

## **Using STELLA and System Concepts To Teach Microeconomics**

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### **Abstract**

Despite the power of our framework as a tool for learning, system dynamics has yet to penetrate into the economics discipline. A different approach to dissemination of system dynamics into the microeconomics mainstream is presented. In contrast with the traditional product-focused strategy, the new approach uses microeconomic theory as a context for the development of student modeling skills. The approach relies heavily on the STELLA software. It is embodied in a book for introductory and intermediate microeconomics students. The general specifications and design of the approach are presented. To illustrate the approach, a sample laboratory session from the book is provided.

### **Introduction**

Throughout its history, the system dynamics framework has offered great potential for increasing our understanding of how systems work. The framework helps us learn in many ways. It helps us to "ask the right questions." Its experimental approach disciplines our thinking. Its dynamic, feedback-based simulations extend our intuition and understanding. Most of us have experienced the power of the framework in facilitating efficient learning in specific subject areas.

Yet, most of us would agree that the potential of system dynamics has not been realized in many disciplines. Despite the power of the framework as a tool for learning, few university departments make extensive use of system dynamics. This is especially apparent in economics departments. Even though the MIT group has integrated economic theory into a comprehensive national economic model that sheds much light on ill-understood economic behaviors, most economists choose either to ignore or to criticize the framework. Most economics teachers neither know, nor do they care, about what the framework can do for them.

Economics thus continues to be taught from the traditional static, equilibrium-oriented perspective. In introductory and intermediate classes, students learn textbook theories by rote. Theory is presented as revealed truth. Students have little opportunity to explore the strengths, weaknesses, and dynamic implications of economic theory. They have even less opportunity to learn about the relevance of system dynamics to their studies. To the extent that students are exposed to the approach, they are told that its models (and hence, the approach itself) are too trivial and simplistic for further consideration (Seneca and Taussig 1979, p. 351). Students of economics absorb the biases and misconceptions of their mentors. Eventually the students grow up to become teachers of economics, and the cycle begins anew.

Clearly, we face difficulties in our attempts to disseminate system dynamics into the economics discipline. Even though we offer a tool which can greatly increase both the efficiency and quality of learning for economics students, we seem unable to make significant inroads into the economics departments in American universities. Our traditional strategy for market penetration -- a series of system dynamicist-built products -- has met resistance in the past and will continue to meet resistance from entrenched economics departments.

To overcome this resistance to system dynamics, we need a different approach to dissemination. We need an approach that works from within the discipline, taking advantage both of what economists have to offer and of the way in which people learn. As an ideal, the new approach will lead to increased efficiency and quality of learning in economics. In addition it will expose system dynamics for what it really is: a powerful process for learning, not a set of products.

This paper describes a new approach to the dissemination of system dynamics into the economics discipline. In pointing to the need for a different approach to dissemination, the first section of the paper addresses the difficulties we face in "imposing" our techniques on the economics profession from the outside. Specifically, the section looks at why our traditional approach to dissemination is unlikely to result in widespread use of system dynamics among economists.

Next, the paper presents the general specifications and design of a new approach to the dissemination of system dynamics in the economics discipline. In contrast with our typical consultant-mode attempts at doing economics with system dynamics, this new approach takes advantage of the skills of economists as it taps into the natural learning styles of students. Operationally, the approach relies heavily on the STELLA experiential learning laboratory software developed at High-Performance Systems. (For more about STELLA, the experiential approach to learning, and the applications of the approach, refer to the papers presented by Barry Richmond and Peter Vescuso.) The approach uses a laboratory session format to facilitate student learning. Students are guided through sessions in which they develop, test, and extend models that reflect both their own experience and economic theory as it applies to real-world behaviors. Through their laboratory work, students gain a deeper understanding of extant economic theory. And, since the laboratory work develops their modeling skills, students gain the tools necessary to enhance and extend the theories found in textbooks.

Finally, to illustrate the approach, the paper provides a sample microeconomics laboratory session. This session is taken from consumer theory. Its intent is to help students better understand the concept of utility that underlies textbook consumer theory, and to provide initial exposure to STELLA modeling. The lab session presented here is very simple -- it is aimed at the undergraduate student who knows little about STELLA or about microeconomic theory. Yet, it helps to illustrate some state-of-the-art concepts in economic thinking. The session, and the STELLA experiential laboratory approach, help students to see the value of system dynamics as a tool for enhancing the efficiency and quality of their thinking processes.

### **Head-butting and Mutual Contempt**

Despite some excellent applications of system dynamics in areas of microeconomic inquiry, we have been unable to make significant inroads into the economics discipline. This is somewhat surprising when one considers that we share the goal of microeconomists when we venture into the field. Both we and they seek to gain insight into the workings of microeconomic systems. Given our shared goal, we should be working together with microeconomists, with each group drawing upon the distinctive competencies of its counterpart. It seems clear that we have not yet captured the synergies of collaborative effort with microeconomists. Far from it. Instead, in our efforts to do microeconomics we act like battering rams. In our applications, we butt our heads against the ivory tower of microeconomic theory in an attempt to destroy the theory from outside. Indeed, it sometimes seems that the only thing we share with microeconomists is an attitude of mutual contempt.

Why has this unproductive situation developed? I don't think fault lies with the system dynamics framework itself. We all recognize the power that the framework offers to those who use it. Nor do I think that fault lies with the microeconomics models and texts that come out of the system dynamics framework. The papers and books associated with the development of the national model at MIT, for example, provide some very powerful insights into the workings of economic systems. Rather, I think that the situation developed because of our almost-exclusive product *focus*. In our zeal to demonstrate our newfound

insights into matters economic, we have neglected to consider the learning style that dominates the mainstream of microeconomics. In a sense, the interaction of our product focus with the learning abilities of microeconomists set the stage for our current situation of head-butting and mutual contempt.

To see the difficulties inherent in our product-focused approach to penetration, think for a moment about the learning abilities that dominate the microeconomics mainstream. Mainstream microeconomists deal well with abstractions, high-level mathematics, and formal logic. Their dominant learning abilities tend to be in the realm of abstract conceptualization and generalization. Because these skills so dominate the microeconomics mainstream, microeconomic theory and practice tends to stress abstract generalizations, often at the expense of real world correspondence. In fact, the microeconomics priesthood seems to be self-selecting. Those budding economists who are unwilling or unable to deal with high-level abstractions fall by the wayside, leaving pure theorists in their place. As one critic observes:

"Apprentice economists are relieved of the need to learn much about the complexities of human motivation, the messy universe of economic institutions, or the real dynamics of technological change. In economics, deduction drives out empiricism. Those who have real empirical curiosity or insight... are dismissed... and marginalized within the profession. In their place departments of economics are graduating a generation of *idiots savants*, brilliant at esoteric mathematics yet innocent of actual economic life." (Kuttner 1985, p. 77).

Thus, an evolutionary dynamic tends to reinforce the ivory tower nature of microeconomics theory and teaching. Microeconomists view the world "from the angelic perspective of hyperplanes cavorting in  $n$ -space" (Daly 1977, p.3) because they enjoy the view, because they are good at it, and because they are less able to deal with the world from a more earthly perspective. Microeconomics is taught from this perspective; hence, those students who share the learning abilities and dispositions of their mentors are selected to become the new members of the microeconomics priesthood.

Our historical product-focused approach has interacted with the microeconomics mainstream in a somewhat perverse way. Although the system dynamics products -- typically, constructed models with associated text -- contain excellent insights into the workings of economic systems (for example, underscoring the importance of stuff like inventories), the products often do not mesh well with the theories and learning abilities of mainstream microeconomists. From their abstract, highly general perspective, the typical microeconomist finds it difficult to understand and see the relevance of our more empirical approach. Except for rare instances, they either ignore or heap unwarranted criticisms on our products (see, for example, the voluminous criticisms surrounding *Urban Dynamics*). Because our product-focus does not mesh well with the microeconomics perspective, our work gets pushed to the margins of the profession.

The static situation is bad enough, but the dynamic interaction is even more perverse. Our products do not appeal to the learning style of microeconomists, and so are rejected by the mainstream. But precisely because our products are rejected, we gain the impetus to increase the rift that divides us from the microeconomists. Rejection of our products by microeconomists provides *prima facie* evidence that the microeconomists lack an understanding of economic systems. We become more arrogant in our thinking, and our microeconomic products diverge further and further from the microeconomics mainstream. Meanwhile, rejection from the mainstream increases, further fueling our mutual contempt.

Thus, our traditional product focus, by failing to deal with the dominant learning style and attitude within the economics discipline, has led to an estrangement between system dynamicists and microeconomists. Because of the self-selective nature of the economics discipline, our attempts at butting our heads against the Ivory tower are unlikely to change the way that microeconomics is taught or practiced. Rather, the product-focused approach to dissemination of system dynamics concepts is likely to increase the estrangement that currently exists. It seems that we need a different approach if we intend to make

system dynamics an integral part of the microeconomics discipline.

### **A New Approach to Dissemination**

Our current relationship with the microeconomics discipline is disappointing. Yet, it is probably the only way that things could have worked themselves out. As Barry Richmond describes in his paper on STELLA, our traditional pathways for transferring skills in system dynamics -- years of formal education followed by more years of apprenticeship -- have limited our ability to spread the *process* of doing system dynamics. To make ourselves visible among microeconomists, we were forced into product-focused efforts at dissemination.

Now, however, we have new tools that can enable efficient transfer of the system dynamics framework into the microeconomics discipline. Specifically, through the use of STELLA, we can design a new approach for disseminating system dynamics skills and insights among the ranks of (unsuspecting) microeconomics teachers and students. This section fleshes out the major goals and implementation strategy of the STELLA approach, as applied to microeconomics. For a discussion of STELLA and the experiential laboratory approach to learning, refer to Barry Richmond's paper. To see how the approach is manifest in the context of physics, check out Peter Vescuso's paper.

The new approach is embodied in a book, entitled Learning Laboratories in: Microeconomics. The book is aimed primarily at students, secondarily at teachers of microeconomics. The major objectives of the book are fourfold. First, the book aims to increase the efficiency and quality of student learning in microeconomics. Because of the dominant learning style of microeconomists, microeconomics is often taught in a manner that is abstract, bloodless, and difficult to understand. The book attempts to help students quickly gain a better understanding of what microeconomic theory really means -- in concrete, nonabstract terms. Through its experimental/experiential approach, the book aims to help students build better quality microeconomic models -- explicit and mental models that reflect actual situations rather than the ideal frictionless world.

Second, the book attempts to demonstrate the value-added of our approach in the study of microeconomics. That is, the book shows the usefulness of system dynamics modeling skills in understanding, testing, and enhancing microeconomic theories. The book aims to present system dynamics concepts in a manner congenial to teachers as well as students. It is an attempt to persuade them that the STELLA learning laboratory approach is a useful, readily available addition to their teaching and research activities.

Third, the book attempts to facilitate the development of student and faculty modeling skills. STELLA removes many of the barriers to learning the art of modeling. With the advent of STELLA, we need not expect that people spend several years "at the feet of the masters" before they gain competence in modeling. Rather, with STELLA and the laboratory session approach, we can expect that students will gain a reasonable measure of modeling expertise as they develop and exercise models of economic situations.

Finally, the hidden agenda. An implicit goal of the book is to plant seeds of revolution within the microeconomics discipline. By providing tools for uncovering and analyzing some of the "gremlins" of economic theory, the book should help to bring about change in the way that microeconomics is taught and practiced.

The strategies for achieving these goals permeate the structure and content of Learning Laboratories in: Microeconomics. The book is structured as a series of laboratory sessions. Within each chapter, a set of laboratory sessions addresses the basic concepts associated with a topic in microeconomic theory. For example, the book's second chapter deals with consumer theory. The third chapter looks at producer theory. Concluding chapters of the book connect producer and consumer via a price system, examining the various modes of competition as well as general equilibrium theory. The sequence of lab sessions and

chapters closely follows the progression of the typical introductory or intermediate microeconomics text.

Overall, the progression of the book is from the simple to the complex. The laboratory models that the students develop, test, and enhance become larger and more complex as they gain understanding of theory and proficiency at STELLA modeling. In addition, as students move through the book, the text relaxes its constraints on student creativity. Guidance in the construction and testing of laboratory apparatus moves from "cookbook" to more complete freedom. In the initial lab session, the students virtually are held by the hand as they develop and test a simple one-level model. By the end of the book, the modeling effort is much more free-form. As they develop their STELLA skills, the students begin to assume primary responsibility for context, reference mode behaviors, experimental tests, and enhancements for their laboratory apparatus. The text guides students with brief descriptions of the relevant theories, as well as through a series of open-ended leading questions.

Similarly, within each chapter the laboratory sessions progress from simple to complex. The underlying logic of the laboratory apparatus moves from "correlational" to "causal." And, the textual guidance within each chapter moves from hand-holding to hints, suggestions, and open-ended questions.

Individual laboratory sessions within each chapter are partitioned so that they form short, relatively independent units. Each laboratory session covers a key aspect of microeconomic theory as it is presented in the textbook and classroom. Yet, the laboratory sessions build upon one another. By the time students have finished a chapter, they should have a good understanding of, for example, the theory of the firm. They will have been provided the opportunity to exercise the theory, to gain an appreciation of its strengths and weaknesses. If they wish, they can extend or enhance the theory.

From this brief description, Learning Laboratories in: Microeconomics might sound a lot like a re-hash of the typical microeconomics textbook. Let me first assure you that this is not the case. Nevertheless, the similarity in format and the book's heavy reliance on textbook theory as a starting place are not accidental. With the book, we at High-Performance Systems want to make system dynamics attractive to microeconomists. We want to demonstrate that the STELLA approach is useful in their discipline. In addition, we want to help students better understand what microeconomic theory is all about. The format of the book and the use of generally accepted microeconomic theory are strategies to achieve these goals. They give the approach some measure of face validity. They are consistent with the way in which economists tend to think, thus making the approach more congenial. Students must learn the generally accepted theories. As a supplement to the student's primary text, then, the book must parallel class work. Finally, of course, generally accepted theory provides a useful starting place for the introduction of real-world assumptions.

Although the outline of Learning Laboratories may look much like the typical textbook, the similarities begin to fade once the laboratory sessions begin. Each laboratory session contains five more or less distinct phases: background and introduction, construction of laboratory apparatus, experimentation with laboratory apparatus, notes or diversions for the serious student, and summary and references. The three intermediate stages are neither linear nor sequential. That is, construction is often interrupted by simple laboratory experiments, which provide impetus for further construction. Diversions are often interspersed throughout the lab sessions. At each of the five stages, the book makes use of several strategies to help students learn STELLA skills as they develop their microeconomic intuition and understanding.

In the background and introduction stage of the typical laboratory session, the student is provided with introductory information about the microeconomic theory to be covered. For example, the introduction to the lab session on indifference curve analysis briefly reviews the "modern theory of the consumer" from microeconomic texts. In addition, the introduction puts the laboratory session in a real-world context of interest to the student. For example, the context of the lab session on indifference curve analysis comes in

the form of the question, "How do you allocate your discretionary income between dinners and movies?" The context, or experiential base for the lab sessions is crucial. Not only does a real-world context facilitate efficient learning (Kolb 1976, p. 22); it also provides a frame of reference from which students can evaluate the reasonableness and real-world correspondence of their laboratory apparatus.

After students pass through the introduction and background, they begin construction of the laboratory apparatus. The text guides students through this process, gradually relaxing its constraint on their creativity as their modeling skills develop. Students are first asked to put up an important accumulation or two. Admittedly, this is often difficult since microeconomic theory seldom if ever uses stocks. Once they have a level on the screen, they attach rates and begin to work their way backward through the logic of each rate. Only after they finish fleshing out the structure of each level do they move on to add more stocks, flows, and logical operators. (Most of the models in the book are quite small, of course.) As described below, students are encouraged to test their apparatus throughout the construction process.

The "expert system" features of STELLA eliminate many of the pitfalls of equation writing. The text also tries to facilitate this process. For example, Learning Laboratories in: Microeconomics makes use of generic "atoms of structure" and "set-aside" formulations to capture processes of production, goal-seeking, "flow-thru," and co-flow. Reliance on generic set-asides keeps students from re-inventing structures that depict well-known flow regulation processes. Instead, students can focus their efforts on the quantity, shape, and type of inputs into the generic structures.

The text guides students when they get into the mechanics of equation writing. For example, dimensional consistency is used as a check as well as guide for searching out the correct form of rate equations. When appropriate, students are asked about the "input" and "output" dimensions of a decision process. They then have the opportunity to juggle the dimensions until they arrive at a decent rate formulation.

In addition, the model construction phase makes great use of the "thought experiment approach to graphical function construction." Whenever a graphical function is to be drawn, students are asked to conduct a thought experiment that reflects upon their own experience. They then render their experiment in graphical form as they draw the graphical function on the screen.

Opportunity to experiment with the laboratory apparatus is provided both during and after construction. Experiments during construction are geared at providing methodological insights (for example, things like steady-state error), while the experiments after construction provide both methodological and substantive insights. The text recommends some fairly specific experiments through the use of "leading questions." For example, a test might begin with the question, "What would happen to your consumption pattern if the price of movies increased by fifty percent?" The text also encourages the student to be creative with their experiments, to play around in their "conceptual sandbox." Often, after the student has built and experimented with a model, he goes back to the construction mode, enhances the model, and tests some more.

The procedure for the experimentation phase of the lab sessions is straightforward. The book provides ample space for students to keep a laboratory notebook. Students are encouraged to maintain their notebook as they work through the lab sessions. Before each test of a model, they document the model, the test that they are performing, their expected behavior from the test, and their dynamic hypothesis. They then simulate the model. Several animation options are available. Depending on the nature of the test, students may simply animate the model, to get a good intuitive feel for its dynamics. Alternatively, they may select time series plots (to compare with their reference mode) or scatter plots (perhaps to derive a demand curve). Once they have output, they are obligated to explain any discrepancies between expected and simulated behavior. Students are also expected to verify their dynamic hypotheses.

"Notes and diversions for the serious student" are interspersed throughout the typical laboratory session.

These diversions pose provocative questions, address interesting issues, or identify some of the gremlins of microeconomic theory. They are intended to help students go beyond the standard textbook treatments. The diversions are often presented as a reference mode or verbal description. The student is asked, "How can you change your current structure in a way that will generate this neat behavior?" Typically, to capture the behavior requires a simple structural change in the student's laboratory apparatus. Alternatively, the student is given a simple structural addition, and is asked to hypothesize the behavior implied by the new structure. Hints are provided in case the student gets stuck, but the diversions are essentially open-ended. The student's learning here is largely self-directed and self-motivating. Everyone likes to figure out a puzzle.

Each lab session ends with a brief summary. The summary quickly reviews the aspect of microeconomic theory that was covered in the laboratory work. It underscores methodological and substantive insights that the students should have gained from their laboratory experience. Finally, the summary provides references that can help students extend their understanding of microeconomics.

To summarize, the structure and content of Learning Laboratories work to meet the major goals of the STELLA approach. The book's format mirrors textbook microeconomics so that the approach is congenial to microeconomists. The lab sessions help to demonstrate textbook theories, so that the value-added of the approach can be seen. STELLA is used to apply theory to actual situations, so that students become invested in the discovery process. And, since students gain STELLA skills as they gain deeper understanding of microeconomic theory, the seeds of future "revolution" are planted from within the discipline.

### **A Sample Lab Session**

The previous section provided a brief description of a new approach to the dissemination of system dynamics into the microeconomics mainstream. This section shows how the approach was made operational. It contains a sample laboratory session, taken from a draft version of Learning Laboratories in: Microeconomics.

When viewed from the perspective of the system dynamicist, the laboratory session presented here is quite simple and tightly directed. What you will see here is the first lab session that students will encounter in the book. The session is taken from consumer theory. It is intended to help students think more clearly about the notion of utility, as well as to ease them into the process of modeling with STELLA. By working through the lab session, students gain an appreciation of the value of system dynamics as a tool for learning as they gain competence in using the system dynamics framework.

#### ***Lab Session in Utility (An Excerpt From the Book)***

Utility is a central concept in consumer theory. In your text, you are likely to have seen the cardinalist and ordinalist approaches to utility. While the cardinalist and ordinalist approaches are "standard" economics, they are not the only approaches to utility that you will find in the marketplace. In the literature, you will find alternative approaches to utility in Daly (1977), Lancaster (1966), and Scitovsky (1976).

The purpose here is not to provide an exhaustive summary of the various utility theories. You can do this yourself. Rather, we will build a simple model as a means to help you internalize concepts of utility as they apply to your own experience. As you internalize these concepts, you can use them to think more clearly about issues of importance to you.

To begin thinking about utility, you might consider a new phenomenon brought about by the personal computer revolution on college campuses. Most likely either you, or someone close to you, owns a personal computer and lots of the associated hardware and software. Think for a moment about the satisfaction that

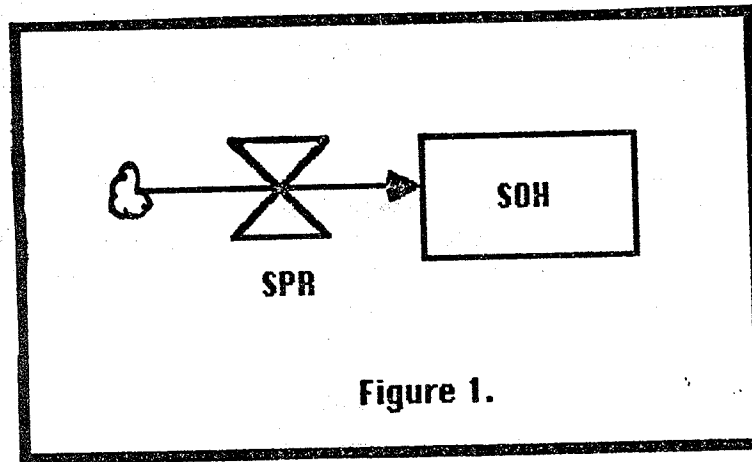
comes about from software purchase and ownership.

It might be useful to think of software (as well as other "consumer durable" types of goods) in much the same way that you would think of a factory -- software is productive equipment in the sense that it enables you to perform new tasks, or to perform old tasks more efficiently. Following this line of reasoning, software provides satisfaction as it helps you to accomplish tasks. As you use your software to perform tasks, it provides you with satisfaction, or utility. (Or, if you prefer, "psychic income." The concept of utility goes under many names!)

If you buy this argument, then what must be true for you to gain utility from software? That's right! You've got to have software on hand before it can be of use to you. Using STELLA, put up a structural construct to represent this necessary condition. Is it a level or a rate? Label your construct.

I put up a level construct, and called it SOH for Software on Hand. The reason for my level representation is straightforward. Unless I have some software on hand, I am unable to do word processing, spreadsheet analysis, or even STELLA models. Until I have a nonzero inventory of software, I am unable to take advantage of my computer. Until I have an accumulation, I cannot use my system and hence cannot gain satisfaction or utility from the solutions it can provide.

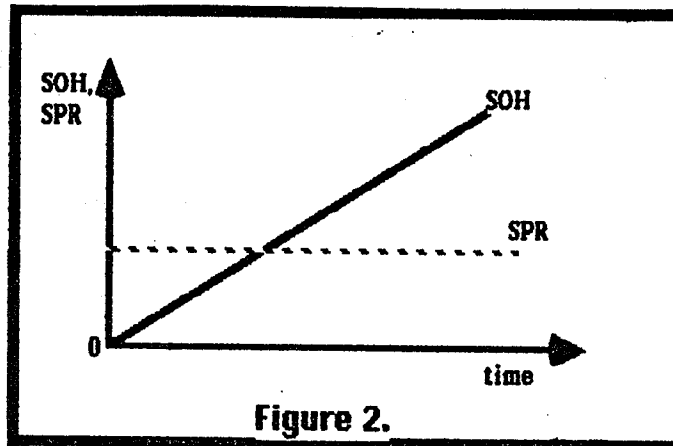
To begin to flesh out this structure, ask yourself what augments the stock of SOH. Simple, right? You augment your personal stock of software through purchases. Select the rate icon, and hook it to the level. Name it. I've called mine SPR, for software purchase rate. Compare your structural diagram with my stylized version, shown in Figure 1.



**TEST:** As a test of your intuition, set SPR equal to some constant, initialize SOH at 0 (for this test, you can assume that you've just begun to purchase software), and animate the structure. Before you animate, document the test, as well as your behavioral hypothesis -- your best guess of how the system will behave -- in your lab notebook. A good way to do this is to sketch out the structure, and then list your assumptions. Next, draw out the hypothesized behavior on a graph. There's no need to be precise about the numbers. Just put time on the horizontal axis and SOH, SPR on the vertical axis. Finally, state your reasoning for the proposed behavior.

Simulation done? Did the system behave as you expected? As you found, if you purchase software at a constant rate (say, three units per week), your stock of software will grow in straight-line fashion. The behavior of your system ought to look something like Figure 2.





As long as you buy the software at a constant rate, the stock will grow! The test here is fairly straightforward. Still, the behavior of simple structures, such as this, can often be surprising. As you progress, you will see how the coupling of simple structures can lead to very complex behavior.

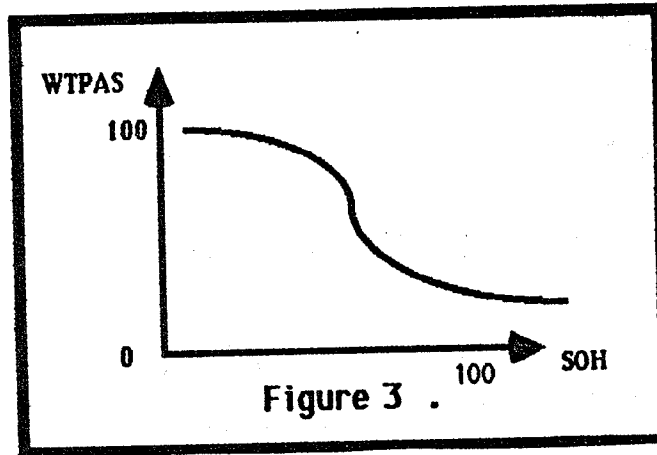
To review, you currently have a structure that represents your private stockpile of software, as well as your software purchase rate. Of interest now is the logic that underlies that purchase rate. Clearly, your decision to purchase software is not as hard-wired as the current depiction. The question, then, is, "What moderates or influences your decision to buy software?"

From the earlier discussion, you can begin to think of your purchase decision in terms of the additional satisfaction that additional software will provide for you. Conduct a thought experiment. After you first purchased your machine, you probably placed a high value on your initial software applications. You bought the machine so that you could accomplish certain tasks, say, word processing, spreadsheet analysis, STELLA modeling and programming. The software applications that accomplish these tasks will provide you with tremendous satisfaction, and are likely to be of great value to you. But once you have these much-needed pieces of software, additional software will provide less added value or utility. Once you have your initial word processing program, an additional word processing application won't give you as much additional help. Similarly, additional spreadsheet packages and programming languages may not add to your ability to perform tasks as much as your initial purchases. Your tenth arcade-style game won't do as much for you as your first.

The results of this thought experiment suggest an interesting relationship between the size of your software stockpile and the added (or marginal) utility of additional software purchases. As your stock of useful software grows, the marginal utility of additional pieces of software declines. Operationally, you can think of the additional satisfaction derived from additional software in terms of your "willingness to pay." That is, the satisfaction from an additional piece of software is worth some amount of money. The amount of money that you are willing to pay to gain this satisfaction is a reflection of its marginal utility. Thus, you may be willing to pay a bundle for your initial software supply, but additional pieces of software better be cheap before you invest your hard-earned dollars on them.

To represent this relationship between software stock and willingness to pay, grab an auxiliary and put it into your model. I call mine WTPAS, for willingness to pay for additional software. Its dimensions are in \$/unit. Select the information arrow, and draw a link from SOH to WTPAS. To define WTPAS, use a graphical function. Mine is shown in Figure 3. Note that my graphical function is a depiction of the results from my thought experiment. It shows that if my software stock is low, I place a premium value

on additional units of software. I am willing to pay \$100 for my initial word processing program -- it will provide me with a lot of satisfaction as I use it to accomplish tasks. As my private cache of software grows, however, my willingness to pay declines, so that by the time I have 100 software applications, the 101st application better be less than \$10, or I won't buy it.

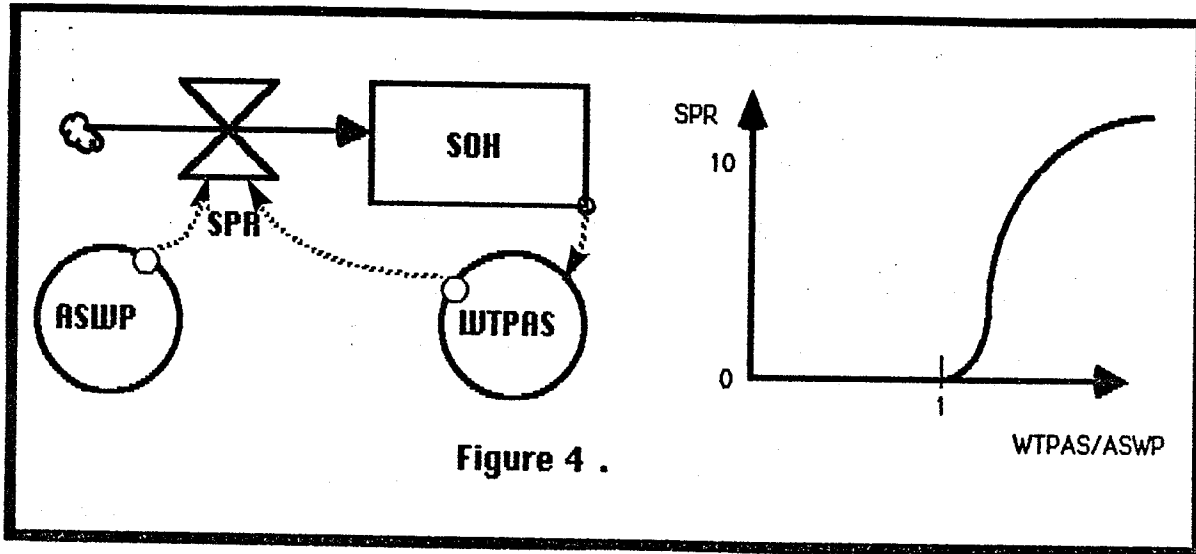


The graphical function that I have drawn reflects the famous "law of diminishing marginal utility". As your stock of software grows, the additional satisfaction from, and hence, the willingness to pay for, additional units of software will eventually decline. Another interpretation for the graph, perhaps more fundamental in nature, comes from producer theory. That interpretation, called the "law of diminishing marginal returns," states that as more and more units of a variable factor (here, software) are applied to a fixed amount of other resources (here, you've only got 24 hours and one computer to use each day), eventually output (here, the number of tasks you can accomplish each day) will increase by correspondingly smaller amounts. In other words, given your limited time and computer resources, that third word processing program isn't going to do as much additional work for you as the first and second ones. In a sense, given the notion of satisfaction from software, the diminishing marginal returns interpretation of the graphical function mirrors the utility interpretation. You are less willing to pay for additional units of software because they provide you with less and less additional satisfaction. But why does marginal utility decline as your software stock grows? It declines because your other resources are fixed, and hence, the additional software will help you to complete fewer additional tasks than the initial pieces of software. We will return to this law of diminishing marginal returns in the next chapter.

But for now, let's complete this laboratory apparatus and do some tests. To do that, we need to link your willingness to pay with the software purchase rate. We need to compare willingness to pay with the going software price, and transform this information into a purchase rate. First, select another circle and place it near to the purchase rate logic. I've labeled mine ASWP, for Average SoftWare Price. For simplicity, and because of wishful thinking, I have given it a value of \$30/unit. Draw information arrows from ASWP, and from WTPAS to the purchase rate symbol.

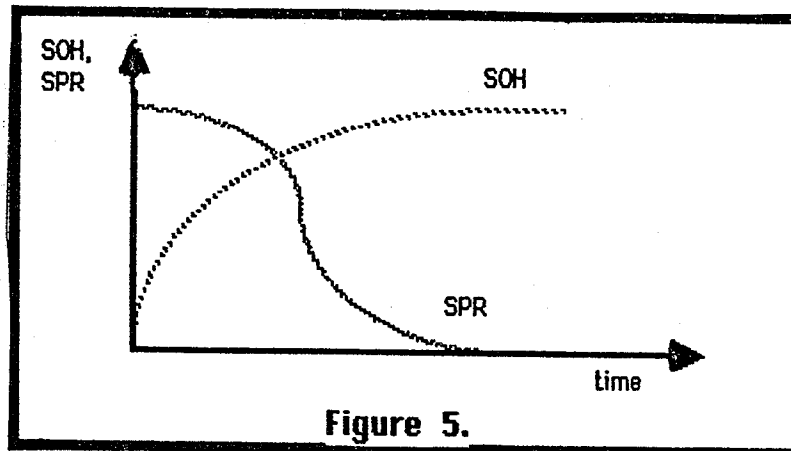
Now, define the purchase rate. To do this, make the purchase rate a graphical function with  $WTPAS/ASWP$  as its input variable, and conduct another thought experiment. We assumed that the going price for software was \$30. Imagine that you were willing to pay exactly \$30 for additional software ( $WTPAS/ASWP=1$ ). How many units per month would you purchase? OK. Now, if you were willing to pay \$100 (you've just bought a machine and desperately need that software!), what would your purchase rate be? Finally, if you are willing to pay something less than \$30, what would the purchase rate be? Simply draw out a graphical function that reflects the results of your thought experiment. Use the "data" from the experiment to establish low, normal, and high consumption rates. Then, draw a smooth curve through

these points. My model structure, and my graphical function for purchase rate are sketched out in Figure 4. All finished? Everything defined? Then you're ready to test your model.



**TEST:** What is the behavior pattern implied by this set of assumptions? Specifically, what are the behavior patterns of the purchase rate and the stock of software on hand? To test your assumptions, set the initial value of your level of software at 0, and animate the structure. Before you do this, you should document your structural assumptions (a structural diagram will do nicely) as well as your behavioral hypothesis -- a quick sketch of the expected behavior of key constructs, coupled with a brief explanation of your reasoning about why the system will behave that way. After you animate the structure, you can reconcile any differences between your hypothesis and the results.

All finished? As you saw, this structure led to some interesting results. Initially, you had no software, so the marginal utility of software, as measured by willingness to pay, was high relative to its price. Thus, your purchase rate was high. Gradually, however, your stockpile of software on hand grew. As a result, the utility of additional software applications declined, and the purchase rate slowed. Finally, once your stock of software was such that the price of additional software exceeded your willingness to pay, you stopped purchasing additional units of software. Once the system reached that state where marginal utility dipped below price, it settled into an equilibrium with the stock of software constant and the purchase rate equal to zero. According to the assumptions you provided, nothing will shake the system from this steady state set of values. A graph from my simulation is shown in Figure 5.



*Note to the serious student.* To test this model further, you might try to animate with different assumptions for the purchase rate graphical function, the willingness to pay graphical function, the average price of software, and the initial value of software on hand. Just remember: change only *one* assumption at a time. Briefly, changing the purchase rate graphical function ought to change the system's speed of response. Changing either willingness to pay or average price ought to change the steady-state value for the software stock. In fact, if the average price is always lower than willingness to pay, your stock will grow forever. If it is always higher, you will not buy anything! Finally, a change in the initial value of the level will limit the duration of your software purchasing spree. In these tests, as in all tests, STELLA will merely trace out the implications of your assumptions. Thus, to understand why the system behaves as it does, you can trace through the logic of your assumptions as you animate them.

But wait, you say. Your "satisfaction function" is not that simple! Not only do you gain satisfaction from using software that you have on hand, but also you derive a psychic "jolt" each time you purchase new pieces of software. It's great fun to search out new software items, and even more fun to play with your software once you get it home. In short, you gain additional utility from software, utility that goes beyond the practical purposes of the software. You derive this additional satisfaction from your software purchase *rate*, not the *stock* of software that you have on hand.

It is a simple matter to introduce this additional notion of software utility into your laboratory apparatus. It will only take a few minutes to introduce another feedback loop into your structure, and to test out the behavioral implications of this new structure. To do this, we need to connect the purchase rate to our notion of willingness to pay, and then back upon itself.

Put up another level, and call it something like ASPR for average software purchase rate. Initialize ASPR at some number that reflects the "normal" value for your purchase rate. Since STELLA assumes that rates of change (like the software purchase rate) cannot be perceived instantaneously, that people take a while to perceive rates of change before they act upon them, we must first run the purchase rate through this accumulation before we can feed that information back to affect the purchase rate. Add a rate to this level. I've called mine CASPR, for change in average software purchase rate.

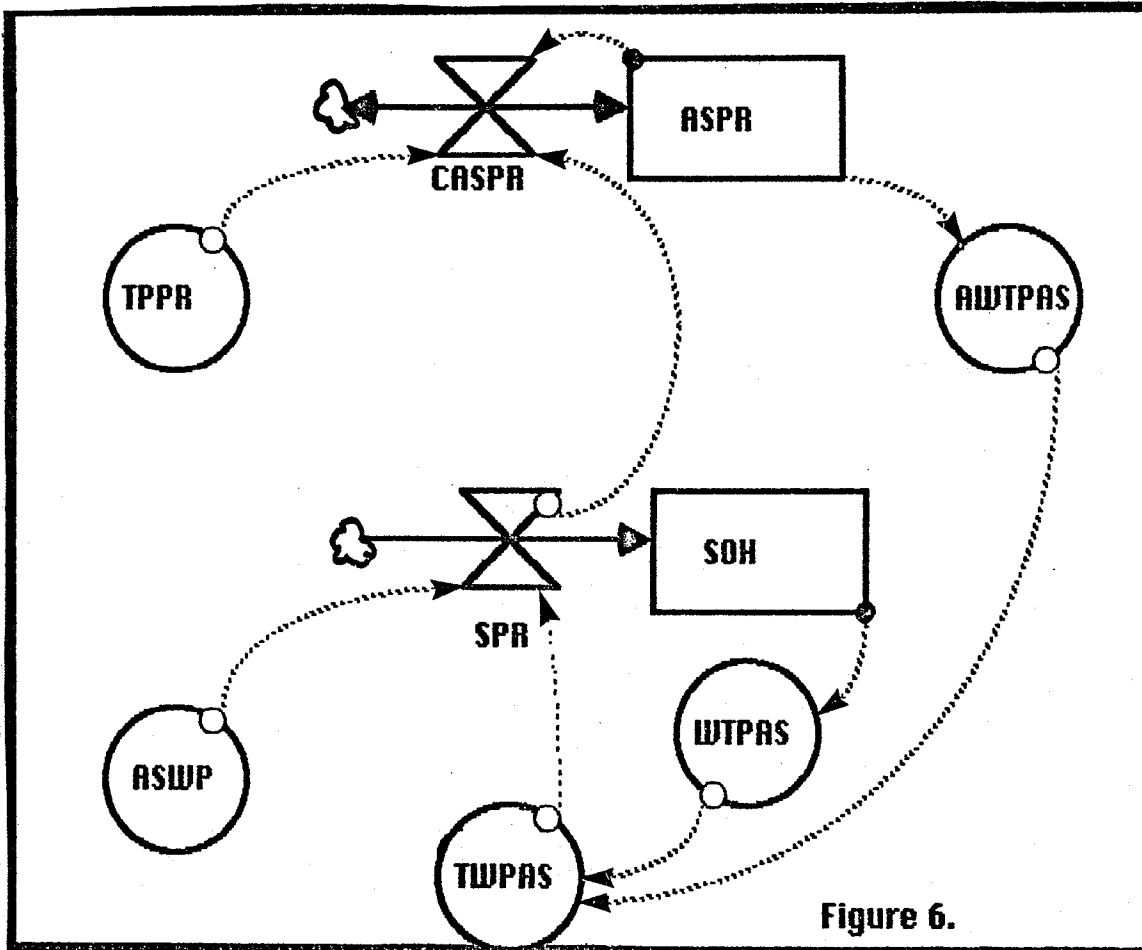
To flesh out this structure, use the "explicit goal-seeking" structural atom from your STELLA documentation. The "stock" here is ASPR, as depicted in your structural diagram. The "desired stock" is SPR, the instantaneous software purchase rate. The "adjustment time" is the time, on average, that it takes you to perceive the instantaneous purchase rate. I call my adjustment time TPPR, for time to perceive purchase rate. I gave it a value of 2 weeks. Your TPPR should reflect your own perception time. The equation for CASPR should follow the form provided in your STELLA documentation.

Now, put up another circle to represent the additional willingness to pay for additional software (I call mine AWPAS), and draw an information arrow from average software purchase rate to the construct. Define the variable as a graphical function, which you can construct by conducting another thought experiment. Ask yourself how much you will be willing to pay for an additional piece of software, given various average consumption rates. Your graphical function probably ought to follow the law of diminishing marginal utility. That is, the larger your average consumption rate, the less intense the psychic shock from, and hence the willingness to pay for, an additional piece of software is likely to be.

To complete the picture, you must connect this notion of additional willingness to pay from the purchase rate with its counterpart from your software stock. Create another circle, and connect it to your purchase rate construct. You might call it TWPAS, for total willingness to pay for additional software. Now dynamite the information arrow from WTPAS to the purchase rate, and connect arrows from WTPAS and AWPAS to TWPAS. Define TWPAS as the sum of the two inputs. By adding the two inputs together, you are assuming that the satisfaction you gain from the stock is independent from the satisfaction you gain from the purchase rate. Finally, draw an information arrow from TWPAS to the purchase rate, and define the

purchase rate as you did before -- as a graphical function, but now with TWPAS/ASWP as its independent variable.

All set for some testing? Your laboratory apparatus ought to look something like Figure 6.



To test this structure, first make sure that all initial values, graphical functions, and constants remaining from the previous test are the same as in that test. What you're trying to do here, is to understand what difference the additional structural elements have on the benchmark behavior from that test. Be sure to document your assumptions, to provide a graphical estimate of the behavior pattern, and to state your explanation for your proposed behavior pattern. Scale the model, and simulate.

An overview of my simulation results is shown in Figure 7. Is it clear why this behavior pattern emanated from the simulation? Early on in the simulation, I had little or no software. Because of this, I was willing to pay a lot to get much-needed applications. In addition, I was willing to pay a considerable amount to enjoy the short-term pleasure of purchasing and playing with new software items. Gradually, as my software stock grew, additional pieces of software on hand provided smaller enhancements in my productivity. My willingness to pay declined as a result. Even so, I still gained short-term satisfaction from purchasing and playing. Eventually, then, my software purchase rate settled into a steady-state pattern. Even though the long-run practical utility of my software might be of dubious value, I continued to purchase software because the short-term satisfaction associated with purchase was worth the additional cost. Thus, my purchase rate was such that the marginal utility (satisfaction, benefit, whatever) from software was equivalent to its cost.

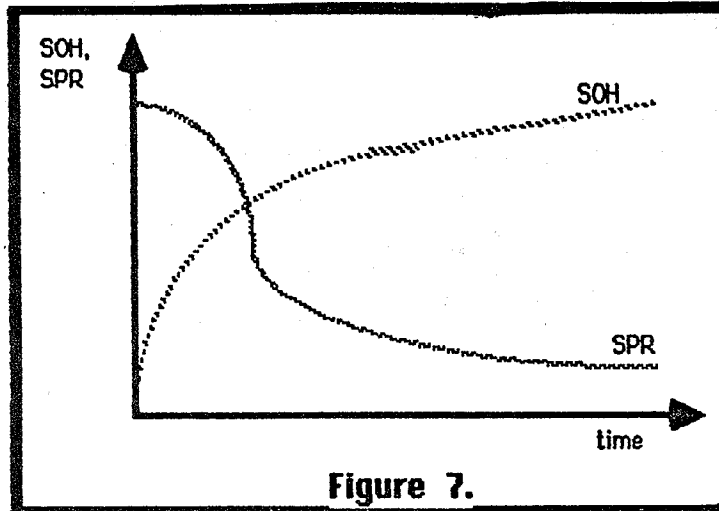


Figure 7.

To further test this model, try varying some of your assumptions. (But remember to vary just one thing at a time). Don't be afraid to play around with the model to explore its implications. Don't worry about "guessing the wrong behavior." View any discrepancies between your expectations and the results as an opportunity to learn! If the model doesn't behave as you expect, just trace through the logic to understand better what's going on as your assumptions interact with one another.

Congratulations. You have just gone through your first STELLA microeconomics lab session. Just like an initial physics lab session, this session has been simple, to help you come up to speed with tools and procedures. Still, you should have carried away both some specific insights about the nature of utility and some general insights about STELLA models.

First, consider the specific insights. There many ways to think about utility. With relatively long-lived items, utility is probably best associated with your stock of goods. That is, goods like software, washing machines, or automobiles can be viewed as inputs to your household productive processes. As you use the software, you derive satisfaction from tasks completed. The conception of utility is closely related to the concept of diminishing marginal returns in producer theory.

With shorter-lived goods, as well as with durable goods, utility can be associated with the "flow" or rate of purchase. You often gain satisfaction both from the act of purchase and from your initial experiences with software. This notion of utility from the flow is of paramount importance in dealing with very short-lived consumption goods, e.g., food, movies, and concerts. With these "instant gratification" items, the link between consumption and satisfaction is straightforward.

The law of diminishing marginal utility applies to both concepts of utility. As your stock of software grows, additional units provide you with less additional satisfaction. As your purchase rate grows, further increases in consumption provide you with less of a psychic "jolt."

You also gained some insight into the nature of STELLA models. You explored the somewhat limited behavior patterns of a 1-level model. You saw how the structure of a system determines its behavior pattern. Finally, you got a chance to play with a simple model of your assumptions, to see what happened as a result of changes in your assumptions...

### **In Summary**

It seems clear that our traditional product-focused attempts at dissemination have failed to appeal to mainstream microeconomists. This paper presented an alternative approach to dissemination. The STELLA experiential laboratory approach, as manifest in Learning Laboratories in Microeconomics takes advantage of the strengths of system dynamics, the abilities of economists, and the way in which people learn. The alternative approach can:

- . help students quickly gain a thorough understanding of microeconomic theory
- . demonstrate the usefulness of system dynamics skills in microeconomic theory and analysis
- . facilitate the development of modeling skills
- . plant the seeds of future "revolution" within the microeconomics discipline.

As they work through the laboratory sessions in Learning Laboratories, students and teachers of economics can begin to appreciate system dynamics for what it is: a powerful *process* for increasing one's ability to learn about systems, not a set of consulting *products*.

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