necessary, the free trial version of *Stella Architect*[10]). First, however, follow the narrative below and start thinking about ways to fill the sub-models with equations that represent *your* behavioral hypotheses on both the supply and demand sides of this very simple model economy.

Opening the SIMM shell reveals that the top level is identical to the diagram displayed in panel (a) of Figure 2.2. It is possible to run the shell model and see flat lines on a graph, but that would only confirm that there are no invalid equations and that the shell model is initialized in equilibrium. Initially, real GDP and real AD are equal to algebraic combinations of constant parameters within the Supply and Demand sub-models, respectively. Examine the equations and units at the top level, and confirm that

real GDP = production capacity * capacity utilization	{USD/year}	(2.1)
real AD = AD / price index	{USD/year}	(2.2)
initial inventories = 2e+12	{USD}	(2.3)

The first two equations are identities, true by definition. The initial value of inventories ($2 trillion) is ten percent of a year's worth of real AD. This inventory/sales ratio assumption is a reasonably accurate weighted average for the current United States economy but, of course, it is a high-variance average of higher ratios for manufacturing industries and lower ratios for service industries.

[9] Googling "proverb, show, tell, involve" will remind anyone who vaguely remembers the proverb and will introduce it to others.

[10] To get the trial version of *Stella Architect*, go to https://iseesystems.com/store/products/trial.aspx. In the text, we keep software-specific instructions to a minimum and put them in footnotes. The video-recorded tutorial includes detailed guidance for building SIMM with *Stella Architect*.

As we explore the sub-models of the SIMM shell, keep in mind that the placeholder parameters will become variables during the modeling process. Also, distinguishing between a sub-model's inputs and outputs is essential to the use of the Template. Regardless of the modeler's hypotheses, using the Template requires thinking hard about what *should* be an output from each sub-model and, consequently, what inputs are needed to make that happen. We begin on the supply side.

Supply Side. Within the Supply sub-model, opening the Target sub-model will reveal four parameters displayed at the top of Figure 2.6. The (green) outputs from this sub-model are production target and capacity target. Initially, both outputs have the same constant values: $20 trillion USD/year. Real AD and inventories are (red) inputs from the top level of SIMM.

Behavioral equations are needed to represent hypotheses about how the values of the outputs could change over time; i.e., how the parameters become variables. That requires formulating quantitative functional relationships between inputs and outputs.

The arrow connecting the Target sub-model to the Output sub-model means that outputs from the former are inputs to the latter.[11]

Inside the Output sub-model, the production and capacity targets are red, indicating they are now inputs. Production capacity and capacity utilization are outputs to the top level of the model and are used to define the equation for real GDP. Capacity utilization is also an output to the Price sub-model. Again, the causal influences on the two outputs will be specified by the modeler's behavioral equations.

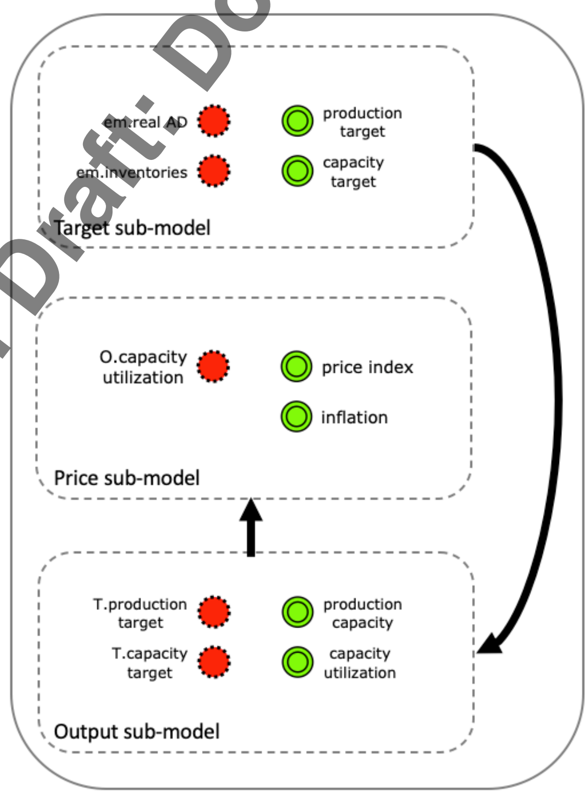


Fig. 2.6 Supply Side Parameters in SIMM Shell

[11] In *Stella Architect*, a connection between sub-models is analogous to a bundled set of wires that can transmit information about more than one variable. In this case, the values of both production target and capacity target are being transmitted to the Output sub-model.

The final sub-model on the supply side is Price, in the middle of Figure 2.6. With only one input—capacity utilization—there is an implicit hypothesis that it influences the values of the price index and inflation. This sub-model awaits specification of those equations.

<u>Demand Side and Flow of Funds</u>. We leave it to the reader to explore the demand side of the SIMM shell (Figure 2.7). There, as expected, each sub-model—Households, Firms, and Government—contains inputs from the others. Of course, each sub-model needs behavioral hypotheses and equations for converting inputs into outputs. In the Firms sub-model, investment is displayed as both a green output and a red input. An assumption in SIMM is that only business firms purchase capital goods used for producing other goods. Therefore, investment spending is simultaneously an output (expenditure) and an input (revenue).

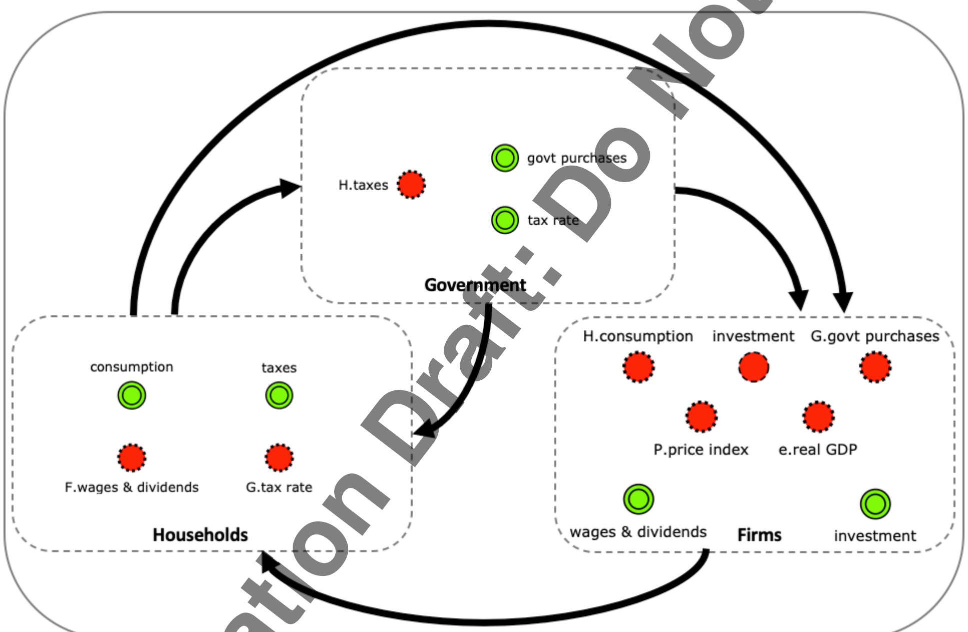


Fig. 2.7 Demand Side Parameters in SIMM Shell

Three of the demand-side outputs merit special attention: household consumption, business firm investment, and government purchases of goods and services. The values of these outputs are transmitted to the Flow of Funds sub-model displayed in panel (d) of Figure 2.2, where their summation constitutes the aggregate demand that is transmitted to the top level of the model.

2.4.2 Equations in SIMM. It is now time to populate the barren sub-models of the SIMM shell with equations that use behavioral hypotheses to formulate causal relationships between sub-model inputs and outputs. Readers who build the model will need to create the stocks, flows, and feedback loops and insert the equations provided for each sub-model. We want to emphasize, however, that the *particular* behavioral equations in SIMM are not our primary interest in this chapter. Instead, we want to demonstrate that the Template is flexible and can accommodate various hypotheses that reflect the thinking of diverse modelers and their purposes.

The source of behavioral hypotheses is the mental model of an individual modeler—how she thinks the economy works. Let's imagine that she has been invited to conduct a brief introductory macro modeling workshop. She hopes to find something useful to convey to a diverse group that includes university students, business people, and professional economists. With that in mind, she selects a small set of simple hypotheses for a demonstration model called SIMM. She realizes her model economy is much too simple for many in her workshop, but she hopes they see something useful in her way of organizing ideas about the economy. Let's narrate how her presentation might unfold, starting on the supply side.

Target Equations. She begins by specifying equations that reflect hypotheses about how an economy's business firms set goals for production—in the near term and for the future. In SIMM, those goals are variables called 'production target' and 'capacity target.'

In SIMM, the distinction between equations for current production and future capacity is simply the relevant time horizon. Current production decisions are influenced by recent sales trends and by production adjustments needed to maintain a reasonably consistent ratio between expected sales and inventories. Simply put, the producers' short run plan is to supply what customers will buy at current prices, even if that means under-utilizing current capacity or working overtime. On the other hand, decisions about changing production capacity for the future are riskier and more costly; producers take more time to estimate future aggregate demand and the relevant trends are measured in years rather than months.

A simple way to formulate these hypotheses is to think of both targets as continuously updated information smoothed over different time periods, with more weight assigned to recent periods (i.e., exponential averaging). Such *information* stocks are used to represent states of perception or expectation based on past trends, and are analogous to the 'adaptive expectations' concept in the economics literature (Pearce 1992, p. 5).[12]

[12] The information stock concept stems from the fact that the value of a real-world flow cannot be measured instantaneously and, therefore, the perception depends on a stream of information collected and averaged (in this case, exponentially) over time. Broader discussion of information smoothing can be found in Forrester (1961, appendix E) and Sterman (2000, chapter 11). The implications of alternative assumptions about expectations are discussed in Carlin and Soskice (2015, chapter 5).

As Figure 2.8 illustrates, stocks can be used to represent the accumulation of information, as well money or materials.[13]

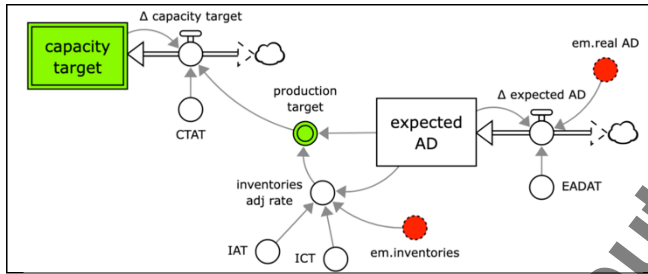


Fig. 2.8 Target Sub-Model in SIMM

The first smoothing process exponentially averages real AD data and generates an expected (short run) AD. Think of this as continuously updating one's expectation of AD as new information becomes available. The production target includes expected AD plus the inventory adjustments necessary to approach the target inventories.

production target = expected AD + inventory adj rate {USD/yr} (2.4)
expected AD_t = expected AD_{t-dt} + Δ expected AD * dt {USD/yr} (2.5)[14]
initial expected AD = 20e+12 {USD/yr} (2.6)
Δ expected AD = (real AD – expected AD) / EADAT {USD/yr/yr} (2.7)
EADAT = expected AD adjustment time = .25 {yr} (2.8)
inventories adj rate = (ICT*expected AD - inventories)/IAT {USD/yr} (2.9)
ICT = inventories coverage target = 0.1 {yr} (2.10)
IAT = inventories adjustment time = 1.0 {yr} (2.11)

The production target is then smoothed over a longer time period to derive the capacity target.

capacity $target_t$ = capacity $target_{t-dt}$ + Δ capacity target*dt {USD/yr} (2.12)
initial capacity target = 20e+12 {USD/yr} (2.13)
Δ capacity target = (production target-capacity target)/CTAT {USD/yr/yr} (2.14)
CTAT = capacity target adjustment time = 1.0 {yr} (2.15)[15]

The modeler specifies the initial values of stocks (e.g., equations 2.6 and 2.13). Note, however, that the SD software automatically specifies equations 2.5 and 2.12 and all other stock accumulation equations in the model; the modeler does not write those equations.[16]

[13] A first-order smooth function in SD software (e.g., SMTH1 in *Stella Architect*) is mathematically equivalent to a stock adjustment process like those displayed in Figure 2.8. The advantage of using the smooth function is its visual simplicity; its icon is one small circle. The disadvantage is that it obscures a feedback process involving the stock and its flow. Here, we use the bulky stock-and-flow icons to reveal those 'local' feedback loops.

[14] **dt** ('delta time') is the length of time the computer takes to recalculate all the variables in a model during a simulation run. It has the same units (e.g., years) as time-related parameters in a model, but it has no counterpart in the real-world system being modeled. It is definitely not a hypothesized 'delay' or 'lag' in decisions or actions. The modeler specifies the value of **dt** and, to avoid integration errors, it should be smaller than the shortest delay parameter in the model.

[15] The adjustment time CTAT refers to setting the target and not for actually adjusting capacity.

[16] Also, to simplify the equation text, we deleted prefixes from the variable names displayed in the diagrams. The prefix refers to the source sub-model and indicates where the variable originates.

Equations 2.4 – 2.15 give operational expression to our workshop leader's behavioral hypotheses. The production target is a short run plan in light of current conditions. Changes in production capacity, however, involve costly employment and investment decisions. The capacity target is therefore assumed to develop more slowly, reflect a long-term strategic outlook, and give less weight to short-term inventory fluctuations.

This first set of equations also illustrates the conversion process required in each sub-model. While *some* conversion process is mandatory, the *specific* process is discretionary. Given the same inputs and outputs, different modelers could use different sets of equations for the conversion process; i.e., they might operationalize different behavioral hypotheses than those used here by our workshop modeler. For example, explicit consideration could be given to the effect of AD's *rate of change* on the capacity target.

Also, the specification of inputs carries with it some implicit hypotheses. For example, a modeler who doubts the significance of inventory adjustments in the production decision might not include inventories as an input to the Target sub-model. In practice, therefore, the Template-guided process encourages this sequence: (1) specify the outputs from each sub-model and (2) let hypotheses about those outputs guide the choice of inputs.

Recall that the SIMM shell model was initialized in equilibrium. Likewise, each set of sub-model equations is in equilibrium, given the initial parameter value assumptions. Thus, an easy validation that sub-model equations have been written correctly is to run SIMM and confirm that it is still in equilibrium before working on the next sub-model. This equilibrium test is the simplest example of a 'partial model test' (Homer 1983, 2012).

<u>Output Equations</u>. Next, the modeler must decide how to specify equations that *use* the information about targets for current production and future capacity. The equations must generate output in the short run and modify capacity to meet production goals expected in the future.

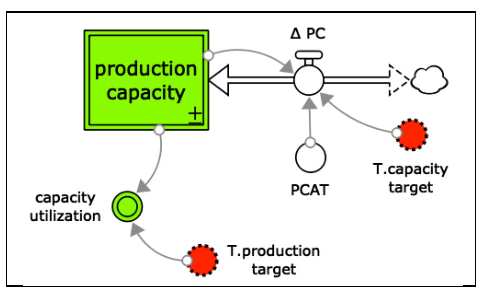


Fig. 2.9 Output Sub-Model in SIMM

Figure 2.9 displays the Output sub-model in SIMM. Changes in production capacity are relatively slow to develop, especially if that involves a big change in investment and employment. In the meantime, the production target forces a decision about capacity utilization, the extent to which employed labor and existing capital equipment will actually be utilized in the near term.

capacity utilization = (production target/production capacity) {unitless} (2.16)[17]
production capacity$_t$ = production capacity$_{t\text{-}dt}$ + Δ PC *dt {USD/yr} (2.17)
initial production capacity = 20e+12 {USD/yr} (2.18)
Δ PC= (capacity target – production capacity) / PCAT {USD/yr/yr} (2.19)
PCAT = production capacity adjustment time = 3.0 {yr} (2.20)

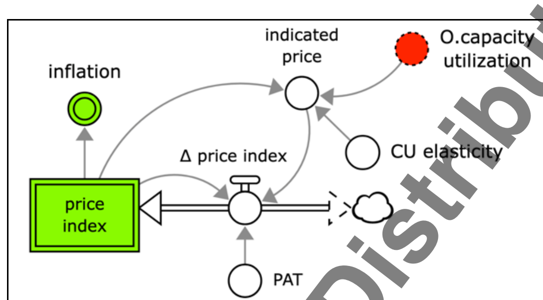


Fig. 2.10 Price Sub-Model in SIMM

Price Equations. Figure 2.10 displays the Price sub-model. The hypothesis is that an increase in capacity utilization above the normal level generates cost pressures that eventually translate into price increases, influencing both the price index and its annual rate of change—inflation. The logic is compelling, but the magnitude of cost pressures stemming from higher-than-normal capacity utilization is an empirical question. Thus, the equation for indicated price includes an easily adjustable elasticity factor.

price index$_t$ = price index$_{t\text{-}dt}$ + Δ price index *dt {unitless} (2.21)
initial price index = 1.0 {unitless} (2.22)
Δ price index = (indicated price – price index) / PAT {per year} (2.23)
PAT = price adjustment time =1.0 {year} (2.24)
indicated price = price index*capacity utilization^CU elasticity {unitless} (2.25)
CU elasticity = 1.0 {unitless} (2.26)
inflation = 100 * TREND(price index,1) {per year} (2.27)[18]

Partial Model Testing. In each of the three supply-side sub-models, the input and output parameters initially planted in the barren shell have now become variables that can change over time. With all variables defined, the supply side can function as a stand-alone model and, if simulated now, it should still generate flat lines on a graph. Equilibrium partial model testing is an essential validation tool, but the supply side model is ready for a more interesting test. What would happen on the supply side after an exogenous shock to real AD? There would be considerable activity on the supply side but, without any feedback effects on the demand side, there would be no multiplier effects. We leave it to the curious reader to try such a test.[19]

Testing the supply side as suggested above is another type of partial model test. It is useful for de-bugging the half-finished model (since it should be in equilibrium before the shock) and for analyzing its behavior after the shock. The supply side is simple enough that the chain of causation should

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[17] In SIMM, capacity utilization is normalized and equal to 1.0 (100%) initially.

[18] In *Stella Architect*, the TREND function computes percentage change over time.

[19] For example, add this term to the real AD equation: STEP(200e+9,1) and run SIMM. It should begin in equilibrium until shocked in year 1 with a $200 billion (one percent) increase in real AD. Don't forget to remove this extra term (or multiply it by zero) before continuing to build SIMM.

be easy to trace in order to compare behavior in each sub-model with expected behavior.

A cautionary note about partial model tests triggered by exogenous shocks: there is no feedback effect on the sub-model being tested. For example, during the test of the supply side model, the demand side neither receives nor returns any effect. Thus, except for the initial shock effect, such partial model tests cannot say much about what would ultimately happen inside the partial model if external feedback loops were active. Bottom line, use partial model tests for limited, well-defined purposes (e.g., de-bugging) and not for answering 'what if…' questions. With this caveat in mind, partial model testing can be useful in another way: testing (and improving) parameter estimates. This validation technique was the main motivation for Homer's (1983, 2012) paper.

Readers are also encouraged to do equilibrium partial model tests on the demand-side sub-models, to which we now turn our attention.

Demand Side Equations. The demand side is all about spending, and each sub-model is structured as a simple stock-flow process. The stock contains money in the form of bank deposits, to which there is an inflow of revenue and an outflow of expenditures (all measured in nominal terms).

In the absence of credit opportunities, the behavioral hypothesis common to each institution is that marginal spending decisions are influenced by the amount of 'money in the bank.' Households might be concerned about financial security, firms might have liquidity and cash flow concerns, and the government in SIMM is restricted (politically or constitutionally) from debt financing. While the motivations can be characterized somewhat differently for each institution, a key parameter for each is the deposits coverage target—the desired number of months' worth of spending 'in the bank.' For example, the households' deposit coverage target is assumed to be nine months.

The implication of this target is that household deposits—most of the money supply—have a direct influence on consumption in SIMM. Business firm deposits also affect consumption because household disposable income includes dividends—the marginal expenditure for business firms after consideration of earnings that might be retained. And, of course, disposable income adds to household deposits. Let us now examine the demand side details.

Firm Equations. The stock-and-flow structure in the Firms sub-model is displayed in Figure 2.11. Business income is the sum of consumption, investment, and government spending on goods and services. Expenditures consist of factor payments (wages and investment[20]) and distributed profits (dividends).

The residual spending issue is about dividends and retained earnings. The deposits coverage target (DCT) is three months. This means the model's firms try to maintain deposits at a level equal to 25% of a year's worth of revenue. If deposits fall below that level, dividend payouts will be reduced and retained earnings will increase. Conversely, dividends will be higher when there is 'more than enough' money in the bank.

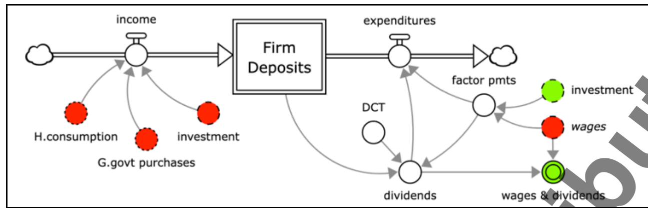


Fig. 2.11 Firms Sub-Model in SIMM

Firm Deposits$_t$ = Firm Deposits$_{t-dt}$ + (income – expenditures) *dt	{USD}	(2.28)
initial Firm Deposits = 5.0e+12	{USD}	(2.29)
income = consumption + investment + govt purchases	{USD/yr}	(2.30)
expenditures = factor pmts + dividends	{USD/yr}	(2.31)
factor pmts = wages + investment	{USD/yr}	(2.32)
wages = real GDP * labor share * price index	{USD/yr}	(2.33)
investment = real GDP * propensity to invest * price index	{USD/yr}	(2.34)
dividends = (Firm Deposits / DCT) – factor payments	{USD/yr}	(2.35)
DCT = deposits coverage target = 0.25	{years}	(2.36)
wages & dividends = wages + dividends	{USD/yr}	(2.37)
propensity to invest = 0.15	{unitless}	(2.38)
labor share = 0.75	{unitless}	(2.39)

<u>Household Equations</u>. In the absence of debt service, consumption spending is the only household outlay in Figure 2.12. As noted earlier, consumption depends on the level of deposits and the coverage target. In SIMM, that target is equal to nine month's worth of disposable income. Consumption is lower than it otherwise would be (and saving is higher) when bank deposits fall below desired levels, and conversely. The smooth function in equation 2.46 causes consumption to adjust gradually to changes in Household Deposits.

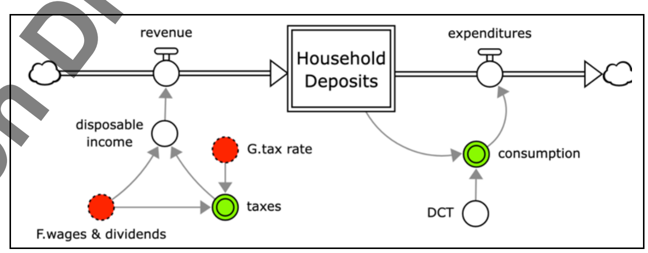


Fig. 2.12 Households Sub-Model in SIMM

Household Deposits$_t$ = Household Deposits$_{t-dt}$ + (revenue – expenditures) * dt	{USD}	(2.40)
initial Household Deposits = DCT * disposable income	{USD}	(2.41)
revenue = disposable income	{USD/yr}	(2.42)
expenditures = consumption	{USD/yr}	(2.43)

[20] Recall that the Firms sector is both the purchaser and the producer of all capital goods in SIMM, which makes investment a component of both expenses and income. Also, note that business firms do not pay taxes in this model because all taxes are paid by households *after* profits are distributed.

disposable income = wages & dividends – taxes {USD/yr} (2.44)
taxes = wages & dividends * tax rate {USD/yr} (2.45)
consumption = SMTH1(Household Deposits / DCT,.25) {USD/yr} (2.46)
DCT = deposits coverage target = 0.75 {years} (2.47)

Government Equations. The final sub-model on the demand side is Government (Figure 2.13). The tax-generated funds in the Govt Deposits stock are 'on deposit' at the central bank and not counted as part of the money supply.

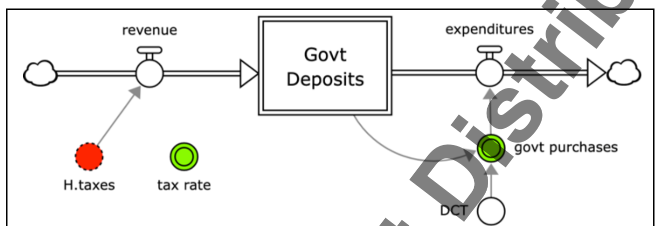


Fig. 2.13 Government Sub-Model in SIMM

The premise is that government spends all the taxes paid, but in a delayed response to the perceived level of available funds. The deposits coverage target is three months. With no option for borrowing, deficit spending is not sustainable, although it occurs over short periods when tax revenues rise or fall, due to the delayed response in the spending function (equation 2.53).

Govt Deposits = Govt Deposits$_{t-dt}$ + (revenue – expenditures) *dt {USD} (2.48)
initial Govt Deposits = DCT * taxes {USD} (2.49)
revenue = taxes {USD/yr} (2.50)
tax rate = 0.20 {unitless} (2.51)
expenditures = govt purchases {USD/yr} (2.52)
govt purchases = SMTH1(Govt Deposits / DCT, .25) {USD/yr} (2.53)
DCT = deposits coverage target = 0.25 {years} (2.54)

Full Model Testing. No additional behavioral equations are required, since the remaining sub-model—Flow of Funds—uses only the identity equations included in the shell version of the model. SIMM is now complete and ready for full model testing. If everything has been defined and connected correctly (confirmed by partial model tests after each sub-model was formulated), the model should still be in equilibrium with real GDP and real AD equal to $20 trillion per year. You should see flat lines when you simulate. If not, review each step in the instructions and eliminate the bugs.

When ready, conduct a more interesting test: the government spending shock described in section 2.3.3. Two scenarios were tested: (1) *with* SIMM's no-debt assumption and (2) *without* that assumption. To replicate those experiments, make two changes in Equation 2.53. To activate the shock needed for both scenarios, add this STEP function to the equation: STEP(400e+9,1). The second scenario requires overriding the deposit target constraint on government spending. This can be done by specifying that the shock is added to the *initial* spending rate, by using the INIT function as follows: SMTH1(INIT(Govt Deposits) / DCT,.25) + STEP(400e+9,1).

In the appendix, we provide an alternative set of equations for the government sector and illustrate a way to redesign fiscal policy. Specifically, we convert the tax rate from a parameter into a variable. The *desired* tax rate depends on the gap between the *desired* level of deposits and the actual level.

2.5 Concluding Thoughts

This chapter has focused on building a macro model from scratch. We also want to recommend the Template as a tool for comparing different ideas about how a macroeconomy works. The Great Recession revealed the fragility of the so-called 'macroeconomic consensus' and its reliance on dynamic stochastic general equilibrium (DSGE) models. Nobel laureate Robert Solow (2008) called the economics storyline inherent in DSGE models a "rhetorical swindle" that the "macro community has perpetrated on itself, and its students" (quoted in Colander, 2008, p. 2). A systematic critique of orthodox (and heterodox) models requires a transparent tool that facilitates comparing models, and we think the Template can be useful for that task (Wheat, Oliskevych, and Novik, 2020).

Organizing alternative sets of behavioral hypotheses in a common framework enables comparing the structure and behavior of competing models. The Template may generate new insights when existing models are re-imagined and re-framed. For example, the algebraic representation of the standard Keynesian Cross model with autonomous (i.e., exogenous) investment is revealed to be problematic when separate household and firm sectors are specified in a dynamic version of that model. The deposit stocks for the separate sectors are *not* constant even when the aggregate flows imply the model is in equilibrium. Stock equilibrium is achieved only by assuming an aggregate private sector with no distinction between households and firm.[21]

We are just getting started with this kind of analysis. Others we have re-framed include basic versions of the IS/LM and AD/AS models, an early SD-based macro model (N. Forrester, 1982), the first published version of *MacroLab* (Wheat, 2007), and the so-called 'three equation' New Keynesian model (Wheat and Oliskevych, 2018). Several chapters in this volume present interesting models that address macroeconomic issues, and we plan to use the Template to re-frame some of those SD-based macro models and compare them with each other and with *MacroLab20*.

Our 'plug and play' metaphor for the modular *MacroLab* Template is not meant to imply that building a model is like connecting components of a home entertainment system. Theory building is hard work. However, after

[21] Then *total* private sector deposits are constant in the Keynesian Cross model (available on request).

alternative hypotheses have been developed, it is relatively easy to place one in the Template and, later, replace it with another and analyze the change in model behavior.

When the modeler adds ('plugs') particular behavioral equations in one sector of a Template-based model, the framework motivates thinking about how they might (or must) fit together with equations in other sectors. As the model takes shape, testing and analysis require simulation runs ('play') to check for math mistakes or other bugs, to stress-test the model under various conditions, and to gain insights regarding the source of dynamic behavior emerging from the model. Stripped to its essence, therefore, 'plug and play' means a relatively easy way to experiment with alternative behavioral equations in a model and analyze the simulated behavior.

Simple macro models lack structural details necessary for generating all the stylized patterns of a real-world economy, but they can provide a foundation on which to build a more realistic model. That is our purpose with SIMM; it is a small dynamic macroeconomic model that is easy to build, understand, critique, and change.

Of course, changing SIMM is not limited to extensions. Total replacement is always an option. It is merely a starter model containing behavioral equations that operationalize simple postulates about complex real-world decisions and actions. Viewed in that light—as statistician George Box (Box and Draper, 1987, p. 424) reminds us about all models—SIMM is 'wrong' because it is not the complete truth; but (Box adds) it still may be 'useful.' It could be useful if it provides some readers of this chapter with insights about the structure and behavior of a national economy. Even more important for our purpose, we consider SIMM useful if it motivates others to try the Template for organizing their own hypotheses into an SD-based macro model while looking for new insights that may emerge. To illustrate that process, we provide a variation of SIMM in in the appendix, where we present an alternative behavioral hypothesis for the government sub-model.

We want to emphasize, however, that the example of an isolated change in the government sub-model illustrates not only the hypothesis substitution process but also an important constraint on that process. The constraint can be expressed in simple terms: it's difficult to do 'just one thing' in a complex feedback system. In the appendix, when *only* the government sub-model equations are modified, the government remains solvent in the face of population-induced obligations, but rising tax rates reduce household disposable income and, consequently, household consumption. The new fiscal policy becomes untenable, economically and politically.

Therefore, our advocacy of 'plug and play' with the Template comes with a caveat. The viability of an alternative hypothesis—including a new policy idea—requires analysis of how the whole system responds to the change in structure. Isolated experimentation with alternative behavioral hypotheses may not produce expected results even if all the parts fit together nicely and the model seems to work. Alterations in one sub-model may necessitate alterations in others. We call this *systemic plug and play* because it requires thinking of an *ensemble* of alternative hypotheses and how they perform together rather than separately. Our caveat, far from being mere fine print on the label, is fundamental to the holistic perspective inherent in the SD approach to macro modeling.

Appendix

As explained in section 2.5, we now experiment with a different government sub-model for SIMM, based on an alternative behavioral hypothesis about fiscal policy. The top panel of Figure 2.A1 displays the original hypothesis, while the alternative is in the bottom panel.

The essential difference between the hypotheses is a constant tax rate in the original sub-model compared to a variable rate in the alternative. The latter also requires the tax base (wages & dividends), an input from the Firms sub-model. Two other new inputs (population and price index) are needed to specify that purchases reflect a policy of maintaining constant real spending per capita. Only new or modified equations are listed below.

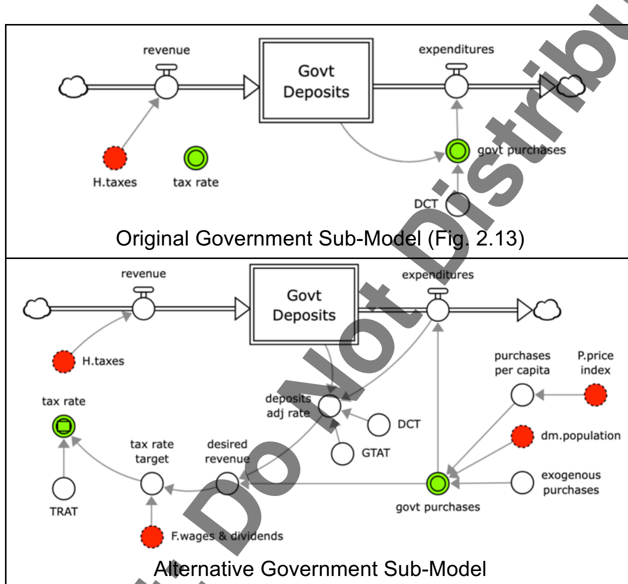
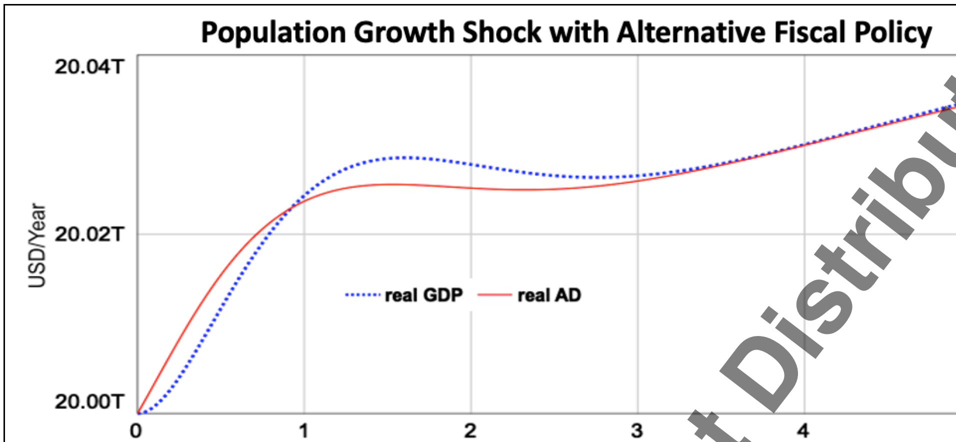


Fig. 2.A1 Two Hypotheses for Fiscal Policy in SIMM

govt purchases = population*purchases per capita + exogenous purchases	{USD/year}	2A.1
purchases per capita = initial purchases per capita * price index	{USD/year/person}	2A.2
exogenous purchases = 200e+9	{USD/year}	2A.3
deposits adj rate = SMTH1((expenditures*DCT-Govt Deposits) / GTAT, .25)	{USD/year}	2A.4
GTAT = government deposits adjustment time = 1	{year}	2A.5
desired revenue = govt purchases + deposits adj rate	{USD/year}	2A.6
tax rate target = desired revenue / wages & dividends	{unitless}	2A.7
tax rate = 100*SMTH1(tax rate target, TRAT, .20)	{unitless}	2A.8
TRAT = tax rate adjustment time = .25	{year}	2A.9
population = 320e+6	{persons}	2A.10
initial purchases per capita = 10000	{USD/year/person}	2A.11

Equation 2A.4 calculates the gap between desired and actual deposits, given the adjustment time for closing the gap. Desired revenue (2A.6) is the sum of government purchases and the deposits adjustment rate. The tax rate target (2A.7) is the quotient of desired revenue and the tax base. Finally, the tax rate (2A.8) adjusts towards the target. The tax rate is still an output to the Households sub-model, and a feedback loop is closed when the households pay the taxes to the government.

We discuss one simulation experiment here; namely, the broad impact of population growth on output, via changes in government spending. In Figure 2A.2, the simulation results reflect a 1 percent annual population growth rate. By year 5, the growth rates for real AD and GDP (top panel) are approaching a steady annual growth rate of only 0.02 percent—just 1/50 of the population growth rate—a rate lower than we might have expected.



Partial Balance Sheet in Year 0 and Year 5

	Households	Firms	Banks	Government	Central Bank	sum
year 0						
Bank Deposits	10.200T	5.000T	-15.200T			0.000T
Central Bank Deposits			15.200T	0.850T	-16.050T	0.000T
year 5						
Bank Deposits	10.143T	5.029T	-15.172T			0.000T
Central Bank Deposits			15.172T	0.878T	-16.050T	0.000T

Fig. 2.A2 GDP, AD, and Balance Sheet Effects of Population Shock

The bottom panel displays the balance sheet effects and shows the money supply *decreasing* by $28 billion over the five-year period. Where does the money go? To the government, where deposits increase by the same amount. The intent of the alternative fiscal policy is to raise taxes to meet the twin goals of real per-capita spending and the maintenance of desired deposits when borrowing is not an option. Those goals are achieved, but the cost is a reduction in the money supply and only weak economic growth. The proximate cause of the small net impact on aggregate demand is found in the Households sub-model, where total and per-capita consumption are declining each year due to the fall in disposable income.

This alternative fiscal policy is not a viable option unless other parts of the model economy are also reformulated to respond to the population change. For example, the labor force should be growing. Moreover, population growth can encourage innovation on the supply side, with implications for production capacity. But our *single* alteration has not addressed those ‘other’ parts of the model economy. As emphasized in section 2.5, it’s hard to do ‘just one thing’ in a complex feedback system. Modelers must consider whether substituting an alternative hypothesis in one part of the model is compatible with hypotheses that remain in other parts.

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