ECONOMIC SUPPLY & DEMAND

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1. ABSTRACT

The main purpose of this paper is to discuss supply and demand in the framework of system dynamics. We first review classical supply and demand. Then we look at how to model supply and demand using system dynamics. Finally, we present a few exercises that will improve understanding of supply and demand and help improve system dynamics modeling skills.

2. INTRODUCTION

This paper emerged as an attempt to use system dynamics to model supply[1] and demand. Classical economics presents a relatively static model of the interactions among price, supply and demand. The supply and demand curves which are used in most economics textbooks show the dependence of supply and demand on price, but do not provide adequate information on how equilibrium is reached, or the time scale involved. Classical economics has been unable to simplify the explanation of the dynamics involved. Additionally, the effects of excess or inadequate inventory are often not discussed.

In the real world, the market price is affected by the inventory of goods held by the manufacturers rather than the rate at which manufacturers are supplying goods.[2] If the manufacturers are supplying goods at a rate equal to the consumer demand, the static classical theory would propose that the market is in equilibrium. However, what if there is a tremendous surplus in the store supply rooms? The manufacturers will lower the price and/or decrease production to return inventory to a desired level.

This paper introduces a model that incorporates elements from classical economics as well as several real-world assumptions. This model will be used to examine some of the interactions among supply, demand and price.

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[1] Supply and production are very similar terms and are often used interchangeably.

[2] Low, Gilbert W. (1974). Supply and Demand in a Single-Product Market (Exercise Prepared for the Economics Workshop of the System Dynamics Conference at Dartmouth College, Summer 1974) (Department Memorandum No. D-2058). M.I.T., System Dynamics Group.

3. CONVENTIONAL SUPPLY AND DEMAND

3.1 Introduction

This section deals with supply and demand as sometimes taught in high-school economics classes. The following descriptions of supply and demand assume a perfectly competitive market, rational consumers, and free entry and exit into the market. Economists also make the simplification that all factors other than price which affect the quantity of goods sold and purchased are held constant. Economists argue that this is a valid assumption because changes in price occur much more quickly than changes in other factors that may affect supply or demand. Examples of these other factors include changes in taste, changes in the state of the economy and long-term changes in production capacity (such as the construction of a new factory).

3.2 Demand

Demand is the rate at which consumers want to buy a product. Economic theory holds that demand consists of two factors: *taste* and *ability to buy*. Taste, which is the desire for a good, determines the willingness to buy the good at a specific price. Ability to buy means that to buy a good at specific price, an individual must possess sufficient wealth or income.

Both factors of demand depend on the market price. When the market price for a product is high, the demand will be low. When price is low, demand is high. At very low prices, many consumers will be able to purchase a product. However, people usually want only so much of a good. Acquiring additional increments of a good or service in some time period will yield less and less satisfaction.[3] As a result, the demand for a product at low prices is limited by *taste* and is not infinite even when the price equals zero. As the price increases, the same amount of money will purchase fewer products. When the price for a product is very high, the demand will decrease because, while consumers may wish to purchase a product very much, they are limited by their *ability to buy*.

The curve in Figure 1 shows a generalized relationship between the price of a good and the quantity which consumers are willing to purchase in a given time period. This is known as a *simple demand curve*.

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[3] This behavior toward aquiring additional increments of a good is called *diminishing marginal utility*.

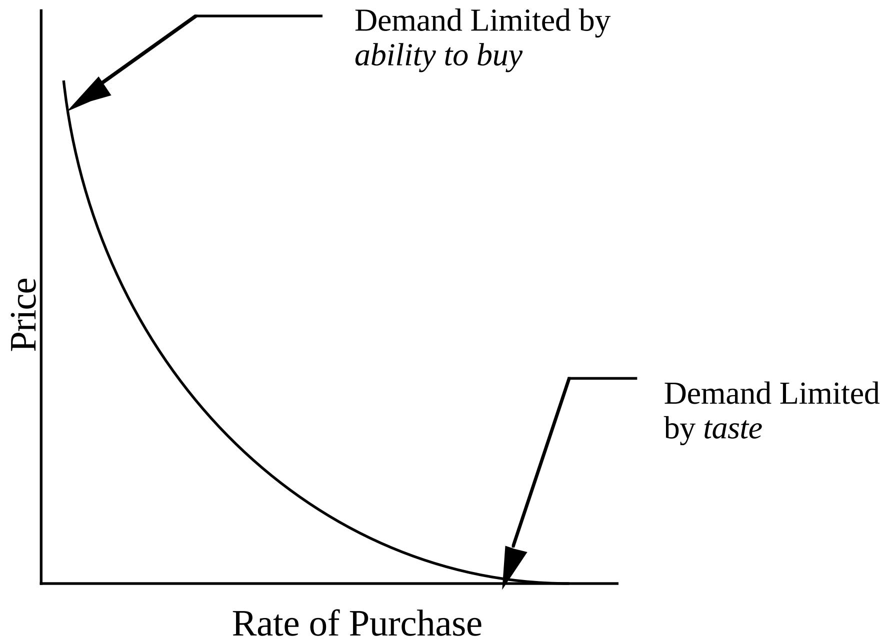

Figure 1: Demand Curve[4]

This curve shows the rate at which consumers wish to purchase a product at a given price.

The simple demand curve seems to imply that price is the only factor which affects demand. Naturally, this is not the case. Recall the assumption made by economists that the other factors which influence changes in demand act over a much larger time frame. These factors are assumed to be constant over the time period in which price causes supply and demand to stabilize.

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[4] The reader should note that the convention in economic theory is to plot the price on the vertical axis and the rate of purchase on the horizontal axis.

3.3 Supply

Willingness and ability to supply goods determine the seller's actions. At higher prices, more of the commodity will be available to the buyers. This is because the suppliers will be able to maintain a profit despite the higher costs of production that may result from short-term expansion of their capacity[5].

In a real market, when the inventory is less than the desired inventory, manufacturers will raise both the supply of their product and its price. The short-term increase in supply causes manufacturing costs to rise, leading to a further increase in price. The price change in turn increases the desired rate of production. A similar effect occurs if inventory is too high. Classical economic theory has approximated this complicated process through the supply curve. The supply curve shown in Figure 2 slopes upward because each additional unit is assumed to be more difficult or expensive to make than the previous one, and therefore requires a higher price to justify its production.

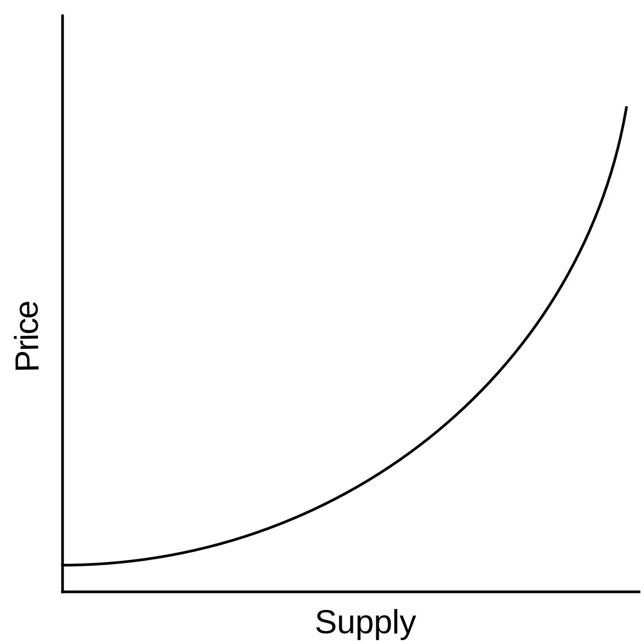

Figure 2: Supply Curve

At high prices, there is more incentive to increase production of a good. This graph represents the short-term approximation of classical economic theory.

[5]Short-term expansion can be achieved by giving workers overtime hours, contracting to an outside source, or increasing the load on current equipment. These types of changes increase per-unit supply costs.

3.4 Interaction Between Supply and Demand

Demand is defined as the quantity (or amount) of a good or service people are willing and able to buy at different prices, while supply is defined as how much of a good or service is offered at each price. How do they interact to control the market?

Buyers and sellers react in opposite ways to a change in price. When price increases, the willingness and ability of sellers to offer goods will increase, while the willingness and ability of buyers to purchase goods will decrease. To illustrate more clearly how the market works, we will look at the following example from the clothing industry.

Table 1 is called a schedule of demand and supply. For each price, it indicates how much clothing is demanded by the consumers per week, and how much clothing is supplied per week. Notice that as price decreases, demand increases and supply decreases. Eventually demand exceeds supply.

Demand and Supply Schedules

Price	Quantity Demanded (per week)	Quantity Supplied (per week)
$50	10	100
$45	14	97
$40	18	94
$35	22	89
$30	28	84
$25	35	77
$20	45	68
$15	57	57
$10	73	40
$5	100	0

Table 1: Demand and Supply Schedules

For each price, the schedule above indicates the quantity (in articles per week) of clothing demanded and supplied.

The market will reach equilibrium when the quantity demanded and the quantity supplied are equal. At $15, supply and demand are equal at 57 articles of clothing per week. To better understand the dynamics involved, suppose that one article of clothing was selling for $30. Producers would be willing to supply 84 articles of clothing per week, but consumers would only be buying 28 articles per week. As a result, the producers would have excess inventory piling up very quickly. In order to get their inventory back to the desired level, the suppliers would have to decrease production and reduce the price. Eventually, the quantity demanded and quantity supplied meet at 57 articles per week at a price of $15.

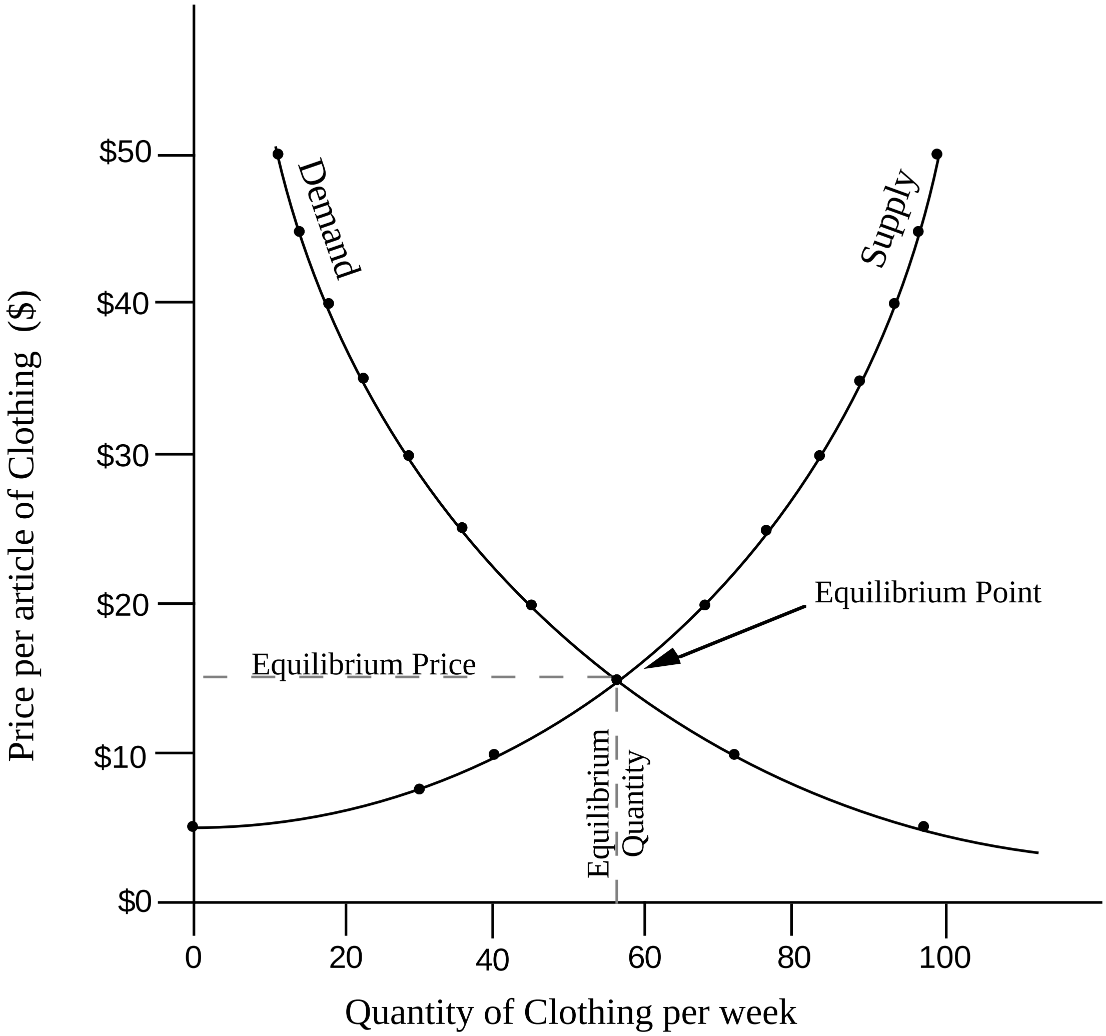

Figure 3: Demand and Supply Curves

These curves were plotted from the data for the clothing market included in Table 1.

Figure 3 plots the demand and supply curves from the data in Table 1. Notice that at $15 the supply and demand curves meet.

4. A SYSTEM DYNAMICS APPROACH TO SUPPLY AND DEMAND

4.1 Introduction

Classical economic theory presents a model of supply and demand that explains the equilibrium of a single product market. The dynamics involved in reaching this equilibrium are assumed to be too complicated for the average high-school student. Economists hold the view that price determines both the supply and the demand. Equlibrium economics defines only the intersection of the supply and demand curves, not how that intersection is reached.

On the other hand, system dynamicists believe that the availability of a product, rather than its rate of production, affects the market price and demand. This means that the inventory (or backlog) of a product is a major determinant in setting price and regulating demand. This model is a hybrid of both views in that it introduces the dynamic effects of inventory into a model that generally replicates the economists' static explanation of supply and demand.

To explore the dynamics of supply and demand we will use the clothing market as an example. Because of a very aggressive marketing campaign, demand for clothes has increased. How will the suppliers and consumers react?

To study the behavior of the market, we will look at its three major components: supply, demand, and price. There will be a series of exercises to help you understand the model. We will first look at consumer demand.

4.2 Demand

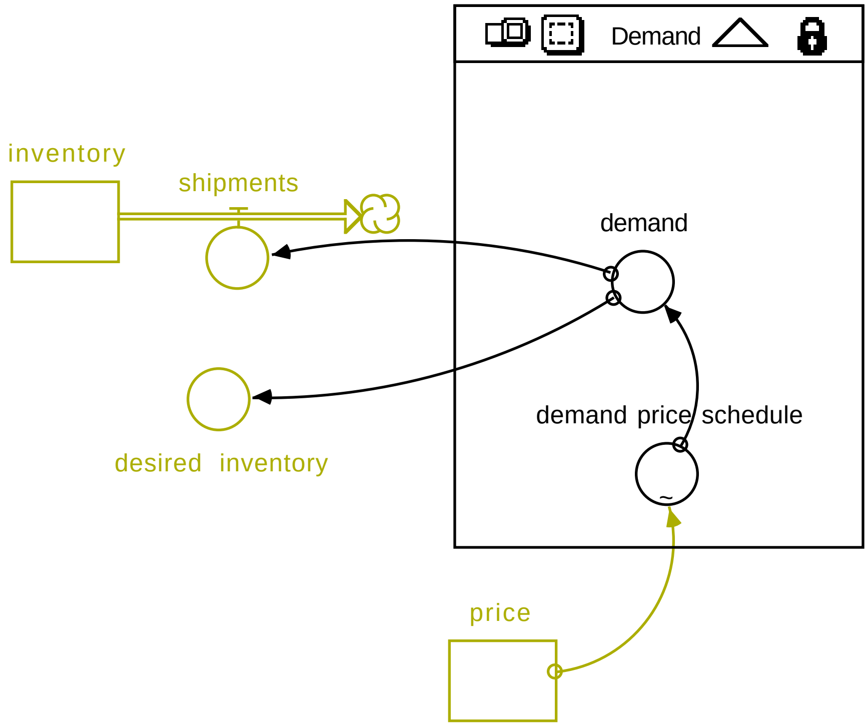

Figure 4: Demand Sector

Demand in this model obeys one simple rule. It is the *demand* as dictated by the *demand price schedule.* The *demand price schedule* is a demand curve that indicates what quantity consumers are willing to buy at a given price. The *demand* directly affects two things. First, it determines the outflow to the *inventory* stock of the suppliers. This model assumes that the rate of *shipments* from the inventory is equal to the *demand*. Additionally, the *demand* sets the size of the supplier's *desired inventory*.

Figure 5 shows the simple demand curve used in the *demand price schedule* graphical function. This curve is somewhat different from the curve shown in Figure 1. Because STELLA and system dynamics standard practice require the input to a graphical function to be on the horizontal axis, it was necessary to reverse the axes. In the curve shown in Figure 5, price is on the horizontal axis instead of the vertical. As discussed earlier, the curve shows that consumers are willing to buy more if the price is lower.

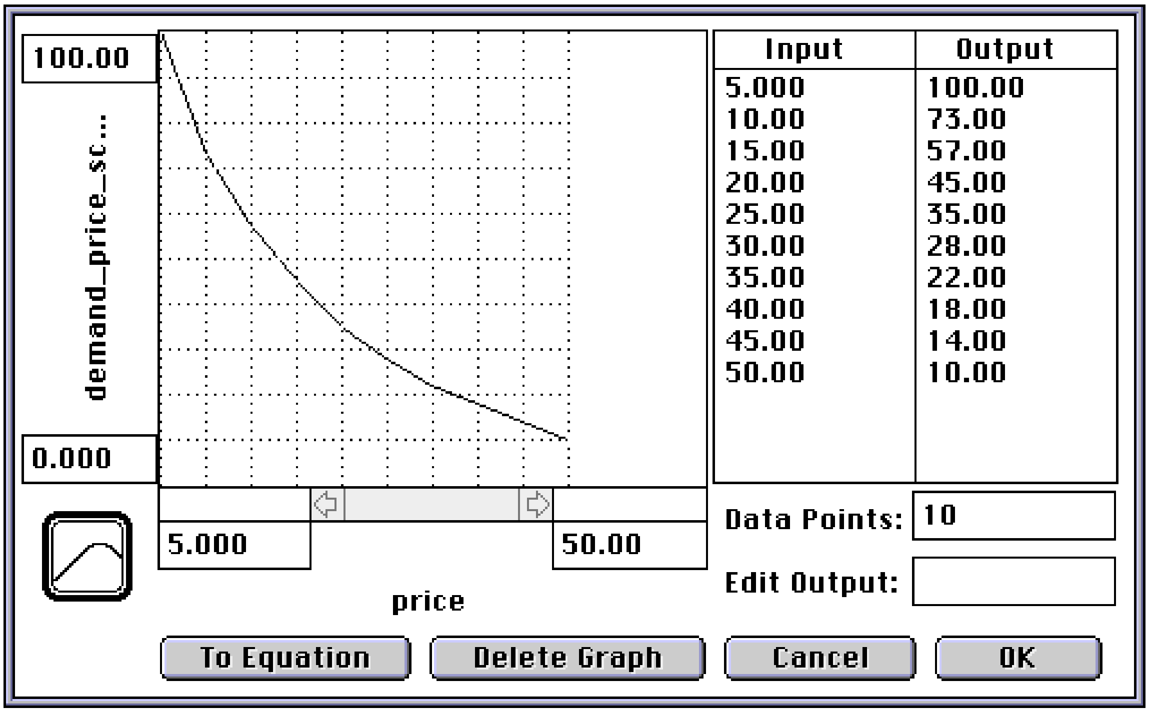

Figure 5: Demand Price Schedule

This curve is a simple demand curve from classical economics with the axes reversed.

4.3 Supply

Below is the supply sector of the model. To simplify the model, we combined the inventories of all the suppliers into one large inventory. The inflow *supply* represents the total production of goods to inventory. The outflow to this stock, *shipments,* is equal to the *demand*.

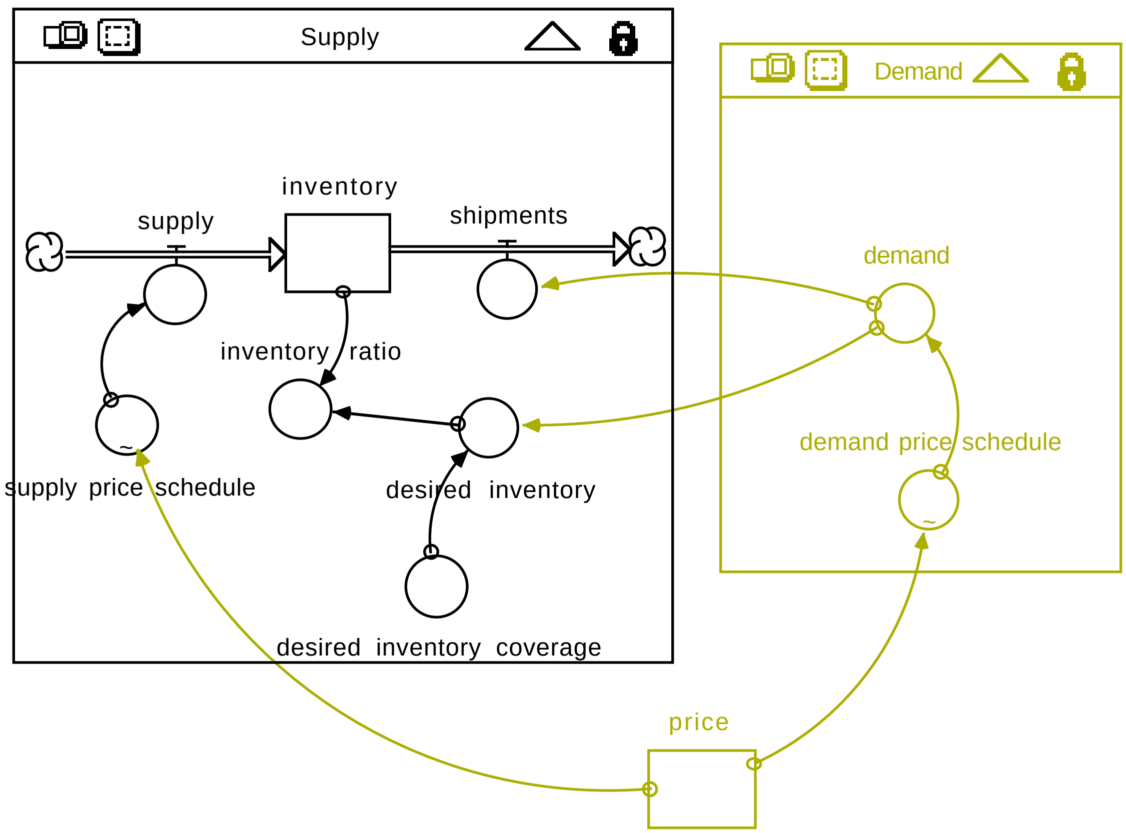

Figure 6: Supply Sector

In Section 3 (Conventional Supply and Demand, page 8) there was no discussion of inventory. Basic classical economic theory does not specifically address the effects of excess or inadequate inventory. This model includes these effects. The *inventory* stock represents the total quantity of clothing in the warehouses of all suppliers.

The *shipments* flow is equal to the weekly demand for clothing. *Desired inventory* is the quantity of clothing the suppliers would like to have in *inventory*. The suppliers like to have enough *inventory* to cover several weeks of *demand*. Therefore, *desired inventory* is the product of *desired inventory coverage* and *demand*. The *inventory ratio* is the ratio of *inventory* to *desired inventory*. The *inventory ratio* will be used to determine *price* later in the modeling process.

Before clothes can be stored in the warehouses, they need to be produced. The *supply* flow is determined by the *supply price schedule*. The *supply price schedule* is a supply curve which indicates how much the producers are willing to produce for each price they receive in the market. The source for this relation is the supply curve provided by classical economic theory[6]. As with the demand curve, the axes must be reversed so that *price* can be an input to the graphical function. The curve used in the *supply price schedule* is shown in Figure 7 below.

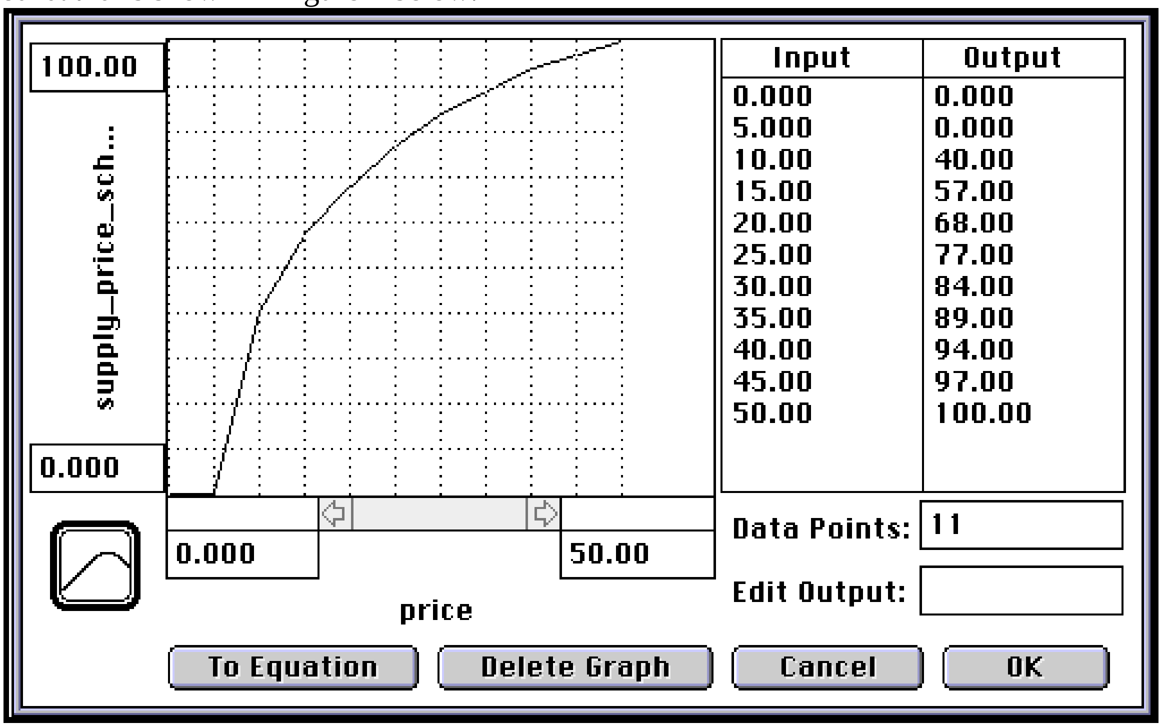

Figure 7: Supply Price Schedule

This curve was derived by taking the simple supply curve from classical economics and reversing the axes. This curve shows the rate of production for a given price.

Below a certain price, the incentive to produce is zero because manufacturers cannot cover the costs of production. As the price rises above that cutoff, supply will increase rapidly. At higher prices, the additional cost of increasing the supply begins to outweigh the benefits of selling at a higher price. As the supply rate continues to

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[6] The reader should note that this curve is being used in place of more complictated dynamic structure. There is no real-world causal relation between the price and the supply rate of a product. The information contained in the graph is an approximation for the behavior that would be produced by including structure which includes the effects of varying production capacity and employment.

increase, it takes larger and larger increases in the market price to justify further increases in supply.

4.4 Interaction between Supply and Demand

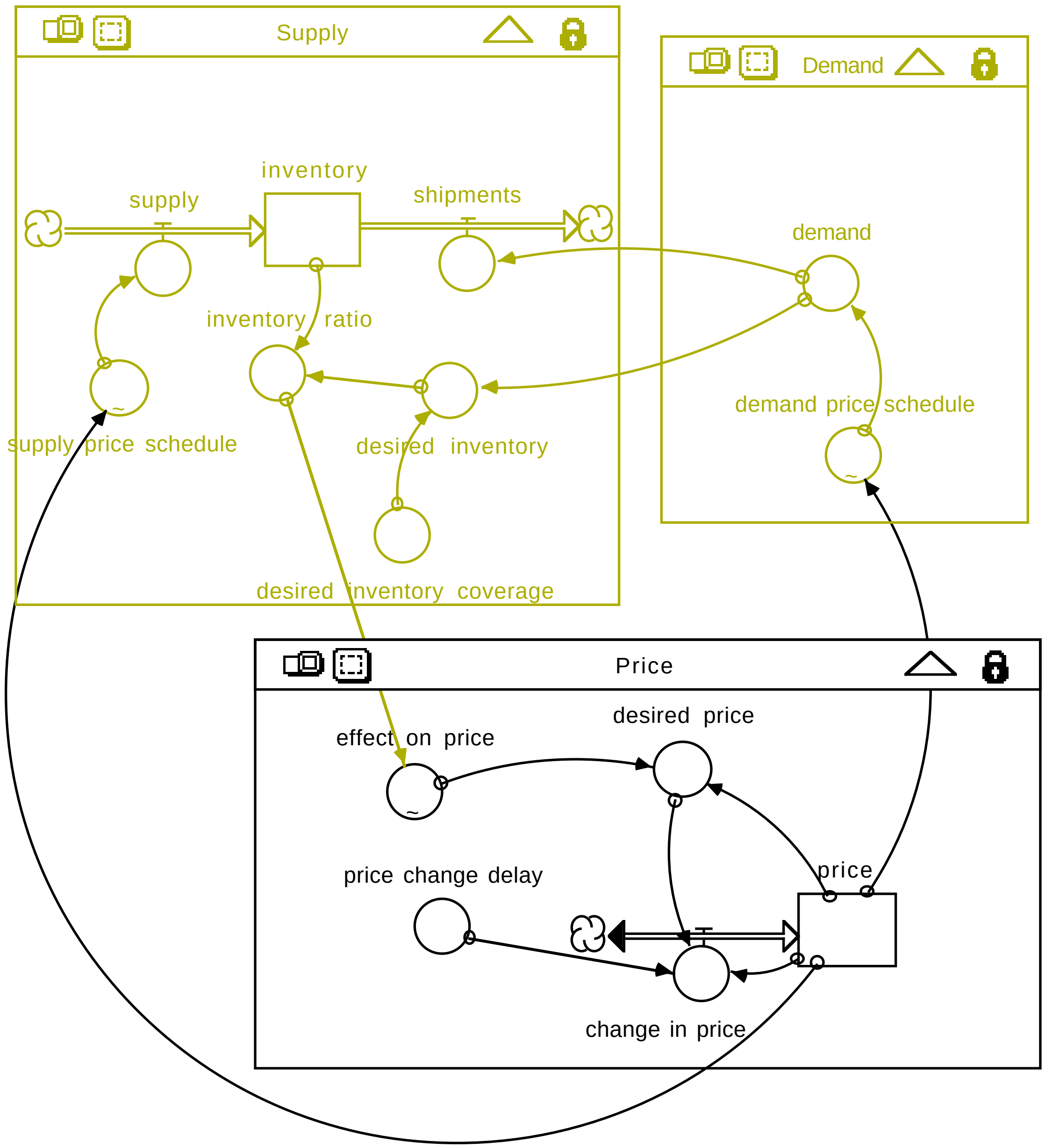

Figure 8: Price Sector

Price affects supply and demand as determined by the *supply price schedule* and the *demand price schedule*. When *price* is high, *demand* is low and *supply* is high. When *price* is low, *demand* is high and *supply* is low. We assumed that the only direct action by a manufacturer to bring inventory to the desired level is to vary price.

The action of the suppliers to regulate the *price* based on the *inventory ratio* is shown in Figure 9. Recall that the *inventory ratio* is defined as the ratio of *inventory* to *desired inventory*.

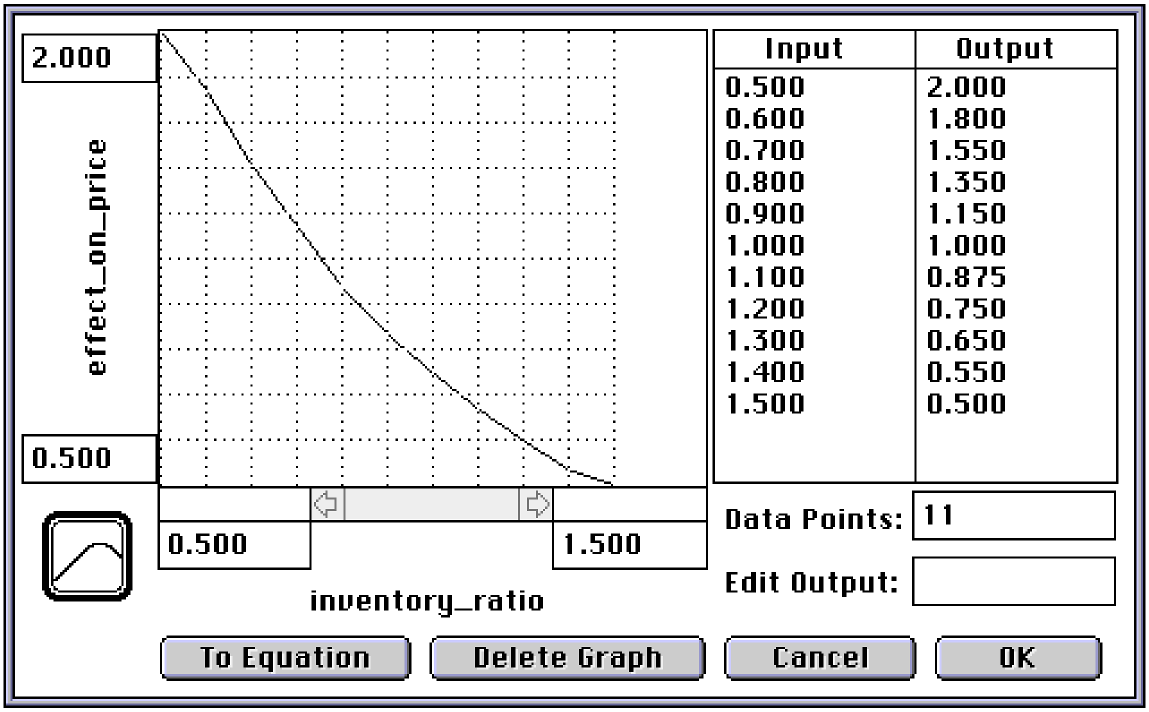

Figure 9: Effect on Price graphical function

When there is excess inventory, the price is lowered and when there is inadequate inventory, the price is raised.

The graphical function shown in Figure 9 represents the action of suppliers to regulate their inventory. When inventory is below the desired inventory, then the inventory ratio is less than one. The graph in Figure 9 shows that an inventory ratio less than 1 gives a value for *effect on price* that is greater than one. This causes the *price* to increase. The increase in *price* causes the *supply* to increase and the *demand* to decrease through their respective price schedules and brings the *inventory* closer the desired value. Multiplying the output of the *effect on price* converter and actual *price* returns *desired price*.

Price was modeled as a stock because prices cannot change instantaneously. People do not have immediate and exact information on the supply (inventory) and demand of the commodity in question. Additionally, when the information becomes available, it takes time to make a decision about changing the price.

5. TESTING THE MODEL

Putting the model together, we get the following:

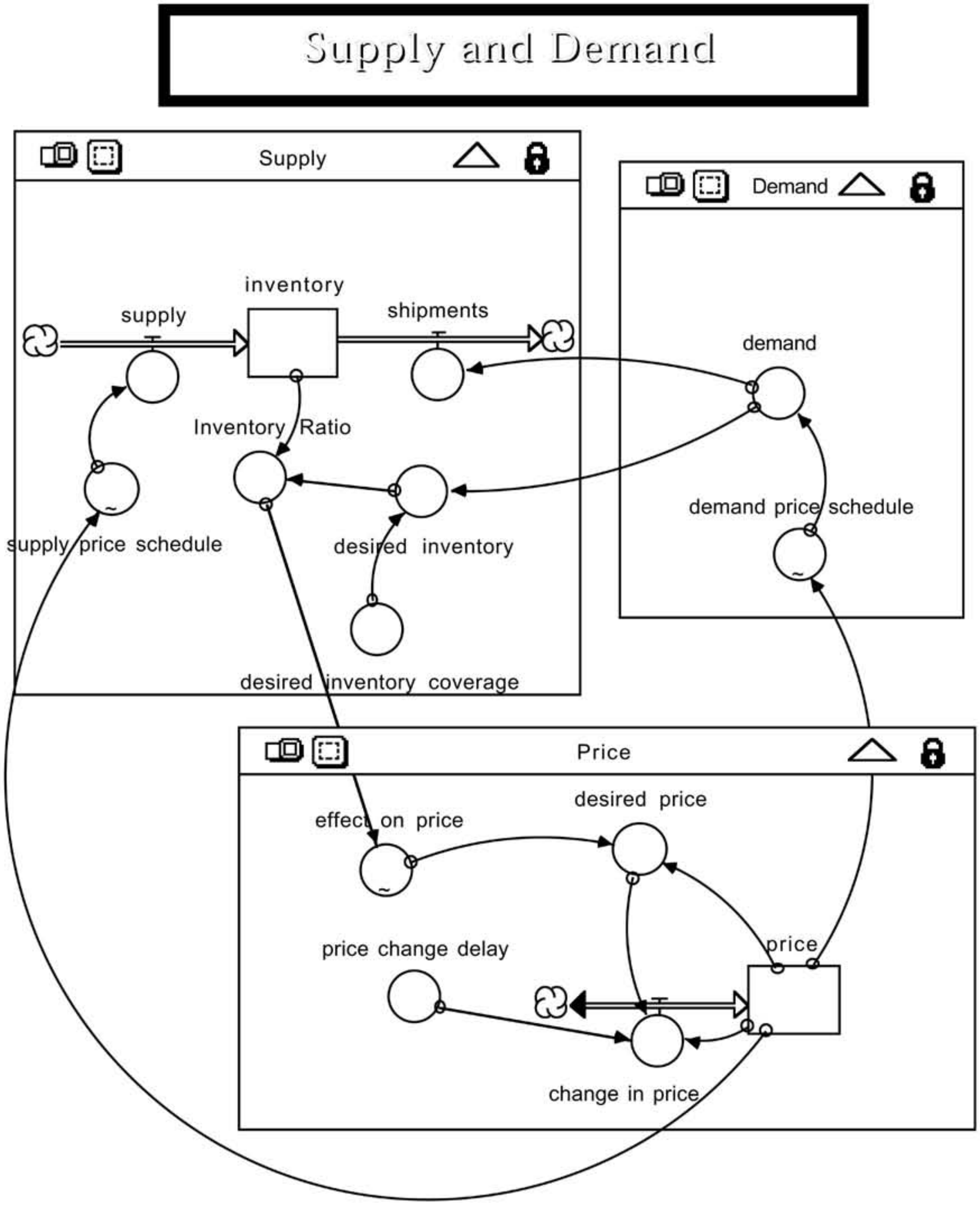

Figure 10: The complete Supply and Demand model

At this point, you may wish to build the STELLA model of supply and demand. The exercises that follow do not require you to run the model, but you may wish to perform some simulations of your own. The complete model equations are included in the appendix, beginning on page 33.

You will analyze three scenarios in this section. The first scenario will be a base case run to observe the response of the model to a step increase in demand. Then you will analyze how the behavior of the system varies from the base case when you change the desired inventory coverage and the price change delay. Solutions start on page 28.

5.1 Increase in Demand

For the base case run, assume the following conditions:

- initial *price* = $15 per article of clothing
- *desired inventory coverage* = 4 weeks
- *price change delay* = 15 weeks

#1: What should *inventory* be in order for the system to be in equilibrium? (Hint: look at the *supply price schedule* and the *demand price schedule*) ________________________

Discuss your reasoning below.

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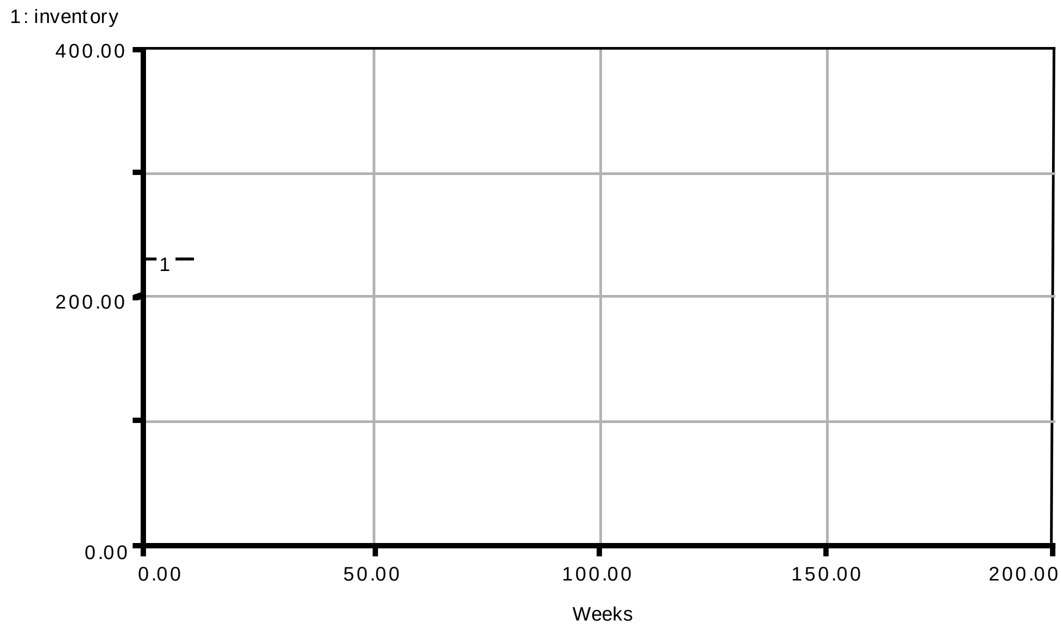
#2: Assume that the system is in equilibrium. *Price* and *inventory* remain the same until the tenth week, at which time there is a permanent increase in *demand* of 10 units. (At each price, the consumer demand is 10 articles per week higher.) What are the new equilibrium values for *price* and *inventory*? ______________________________________

#3: Draw below what you think will happen to *inventory* in response to an increase in demand.



Explain your reasoning:

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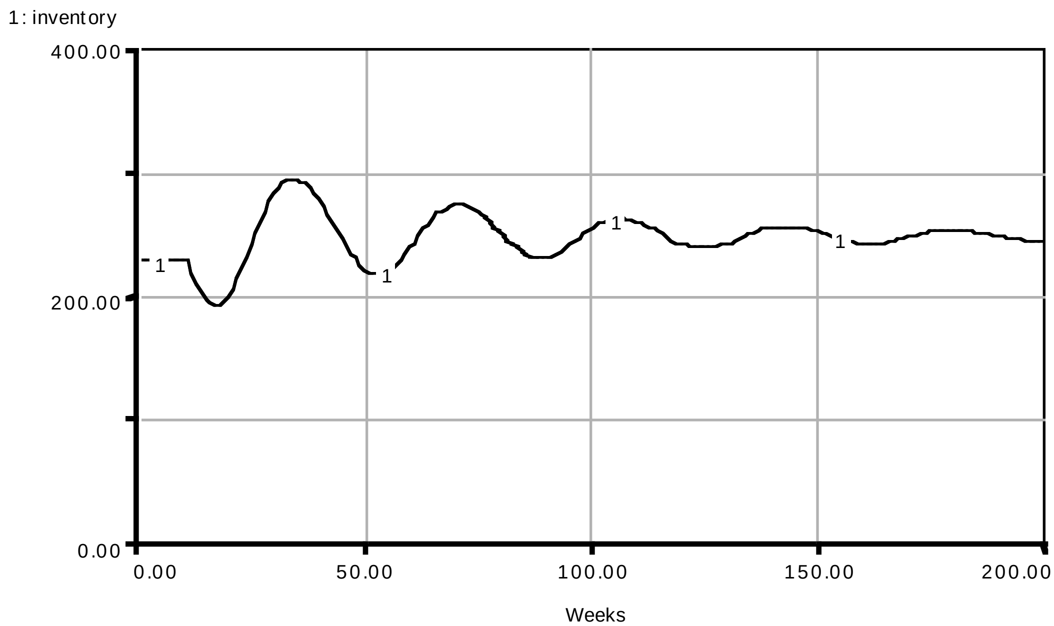
5.2 Desired Inventory Coverage

We will now explore the response of the system to an increase in demand for different values of the *desired inventory coverage* (the number of weeks of desired inventory coverage). Presently *desired inventory coverage* is 4 weeks and the system is in equilibrium. The response of the system to a step increase in demand with *desired inventory coverage* = 4 weeks is shown below.

#4: If we change *desired inventory coverage* to 6 weeks, how would the system react to the same increase in demand? On the graph below, draw the expected behavior.

#5: Now, draw on the same graph what you expect the behavior of *inventory* will be if *desired inventory coverage* is equal to 2 weeks and there is an increase in demand.



Explain your reasoning:

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5.3 Price Change Delay

We are now ready to discuss the effect of varying the *price change delay*. The delay obviously affects how quickly the price changes, and in the following exercises we will see how well you can predict the behavior of price when that delay is modified.

#6: Currently, the *price change delay* is 15 weeks. Assuming everything else remains unchanged (system in equilibrium), would *price* or *inventory* change over time if the delay is suddenly shortened? ___________________

Why or why not?

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#7: Would you expect the system to reach equilibrium more quickly when the *price change delay* is equal to 30 weeks or 15 weeks? _____________

Explain your reasoning:

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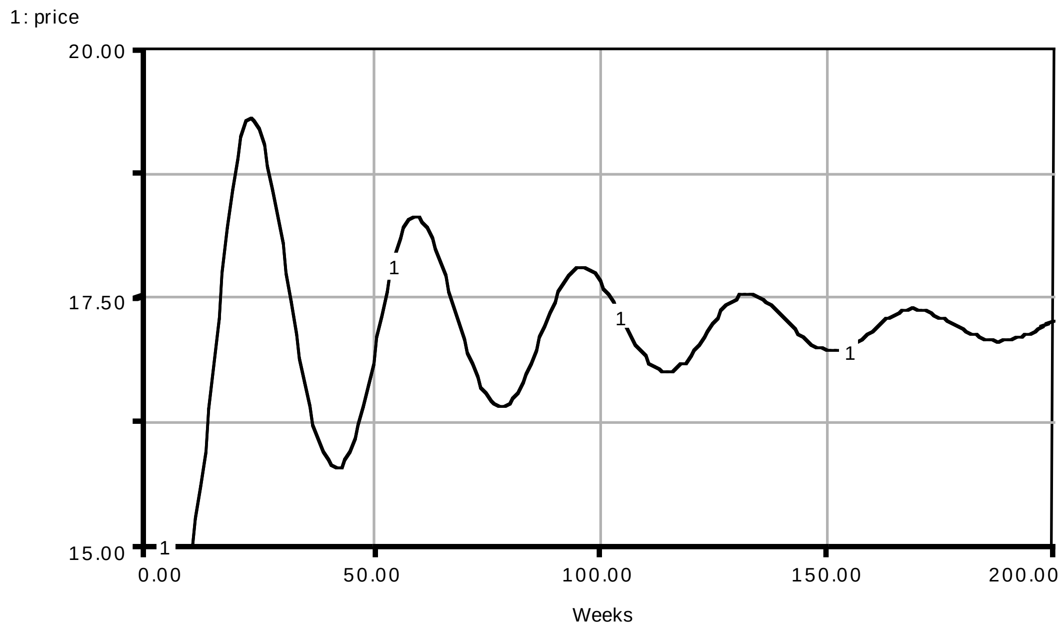
The graph below shows the response of the system to a step increase in demand when the *price change delay* is 15 weeks.

#8: If the *price change delay* is changed to 5 weeks, how would the system react to an increase in demand? On the graph below, draw the expected behavior of *price*.

#9: Now, draw on the same graph what you expect the behavior of *price* to be if *price change delay* is changed to 30 weeks and there is an increase in demand.



Explain your reasoning:

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5.4 Further Exploration

Naturally, no system dynamics model is ever complete. We believe that the model presented is adequate for the purposes of this paper, but there are many possibilities for enhancing it. One possibility is to include the effect of available inventory on demand. The current model assumes that if a product is not currently available, the consumer will simply place an order and wait for the product to arrive, creating negative inventory, or backlog. You may also wish to include structure for increasing the capacity of the supplier. This would allow for increased production without raising the per-item cost. You could also experiment with the dynamics of a non-durable good market (i.e., food). The possibilities are unlimited and it will help enhance your modeling skills.

6. SOLUTIONS TO EXERCISES

6.1 Increase in Demand

#1: In equilibrium, all stocks must remain constant. The *price* will remain constant when the *inventory ratio* is one. Therefore, in equilibrium, the *inventory* is equal to the *desired inventory*. By looking at the supply and demand curves contained in the graphical functions of *Demand Price Schedule* and *Supply Price Schedule* we can see that the equilibrium price is $15 when *demand* and *production* both equal 57 articles of clothing per week. Since the *desired inventory coverage* is 4 weeks, the equilibrium *inventory* is 228 articles of clothing.

#2: An increase in *demand* of 10 articles of clothing per week means that the demand curve in the *demand price schedule* is shifted up by 10. An easy way to figure out the new equilibrium *price* is to plot the supply curve and the new demand curve on the same graph and find the intersection. Doing this shows that the new equilibrium *price* will be about $17 with *production* and *demand* slightly less than 62 articles per week. The new equilibrium *inventory* is then 62*4 or 248 articles of clothing.

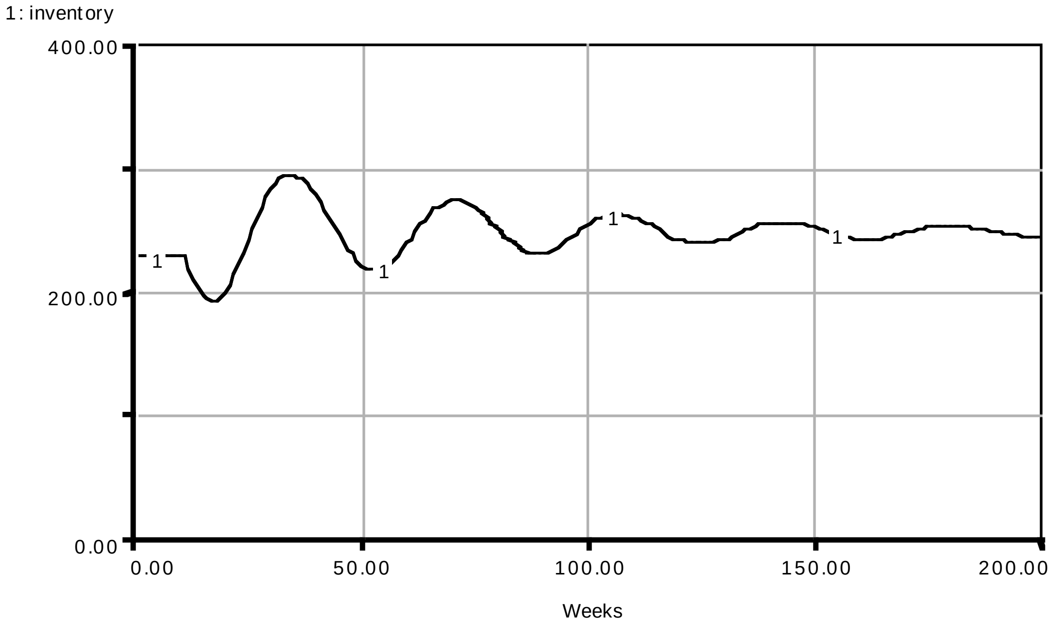


Figure 11: Step in Demand

Inventory decreases at first due to increased demand. It then overshoots and oscillates to a new equilibrium.

#3: The increase in *demand* causes the *desired inventory* to immediately shoot up by 40 articles of clothing (10 articles per week * 4 weeks of coverage). At the same time, *inventory* begins to drop because *shipments* are higher than *supply*. These cause the *inventory ratio* to drop, resulting in an increase in *price*. The *price* increase causes the *demand* to fall and *supply* to increase allowing the *inventory* to catch up to the *desired inventory*. However, the *price* continues to rise until the *inventory* has overshot its equilibrium value. At this point the inventory ratio becomes positive, causing the *price* to begin falling. Although the price is falling, it remains above its equilibrium value causing the inventory to continue increasing beyond its equilibrium. Eventually, the price falls below the equilbrium price and causes the inventory to begin decreasing, but the inventory again overshoots and the system oscillates to its new equilibrium with inventory equal to about 248. A graph of this behavior is shown in Figure 11.

6.2 Desired Inventory Coverage

#4 & #5: The *desired inventory coverage* affects the size of the *desired inventory.* The response of the system to an increase in demand was very different for the three values of *desired inventory coverage*. When the *desired inventory coverage* was 2 weeks, the inventory seemed to exhibit sustained oscillation. As the coverage was increased to 4 and 6 weeks, the reaction to an increase in demand was smaller and stabilized more quickly. This behavior shows that there is a tradeoff when considering the size of inventory coverage. When the *desired inventory coverage* is high, inventory remains fairly stable and is not greatly affected by changes in demand. Unfortunately, maintaining a large inventory can be costly. Lower values for *desired inventory coverage* are less costly to maintain, but react dramatically to changes in demand. Figure 12 shows the model runs for *desired inventory coverage* equal to 2, 4 and 6 weeks. (Curves 1, 2 and 3 respectively.)

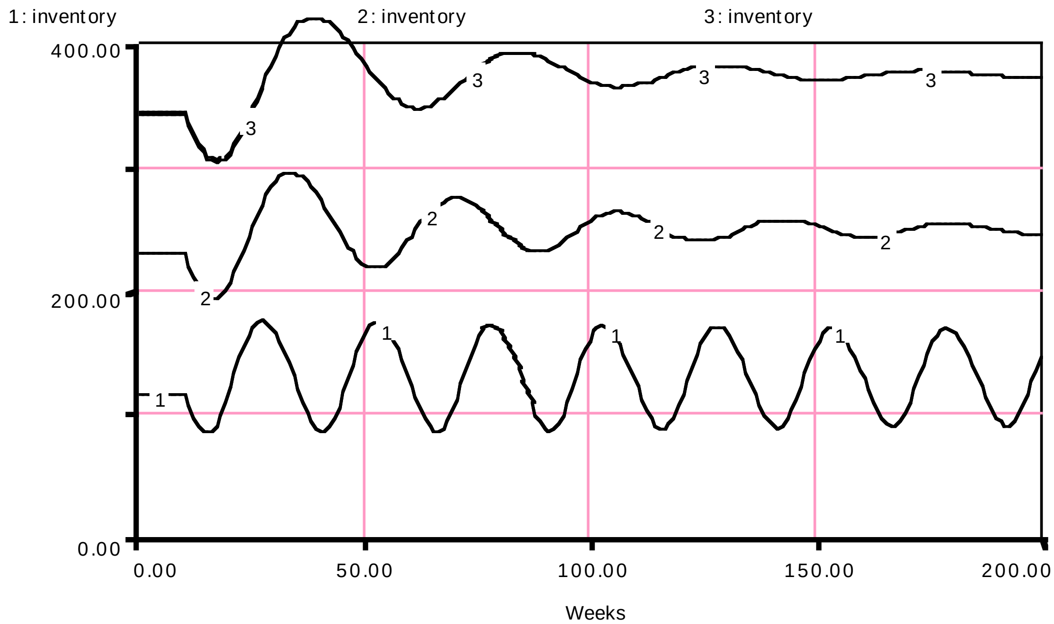


Figure 12: Change in desired inventory coverage
Variations in desired inventory coverage have a large effect on the behavior of the system. Higher coverage allows the inventory to maintain stable, but is costly to maintain.

6.3 Price Change Delay

#6: The *price change delay* does not affect the equilibrium state of the model. This delay only comes into effect when the *price* is changing. Any change in the *price change delay* will not affect the model if it is already in equilibrium.

#7: When the model is knocked out of equilibrium, the *price change delay* affects how it approaches its new equilibrium. When the *price change delay* is short (5 weeks), the *price* changes rapidly and overshoots its equilibrium value. The *price* also converges on its equilibrium quickly. As the *price change delay* increases (15 weeks and 30 weeks), the changes are more gradual, the overshoot smaller and the equilibrium takes longer to reach.

#8, #9: The graphs below show the reaction of *price* to an increase in *demand* when the *price change delay* is 5, 15 and 30 weeks.

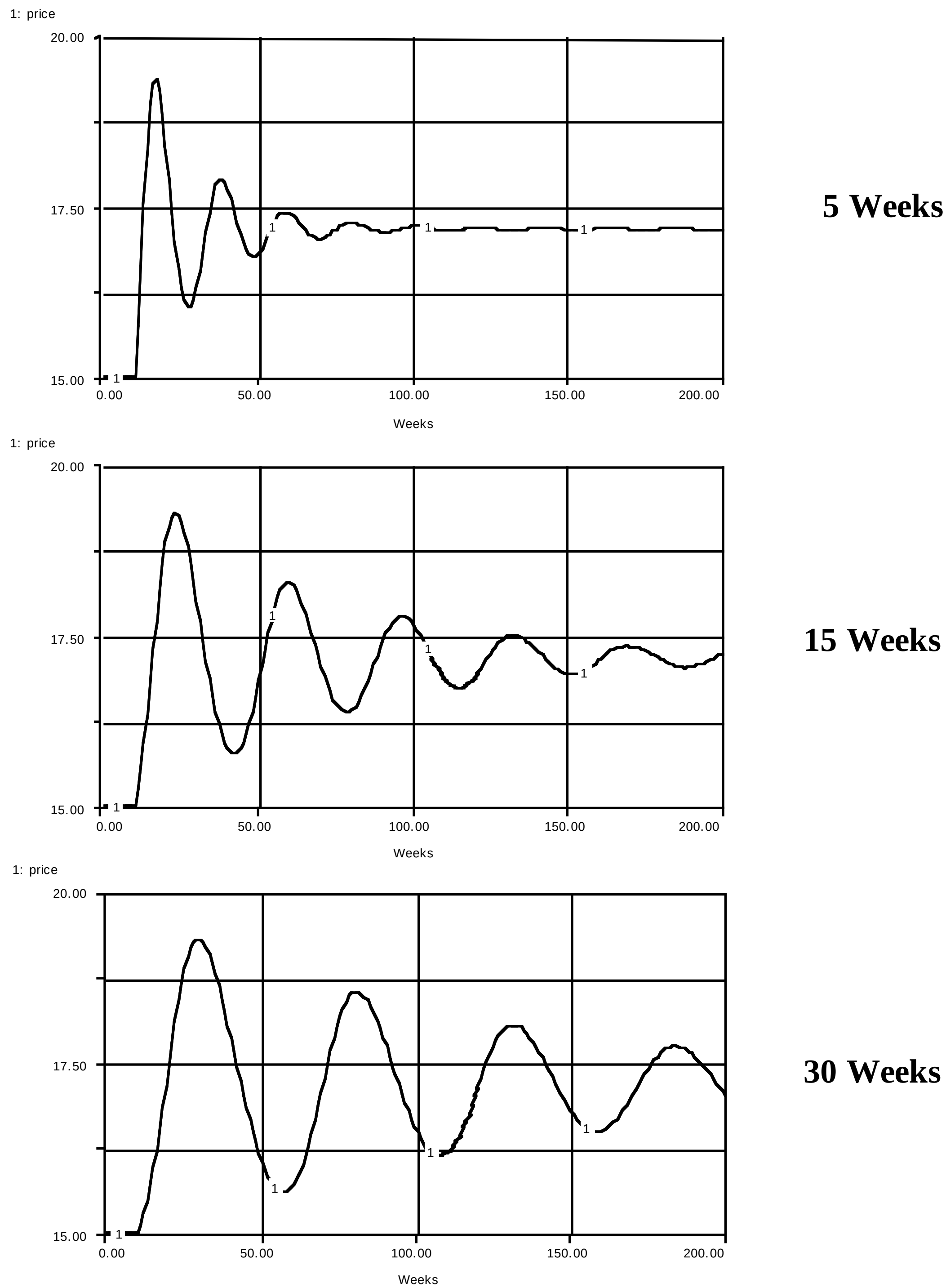


Figure 13: Variations in price change delay

7. APPENDIX

7.1 Model Equations

Demand Sector

demand = demand_price_schedule+step(10,10)
DOCUMENT: This is the rate at which consumers wish to purchase clothing from the company. The step function is used to jar the system out of equilibrium.
UNITS: shirts per week

demand_price_schedule = GRAPH(price)
(5.00, 100), (10.0, 73.0), (15.0, 57.0), (20.0, 45.0), (25.0, 35.0), (30.0, 28.0), (35.0, 22.0), (40.0, 18.0), (45.0, 14.0), (50.0, 10.0)
DOCUMENT: This is based on the simple demand curve. At some particular price, the consumers are willing and able to purchase clothing at a certain rate; the lower the price, the higher the demand.
UNITS: shirts per week

Price Sector

price(t) = price(t - dt) + (change_in_price) * dt
INIT price = 15
DOCUMENT: Price is modeled as a stock in order to model the delays inherent in changes in price.
UNITS : dollars per shirt

INFLOWS:

> **change_in_price** = ((desired_price)-price)/price_change_delay
> DOCUMENT: Change in price can be either positive or negative depending on the effect_on_price. If the effect_on_price > 1, then price will increase. If the effect_on_price < 1, then the price decreases. If effect_on_price = 1, price remains same. Price changes slowly, so we divide the change by price_change_delay.
> UNITS: price/week or ($/shirt)/week

desired_price = effect_on_price*price
DOCUMENT: This is the equilibrium price as set by the inventory_ratio. The actual price will reach this value after a delay specified by the price_change_delay.
UNITS: dollars per shirt

price_change_delay = 15
DOCUMENT: Prices do not change instantaneously. This value determines how quickly price can change.
UNITS : weeks

effect_on_price = GRAPH(inventory_ratio)
(0.5, 2.00), (0.6, 1.80), (0.7, 1.55), (0.8, 1.35), (0.9, 1.15), (1, 1.00), (1.10, 0.875), (1.20, 0.75), (1.30, 0.65), (1.40, 0.55), (1.50, 0.5)
DOCUMENT: This graphical function regulates price change. When the inventory > desired_inventory then the inventory_ratio is >1 and price must be reduced. When the inventory ratio is <1, price must be increased.
UNITS: dimensionless

Supply Sector

inventory(t) = inventory(t - dt) + (supply - shipments) * dt
INIT inventory = desired_inventory
DOCUMENT: Inventory is the stock of produced clothing in the company's warehouse.
UNITS: shirts

INFLOWS:

> **supply** = supply_price_schedule
> DOCUMENT: The price supply schedule is based on a classical short-term supply curve. The company uses this algorithm to set a desirable supply rate for a given price. This curve is being used in lieu of more complitated dynamic structure.
> UNITS = shirts per week

OUTFLOWS:

> **shipments** = demand
> DOCUMENT: This is equal to the demand. The shipments deplete the inventory.
> UNITS: shirts per week

desired_inventory = demand*desired_inventory_coverage
DOCUMENT: Desired inventory is how much inventory the suppliers would like to have. It is calculated as how many weeks worth of demand they would like to store in inventory.
UNITS: shirts

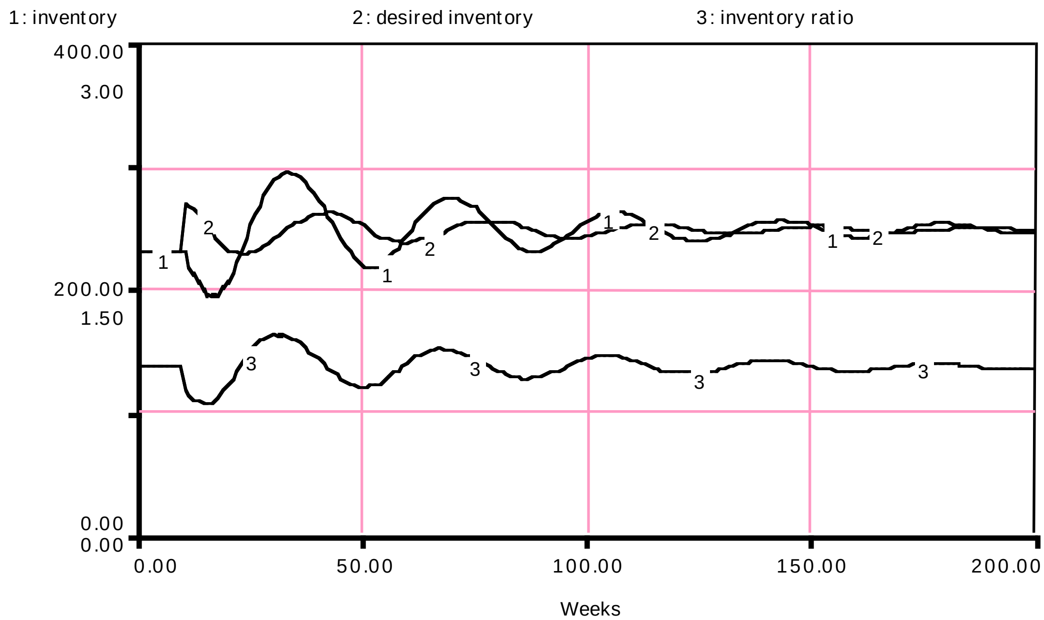
desired_inventory_coverage = 4
DOCUMENT: This value sets how many weeks of demand the suppliers would like to keep in inventory.
UNITS: weeks

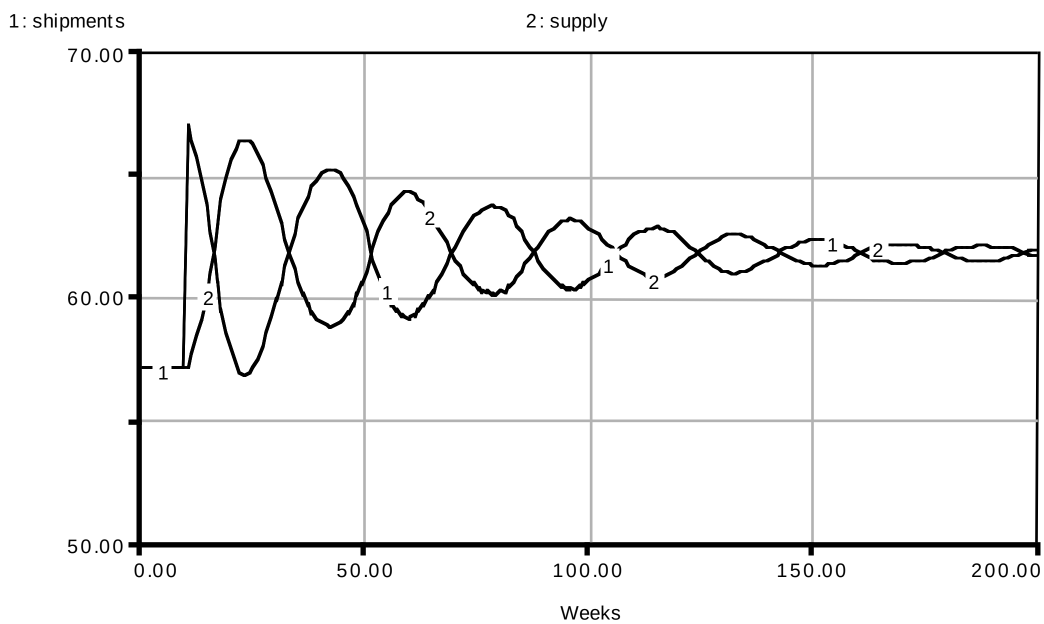
inventory_ratio = inventory/desired_inventory
DOCUMENT: This is the ratio of inventory to desired inventory.
UNITS: dimensionless

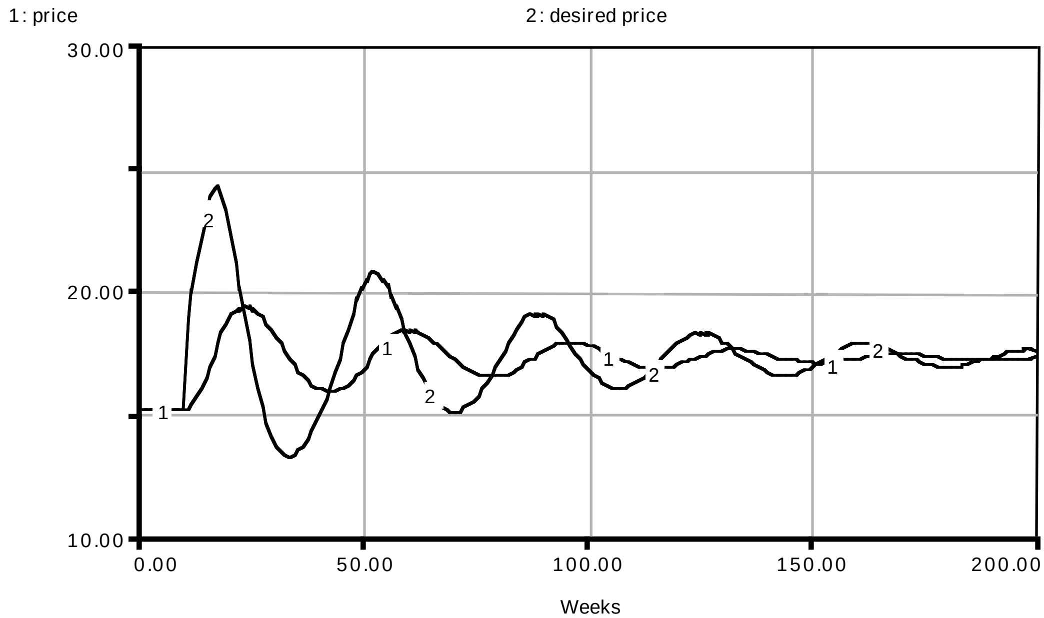
supply_price_schedule = GRAPH(price)
(0.00, 0.00), (5.00, 0.00), (10.0, 40.0), (15.0, 57.0), (20.0, 68.0), (25.0, 77.0), (30.0, 84.0), (35.0, 89.0), (40.0, 94.0), (45.0, 97.0), (50.0, 100)
DOCUMENT: This is a short-term supply curve. At higher prices there is more incentive to produce, more producers can enter the market, etc. This is why this curve points upward as price increases.
UNITS: shirts per week.

7.2 Typical Model Behavior

These graphs represent the behavior of the model set up with the values in the equations listed above. The model is initialized in equilibrium and there is a step increase in demand of 10 units/week after 10 weeks.






1: price
2: desired price
30.00
20.00
10.00
0.00
50.00
100.00
150.00
200.00
Weeks