Teaching Introductory Microeconomics Using System Dynamics: Reflections on an Experiment at WPI

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Abstract

Traditional microeconomics makes extensive use of static equilibrium tools to understand the behavior of consumers and producers in markets. Yet we all know that product, labor, and capital markets are all highly dynamic and rarely, if ever, in equilibrium. Would a system dynamics approach offer greater insight?

Last fall this author had the opportunity to teach an introductory microeconomics class to undergraduates at WPI. Because this course was microeconomics, and not system dynamics, the topics covered were those that one would expect to see in a typical microeconomics course, for example: (1) comparative advantage, specialization, and trade; (2) markets as a means of allocating scarce resources; and, (3) the failures of markets and how governments deal with these failures. The author used a mix of traditional microeconomics tools and system dynamics to present the topics.

This paper describes the topics covered in this course, the use of traditional economic methods, and how (and what) system dynamics was introduced. It concludes with some reflections on how the course went, and where I suggest we might go from here (including the sharing of experiences, ideas, and materials with others teaching economics). The primary audience for this paper is system dynamicists looking to teach the concepts of microeconomics. I therefore spend some time discussing the basics of microeconomics as traditionally taught, but do not discuss the basics of system dynamics. For those readers whose training is in economics, I apologize in advance and hope that some of the ideas here might prompt you to seek additional information on system dynamics elsewhere (including the course materials and references in this paper).

Introduction

Economics is the study of how a society deals with the problem of scarcity. Broadly speaking, our desires almost always exceed our resources – we need and/or want more than we can produce. Economics addresses how we deal with this problem – i.e., how a society grows, allocates and manages its scare resources.

Economics at the college level is usually introduced via two courses: macroeconomics and microeconomics. In fact, this dichotomy continues in advanced courses and to some extent in practice as well. According to Mankiw [2001], macroeconomics is "the study of economy-wide phenomena, including inflation, unemployment, and economic growth;" microeconomics is "the study of how households and firms make decision and how they interact in markets." While this separation seems artificial, and even incorrect, to a system dynamicist, it is the traditional way in which economics is studied.

While the exact content will obviously depend on the instructor and particulars of the course (its duration, whether taught before or after macro), introductory micro usually covers the following five topics:

1. Comparative advantage, specialization and trade;
2. Markets as a means of executing trades and allocating resources, i.e., of balancing supply and demand;
3. "Failures" of markets (e.g., monopolies and oligopolies, leaving some behind, and dealing with common goods);
4. Product, labor, and capital markets; and
5. Externalities, common goods, and environmental economics

Underlying the teaching of economics are several important assumptions regarding behavior. First, that people act rationally (for example, weighing the costs and benefits of each possibility and acting to maximize the net benefit, usually with the further assumption of perfect information). Second, that people consider opportunity costs rather than just direct or out-of-pocket costs. And third, people act at the margin, i.e., evaluating decisions on the marginal cost or benefit of the action. As will be discussed further below, these concepts are taught in traditional micro economics using the ideas and tools of marginal utility, average and marginal cost, production functions, elasticity, and comparative statics.

Such is the teaching of microeconomics at WPI, where I had the opportunity to teach introductory microeconomics in the Fall 2002. In that course, I introduced the use of system dynamics ideas and models to address micro-economic problems. When one thinks of system dynamics applied to economics, one usually thinks of its application to macroeconomics, although with an emphasis on macro behavior from micro structure (Forrester [1979], Mass [1975], Forrester [1982], Radzicki [2003]). However, system dynamics has also been applied to what economists would traditionally consider microeconomic problems – understanding the behavior of firms and industries, and regulatory policy (Meadows [1970], Ford [1997]; Paich and Sterman [1993]; Lyneis [2000]).

This paper describes the topics covered in this course, the use of traditional economic methods, and how system dynamics was introduced. It concludes with some reflections on how the course went, and where I suggest we might go from here.

Teaching Approach and Materials Used

This was a course in microeconomics, not in system dynamics. Therefore, it was felt that the five topics and ideas/analysis tools noted above must be covered. As a result, the approach taken was to cover the topics using both traditional economics methods and system dynamics. There were several reasons for this. First, some of the topics are best taught using the

traditional approaches. Second, certain of the traditional approaches provide structure and parameters for the system dynamics models. And third, because some of the students in the course may go on to study economics elsewhere, it was felt that some background in the traditional methods should be given. For each of the topics, the merged teaching approach is discussed and illustrated below. As a traditional textbook for this course, I used Mankiw [2001], although Baumol and Blinder [2003], Parkin [2001], and Stiglitz and Walsh [2002] are also common texts. For the system dynamics, Sterman [2000] was put on reserve but the primary source of information was lectures and lecture notes posted to the course website.

1. Comparative advantage, specialization and trade

Almost all micro textbooks devote a chapter to "trade." This is usually done first thing as it sets the stage for the need for markets to facilitate the trade and allocation of resources. Trade here includes both trade between individuals as well as countries. These chapters discuss the concepts of absolute advantage, comparative advantage, and the resultant gains to be made from specialization and trade. These ideas were introduced using traditional economics concepts, including production possibilities frontiers and opportunity cost. As these have no direct connection to the system dynamics topics, I will not discuss these ideas further in this paper.

2. Markets as a means of allocating resources, i.e., of balancing supply and demand

A significant portion of microeconomics textbooks and courses covers the topic of allocating resources via markets. By allocating resources, economists mean balancing supply and demand. Traditional economics teaches this topic via supply and demand curves and the process of comparative statics. I used this same approach to introduce the concepts of markets, supply, and demand. A brief summary follows as it is used as the starting point for the system dynamics model structure.

Figure 1 shows a typical demand curve for the product ice cream cones. As price *increases*, quantity demanded *decreases* either because users cannot afford to buy more, or because of "diminishing marginal utility" (in some courses and textbooks, the theory of consumer choice is discussed in some detail before introducing the demand curve, or after introducing it to justify the shape of the demand curve; I skipped the details of this theory and relied on common sense summary arguments to justify the shape of the demand curve). Economists distinguish between changes in "quantity demanded" and changes in "demand." Changes in quantity demanded reflect changes as a direct result of changes in price. A system dynamicist might view this as the short-term feedback response. Changes in demand reflect changes in the entire demand curve as a result of non-price factors, such as the weather, price of substitutes, etc. To a system dynamicist, some changes in demand are exogenous and others reflect other or longer-term feedback responses. These differences are illustrated in Figure 2.

Figure 1. Demand Curve

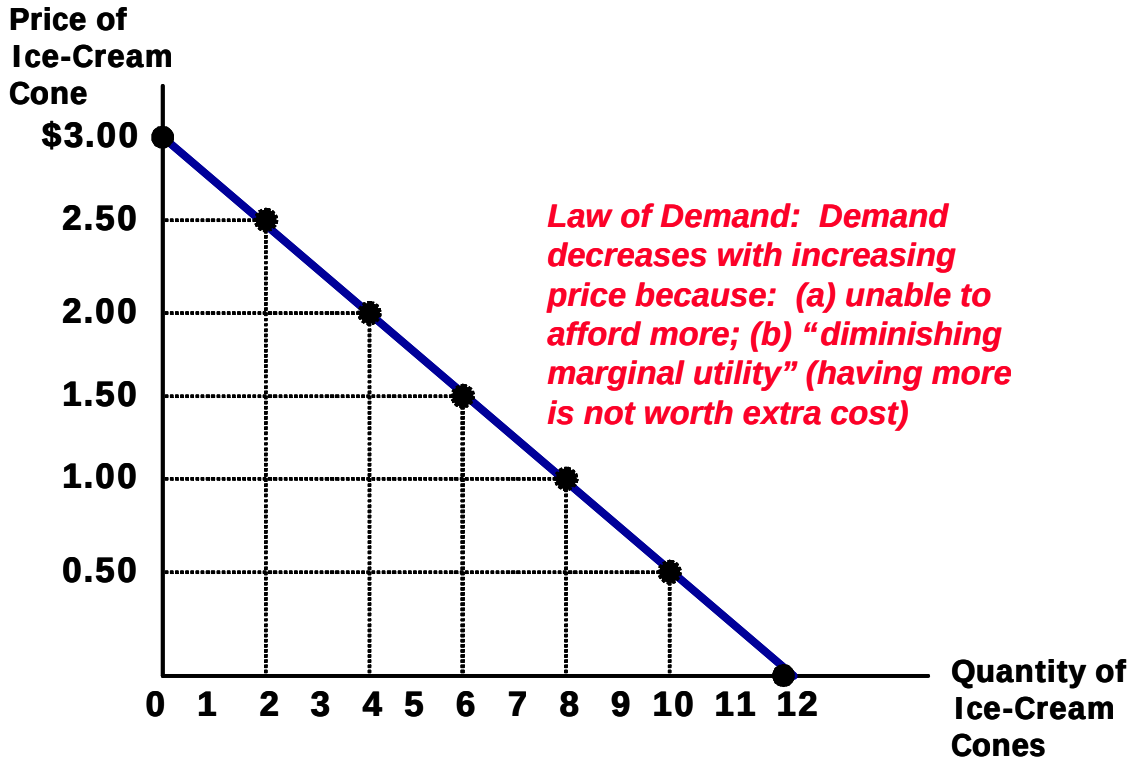
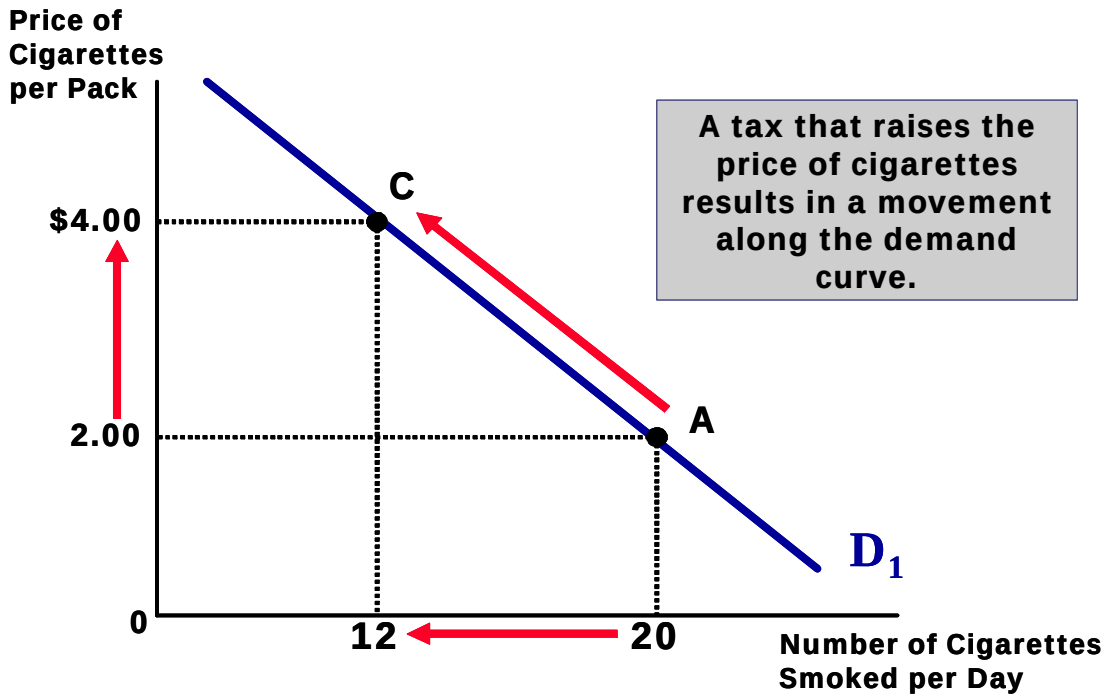


Figure 2. Quantity demanded versus shifts in the demand curve.

a. Change in quantity demanded as a function of changes in price



b. Shift in demand curve of …

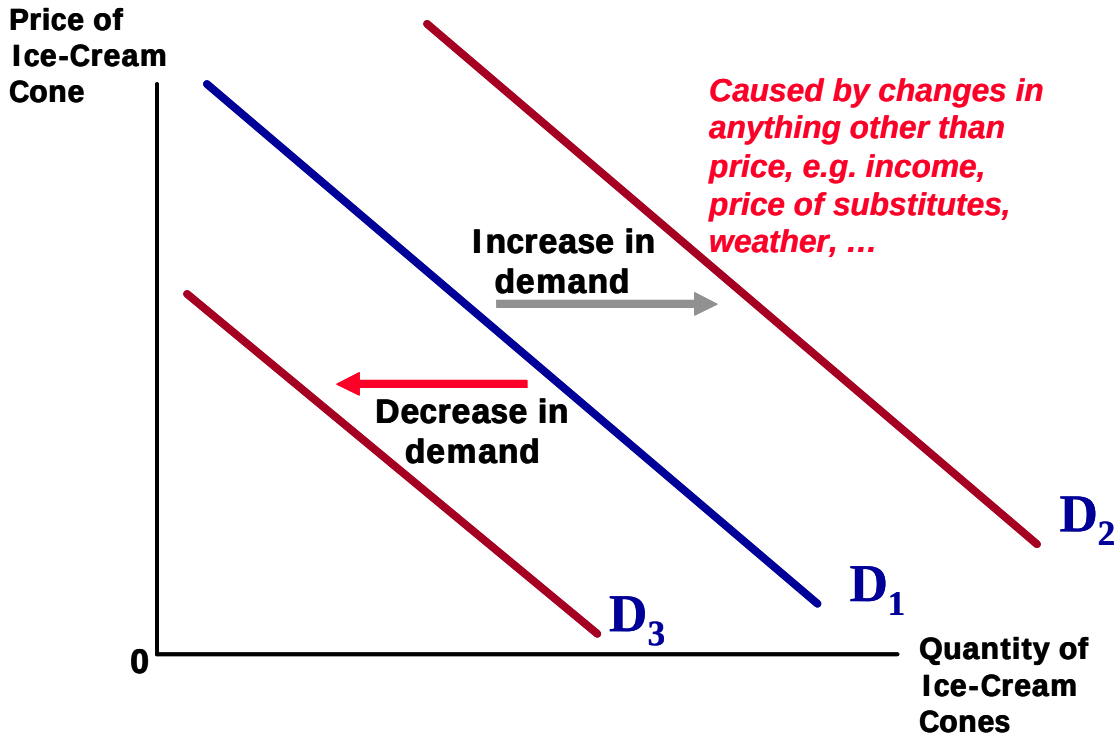
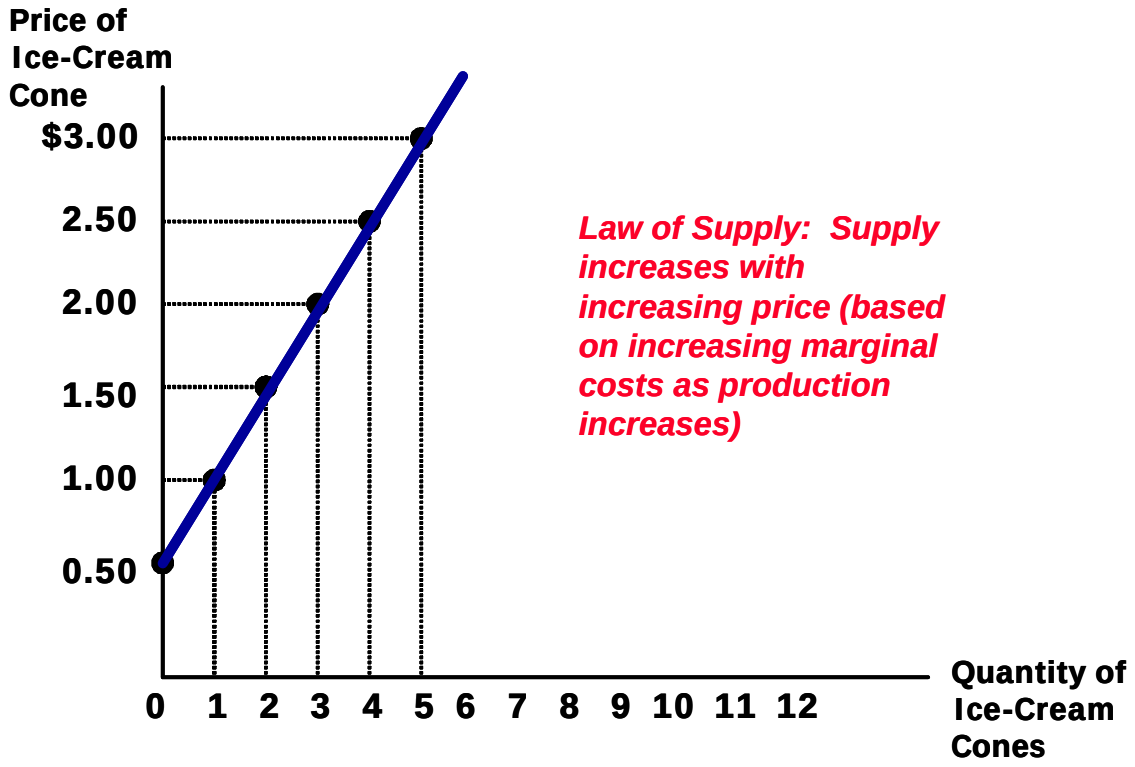


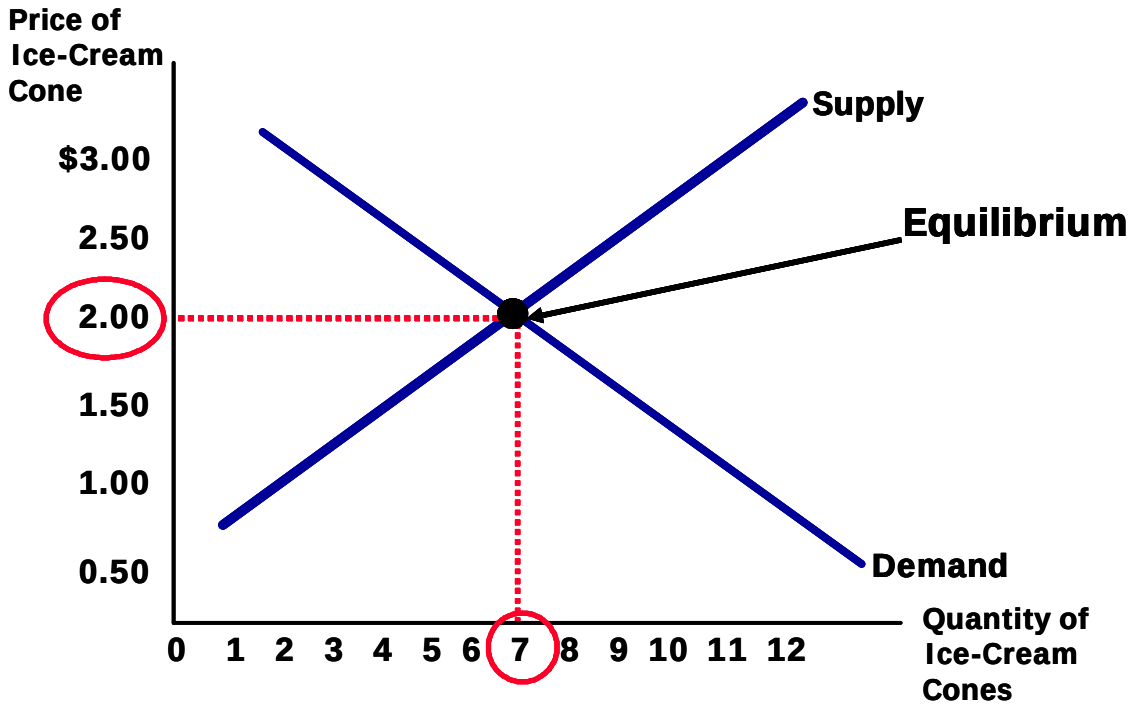
Figure 3 shows a typical supply curve. As price *increases*, quantity supplied *increases.* There are two reasons why supply might increase with higher prices: first, because additional, higher-cost producers become willing to supply, and second, because of additional production from current producers, given the assumption that marginal costs increase as production increases (again, most texts and courses spend some time on the cost structure of the firm, and how total, average, and marginal costs change as production volume increases; I covered this later in the term before introducing the difference between a perfectly competitive market and a monopolistic market). Again, economists distinguish between "quantity supplied" and "supply." Changes in quantity supplied result from the direct feedback effect of changes in price; changes in "supply" reflect shifts in the supply curve right or left caused by such factors as changes in technology (embodied in capital stock), shifts in input prices, etc. Again, some of these factors may be exogenous, and other the result of longer-term feedback effects.

Figure 3. Supply Curve



Markets are in balance, or cleared, when supply equals demand. This occurs at the intersection of the supply and demand curves as illustrated in Figure 4. If there is an initial imbalance, suppliers either increase or lower their prices until the market is cleared.

Figure 4. Equilibrium of Supply and Demand



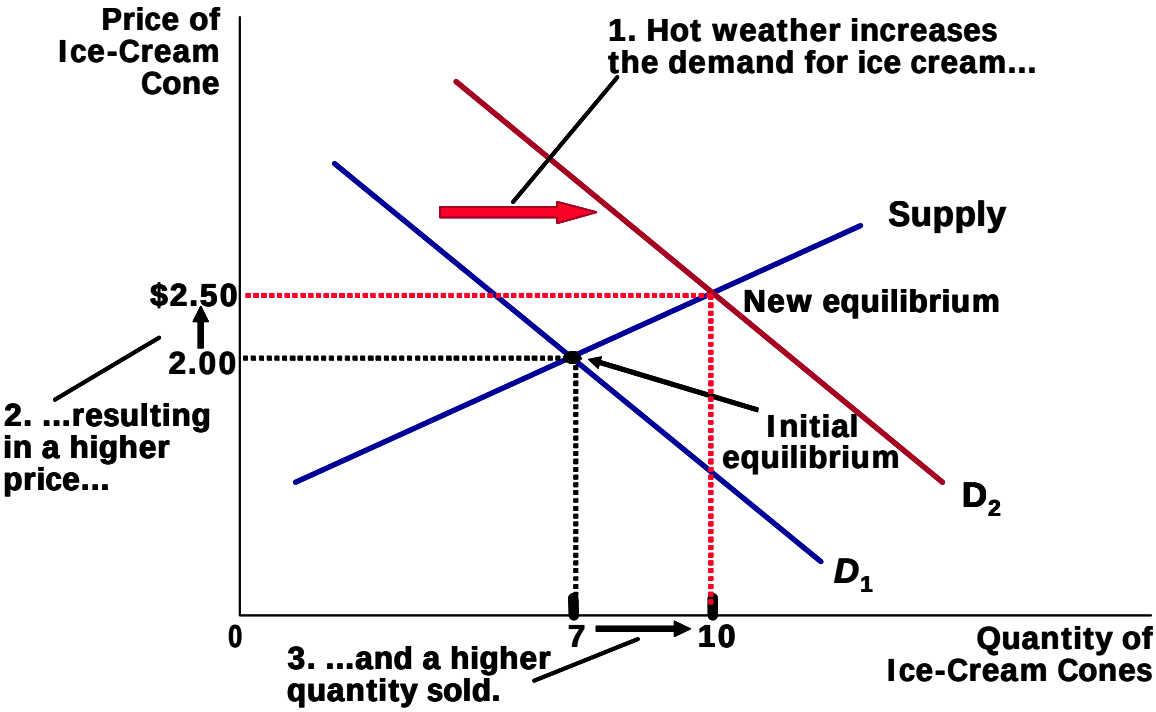
Economists use these supply and demand curves in the process of "comparative statics" to determine how an event or policy change will affect market equilibrium. This process consists of three steps:

1. Decide whether the event shifts the supply or demand curve (or both);
2. Decide whether the curve(s) shift(s) to the left or to the right; and
3. Examine how the shift affects equilibrium price and quantity.

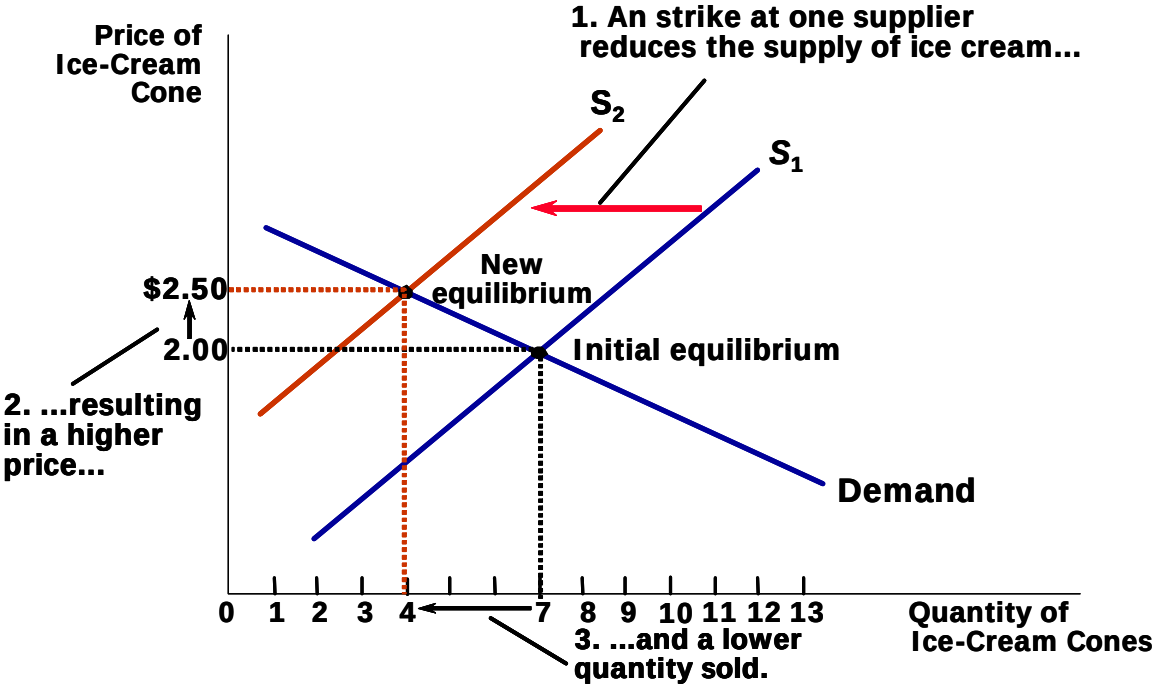
These steps are illustrated in Figure 5.

Figure 5. Comparative Statics

a. How an increase in demand affects the equilibrium



b. How a decrease in supply affects the equilibrium



Missing from the discussion thus far is any concept of time. This is partially introduced in traditional economics during the discussion of elasticity. Elasticity is the change in quantity (supplied or demanded) in response to a change in some input factor (usually price, but also income, price of complements, price of substitutes, etc.). In order to determine elasticity, one needs to consider time. For example, supply may be inelastic (i.e., not change much with changes in price) in the short-term because of delays and constraints in increasing or decreasing production, but elastic in the long-term. Similarly for demand. Therefore, in performing a comparative statics analysis to estimate the impact of event "X", I require my students to conduct four rather than three steps:

1. Determine the time frame of the analysis; estimate shapes of supply and demand curves based on the expected elasticities in that time frame (and they might be asked to perform this analysis for two time frames, e.g., short-term and long-term);
2. Decide whether the event shifts the supply or demand curve (or both);
3. Decide whether the curve(s) shift(s) to the left or to the right; and
4. Examine how the shift affects equilibrium price and quantity.

Comparative statics provides some useful insights to students, specifically that:

- People acting in their self-interest tend to drive the market toward equilibrium.
- Market systems are efficient in allocating resources (further analysis of the supply and demand curves, done in class and texts, shows that the equilibrium produced by the market maximizes what economists call consumer and producer "surplus")
- Market systems enhance productivity growth by encouraging self-interested behavior.
- Attempts to interfere with the market reduce the benefits (analysis of price caps, floors, and taxes are shown to reduce the total surplus to consumers and producers).

However, comparative statics has several serious shortcomings. First, the path to the new equilibrium is generally undefined. Economists are hazy about how the balancing occurs, often stating that it occurs either as a result of "negotiation and bargaining between buyer and seller," or of "competition." Moreover, how quickly and/or smoothly this process occurs is not discussed. Some economists gloss over the problem, or assume that the adjustment process is not important as long as a new equilibrium is reached:

> "How quickly equilibrium is reached varies from market to market, depending on how quickly prices adjust. In most free markets, however, surpluses and shortages are only temporary because prices eventually move toward their equilibrium levels. Indeed, this phenomenon is so pervasive it is sometimes called the law of supply and demand: the price of any good adjusts to bring the supply and demand for that good into balance." [Mankiw 2001, p. 81]
>
> If you read the news, you would get the impression that the market never does a good job. It makes credit card interest rates are too high. It makes the wages of fast-food workers are too low. It causes the price of coffee to go through the ceiling every time Brazil has a serious frost. It increases the world price of oil whenever political instability threatens the Middle East. These examples are not cases of market failure. They are examples of the market doing its job of helping us to allocate our scarce resources and ensure that they are used in the activities in which they are most highly valued. [Parkin 2000, p.9]

However, not everyone is happy about economists' lack of concern about disequilibria. In the article "Heretics of the Market" by Ted C. Fishman, *Worth*, April 1997, the author makes several points:

> In the mainstream [economic] view, financial markets are populated by rational, perfectly informed traders, who buy and sell in an orderly fashion in reaction to news. Yet, in fact, markets move unpredictably, often seeping to extremes of euphoria or despair that are unjustified by the news…. And it has even less to offer in explaining the causes of economic growth at all. According to mainstream economics, markets tend toward equilibrium, a relatively static state in which prices and goods match up. But in real life, the economy rarely rests, and when it grows it does so in fits and starts. Mainstream economics has virtually nothing convincing to say about what causes growth to speed up or slow down….And finally, critics of mainstream economics, inside and outside the profession, ask, How can economics make any claim to being a science when its predictive powers are so limited? Physicists can time the arrival of a comet to the minute, but economists can't predict the next day's interest rates.
>
> [John] Reed [Chairman of Citicorp] felt that as academic economics grew rich in theory and method it increasingly disengaged from real-world problems. He found particularly rankling that his own bank's economists hadn't offered any warning of the Latin-America debt crisis in the early 1980s. Blindsided, Citibank dropped billions. Reed complained that the bank's models took as givens the very things – interest rates, stock volatility, and currency-exchange rates – that bankers need to predict. More fundamentally, the models assumed a world in which prices and goods were largely in balance, leading to a picture of a global economy that was, for the most part, static. Even the most casual observer knew that just the opposite was true: The world economy is in constant flux and frequently in upheaval. [Fishman, p. 102-103]

As system dynamicists, we would argue that the behavior of these markets in total affects, and is affected by, the behavior of the economy as a whole. The path toward equilibrium matters.

A second problem with comparative statics is that it makes too many assumptions about "other things remaining equal," when in fact other things rarely remain equal. The analysis is therefore incomplete and often ignored in policy debates. Economists know, for example, that price caps (e.g. rent control) are inefficient in that they reduce total consumer and producer surplus. But how then do we deal with people who cannot afford housing? Taxes and direct payments to tenants? This option also has its shortcomings. Which is better, rent control or subsidies? Similarly, how should we deal with the financial problems of farmers? In the comparative statics analysis, side effects not considered explicitly and the long-term consequences often ignored. As a result, comparative statics does not help us understand why markets are unstable, or when and how to interfere with supply-demand laws to improve overall performance in the long-run (but, as a famous economist once pointed out, "In the long-run we're all dead"). As a policy tool, comparative statics is often ignored.

Students readily recognize these problems. Questions often arise in class that have to be answered with "We are assuming other things remain equal." Or, "We are considering only the short-term in this analysis." But I also used system dynamics to bring home these short-comings. For example, I gave the students several articles to read about rent control, and ask them what they would do and why. We then have a discussion using comparative statics, followed by a discussion using system dynamics (reference modes and causal-loop diagram).

In summary, supply-demand curves and comparative statics provide a useful initial framing of the problem of balancing supply and demand. They are relatively easy to explain and provide

some useful insights. However, their shortcomings are also apparent and lead naturally into the system dynamics methodology.

3. "Failures" of markets

As hinted at in the quote by Parkin above, economists recognize that markets are not always perfect in dealing with problems of scarcity and resource allocation. In particular, economic texts explicitly discuss three "failures" of markets that must be addressed by other means.

1. People try to push the limits to their advantage (e.g., by reducing the number of competitors; stretching and/or breaking the laws);
2. Some are left behind and unable to buy the "necessities of life";
3. For some goods – common goods – the market mechanism does not ***automatically*** work efficiently on its own;

To this list above, I add a fourth:

4. Markets can be unstable to the detriment of players and the economy as a whole

Pushing the limits. Some people will always try to cheat the system and make money in ways that do not create value to society as a whole. We have therefore developed laws and regulations to guide acceptable behavior. These laws and regulations evolve in response to the inventiveness of businessmen and capitalists. For example, in response to the excesses of the 1920's (and before), various antitrust laws were passed (and also regulations on how much stock can be bought on margin, etc.).

But even behaving legally, some industries move from being "perfectly competitive" to becoming oligopolies and even monopolies. Traditional microeconomics discusses the differences between monopoly, oligopoly, monopolistic competition, and perfect competition. The discussion of monopolies centers on how they might arise, their impact on the efficiency of markets (consumer and producer surplus), natural monopolies and their regulation, and antitrust laws. Oligopoly discussion involves their impact on efficiency of markets and discussions of strategy using game theory. Finally, monopolistic competition introduces the concepts of non-price competition. In teaching these topics, I summarize the main ideas presented by traditional economics, and then supplement them with a discussion about how a company builds dominance via exploiting positive feedback loops using some of the materials from Sterman[2000, Chapter 10]). The growth of Microsoft and the recent antitrust case against it provide a good discussion of the issues, especially in an engineering school. I then discuss how different market structures affect stability using system dynamics (see section below).

Some people are left behind. Other than pointing out this problem and showing how market interventions (price caps and/or floors) are ineffective ways of dealing with the problem, traditional economics does not deal with this in introductory microeconomics courses (and neither did I).

Public goods. Some products are what might be called "public goods" – for example, national defense, basic research, education, fighting poverty. Investment in these goods benefits society as a whole, often more than the investment would benefit an individual provider. Hence these goods are properly seen as being provided by governments outside of the market system. Other than a short discussion of this, traditional economics does not deal with this in introductory courses (and neither did I).

Market Instability. As noted above, markets are rarely in equilibrium. Why should we care? There are several reasons. First, understanding dynamics should allow us to forecast better (avoid investing at the peak!) and manage our companies better (e.g., counter-cyclical investments, increase price or production?)(see Lyneis [2000]). Second, understanding dynamics should allow us to manage our economies better. At an industry level, how might we improve stability – buffer stocks? price supports? minimum wage laws? At an economy level, how does the behavior of the parts affect the behavior of the whole? And finally, understanding dynamics will better allow us to avoid the "law of unintended consequences." We must consider how what we do today will affect the opportunities and problems of the future.

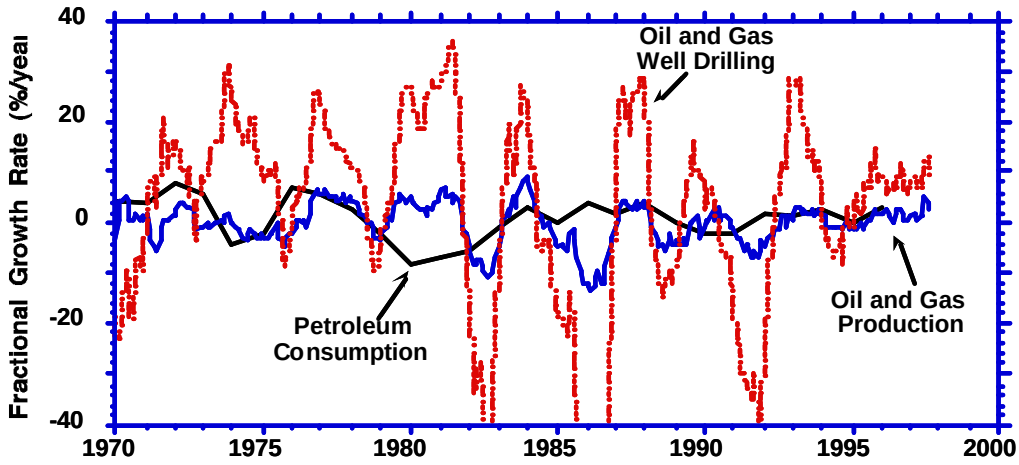
Focusing on micro-economic dynamics – the behavior of industries – we observe four basic dynamic patterns:

1. Supply-chain (as illustrated by the "beer game")
2. Production and Investment Cycles in Mature Industries (from commodities to monopolies)
3. Boom and Bust in New Industries and Products
4. Bubbles, panics, and manias

These behaviors are illustrated in Figure 6. I have borrowed these from Sterman [2000] as noted. In class, I supplement these with numerous transparencies of behaviors taken from newspaper and magazine articles. For bubbles, I show the behavior of stock prices.

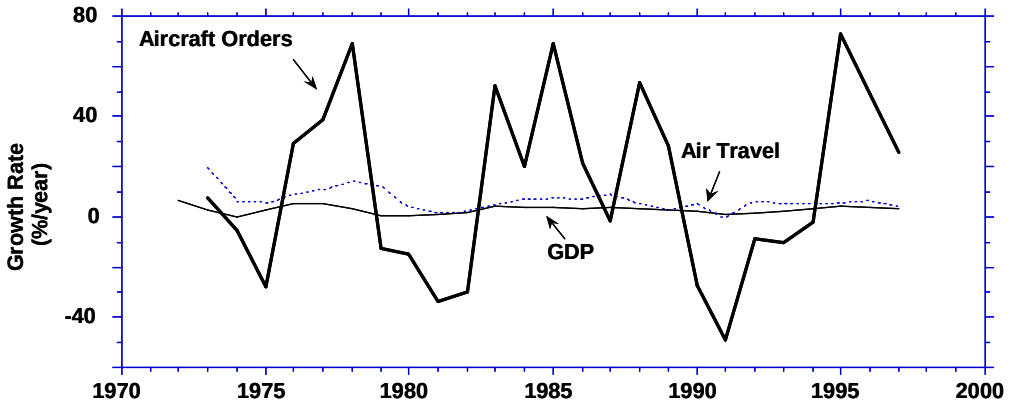
Figure 6. Examples of market dynamics

a. Supply-chain dynamics in the oil and gas industry



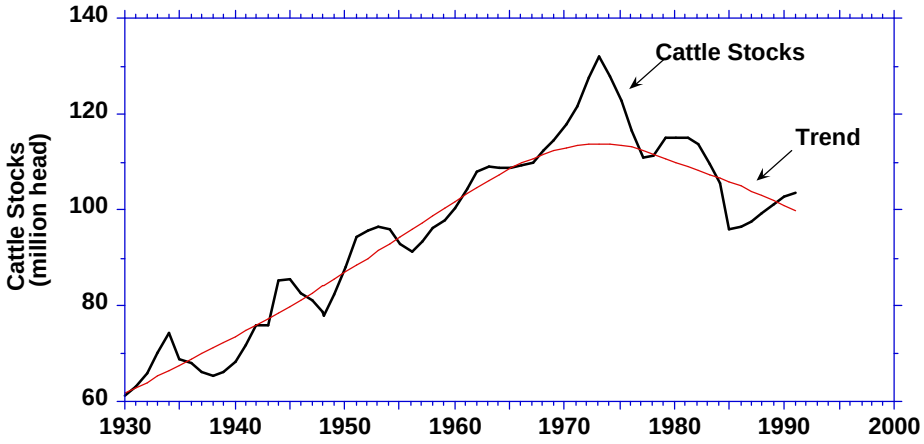
Sterman [2000] Figure 17-3a Amplification in supply chains
Oil and gas drilling fluctuates far more than production or consumption.
The graph shows 12-month centered moving averages of the annualized fractional
Growth rate calculated from the monthly data.

b. Supply-chain dynamics in the commercial jet aircraft industry

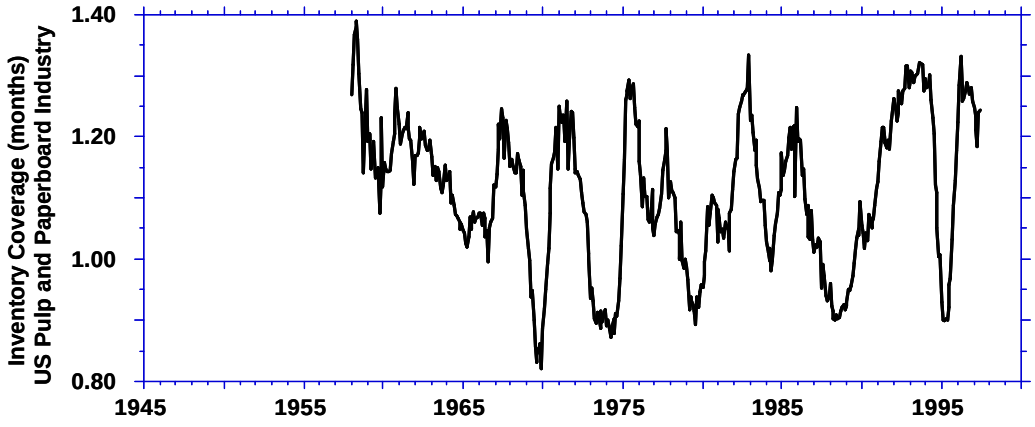


Sterman [2000] Figure 20-4 Worldwide aircraft orders. Annual growth rate in orders for commercial aircraft (jets with > 50 seats), commercial air travel (revenue passenger km/year), and GDP weighted by each region's share of world air travel demand. Demand for aircraft exhibits a large amplitude cycle of roughly 10 years.

c. Cycles in a mature commodity industry

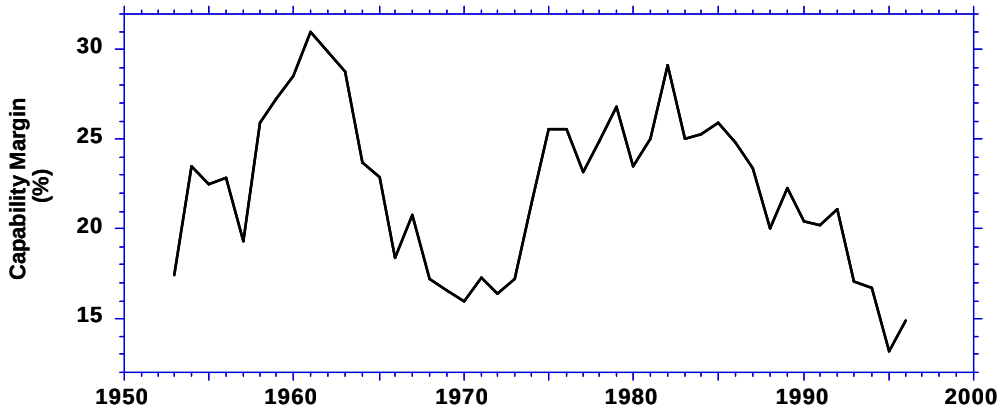


d. Cycles in an oligopolistic industry



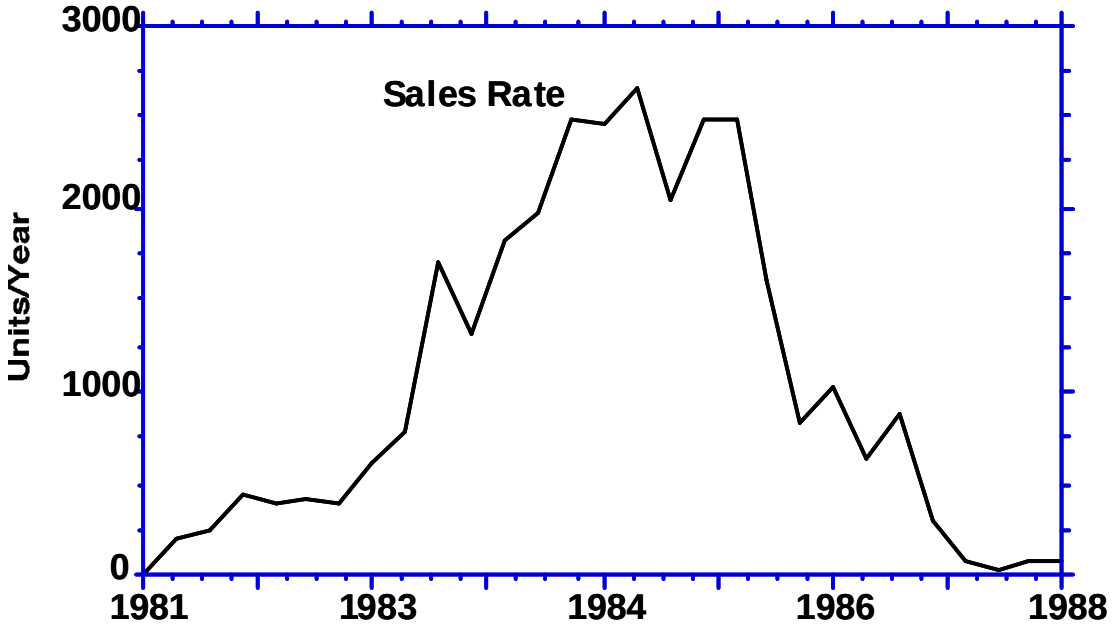
Sterman [2000] Figure 20-18b Pulp and paper, inventory coverage

e. Cycles in a monopolistic industry



Sterman [2000] Figure 20-5 US electric utility capability margin
Capability margin is the margin by which generation capacity exceeds peak summer load.

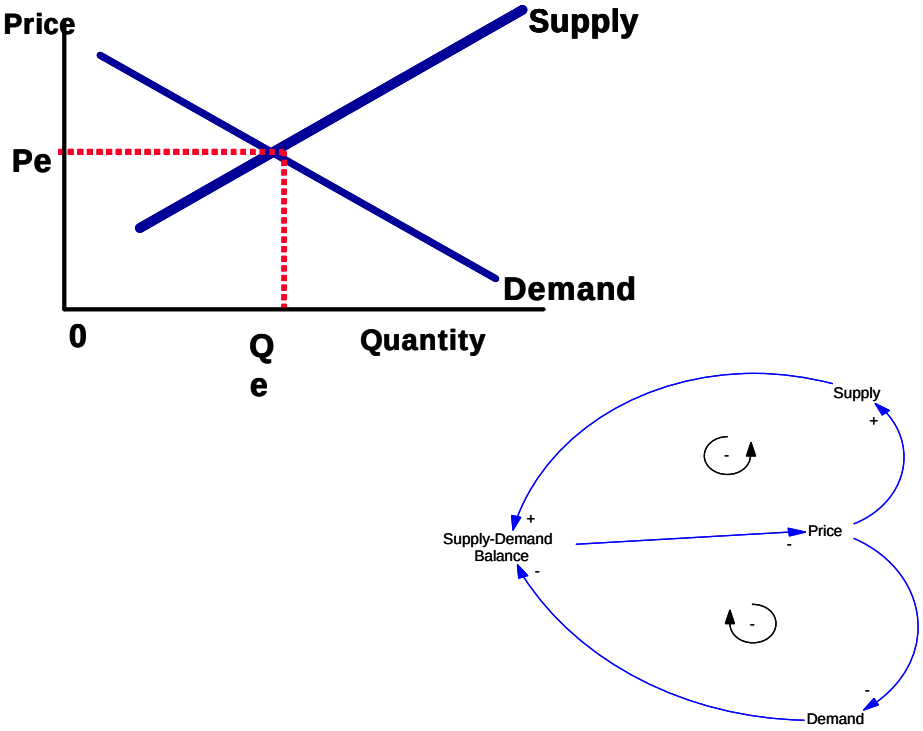
f. Boom and bust in a new industry



Sterman [2000] Figure 9-14 Sales of the Digital Equipment Corporation VAX 11/750 in Europe

After this introduction, I discuss system dynamics basics (feedback loops, stocks and flows), and then move into a discussion of how the basic supply-demand curves can be viewed from a system dynamics perspective. As shown in Figure 7, we first discuss how the supply-demand curves in reality reflect two negative feedback loops – an increase in price causes an increase in supply (and/or decrease in demand), which in turn improve the supply-demand balance and counteract the increase in price.

Figure 7. Relating Comparative Statics to Dynamics



This diagram initiates a discussion of how equilibrium is reached. Where are the delays – do supply and demand change instantaneously? Further, given that buyers and sellers do not know the supply and demand curves, how are price changes determined? This leads to the stock-flow diagram in Figure 8a, in which response delays are noted, and in which price is represented as a stock. Change in price responds to the supply-demand balance. When supply exceeds demand, prices decrease and keep decreasing until supply and demand are brought back into balance. And conversely when demand exceeds supply, prices decrease. As shown in Figure 8b, this structure produces damped oscillations to the new equilibrium depending on the length and order of delays.

Figure 8a. Supply-demand model with delays …

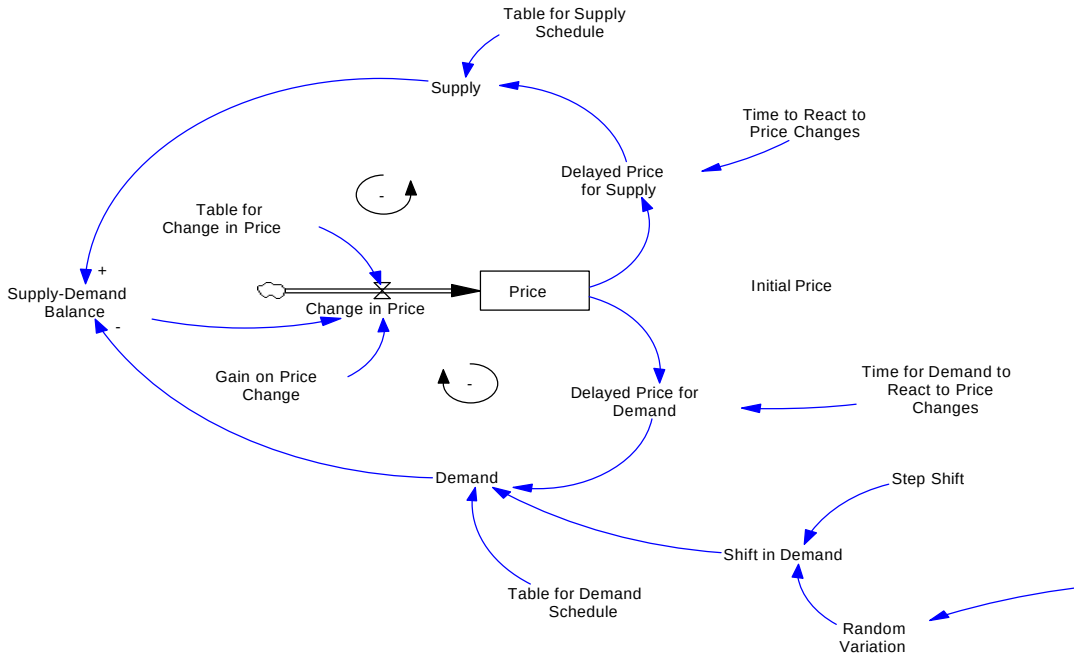
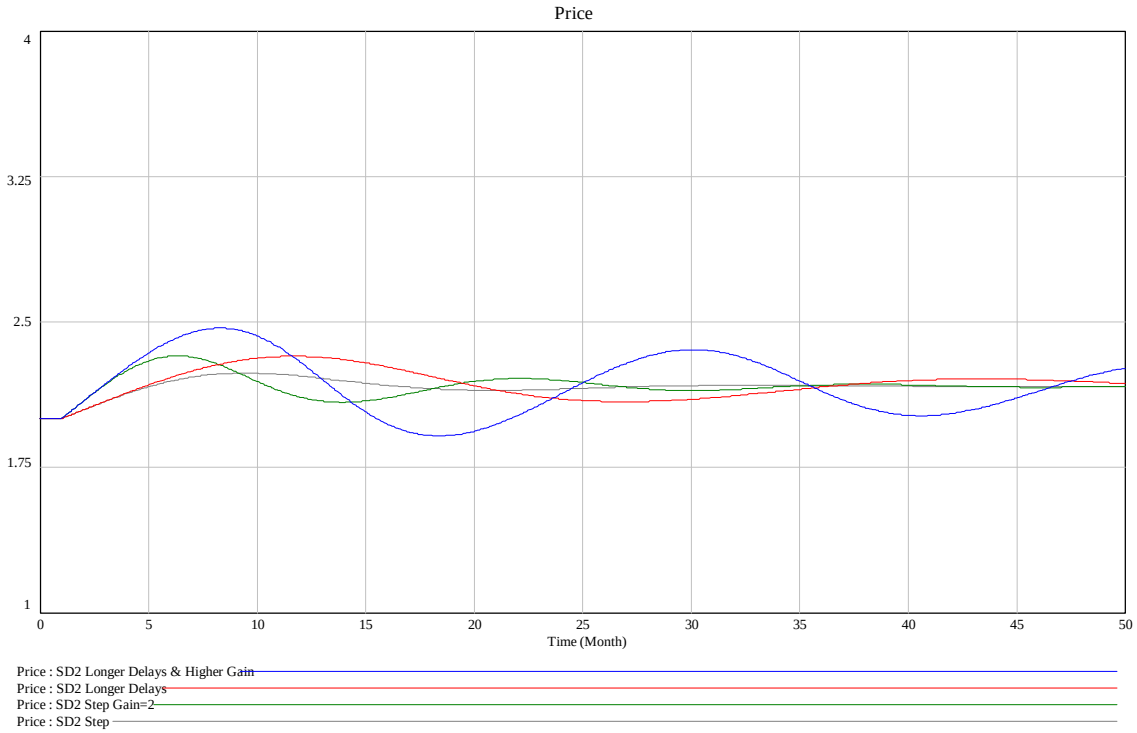
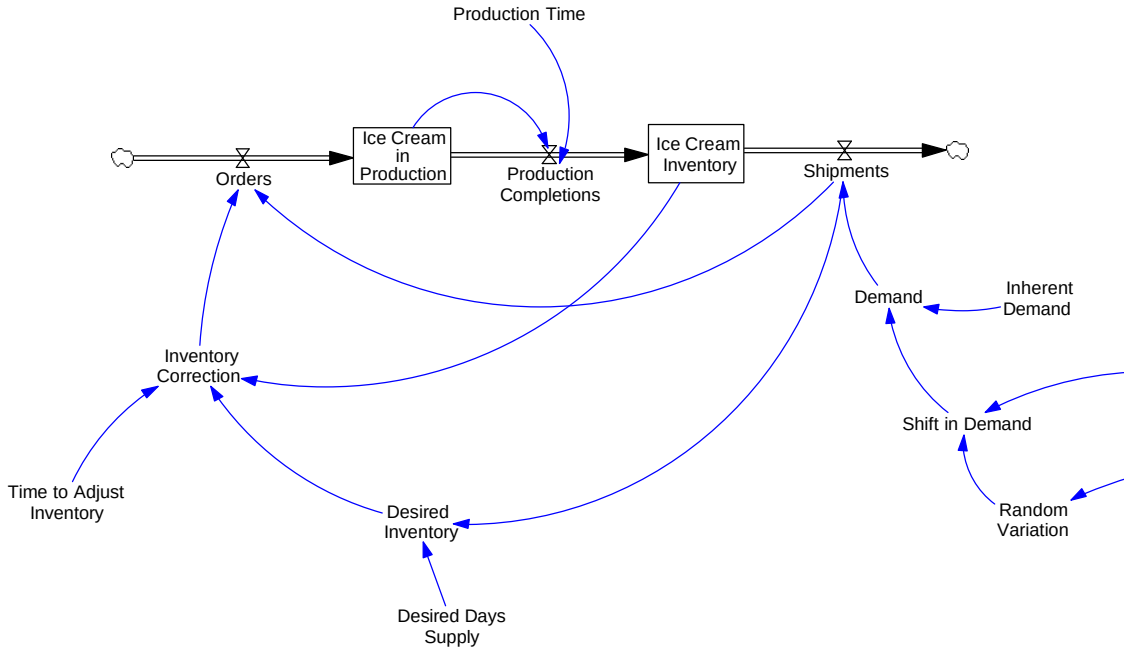


Figure 8b. …produces oscillations movement to equilibrium price depending on length and order of delays



While the structure in Figure 8 captures some of the causes of instability, it also raises additional questions. Specifically, what is "supply?" Answering this question leads to the concepts of inventory and production delays, and the model of one-stage of a supply chain shown in Figure 9. We build the model in class, show its behavior, and discuss amplification down the supply chain. We conclude with a discussion of how to increase stability. (While logistics precluded it in this course, the Beer Game would make an excellent lead-in to the supply chain discussion.)

Figure 9. Structure of one component of a supply chain



Next, I introduce a more complex model that captures one supply chain with price feedback, and with capacity as a resource as shown in Figure 10 (based on Sterman's [2000] commodity model, Chapter 20). I use this model to show how perfect competition produces cycles of two periodicities. Then, interweaved with the traditional microeconomics discussion of market structures noted above, I show how monopolies and oligopolies change the structure of the basic commodity model, and thus its behavior (Figures 11, 12, and 13). For example, monopolists substitute a more explicit desired production decision rule for the capacity utilization and expansion loops, and prices are based on markup on unit costs. Monopolies thereby tend to stabilize behavior somewhat. Oligopolists, however, reintroduce instability via the process of forecasting and market share competition.

Figure 10. Commodity/perfect competition model

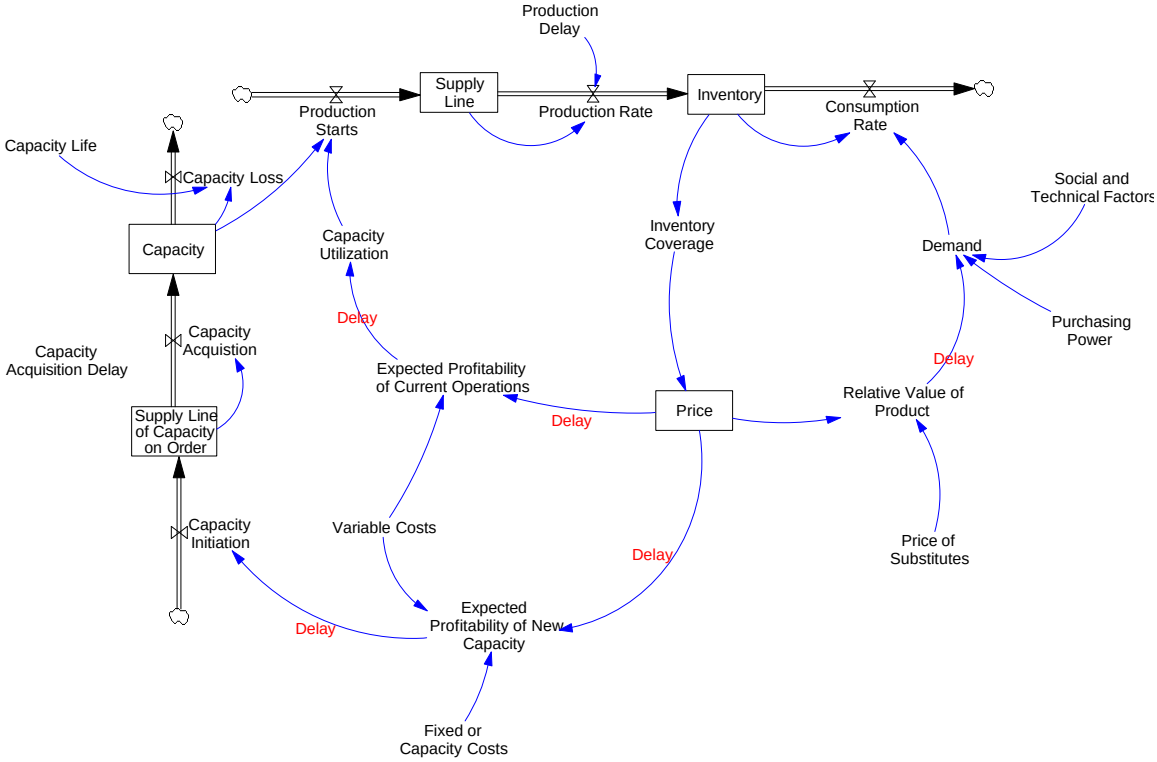


Figure 11. Monopolistic actions

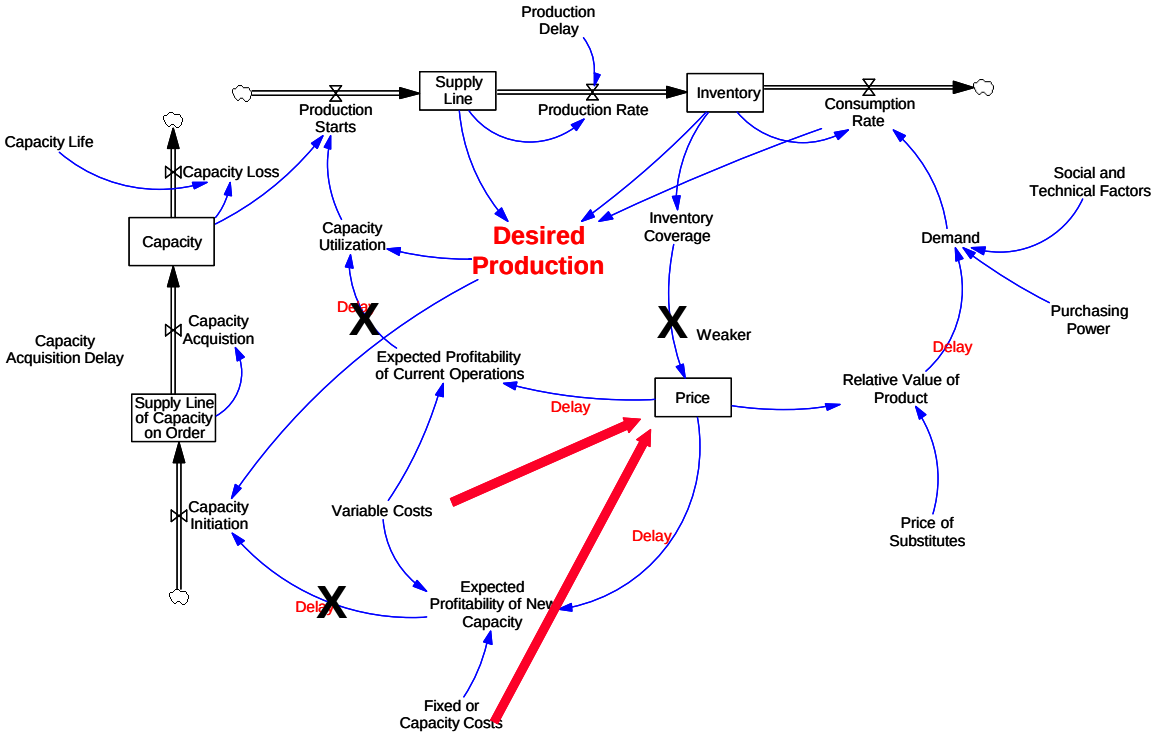


Figure 12. Oligopolist's actions

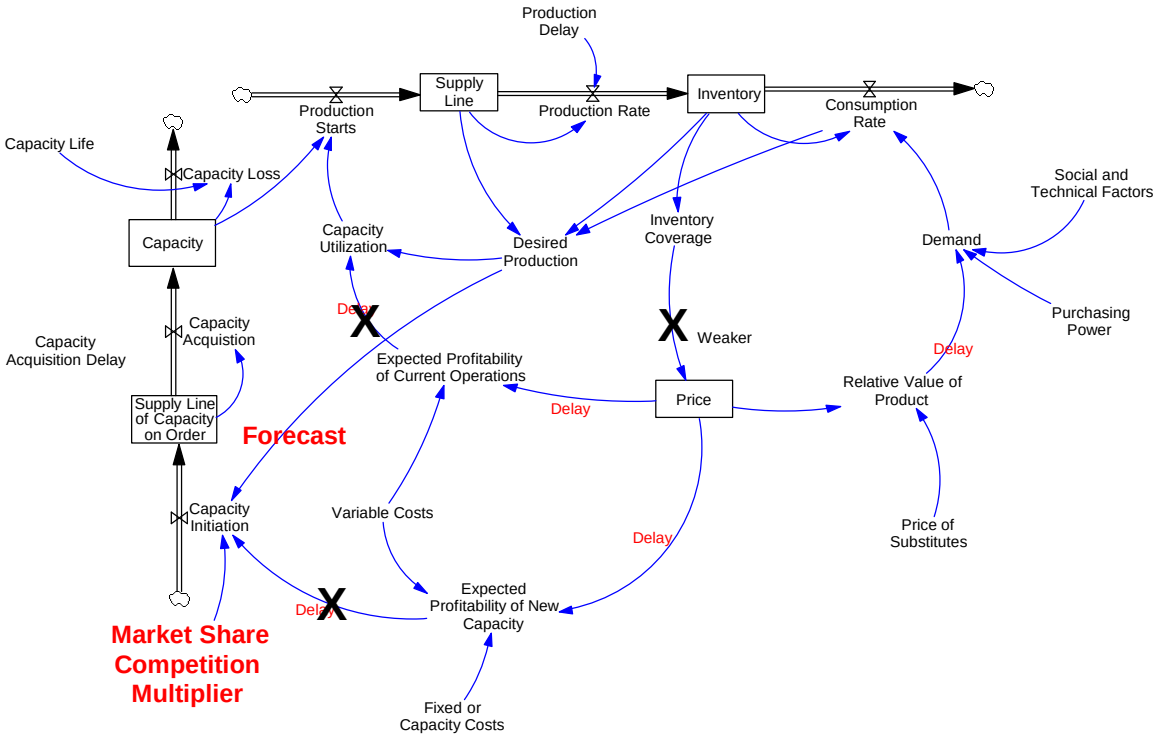
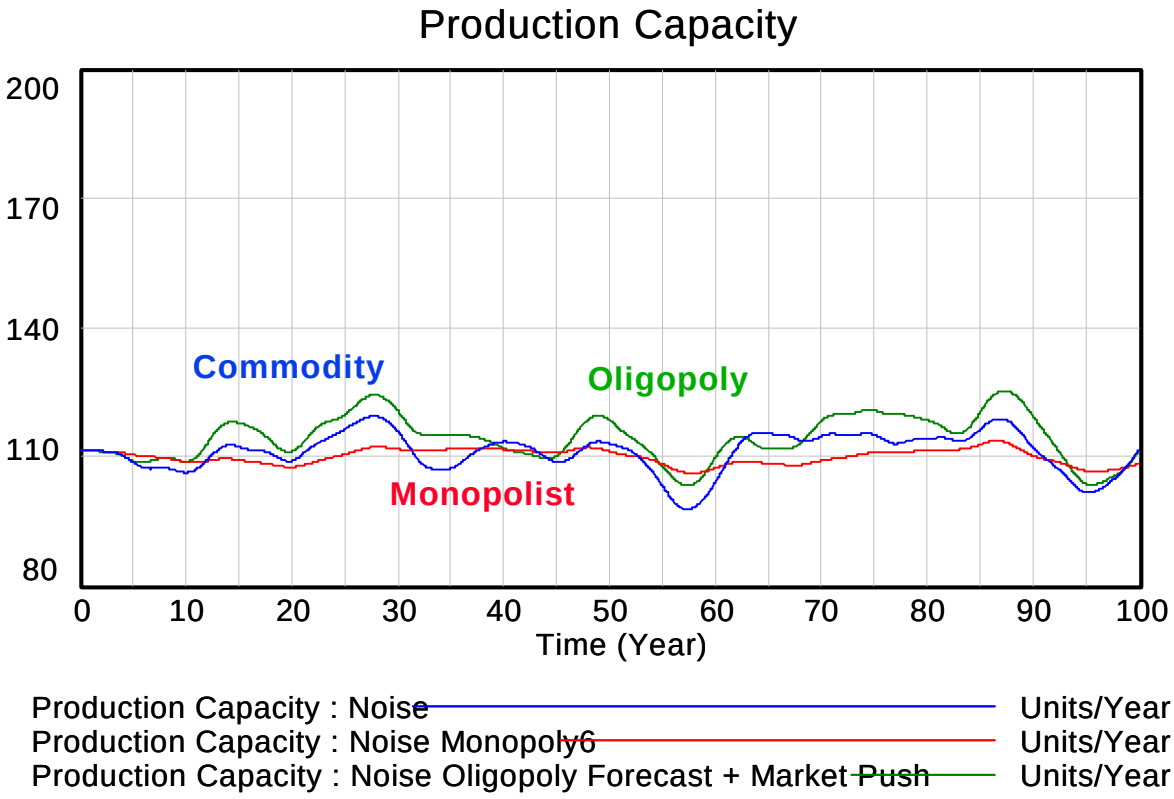
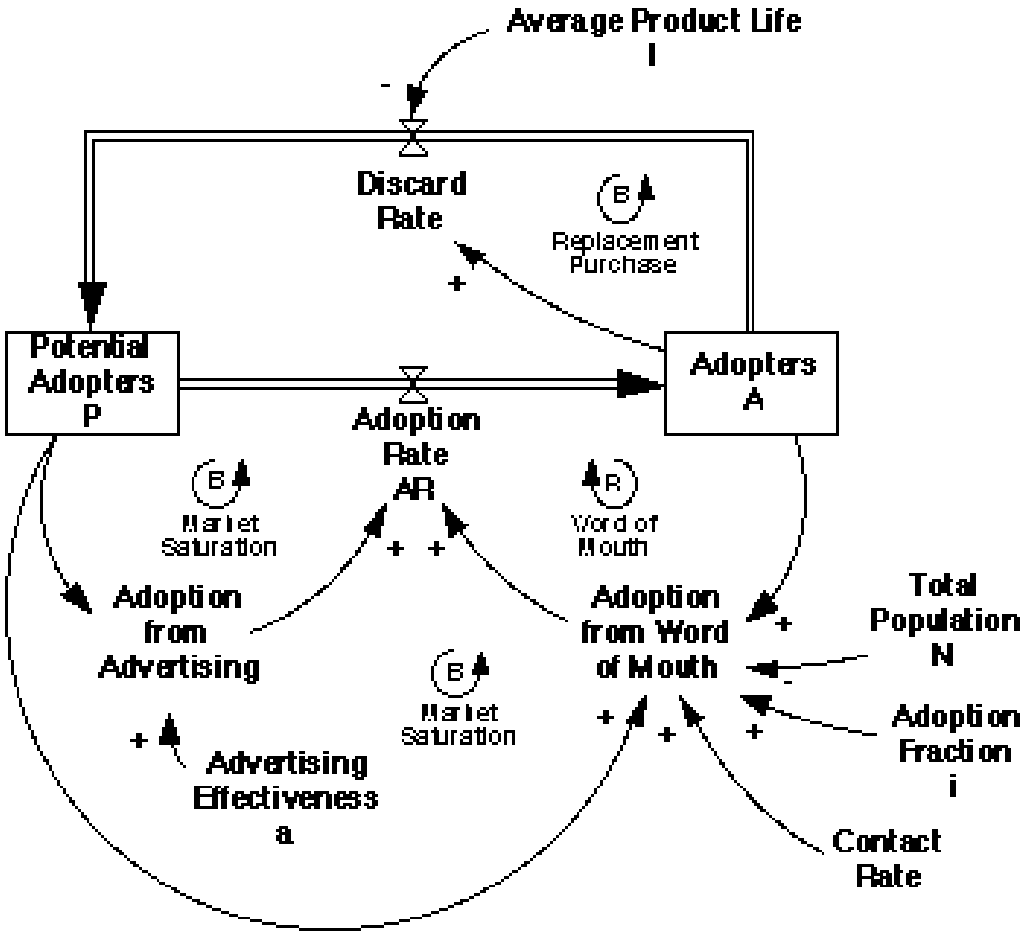


Figure 13. Different behavior produced by different market structures



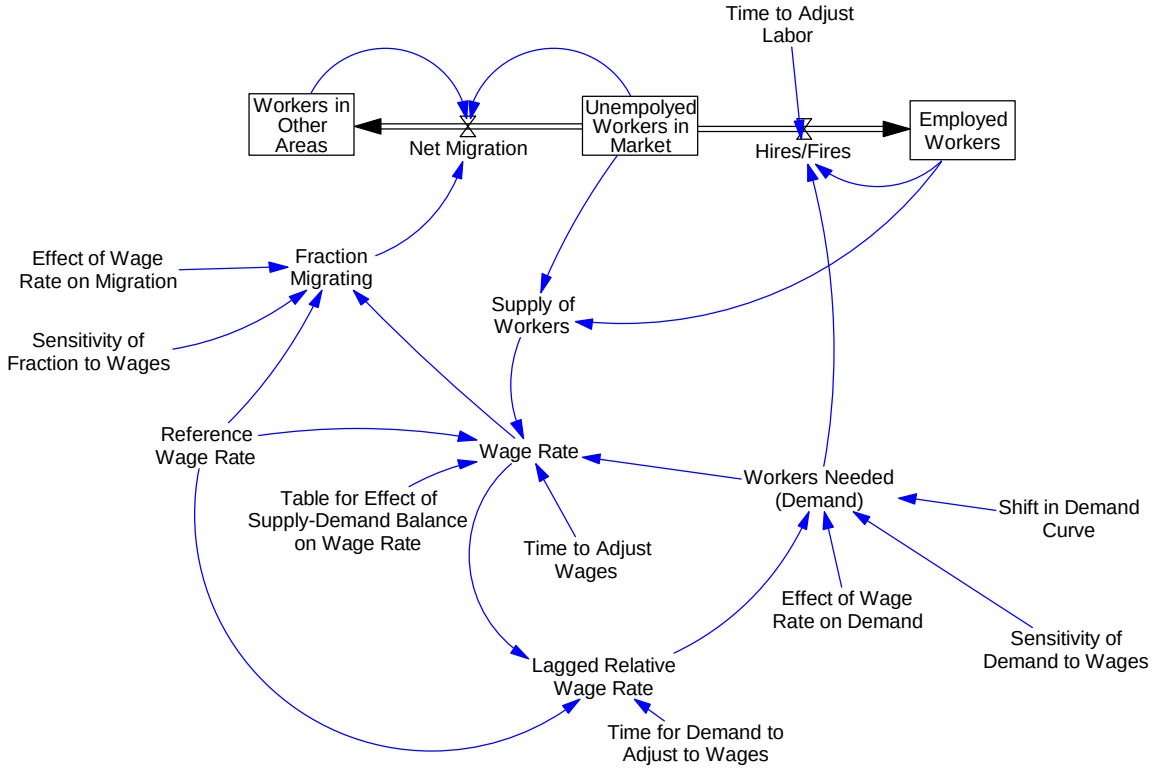
We conclude with a discussion of boom and bust using a diffusion model illustrated in Figure 14 (similar to Sterman [2000], Chapter 9), and extending that to consider capacity, stock prices, and bubbles. All along, I give examples, quotes from newspaper articles, and data to make the discussion more real. At the end, the students have seen a wide range of industry behavior and the structure that causes it. They have related the basic ideas of system dynamics to industry structure and behavior.

Figure 14. Boom and bust structure



Product, labor, and capital markets. In most economics texts, the discussion of supply and demand is illustrated using a product market (e.g., ice cream cones), with the occasional labor market introduced to discuss the impact of minimum wages. With this background, later in the term the texts quickly show how the basic supply-demand curves apply to other markets such as labor, financial capital, and land. With regard to labor markets, the texts then discuss earnings differentials and public policy related to wages (minimum wages, discrimination, equal pay for equal work). I summarize this discussion and augment it with newspaper articles on the supply and demand for engineers. We then use a mixed stock-flow-causal diagram shown in Figure 15 to understand the observed behavior, and introduce the idea of wage inflation.

Figure 15. Labor market structure



Externalities, common goods, and environmental economics. Another failure of markets is in dealing with externalities and common resources. We follow the traditional economics discussion of externalities, but then use system dynamics to discuss the tragedy of the commons. The "Fishbanks" game and model are excellent for this. Finally, I devote one class to the structure and issue raised by World Dynamics [Forrester, 1971; Meadows, et. al. 1974; Meadows, et. al., 1992].

Reflections and Next Steps

All students at WPI are required to take two social science courses in order to graduate. These courses are selected from economics, psychology, system dynamics, and public policy. Therefore, introductory classes can be large (88 in my case), and most students are there because they have to be. It should also be noted that each course is 7 weeks long and meets 4 times a week.

How did the students like it, and did they learn "more?" This is difficult to answer. Certainly class attendance was well above the norm for other social science classes, but this could have been because there was no textbook and most of the material was presented in class. Course evaluations were positive (in spite of two exceptionally long exams and a research essay!), with many finding the subject matter "interesting." But unfortunately we did not do a controlled experiment (e.g., same instructor using traditional methods). A number of students appreciated

the insights the course gave to our current economic situation (except for the outlook for computer science engineers!), and mentioned how they were better able to appreciate the news and discussions they have had with business people. However, the course has not yet attracted students to the system dynamics courses.

What worked and what did not? This was my first experience teaching undergraduates (rather than engineering and business graduate students). In retrospect, too much material was covered, and it was therefore done too quickly. In particular, the system dynamics needed to be presented more slowly and in less detail. The complete commodity/monopoly/oligopoly model was probably too advanced for an introductory course, but would fit well in an intermediate micro course. In addition, the students did not get any hands-on experience with the models. In other courses, I have made much greater use of games (Fishbanks, Beer Game, B&B) followed by models of the games that students (in part) developed and could experiment with. I believe that this approach could work well in economics, although at WPI the class size and course schedule presents implementation difficulties in the introductory courses.

Next Steps. I am scheduled to teach this course again in the spring of 2004. That will give me a chance to revise and improve the course materials. After that experience, I will have a much better set of lecture notes, models, and exercises for teaching microeconomics using system dynamics. In the interim, I would like to share experiences, ideas, and materials with others teaching economics.

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