Papers

Feedback Loops in the Macro Instructor's Toolkit

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Abstract

This article describes a diagramming method for supplementing a macroeconomics lecture or an entire course. Simple word-and-arrow diagrams are used to show ceteris paribus causal relationships between two variables, and each two-variable link is then added to other links to form feedback loops. The primary purpose is to enable students to visualize how the major reinforcing loop in an economy is regulated over time by key counteracting loops involving prices, wages, interest rates, and exchange rates. The complete set of feedback loop diagrams is derived from a simulation model that students use to "test drive" an economy. However, the feedback loop approach can be used as a teaching tool in any economics course, with or without the simulator. Related research suggests that, when compared to graphical comparative statics, the feedback method is preferred by students and is more effective when explaining economic dynamics.

JEL: A22, C91, E32
Key words: dynamics, education, feedback, macroeconomics, simulation

Five years ago, Cohn et al. (2001) published experimental results that raised doubts about the efficacy of static graphs as a supplementary instructional tool in undergraduate macroeconomics. More research on that issue is imperative since graphical analysis of comparative statics is a standard instructional method for teaching undergraduate economics (Kennedy 2000). Prompted in part by the Cohn findings, another method for supplementing macro instruction has been developed over the past five years.[1] Called the ***feedback method***, it utilizes the diagramming and simulation tools of system dynamics modeling instead of requiring students to manipulate equations or rely exclusively on static graphs. The instructional goal is to make economic dynamics accessible to students who lack the mathematical training normally considered a prerequisite for such access.

This paper is part of a series that considers the feedback method as a supplement to conventional macroeconomics instruction (Wheat, 2007a, b, c). The method described here can be used by instructors who continue to use graphs for representing and explaining economic models. In fact, one hypothesis that has emerged from recent research is that feedback loops may even complement traditional instruction methods. Section 1 highlights the history of feedback thinking in economics, using a feedback loop example. Section 2 explains the concepts and techniques. The example in section 3 shows how the feedback method can be used to introduce a macro course. Section 4 summarizes assessment research, and the last section has some additional thoughts on using the feedback method.

1. Feedback Thinking in Economics

The tradition of feedback thinking in economics is documented in Mayr (1970, 1971), Cochrane and Graham (1976), and Richardson (1991). Evidence abounds that 18th and early

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[1] The macroeconomics principles course is delivered via the Internet to students enrolled at Virginia Western Community College in Roanoke, Virginia.

19th century economists such as Hume (1752), Smith (1776), Malthus (1798), Mill (1848), and Marx (1867) thought in terms of reinforcing and counteracting processes involving mutual causation (Richardson, 1991, pp. 59-79). The movement towards formal modeling in the late 19th and early 20th centuries caused feedback issues to be seen as "circularity problems" needing a workaround. One manifestation was the debate about the direction of causality between price and quantity (demanded or supplied). Oversimplifying, we can say that Walras considered price the *independent* variable while Marshall considered price the *dependent* variable (Morgan 1990). Resolution of that argument had implications for specification of early econometric models and also for the labeling of the horizontal and vertical axes in early graphical representations of demand curves. Anticipating the causal link terminology explained in section 2, we can write Walras' hypotheses as shown in Figure 1.

independent variable	type of effect ("s" or "o")	dependent variable
price	$\xrightarrow[s]{}$	supply
price	$\xrightarrow[o]{}$	demand

Figure 1. Walras' Hypotheses as Causal Links

The arrows in the middle column of Figure 1 point toward the dependent variable, and the "s" and "o" labels represent "same" and "opposite" direction effects, respectively. These symbolic hypotheses would be read as follows: *If price changes, then supply changes in the same direction while demand moves in the opposite direction*.

Marshall's view, on the other hand, could be represented by the hypothesized links in Figure 2, which would be read: *When a movement in supply occurs, price moves in the opposite direction. When a movement in demand occurs, price responds by moving in the same direction.*

independent variable	type of effect ("s" or "o")	dependent variable
supply	$\xrightarrow[o]{}$	price
demand	$\xrightarrow[s]{}$	price

Figure 2. Marshall's Hypotheses as Causal Links

The dispute reflected a conspicuous disregard for *time* as a relevant issue, at least in this context.[2] Viewed over time with the aid of two counteracting feedback loops, the apparent contradiction of the perspectives can be reconciled. When the consolidated hypotheses are displayed in Figure 3, with cross marks (||) indicating a delayed effect, the distinction between *independent* and *dependent* variable loses meaning.

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[2] Obviously, they did not think in static terms. Marshall, for example, stressed that price elasticity of demand depended on the passage of time. Even Walras' auctioneer had to process information in a time-consuming iterative process of matching supply and demand before arriving at an equilibrium price (Pressman, 1999).

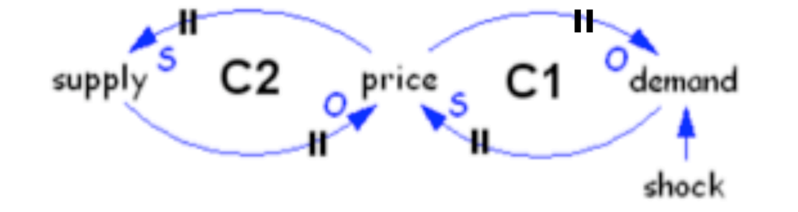

Figure 3. Feedback Loop Version of both Walras' and Marshall's Hypotheses

Figure 4 shows the simulated behavior arising from the hypothesized feedback structure above (Figure 3) after an exogenous shock to demand. To interpret the behavior in Figure 4, use the structure in Figure 3. Begin by assuming that a permanent exogenous shock disturbs the equilibrium. After suppliers take time to evaluate the reliability of the signal that demand has increased, price would rise. Blinder's (1997) survey of 186 firms suggests that when business managers see signs of changing demand, they wait an average of three months before adjusting prices. The rising price would, in turn, put downward pressure on demand, the full effect of which would develop over time. Meanwhile, suppliers respond to the rising price by stepping up production, but it takes time to organize the requisite factors of production. When supply eventually responds, that puts downward pressure on prices, but with a delay. The damped oscillatory behavior and the amplitude and period for each curve depend on parameter assumptions for delay times and price elasticities.

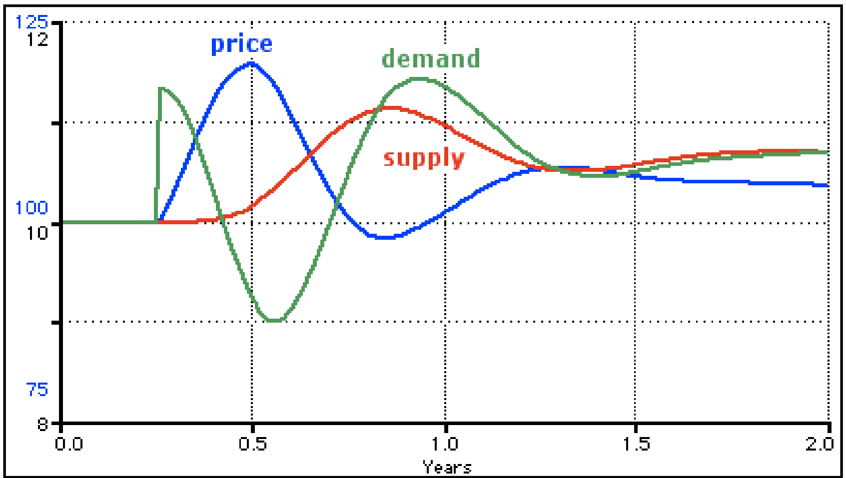

Figure 4. Simulated Behavior of Figure 3 Model

This demonstration of feedback analysis is a micro rather than macro example, and a simple one at that. However, it illustrates a familiar substantive issue that is intended to enable readers to make a quick, initial judgment of the potential value of the feedback perspective. One benefit is that the crux of theoretical disputes can be visualized in a simple diagram. Then simulation (mentally, if the model is as simple as this one, or using a computer as illustrated in Figure 4) enables testing the implications of the feedback model. Competing theories can be tested separately or, as in this case, in combination. One might conclude, for example, that this simplified debate between Walras and Marshall reflected a difference of opinion about the relative delays that influence price, demand, and supply. At the macro level, some of the differences between the Keynesian and Classical perspectives seem to hinge on different assumptions about delay times on the demand and supply sides of the economy.

Tinbergen (1939) was perhaps the first macroeconomist to explicitly acknowledge that mutual causation takes *time*, and that circularity was not a logical fallacy when *viewed over time*. Feeling compelled to justify an observed two-way causal relationship between profits and investment, he wrote:

> *Taking the fall in general investment from 1929 to 1930—which contributed considerably...to the fall in profits in 1930—we find...that profits one-half year before were the chief explanatory series. Here we meet a very important feature. It would seem as if this were a circular reasoning: profits fell because investment fell, and investment fell because profits fell. This is, however, an inexact statement. Profits in period t fell because investment in period t fell, but the latter fell because of a fall in profits in period t - 1/2; and owing to this time lag there is no danger of circular reasoning.* (cited in Richardson, 1991, p. 44)

Richardson (1991) found Tinbergen's pioneering econometric model of U.S. business cycles "replete with feedback loops," and he has also documented the feedback perspective embedded in the work of these early 20th century economists: Keynes, Goodwin, Boulding, Tustin, Allen, Simon, and Phillips. Over the past fifty years, the application of feedback analysis to economics has been central to the work of those operating within the system dynamics paradigm established by J. W. Forrester (1958). Examples include J.W. Forrester (1961, 1968, 1976, 1979), Mass (1975, 1980), N. Forrester (1973, 1982), Low (1980), J. Forrester, Mass, and Ryan (1980), Senge (1980), Sterman (1985), Radzicki (1988, 1993, 2003), Moxnes (1992), Saleh and Davidsen (2001), Harvey (2002), Atkinson, (2004), Saeed (2004), and Yamaguchi (2006). Another conspicuous application of feedback analysis has been the work of complexity theorists at the Santa Fe Institute. See, for example, Anderson, Arrow, and Pines (1988), Arthur, Durlauf, and Lane (1997), and Arthur (1994).

Although the feedback perspective has surfaced repeatedly in economists' thinking over two centuries, and although modeling feedback effects has been a persistent issue among econometricians in the most recent seventy-five years, there is little mention of feedback in modern textbooks. Perhaps the clearest pedagogically relevant evidence of feedback thinking by economics textbook authors is the ubiquitous circular flow diagram. Figure 5 displays an adaptation of such a diagram in Mankiw (2007). The circular flow diagram lacks the structure required of a feedback loop. However, it provides two useful insights. First, it implies an interaction between the real economy and the nominal economy. In addition, it suggests the *potential* for a reinforcing feedback process that most textbooks identify and call the "multiplier" process.

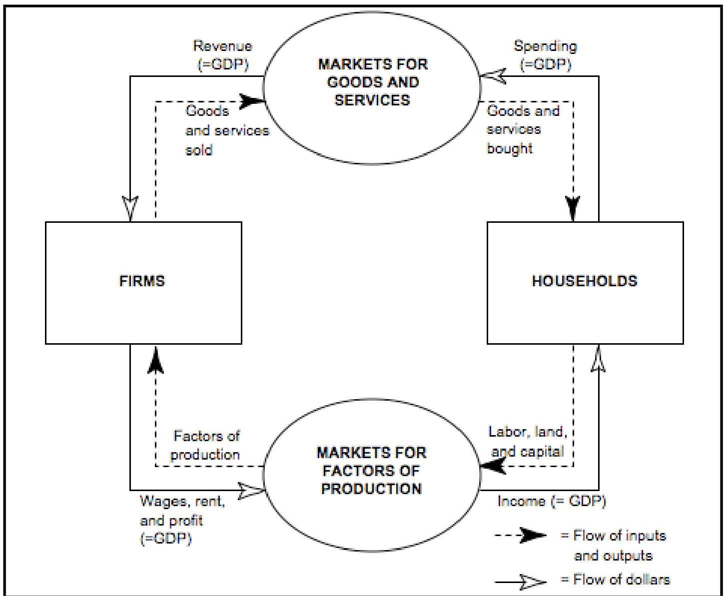

Figure 5. Circular Flow Diagram Lacks Structure Needed in a Feedback Loop
Diagram Adapted from Mankiw (2007, p. 93)

The DeLong (2002) text, for example, offers this characterization of the multiplier process (illustrated in Figure 6):

> *[A]n increase in spending causes an increase in production and incomes, which leads further to an increase in spending. This* ***positive feedback loop*** *amplifies the effect of any initial shift.*[3]

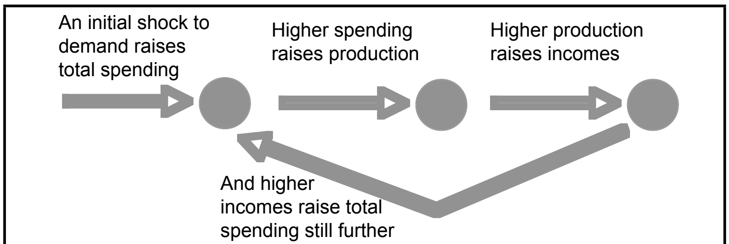

Figure 6. Positive Feedback Loop
Adapted from DeLong (2002, p. 248)

The standard circular flow diagram has weaknesses, however. One flaw in most versions is the unstated equilibrium assumption. Only in equilibrium would the four dollar flows be equal and would " = GDP" as Figure 5 suggests. Undergraduates can grasp the equilibrium/disequilibrium distinction if it is explicit. However, when the assumption is implicit in a diagram or text, they miss its significance. Moreover, students have difficulty coping with the persistent misuse of the GDP concept itself. When textbook authors (e.g., Mankiw 2007, pp. 91, 92, and 166) repeatedly assert that GDP *is* income or *is* sales instead of saying that the *value* of GDP (in equilibrium) is equal to the *value* of income and sales,

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[3] Emphasis added. As noted in section 2, positive loops are also called reinforcing loops.

then students struggle to keep in mind that the "P" in GDP stands for product(*ion*) requiring employment of factors such as land, labor, and capital. Most textbook circular flow diagrams perpetuate the confusion.

The circular flow diagram also has serious limitations as a feedback model of the economy. First, it fails to show counteracting loops that control tendencies for growth or decline. For example, DeLong's textbook model (Figure 6) is not accompanied by any nearby suggestion that the multiplier has limits. Indeed, as shown in Figure 6, if the loop received a shove or a tug, a boom or bust would develop without an endogenous end. Secondly, the typical circular flow diagram suffers from failure to acknowledge the significance of material and information delays in the reinforcing and counteracting processes that connect production, income, and sales. Feedback, by definition, requires time. Any conceptual scheme that trivializes real time is incapable of representing feedback phenomena and, therefore, is incapable of representing endogenous change-over-time; i.e., dynamics. The feedback method described in this paper builds on the dynamic insights of the circular flow model but safe-guards GDP as a production concept, includes time as an explicit influence, acknowledges disequilibrium in a macroeconomy, and identifies counteracting feedback loops that exert goal-seeking pressures necessary for a market economy to regulate itself.

2. Links and Loops

In the previous section, the Walras-Marshall debate was reviewed with links and loops without much explanation of those terms. Here, we provide more detail about these symbolic tools. We begin with the concept of a causal link—a *ceteris paribus* cause-and-effect relationship between two variables. Then we show how two or more links can be joined in a closed feedback loop.

Word-and-arrow diagrams sometimes appear in economics textbooks. Sexton (2002, p. 269), for example, uses an arrow pointing up (↑) or down (↓) in front of a variable to show whether it is increasing or decreasing in value. He uses a horizontal double-arrow (==>) between a "cause" and an "effect." To express one of Marshall's hypotheses in Figure 2, for example, Sexton would write the expression in Figure 7 to mean that an increase in supply would cause a decrease in price. To show Marshall's hypothesis about price when supply *decreases*, Sexton would use the expression in Figure 8.

↑ supply ==> ↓ price

Figure 7. Sexton and Marshall (1)

↓ supply ==> ↑ price

Figure 8. Sexton and Marshall (2)

Figure 9 shows how both versions of the Marshall hypothesis would be explained in a single causal link used in system dynamics diagramming.

supply $\xrightarrow[-]{}$ price

Figure 9. Marshall Causal Link

The minus sign (-) in Figure 9 means that price would *decrease* if supply *increased*. If the supply *decreased*, then the minus sign (-) means that price would *increase*. In other words, the polarity of the link is suggestive of two variables moving in opposite directions. If the link had been labeled with a plus sign (+), that would suggest two variables moving in the same direction.[4] Thus, the interpretation of link polarity is similar to the interpretation of the sign of a correlation coefficient. However, system dynamics models connect variables that have causal rather than merely correlational relationships.

Some students prefer a labeling method that uses letter symbols instead of plus and minus signs. That method uses "s" (instead of +) and "o" (instead of -), with "s" meaning *same* direction effect and "o" meaning *opposite* direction effect. The s/o labels are used with the Virginia students. They would see Marshall's hypothesis written symbolically as it appears in Figure 10. The s/o method will be used in the remainder of this paper.

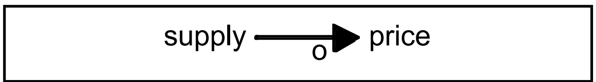

Figure 10. Marshall Causal Link, with "o"

In a causal link, it makes no difference whether the "causal" variable is on the right or left or top or bottom. All of the links in Figure 11 have the same meaning.

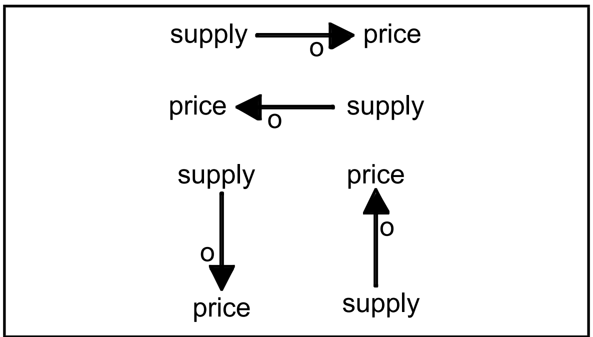

Figure 11. Equivalent Links

Combining links is a straightforward process after each two-variable link has been hypothesized. Figure 12 shows a combination of Marshall's hypothesis about supply and price (from Figure 2) with Walras' hypothesis about price and demand (from Figure 1).

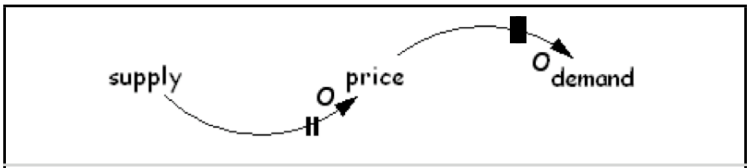

Figure 12. Combining Two Links

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[4] If the first variable is a *flow* and the second variable is the associated *stock*, then a plus (+) sign should be interpreted as "addition" to the stock. A minus (-) sign would indicate "subtraction" from the stock. For example, production *adds* to inventories, and sales *subtract* from inventories.

The "o" is equivalent to a minus (-) sign. Therefore, the net effect of combining the two links in Figure 12 is equivalent to multiplying two negative numbers together to get a positive number. An exogenous increase in supply, therefore, increases demand, or more precisely, quantity demanded. This is equivalent to a rightward shift of a product supply curve, followed by a reduction in price (after a delay in which the expected market response was considered) and a rise in the quantity demanded.

In Figure 13, after an exogenous shock affects demand, then demand has a delayed effect on price. Eventually, price changes and puts pressure on demand. Such mutual circular causation, which necessarily requires a time lag *somewhere along the loop,* is called ***feedback***. In this particular example, if the initial shock increased demand, then the rising demand would put upward pressure on prices. The eventual rise in prices would have the opposite effect on demand in a subsequent time period—the rising price would put downward pressure on demand, making it lower than it would be otherwise.

When a feedback loop contains an *odd* number of "o" links (or minus signs), it will counteract or negate a previous trend. When a loop (such as C in Figure 13) has that effect, it is called a *negative* loop or *counteracting* loop or *balancing* loop. Each term has the same meaning, and they are used interchangeably.

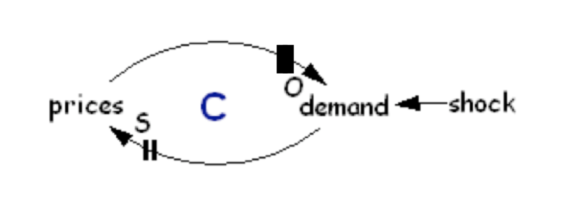

Figure 13. Counteracting Loop

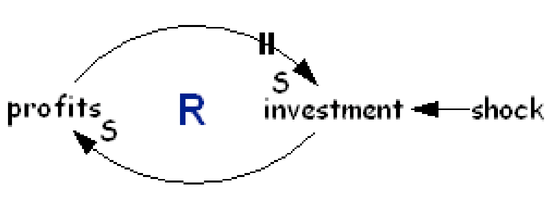

Figure 14. Tinbergen's Reinforcing Loop

The other type of feedback loop is called either a *positive* loop or a *reinforcing* loop; again, the terms are synonymous. Figure 14 illustrates the previously discussed empirical relationship that Tinbergen (1939) justified on the basis of the "time lag" between profits and investment. A "walk-around-the-loop" in Figure 14 reveals that loop R reinforces a previous trend. After an exogenous shock boosts investment, profits rise. Somewhat later, the rise in profits encourages more investment. The initial trend reinforces itself, and confirmation comes from counting an *even* number of "o" links (namely, zero) around the loop.

As Tinbergen emphasized, there is "no danger of circular reasoning" when conceptualizing such loops if proper attention is given to time lags. There must be some delay in *at least one* link in a feedback loop. In system dynamics modeling, delays are associated with the build-up and depletion of stocks—accumulations of material (e.g., inventories) or information (e.g., profit data that must be collected, analyzed, and acted upon before influencing investment). When delays are long, a feedback loop responds slowly to changes along its links. In that case, a positive loop would grow or decline more slowly in response to a shove or tug. A negative loop is goal-seeking, but if some of its links adjust slowly, the loop's countervailing influence will be relatively weak and its progress toward a goal will be relatively slow. Moreover, if such delays in a counteracting loop involve more than one stock, oscillations may occur. Time matters.

3. Introducing the Feedback Method

In the macroeconomics distance learning course at Virginia Western, the feedback method does more than supplement standard instruction. It is the central organizing feature. Therefore, the course begins on parallel tracks. While students are getting the standard textbook introduction to measurement of economic indicators during the first few weeks, they are also viewing historical time series data with *MacroLab's* interface and learning to "read and write" simple links and loops. The students first practice their new skills in hypotheses-building exercises. They are required to develop *ceteris paribus* cause-and-effect hypotheses about the economic indicators they have been studying. After viewing historical data on employment and the unemployment rate, for example, each student is asked, "What might cause the level of employed labor to change?" The answer has to be expressed in a word-and-arrow diagram, and the student must write a few sentences that interpret the intended meaning of the link.

#1	*consumption* → *employed labor* (S)
If consumers begin to increase their levels of consumption of goods and services more employees will be need to fulfill those desires. The reverse is true, if people begin to lessen their use of these services then the employees will not be needed and employment will be down, along with the demand.	
#2	*fuel prices* → *employed labor* (O)
Due to the recent increase of fuel cost and the current slowing of the economy the demand for certain products causes manufacturers to increase their prices and cut production. In return this causes a decrease in manpower, which later results in layoffs.	

Figure 15. Hypotheses from Two Students

For example, the hypotheses in Figure 15 were offered by two students writing in the *Blackboard* threaded discussion forum of their distance learning course. These two hypotheses, despite some glaring weaknesses, are among the better ones received in the first assignment. Initially, some students can say little more than "employment goes up when the economy goes up."

However, the students' hypotheses always motivate follow-up discussion aimed at clarifying misconceptions or faulty logic. After more reading and several similar assignments —plus numerous *Blackboard* postings—the students eventually begin to grasp the *ceteris paribus* links in Figure 16, most of which represent hypothesized behavioral relationships that develop over time. The link from employment to GDP is assumed to occur without significant delay. The last link, of course, expresses a definitional relationship. As the course develops, many other paired cause-and-effect links are identified and discussed. At appropriate stages, the links are combined into loops. The students are virtually engaged in building a conceptual macro model.

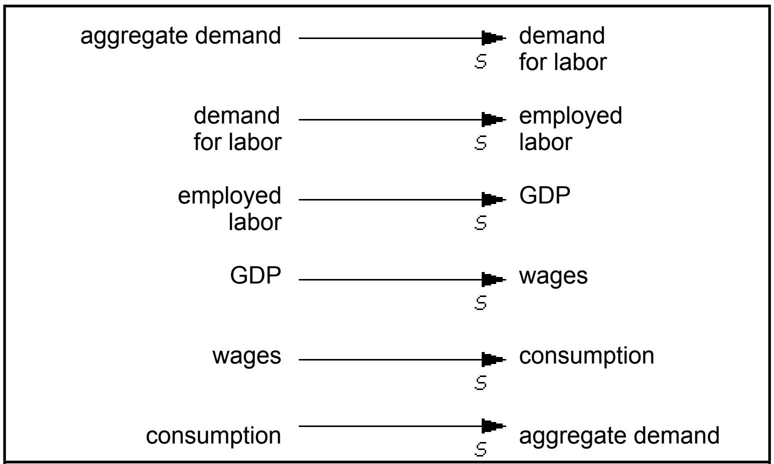

Figure 16. Causal Link Hypotheses for Loop R in Figure 17

The first feedback loop constructed uses the links in Figure 16. It is the **reinforcing loop** (R1 in Figure 17) suggested by the standard textbook circular flow diagram. For initial simplicity, all income is treated as wages, and there is no saving or investment, no government, no central bank, no foreign trade, and productivity is strictly exogenous. As more loops are added to the model, such influences will be added and endogenized (i.e., their values will be determined by feedback within the model). Students learn that R1 is an example of a reinforcing feedback loop, which "feeds on itself." They sometimes call it the "boom or bust loop" because its reinforcing effects could be either virtuous or vicious. A review of historical trends and a little time spent with the *MacroLab* simulator, however, contradict any expectations that a mature economy skates perilously along a razor's edge.

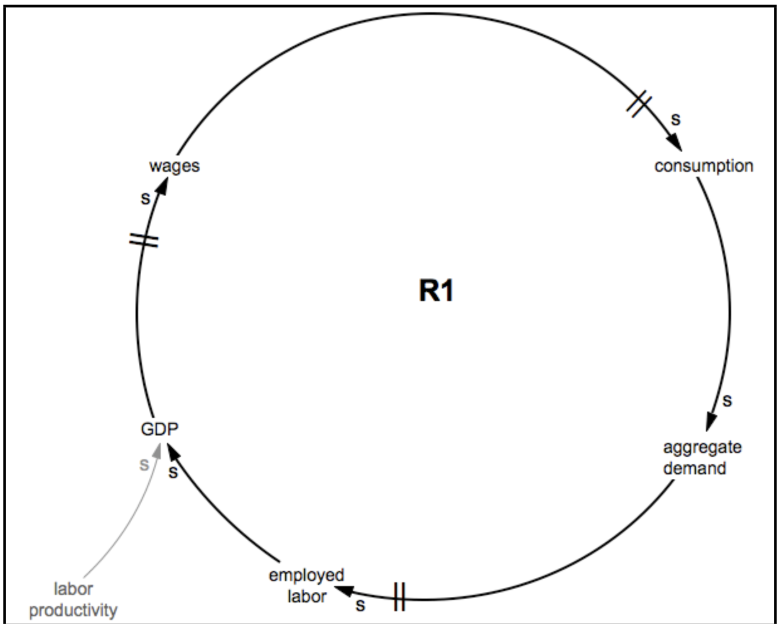

Figure 17. Simplified Main Reinforcing Loop

Answering the "Why not?" question requires finding some counteracting feedback loops, and that means thinking about some new links. We usually focus next on hypotheses that involve real aggregate demand, product prices, and inventories. The first three links in Figure 18 form the counteracting feedback loop C1 in Figure 19.

$\text{inventories} \xrightarrow{o} \text{price}$

$\text{price} \xrightarrow{o} \text{real aggregate demand}$

$\text{real aggregate demand} \xrightarrow{o} \text{inventories}$

$\text{GDP} \xrightarrow{s} \text{inventories}$

Figure 18. Causal Link Hypotheses for Loop C1 in Figure 19

Figure 19 includes the hypothesis that an exogenous rise in consumer confidence would give a boost to consumption (and aggregate demand). The significance of any consumer confidence effect is an empirical question, but the link illustrates a demand-side shock that students can grasp at an early stage in the course. The increase in real aggregate demand reduces inventories, which leads eventually to price increases that slow the growth in real aggregate demand. Thus, loop C1 has the effect of counteracting the initial momentum for growth.[5]

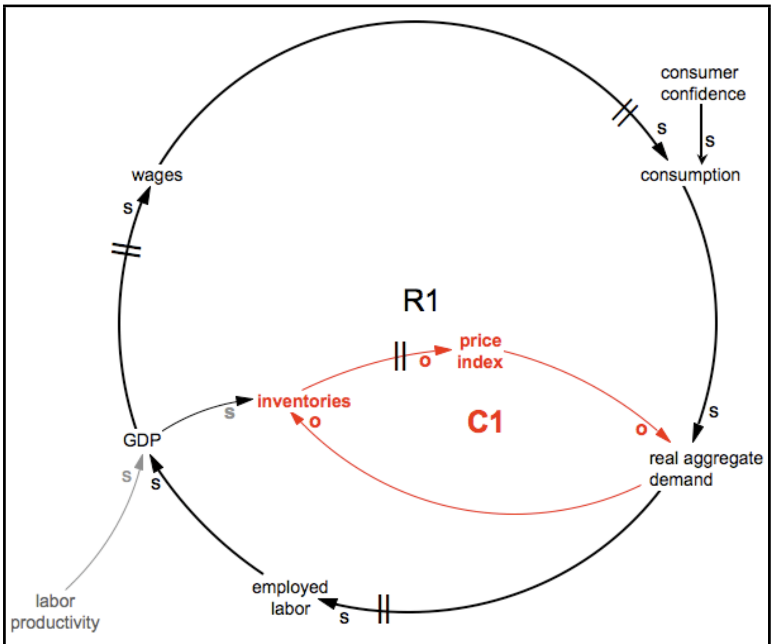

Figure 19. Demand-Inventory-Price Counteracting Loop

[5] Implicit in Figure 19 is that wages and consumption are nominal quantities. Since consumption is the only component of aggregate demand in the diagram, real aggregate demand is equal to consumption divided by the price index. Not shown in this diagram is the multiplying of real wages by the price index to obtain nominal wages.

Before other loops are added to the diagram, students have an opportunity to consider factors that determine the strength of a loop. Using the *MacroLab* simulator, they conduct experiments with different parameter assumptions. The response time of a loop is clearly an important parameter, and students simulate the effects of different price adjustment times in loop C1. However, computer software is not required to imagine the results in simple cases. Even without a computer, intuition suggests that a spending increase matched almost immediately by a price increase would counteract the spending trend sooner than a price increase that was delayed for months. Less obvious but still amenable to mental simulation is the return trajectory. Assuming *short* price delays, a brief rise in spending would be followed by an equally brief downturn and a smooth approach to its original equilibrium rate. If price delays were *long*, however, the spending trend could oscillate before stabilizing.

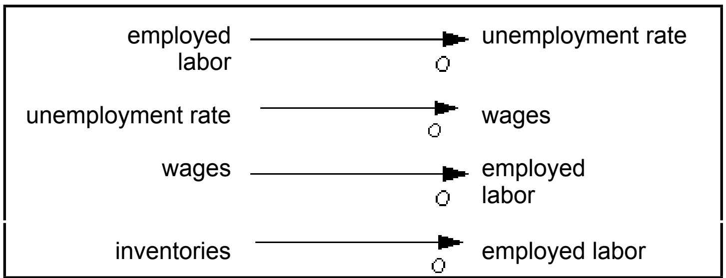

Figure 20. Causal Link Hypotheses for Loops in Figures 21 and 22

Figure 20 lists additional links developed early in the course—again, with student involvement. After the students grasp these links, they are more likely to understand the counteracting feedback loops displayed in Figures 21 and 22.

In Figure 21, for example, loop C2 could receive a boost from exogenous growth in the labor force, which would raise the unemployment rate initially. However, the rising unemployment rate would depress starting wages and encourage more employment. Eventually, the unemployment rate would retreat toward its prior level.

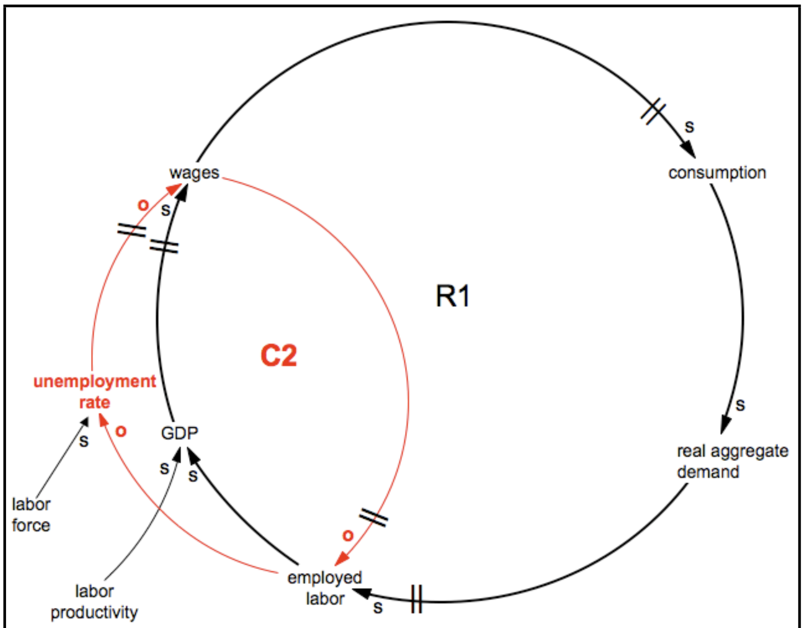

Figure 21. Wages-Labor-Unemployment Counteracting Loop

Loop C3 in Figure 22 can be used to show what happens when inventories initially rise above desired levels (following a drop in aggregate demand, for example). The resulting decline in the demand for labor puts downward pressure on employment and GDP. That reduces additions to inventories, but inventory levels will not decline until GDP falls below real aggregate demand.

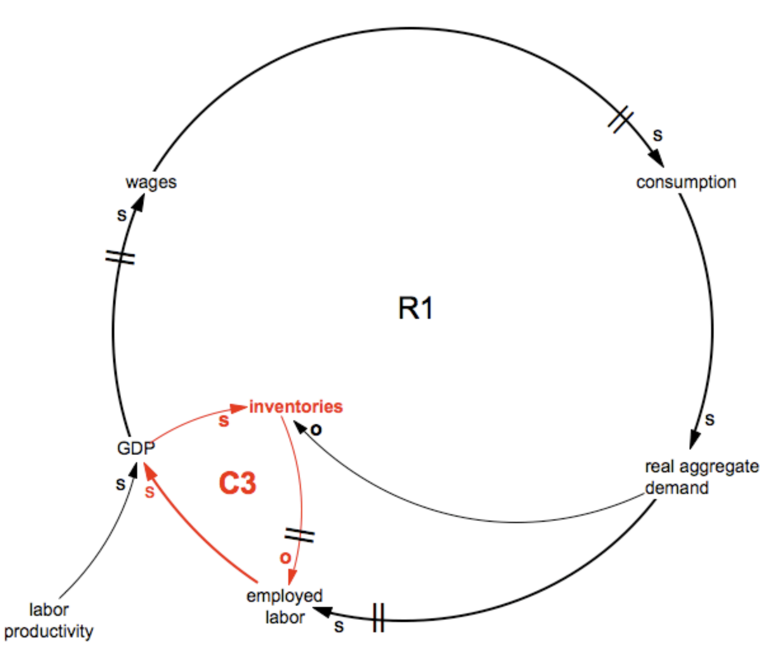

Figure 22. Inventory-Labor-GDP Counteracting Loop

The learning objective in this opening round of feedback method instruction is straightforward. First, show the potential for growth and decline in loop R1. Then illustrate that counteracting loops are the self-regulators built into a developed market economy. Loops C1-C3 are important examples, but other counteracting loops will emerge as the model develops during the course. The potential for a market economy to regulate itself, of course, does not guarantee that corrective adjustments will be timely or politically acceptable. Using the feedback method does not presume the absence of economic policy. In fact, *MacroLab* has endogenous fiscal and monetary sectors that respond to economic conditions according to hypothesized links in the model.

This section has demonstrated how the feedback method could be used to *introduce* a course in macroeconomics. The rest of the course involves exploring the "sides" of the economy—supply side and demand side—and the sectors within each side (e.g., government sector, monetary sector, foreign sector) and the sub-models within each sector (e.g., labor, capital, pricing, consumption, interest rates, income distribution, and government budgeting). In each case, the approach is similar: identify key links, connect the loops, and analyze the potential behavior of the loops. Of course, the net influence of all the loops in the system may not be at all intuitive, and that is why simulation capability adds so much to the feedback method.

The feedback loops are simplified representations of the underlying stock-and-flow model that can be used to simulate behavior in the model economy. Although instructors can use the feedback method to supplement their lectures without computer support, simulation is central to the system dynamics method. Moreover, the ability to simulate different sectors of the economy—to turn sectors ON and OFF and simulate—presents powerful learning opportunities (e.g., simulating *with* and *without* the foreign sector). The interface also permits students to make experimental modifications to parameters and structure for the purpose of exploring, for example, how changes in government policy affect economic performance.

4. Feedback Method Research

The pedagogical potential of the feedback method has received support from a series of experiments aimed at identifying student preferences and measuring student performance when using the feedback method. The first two experiments examined student *preferences* with respect to teaching and learning dynamics. In both, students preferred the feedback approach over conventional methods that relied on equations or graphs (Wheat 2007a, b).

The third and fourth experiments focused on student *performance*. Following Cohn et al., the third experiment assessed the value added by a stock-and-flow feedback diagram to mere textual instruction about GDP. The common belief that comprehension of information is fostered by visualization of that information is supported by scientific research (Wolfe 2001, Shaw 2000), but the Cohn results show that not every picture is worth the proverbial opportunity cost. In the GDP experiment, however, students receiving the feedback diagram *were* more likely to score higher on post-tests, and their learning gains were also significantly higher (Wheat, 2007c).

The fourth experiment was a direct comparison of the pedagogical value of graphs and feedback loops. Students in two groups learned about the so-called "sticky price theory" of business cycles. The instruction for one group utilized a textbook AS/AD graph, while the other method presented the effects of sticky prices in terms of two interacting feedback loops. The students using the feedback method outperformed those who relied on the graph (Wheat 2007d).

A definitive explanation for the performance advantage of the feedback method in these experiments is probably a task for cognitive psychologists. However, the pedagogical potential of the feedback method was suggested by Forrester's (1994, p. 81) description of system dynamics as a "…*framework* into which facts can be placed [so that] learning becomes more relevant and meaningful." The need for such a learning framework had been expressed by educational psychologist Jerome Bruner (1960, p. 24), who said that "the most basic thing that can be said about human memory…is that unless detail is placed into a *structured pattern*, it is rapidly forgotten." Students' own explanations during the first preference experiment may shed some light on this issue. When selecting the feedback diagram over the graph, the phrase "describes a process" was most often used to explain the choice (Wheat 2007a). Future research should include efforts to better understand how students form mental models of economic processes.

5. Final Comments

Each link in a model—whether at the stock-and-flow equation level or at the feedback diagram level illustrated in this paper—represents a *hypothesis* about behavioral relationships. Instructors who see some merit in the feedback method may, nevertheless, have a mental model of the economy that translates into different hypotheses and links than those illustrated here. A particular strength of the feedback method is that it makes clear to students how theories are constructed and tested. Moreover, this particular approach facilitates—indeed, encourages—experimentation with different parameter and structural assumptions. Nothing could be further from chalk-and-talk or, in this slideshow era, point-and-click.

Any assessment of the merits of the feedback method would be incomplete without consideration of unintended consequences. It is conceivable, for instance, that emphasis on feedback loops in an introductory course would reduce reliance on static graphs to such an extent that students would remain "graph illiterate" and have difficulty in other economics courses that presume students have a working familiarity with graphs. The obvious way to avoid that scenario is to teach *both* graphs and feedback loops. That may not seem worth the effort unless one believes there is synergy in teaching both, and that in itself is an interesting hypothesis. For example, does working with loops facilitate understanding of graphs? In an experiment requiring students to choose between an AS/AD graph and a pair of feedback loops to explain business cycles, a statistically significant majority preferred the loops (Wheat, 2007a). One student added this comment to explain his choice:

> *Method 1* [graph] *is a weird graph. I have never interpreted something that complex. But then as I began to understand the second method* [loops], *I was able to understand more about the first method* [graph].

Future research should examine how the graphs and feedback loops can be used in complementary ways. Both belong in the macro instructor's toolkit.

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