Chapter 2

Supply and Demand

Talk is cheap because supply exceeds demand.

When asked "What is the most important thing you know about economics?" many people reply, "Supply equals demand." This statement is a shorthand description of one of the simplest yet most powerful models of economics. The supply-and-demand model describes how consumers and suppliers interact to determine the *quantity* of a good or service sold in a market and the *price* at which it is sold. To use the model, you need to determine three things: buyers' behavior, sellers' behavior, and how buyers' and sellers' actions affect price and quantity. After reading this chapter, you should be able to use the supply-and-demand model to analyze some of the most important policy questions facing your country today, such as those concerning international trade, minimum wages, and price controls on health care.

After reading that grandiose claim, you might ask, "Is that all there is to economics? Can I become an expert economist that fast?" The answer to both questions, of course, is no. In addition, you need to learn the limits of this model and which other models to use when this one does not apply. (You must also learn the economists' secret handshake.)

Even with its limitations, the supply-and-demand model is the most widely used economic model. It provides a good description of how markets function, and it works particularly well in markets that have many buyers and many sellers, such as most agriculture and labor markets. Like all good theories, the supply-and-demand model can be tested—and possibly shown to be false. But in markets where it is applicable, it allows us to make accurate predictions easily.

In this chapter, we examine eight main topics:

1. **Demand:** The quantity of a good or service that consumers demand depends on price and other factors such as consumers' incomes and the price of related goods.
2. **Supply:** The quantity of a good or service that firms supply depends on price and other factors such as the cost of inputs that firms use to produce the good or service.
3. **Market Equilibrium:** The interaction between consumers' demand curve and firms' supply curve determines the market price and quantity of a good or service that is bought and sold.
4. **Shocking the Equilibrium: Comparative Statics:** Changes in a factor that affect demand (such as consumers' incomes), supply (such as a rise in the price of inputs), or a new government policy (such as a new tax) alter the market price and quantity of a good.
5. **Elasticities:** Given estimates of summary statistics called elasticities, economists can forecast the effects of changes in taxes and other factors on market price and quantity.

6. **Effects of a Sales Tax:** How a sales tax increase affects the equilibrium price and the quantity of a good and whether the tax falls more heavily on consumers or on suppliers depend on the supply and demand curves.
7. **Quantity Supplied Need Not Equal Quantity Demanded:** If the government regulates the prices in a market, the quantity supplied might not equal the quantity demanded.
8. **When to Use the Supply-and-Demand Model:** The supply-and-demand model applies only to competitive markets.

2.1 Demand

The amount of a good that consumers are *willing* to buy at a given price during a specified time period (such as a day or a year), holding constant the other factors that influence purchases, is the **quantity demanded.** The quantity demanded of a good or service can exceed the quantity *actually* sold. For example, as a promotion, a local store might sell DVDs for $1 each today only. At that low price, you might want to buy 25 DVDs, but because the store has run out of stock, you can buy only 10 DVDs. The quantity you demand is 25—it's the amount you *want*—even though the amount you *actually buy* is only 10.

Potential consumers decide how much of a good or service to buy on the basis of its price, which is expressed as an amount of money per unit of the good (for example, dollars per pound), and many other factors, including consumers' own tastes, information, and income; prices of other goods; and government actions. Before concentrating on the role of price in determining demand, let's look briefly at some of the other factors.

Consumers make purchases based on their *tastes*. Consumers do not purchase foods they dislike, works of art they hate, or clothes they view as unfashionable or uncomfortable. However, advertising may influence people's tastes.

Similarly, *information* (or misinformation) about the uses of a good affects consumers' decisions. A few years ago when many consumers were convinced that oatmeal could lower their cholesterol level, they rushed to grocery stores and bought large quantities of oatmeal. (They even ate some of it until they remembered that they couldn't stand how it tastes.)

The *prices of other goods* also affect consumers' purchase decisions. Before deciding to buy Levi's jeans, you might check the prices of other brands. If the price of a close *substitute*—a product that you view as similar or identical to the one you are considering purchasing—is much lower than the price of Levi's jeans, you may buy that other brand instead. Similarly, the price of a *complement*—a good that you like to consume at the same time as the product you are considering buying—may affect your decision. If you eat pie only with ice cream, the higher the price of ice cream, the less likely you are to buy pie.

Income plays a major role in determining what and how much to purchase. People who suddenly inherit great wealth may purchase a Mercedes or other luxury items and would probably no longer buy do-it-yourself repair kits.

Government rules and regulations affect purchase decisions. Sales taxes increase the price that a consumer must spend on a good, and government-imposed limits on the use of a good may affect demand. If a city's government bans the use of skateboards on its streets, skateboard sales fall.

Other factors may also affect the demand for specific goods. Some people are more likely to buy two-hundred-dollar pairs of shoes if their friends do too. The demand for small, dying evergreen trees is substantially higher in December than in other months.

Although many factors influence demand, economists usually concentrate on how price affects the quantity demanded. The relationship between price and the quantity demanded plays a critical role in determining the market price and quantity in a supply-and-demand analysis. To determine how a change in price affects the quantity demanded, economists must hold constant other factors, such as income and tastes, that affect demand.

THE DEMAND FUNCTION

The **demand function** shows the correspondence between the quantity demanded, price, and other factors that influence purchases. For example, the demand function might be

$$Q = D(p, p_s, p_c, Y), \tag{2.1}$$

where Q is the quantity demanded of a particular good in a given time period, p is its price per unit of the good, p_s is the price per unit of a substitute good (a good that might be consumed instead of this good), p_c is the price per unit of a complementary good (a good that might be consumed jointly with this good, such as cream with coffee), and Y is consumers' income.

An example is the estimated demand function for processed pork in Canada:[1]

$$Q = 171 - 20p + 20p_b + 3p_c + 2Y, \tag{2.2}$$

where Q is the quantity of pork demanded in million kilograms (kg) of dressed cold pork carcass weight per year, p is the price of pork in Canadian dollars per kilogram, p_b is the price of beef (a substitute good) in dollars per kilogram, p_c is the price of chicken (another substitute good) in dollars per kilogram, and Y is the income of consumers in dollars per year. Any other factors that are not explicitly listed in the demand function are assumed to be irrelevant (such as the price of llamas in Peru) or held constant (such as the price of fish).

Usually, we're primarily interested in the relationship between the quantity demanded and the price of the good. That is, we want to know the relationship between the quantity demanded and price, holding all other factors constant. For example, we could set p_b, p_c, and Y at their averages over the period studied: $p_b = \$4$ per kg, $p_c = \$3\frac{1}{3}$ per kg, and $Y = 12.5$ thousand dollars. If we substitute these values

[1]Because prices, quantities, and other factors change simultaneously over time, economists use statistical techniques to hold constant the effects of factors other than the price of the good so that they can determine how price affects the quantity demanded. (See Appendix 2 at the end of the chapter.) Moschini and Meilke (1992) used such techniques to estimate the pork demand curve. In Equation 2.2, I've rounded the number slightly for simplicity. As with any estimate, their estimates are probably more accurate in the observed range of pork prices ($1 to $6 per kg) than at very high or very low prices.

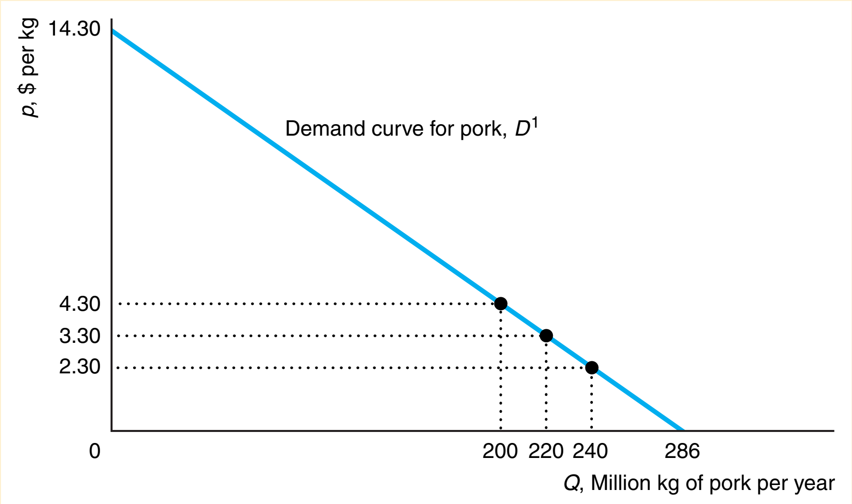

Figure 2.1 A Demand Curve. The estimated demand curve, D^1, for processed pork in Canada (Moschini and Meilke, 1992) shows the relationship between the quantity demanded per year and the price per kg. The downward slope of the demand curve shows that, holding other factors that influence demand constant, consumers demand less of a good when its price is high and more when the price is low. A change in price causes a *movement along the demand curve.*

for p_b, p_c, and Y in Equation 2.2, we can rewrite the quantity demanded as a function of only the price of pork:

$$\begin{aligned} Q &= 171 - 20p + 20p_b + 3p_c + 2Y \\ &= 171 - 20p + (20 \times 4) + \left(3 \times \frac{1}{3}\right) + (2 \times 12.5) \qquad (2.3) \\ &= 286 - 20p = D(p). \end{aligned}$$

We can graphically show this relationship, $Q = D(p) = 286 - 20p$, between the quantity demanded and price. A **demand curve** is a plot of the demand function that shows the quantity demanded at each possible price, holding constant the other factors that influence purchases. Figure 2.1 shows the estimated demand curve, D^1, for processed pork in Canada. (Although this demand curve is a straight line, demand curves may be smooth curves or wavy lines.) By convention, the vertical axis of the graph measures the price, p, per unit of the good: dollars per kilogram (kg). The horizontal axis measures the quantity, Q, of the good, per physical measure of the good per time period: million kg of dressed cold pork carcass weight per year.

The demand curve, D^1, hits the price (vertical) axis at \$14.30, indicating that no quantity is demanded when the price is \$14.30 or higher. Using Equation 2.3, if we set $Q = 286 - 20p = 0$, we find that the demand curve hits the price axis at $p = 286/20 =$ \$14.30. The demand curve hits the horizontal quantity axis at 286 million kg—the amount of pork that consumers want if the price is zero. If we set the price equal to zero in Equation 2.3, we find that the quantity demanded is $Q = 286 - (20 \times 0) = 286$.[2] By plugging the particular values for p in the figure into the demand equation, we can determine the corresponding quantities. For example, if $p = \$3.30$, then $Q = 286 - (20 \times 3.30) = 220$.

Effect of a Change in Price on Demand. The demand curve in Figure 2.1 shows that if the price increases from \$3.30 to \$4.30, the quantity consumers demand decreases by 20 units, from 220 to 200. These changes in the quantity demanded in response to changes in price are *movements along the demand curve*. The demand curve is a concise summary of the answers to the question "What happens to the quantity demanded as the price changes, when all other factors are held constant?"

One of the most important empirical findings in economics is the **Law of Demand:** Consumers demand more of a good the lower its price, holding constant tastes, the prices of other goods, and other factors that influence the amount they consume.[3] One way to state the Law of Demand is that the demand curve slopes downward, as in Figure 2.1.

Because the derivative of the demand function with respect to price shows the *movement along the demand curve as we vary price,* another way to state the Law of Demand is that this derivative is negative: A higher price results in a lower quantity demanded. If the demand function is $Q = D(p)$, then the Law of Demand says that $\mathrm{d}Q/\mathrm{d}p < 0$, where $\mathrm{d}Q/\mathrm{d}p$ is the derivative of the D function with respect to p. (Unless we state otherwise, we assume that all demand (and other) functions are continuous and differentiable everywhere.) The derivative of the quantity of pork demanded with respect to its price in Equation 2.3 is

$$\frac{\mathrm{d}Q}{\mathrm{d}p} = -20,$$

which is negative, so the Law of Demand holds.[4] Given $\mathrm{d}Q/\mathrm{d}p = -20$, a small change in price (measured in dollars per kg) causes a 20-times-larger fall in quantity (measured in million kg per year).

This derivative gives the change in the quantity demanded for an infinitesimal change in price. In general, if we look at a discrete, relatively large increase in price, the change in quantity may not be proportional to the change for a small increase in price. However, here the derivative is a constant that does not vary with price, so the same derivative holds for large as well as for small changes in price.

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[2]Economists typically do not state the relevant physical and time period measures unless these measures are particularly useful in context. I'll generally follow this convention and refer to the price as, say, \$3.30 (with the "per kg" understood) and the quantity as 220 (with the "million kg per year" understood).

[3]In Chapter 4, we show that the Law of Demand need not hold theoretically; however, available empirical evidence strongly supports the Law of Demand.

[4]We can show the same result using the more general demand function in Equation 2.2, where the demand function has several arguments: price, prices of two substitutes, and income. With several arguments, we need to use a partial derivative with respect to price because we are interested in determining how the quantity demanded changes as the price changes, holding other relevant factors constant. The partial derivative with respect to price is $\partial Q/\partial p = -20 < 0$. Thus using either approach, we find that the quantity demanded falls by 20 times as much as the price rises.

For example, let the price increase from $p_1 = \$3.30$ to $p_2 = \$4.30$. That is, the change in the price $\Delta p = p_2 - p_1 = \$4.30 - \$3.30 = \$1$. (The Δ symbol, the Greek letter capital delta, means "change in" the following variable, so Δp means "change in price.") As Figure 2.1 shows, the corresponding quantities are $Q_1 = 220$ and $Q_2 = 200$. Thus if $\Delta p = \$1$, the change in the quantity demanded is $\Delta Q = Q_2 - Q_1 = 200 - 220 = -20$, or 20 times the change in price.

Because we put price on the vertical axis and quantity on the horizontal axis, the slope of the demand curve is the reciprocal of the derivative of the demand function: slope $= \mathrm{d}p/\mathrm{d}Q = 1/(\mathrm{d}Q/\mathrm{d}p)$. In our example, the slope of demand curve D^1 in Figure 2.1 is $\mathrm{d}p/\mathrm{d}Q = 1/(\mathrm{d}Q/\mathrm{d}p) = 1/(-20) = -0.05$. We can also calculate the slope in Figure 2.1 using the rise-over-run formula and the numbers we just calculated (because the slope is the same for small and for large changes):

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta p}{\Delta Q} = \frac{\$1 \text{ per kg}}{-20 \text{ million kg per year}} = -\$0.05 \text{ per million kg per year}.$$

This slope tells us that to sell one more unit (million kg per year) of pork, the price (per kg) must fall by 5¢.

Effects of Changes in Other Factors on Demand Curves. If a demand curve measures the effects of price changes when all other factors that affect demand are held constant, how can we use demand curves to show the effects of a change in one of these other factors, such as the price of beef? One solution is to draw the demand curve in a three-dimensional diagram with the price of pork on one axis, the price of beef on a second axis, and the quantity of pork on the third axis. But just thinking about drawing such a diagram probably makes your head hurt.

Economists use a simpler approach to show the effect on demand of a change in a factor other than the price of the good that affects demand. A change in any factor other than the price of the good itself causes a *shift of the demand curve* rather than a *movement along the demand curve*.

If the price of beef rises while the price of pork remains constant, some people will switch from beef to pork. Suppose that the price of beef rises by 60¢ from \$4.00 per kg to \$4.60 per kg but that the price of chicken and income remain at their average levels. Using the demand function 2.2, we can calculate the new demand function relating the quantity demanded to only the price:[5]

$$Q = 298 - 20p. \tag{2.4}$$

The higher price of beef causes the entire pork demand curve to shift 12 units to the right from D^1, corresponding to demand function 2.3, to D^2, demand function 2.4, in Figure 2.2. (In the figure, the quantity axis starts at 176 instead of 0 to emphasize the relevant portion of the demand curve.)

Why does the demand function shift by 12 units? Using the demand function 2.2, we find that the partial derivative of the quantity of pork demanded with respect to the

[5]Substituting $p_b = \$4.60$ into Equation 2.2 and using the same values as before for p_c and Y, we find that

$$Q = 171 - 20p + 20p_b + 3p_c + 2Y = 171 - 20p + (20 \times 4.60) + \left(3 \times 3\tfrac{1}{3}\right) + (2 \times 12.5) = 298 - 20p.$$

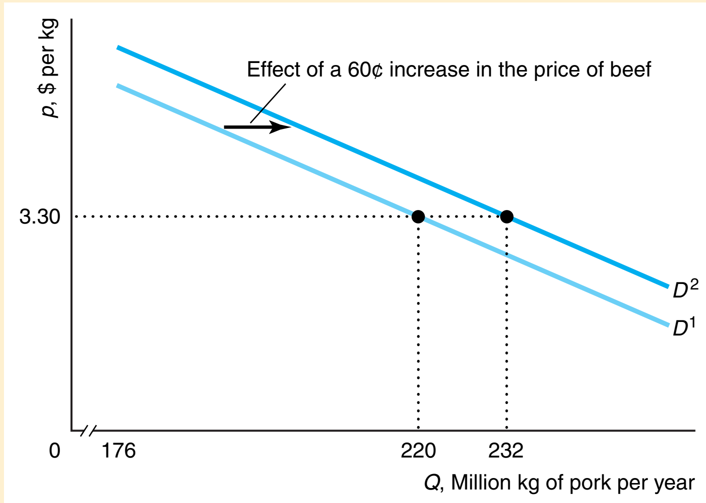


Figure 2.2 A Shift of the Demand Curve. The demand curve for processed pork shifts to the right from D^1 to D^2 as the price of beef rises from \$4 to \$4.60. As a result of the increase in beef prices, more pork is demanded at any given price.

price of beef is $\partial Q/\partial p_b = 20$. Thus if the price of beef increases by 60¢, the quantity of pork demanded rises by $20 \times 0.6 = 12$ units, holding all other factors constant.

To analyze the effects of a change in some variable on the quantity demanded properly, we must distinguish between a *movement along a demand curve* and a *shift of a demand curve*. A change in the *price of a good* causes a *movement along its demand curve*. A change in *any other factor besides the price of the good* causes a *shift of the demand curve*.

APPLICATION

Sideways Wine

In the Academy Award–winning movie *Sideways,* the lead character, a wine snob, wildly praises pinot noir wine, saying that its flavors are "haunting and brilliant and thrilling and subtle." Bizarrely, the exuberant views of this fictional character apparently caused wine buyers to flock to pinot noir wines, dramatically shifting the U.S. and British demand curves for pinot noir to the right (similar to the shift shown in Figure 2.2).

Between October 2004, when *Sideways* was released in the United States, and January 2005, U.S. sales of pinot noir jumped 16% to record levels (and 34% in California, where the film takes place), while the price remained relatively constant. In contrast, sales of all U.S. table wines rose only 2% in this period. British consumers seemed similarly affected. In the five weeks after the film opened in the United Kingdom, pinot sales increased 20% at Sainsbury's and 10% at Tesco and Oddbins, which ran a *Sideways* promotion.[6]

[6]Sources for the applications appear at the back of the book.

SUMMING DEMAND FUNCTIONS

If we know the demand curve for each of two consumers, how do we determine the total demand for the two consumers combined? The total quantity demanded *at a given price* is the sum of the quantity each consumer demands at that price.

We can use the demand functions to determine the total demand of several consumers. Suppose the demand function for Consumer 1 is

$$Q_1 = D^1(p),$$

and the demand function for Consumer 2 is

$$Q_2 = D^2(p).$$

At price is p, Consumer 1 demands Q_1 units, Consumer 2 demands Q_2 units, and the total demand of both consumers is the sum of the quantities each demands separately:

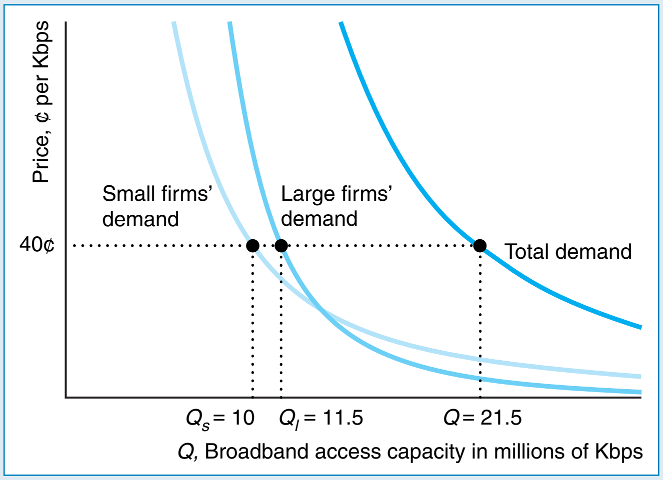
$$Q = Q_1 + Q_2 = D^1(p) + D^2(p).$$

We can generalize this approach to look at the total demand for three or more consumers.

APPLICATION

Aggregating the Demand for Broadband Service

We illustrate how to combine individual demand curves to get a total demand curve graphically using estimated demand curves of broadband (high-speed) Internet service (Duffy-Deno, 2003). The figure shows the demand curve for small firms (1–19 employees), the demand curve for larger firms, and the total demand curve for all firms, which is the horizontal sum of the other two demand curves.



At the current average rate of 40¢ per kilobyte per second (Kbps), the quantity demanded by small firms is $Q_s = 10$ (in millions of Kbps) and the quantity demanded by larger firms is $Q_l = 11.5$. Thus the total quantity demanded at that price is $Q = Q_s + Q_l = 10 + 11.5 = 21.5$.

2.2 Supply

Knowing how much consumers want is not enough, by itself, to tell us the market price and quantity. To determine the market price and quantity, we also need to know how much firms want to supply at any given price.

The **quantity supplied** is the amount of a good that firms *want* to sell during a given time period at a given price, holding constant other factors that influence firms' supply decisions, such as costs and government actions. Firms determine how much of a good to supply on the basis of the price of that good and other factors, including the costs of production and government rules and regulations. Usually, we expect firms to supply more at a higher price. Before concentrating on the role of price in determining supply, we'll briefly consider the role of some of the other factors.

Costs of production affect how much of a good firms want to sell. As a firm's cost falls, it is willing to supply more of the good, all else the same. If the firm's cost exceeds what it can earn from selling the good, the firm sells nothing. Thus factors that affect costs also affect supply. A technological advance that allows a firm to produce a good at a lower cost leads the firm to supply more of that good, all else the same.

Government rules and regulations affect how much firms want to sell or are allowed to sell. Taxes and many government regulations—such as those covering pollution, sanitation, and health insurance—alter the costs of production. Other regulations affect when and how the product can be sold. For instance, the sale of cigarettes and liquor to children is prohibited. Also, most major cities around the world restrict the number of taxicabs.

THE SUPPLY FUNCTION

The **supply function** shows the correspondence between the quantity supplied, price, and other factors that influence the number of units offered for sale. Written generally, the processed pork supply function is

$$Q = S(p, p_h), \tag{2.5}$$

where Q is the quantity of processed pork supplied per year, p is the price of processed pork per kg, and p_h is the price of a hog. The supply function, Equation 2.5, also may be a function of other factors such as wages, but by leaving them out, we are implicitly holding them constant. Based on Moschini and Meilke (1992), the linear pork supply function in Canada is

$$Q = 178 + 40p - 60p_h, \tag{2.6}$$

where quantity is in millions of kg per year and the prices are in Canadian dollars per kg.

If we hold the price of hogs fixed at its typical value of \$1.50 per kg, we can rewrite the supply function in Equation 2.6 as[7]

$$Q = 88 + 40p. \tag{2.7}$$

[7] If p_h = \$1.50, then Equation 2.6 is

$$Q = 178 + 40p - 60p_h = 178 + 40p - (60 \times 1.50) = 88 + 40p.$$

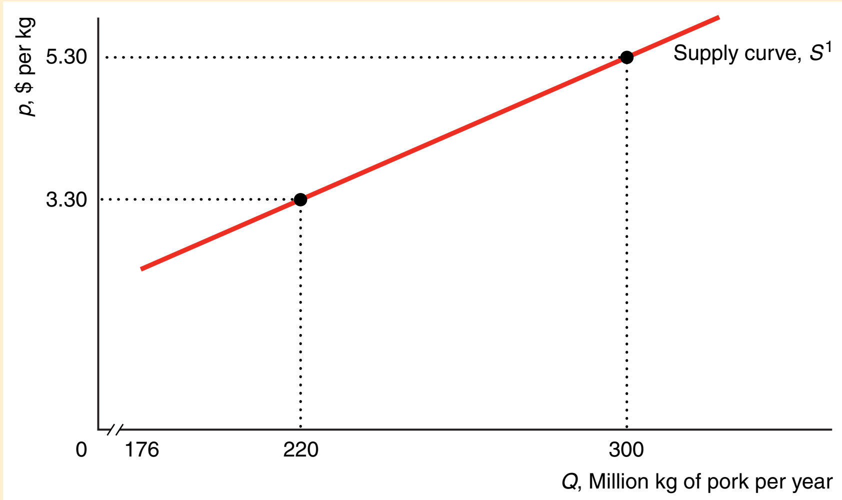


Figure 2.3 A Supply Curve. The estimated supply curve, S^1, for processed pork in Canada (Moschini and Meilke, 1992) shows the relationship between the quantity supplied per year and the price per kg, holding cost and other factors that influence supply constant. The upward slope of this supply curve indicates that firms supply more of this good when its price is high and less when the price is low. An increase in the price of pork causes a *movement along the supply curve*, resulting in a larger quantity of pork supplied.

Corresponding to this supply function is a **supply curve,** which shows the quantity supplied at each possible price, holding constant the other factors that influence firms' supply decisions. Figure 2.3 shows the estimated supply curve, S^1, for processed pork.

Because we hold fixed other variables that may affect the quantity supplied, such as costs and government rules, the supply curve concisely answers the question "What happens to the quantity supplied as the price changes, holding all other factors constant?" As the price of processed pork increases from $3.30 to $5.30, holding other factors (the price of hogs) constant, the quantity of pork supplied increases from 220 to 300 million kg per year, which is a *movement along the supply curve*.

How much does an increase in the price affect the quantity supplied? By differentiating the supply function 2.7 with respect to price, we find that $dQ/dp = 40$. This derivative holds for all values of price, so it holds for both small and large changes in price. That is, the quantity supplied increases by 40 units for each $1 increase in price.

Because this derivative is positive, the supply curve S^1 slopes upward in Figure 2.3. Although the Law of Demand requires that the demand curve slope downward, there is *no* "Law of Supply" that requires the market supply curve to have a particular slope. The market supply curve can be upward sloping, or vertical, horizontal, or downward sloping.

A change in a factor other than price causes a *shift of the supply curve*. If the price of hogs increases by 25¢, the supply function becomes

$$Q = 73 + 40p. \tag{2.8}$$

By comparing this supply function to the original one in Equation 2.7, $Q = 88 + 40p$, we see that the supply curve, S^1, shifts 15 units to the left, to S^2 in Figure 2.4.

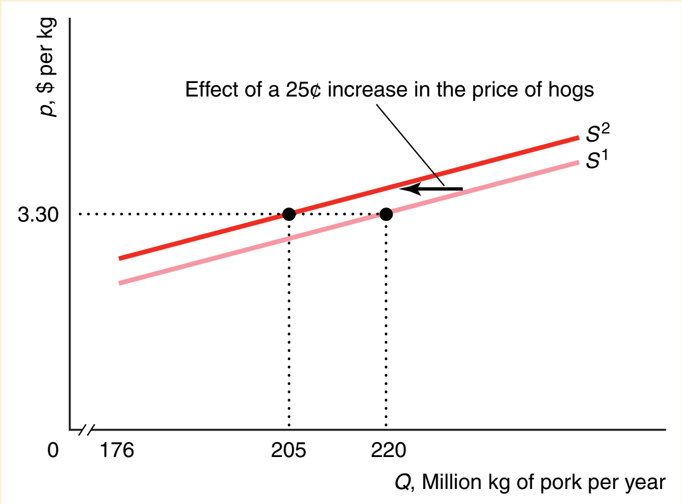


Figure 2.4 A Shift of a Supply Curve. An increase in the price of hogs from \$1.50 to \$1.75 per kg causes a *shift of the supply curve* from S^1 to S^2. At the price of processed pork of \$3.30, the quantity supplied falls from 220 on S^1 to 205 on S^2.

Alternatively, we can determine how far the supply curve shifts by partially differentiating the supply function 2.6 with respect to the price of hogs: $\partial Q/\partial p_h = -60$. This partial derivative holds for all values of p_h and hence for both small and large changes in p_h. Thus a 25¢ increase in the price of hogs causes a $-60 \times 0.25 = -15$ units change in the quantity supplied of pork at any given constant price of pork.

Again, it is important to distinguish between a *movement along a supply curve* and a *shift of the supply curve*. When the price of pork changes, the change in the quantity supplied reflects a *movement along the supply curve*. When costs, government rules, or other variables that affect supply change, the entire *supply curve shifts*.

SUMMING SUPPLY FUNCTIONS

The total supply curve shows the total quantity produced by all suppliers at each possible price. For example, the total supply of rice in Japan is the sum of the domestic and the foreign supply curves of rice.

Suppose that the domestic supply curve (panel a) and foreign supply curve (panel b) of rice in Japan are as Figure 2.5 shows. The total supply curve, S in panel c, is the horizontal sum of the Japanese *domestic* supply curve, S^d, and the *foreign* supply curve, S^f. In the figure, the Japanese and foreign supplies are zero at any price equal to or less than $\underline{p}$, so the total supply is zero. At prices above $\underline{p}$, the Japanese and foreign supplies are positive, so the total supply is positive. For example, when the price is p^*, the quantity supplied by Japanese firms is Q_d^* (panel a), the quantity supplied by foreign firms is Q_f^* (panel b), and the total quantity supplied is $Q^* = Q_d^* + Q_f^*$ (panel c). Because the total supply curve is the horizontal sum of the domestic and foreign supply curves, the total supply curve is flatter than either of the other two supply curves.

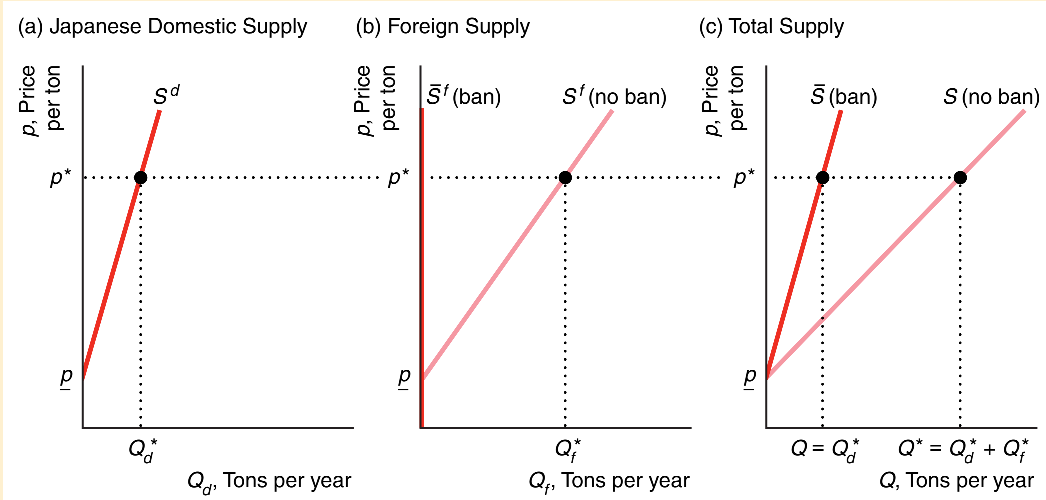


Figure 2.5 Total Supply: The Sum of Domestic and Foreign Supply. If foreigners may sell their rice in Japan, the total Japanese supply of rice, S, is the horizontal sum of the domestic Japanese supply, S^d, and the imported foreign supply, S^f. With a ban on foreign imports, the foreign supply curve, $\bar{S}^f$, is zero at every price, so the total supply curve, $\bar{S}$, is the same as the domestic supply curve, S^d.

EFFECTS OF GOVERNMENT IMPORT POLICIES ON SUPPLY CURVES

We can use this approach for deriving the total supply curve to analyze the effect of government policies on the total supply curve. Traditionally, the Japanese government has banned the importation of foreign rice. We want to determine how much less rice is supplied at any given price to the Japanese market because of this ban.

Without a ban, the foreign supply curve is S^f in panel b of Figure 2.5. A ban on imports eliminates the foreign supply, so the foreign supply curve after the ban is imposed, $\bar{S}^f$, is a vertical line at $Q_f = 0$. The import ban has no effect on the domestic supply curve, S^d, so the supply curve is the same as in panel a.

Because the foreign supply with a ban, $\bar{S}^f$, is zero at every price, the total supply with a ban, $\bar{S}$, in panel c is the same as the Japanese domestic supply, S^d, at any given price. The total supply curve under the ban lies to the left of the total supply curve without a ban, S. Thus the effect of the import ban is to rotate the total supply curve toward the vertical axis.

The limit that a government sets on the quantity of a foreign-produced good that may be imported is called a **quota.** By absolutely banning the importation of rice, the Japanese government sets a quota of zero on rice imports. Sometimes governments set positive quotas, $\bar{Q} > 0$. The foreign firms may supply as much as they want, Q_f, as long as they supply no more than the quota: $Q_f \le \bar{Q}$.

2.3 Market Equilibrium

The supply and demand curves determine the price and quantity at which goods and services are bought and sold. The demand curve shows the quantities that consumers want to buy at various prices, and the supply curve shows the quantities that firms want to sell at various prices. Unless the price is set so that consumers want to buy exactly the same amount that suppliers want to sell, either some buyers cannot buy as much as they want or some sellers cannot sell as much as they want.

When all traders are able to buy or sell as much as they want, we say that the market is in **equilibrium:** a situation in which no participant wants to change its behavior. A price at which consumers can buy as much as they want and sellers can sell as much as they want is called an *equilibrium price*. The quantity that is bought and sold at the equilibrium price is called the *equilibrium quantity*.

FINDING THE MARKET EQUILIBRIUM

This little piggy went to market . . .

To illustrate how supply and demand curves determine the equilibrium price and quantity, we use our old friend, the processed pork example. Figure 2.6 shows the supply, *S*, and the demand, *D*, curves for pork. The supply and demand curves intersect at point *e*, the market equilibrium, where the equilibrium price is \$3.30 and the equilibrium quantity is 220 million kg per year, which is the quantity that firms want to sell and the quantity that consumers want to buy at the equilibrium price.

We can determine the processed pork market equilibrium mathematically using the supply and demand functions, Equations 2.3 and 2.4. We use these two functions to solve for the equilibrium price at which the quantity demanded equals the quantity supplied (the equilibrium quantity).

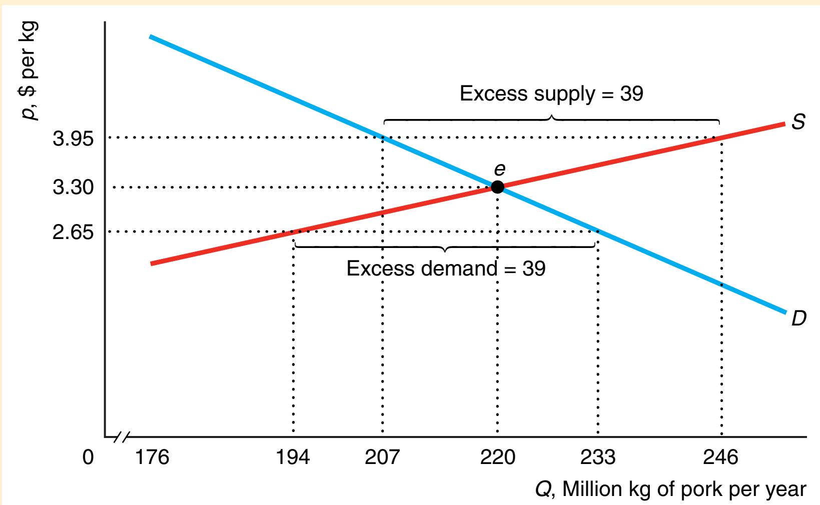


Figure 2.6 Market Equilibrium. The intersection of the supply curve, *S*, and the demand curve, *D*, for processed pork determines the market equilibrium point, *e*, where p = \$3.30 per kg and Q = 220 million kg per year. At the lower price of p = \$2.65, the quantity supplied is only 194, whereas the quantity demanded is 233, so there is excess demand of 39. At p = \$3.95, a price higher than the equilibrium price, there is an excess supply of 39 because the quantity demanded, 207, is less than the quantity supplied, 246. When there is excess demand or supply, market forces drive the price back to the equilibrium price of \$3.30.

The demand function, Equation 2.3, shows the relationship between the quantity demanded, Q_d, and the price:

$$Q_d = 286 - 20p.$$

The supply function, Equation 2.4, describes the relationship between the quantity supplied, Q_s, and the price:

$$Q_s = 88 + 40p.$$

We want to find the price at which $Q_d = Q_s = Q$, the equilibrium quantity. Because the left-hand sides of the two equations are equal in equilibrium, $Q_s = Q_d$, the right-hand sides of the two equations must be equal:

$$286 - 20p = 88 + 40p.$$

Adding $20p$ to both sides of this expression and subtracting 88 from both sides, we find that $198 = 60p$. Dividing both sides of this last expression by 60, we learn that the equilibrium price is $p = \$3.30$. We can determine the equilibrium quantity by substituting this equilibrium price, $p = \$3.30$, into either the supply or the demand equation:

$$\begin{aligned} Q_d &= Q_s \\ 286 - (20 \times 3.30) &= 88 + (40 \times 3.30) \\ 220 &= 220. \end{aligned}$$

Thus the equilibrium quantity is 220.

FORCES THAT DRIVE THE MARKET TO EQUILIBRIUM

A market equilibrium is not just an abstract concept or a theoretical possibility. We observe markets in equilibrium. Indirect evidence that a market is in equilibrium is that you can buy as much as you want of a good at the market price. You can almost always buy as much as you want of milk, ballpoint pens, and most other goods.

Amazingly, a market equilibrium occurs without any explicit coordination between consumers and firms. In a competitive market such as that for agricultural goods, millions of consumers and thousands of firms make their buying and selling decisions independently. Yet each firm can sell as much as it wants; each consumer can buy as much as he or she wants. It is as though an unseen market force, like an *invisible hand*, directs people to coordinate their activities to achieve a market equilibrium.

What really causes the market to move to an equilibrium? If the price is not at the equilibrium level, consumers or firms have an incentive to change their behavior in a way that will drive the price to the equilibrium level.[8]

If the price were initially lower than the equilibrium price, consumers would want to buy more than suppliers would want to sell. If the price of pork is \$2.65 in Figure 2.6, firms will be willing to supply 194 million kg per year, but consumers will demand 233 million kg. At this price, the market is in *disequilibrium*, meaning that the quantity demanded is not equal to the quantity supplied. There is **excess demand**—the amount by which the quantity demanded exceeds the quantity supplied at a specified price—of 39 (= 233 − 194) million kg per year at a price of \$2.65.

[8]Our model of competitive market equilibrium, which occurs at a point in time, does not formally explain how dynamic adjustments occur. The following explanation, though plausible, is just one of a number of possible dynamic adjustment stories that economists have modeled.

Some consumers are lucky enough to be able to buy the pork at $2.65. Other consumers cannot find anyone who is willing to sell them pork at that price. What can they do? Some frustrated consumers may offer to pay suppliers more than $2.65. Alternatively, suppliers, noticing these disappointed consumers, may raise their prices. Such actions by consumers and producers cause the market price to rise. As the price rises, the quantity that firms want to supply increases and the quantity that consumers want to buy decreases. This upward pressure on price continues until it reaches the equilibrium price, $3.30, where there is no excess demand.

If, instead, price is initially above the equilibrium level, suppliers want to sell more than consumers want to buy. For example, at a price of pork of $3.95, suppliers want to sell 246 million kg per year but consumers want to buy only 207 million, as the figure shows. At $3.95, the market is in disequilibrium. There is an **excess supply**—the amount by which the quantity supplied is greater than the quantity demanded at a specified price—of 39 (= 246 − 207) at a price of $3.95. Not all firms can sell as much as they want. Rather than incur storage costs (and possibly have their unsold pork spoil), firms lower the price to attract additional customers. As long as price remains above the equilibrium price, some firms have unsold pork and want to lower the price further. The price falls until it reaches the equilibrium level, $3.30, where there is no excess supply and hence no more pressure to lower the price further.

In summary, at any price other than the equilibrium price, either consumers or suppliers are unable to trade as much as they want. These disappointed people act to change the price, driving the price to the equilibrium level. The equilibrium price is called the *market clearing price* because it removes from the market all frustrated buyers and sellers: There is no excess demand or excess supply at the equilibrium price.

2.4 Shocking the Equilibrium: Comparative Statics

If the variables we hold constant in the demand and supply functions do not change, an equilibrium can persist indefinitely because none of the participants applies pressure to change the price. However, the equilibrium changes if a shock occurs such that one of the variables we were holding constant changes, causing a shift in either the demand curve or the supply curve.

Comparative statics is the method that economists use to analyze how variables controlled by consumers and firms—here, price and quantity—react to a change in *environmental variables* (also called *exogenous variables*), such as prices of substitutes and complements, income, and prices of inputs. The term *comparative statics* literally refers to comparing a *static* equilibrium—an equilibrium at a point in time—from before the change to a static equilibrium after the change. (In contrast, economists may examine a dynamic model, in which the dynamic equilibrium adjusts over time.)

COMPARATIVE STATICS WITH DISCRETE (RELATIVELY LARGE) CHANGES

We can determine the comparative statics properties of an equilibrium by examining the effects of a discrete (relatively large) change in one environmental variable. We can do so by solving for the before- and after-equilibria and comparing them using mathematics or a graph. We illustrate this approach using our beloved pork example. Suppose all the environmental variables remain constant except the price of hogs,

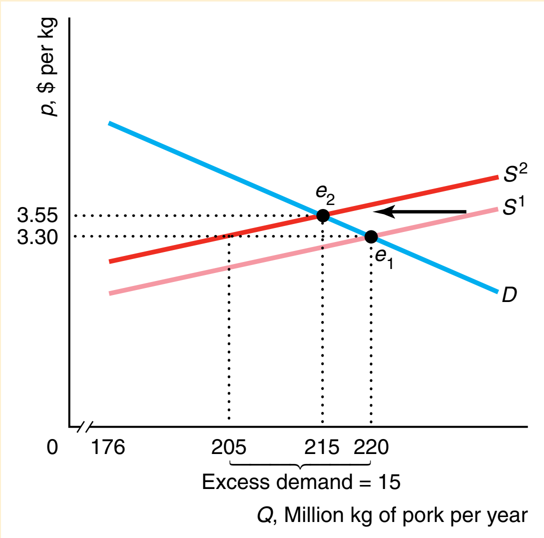


Figure 2.7 The Equilibrium Effect of a Shift of the Supply Curve. A 25¢ increase in the price of hogs causes the supply curve for processed pork to shift to the left from S^1 to S^2, driving the market equilibrium from e_1 to e_2, and the market equilibrium price from \$3.30 to \$3.55.

which increases by 25¢. It is now more expensive to produce pork because the price of a major input, hogs, has increased.

Because the price of hogs is not an argument to the demand function—a change in the price of an input does not affect consumers' desires—the demand curve does not shift. As we have already seen, the increase in the price of hogs causes the supply curve for pork to shift 15 units to the left from S^1 to S^2 in Figure 2.7.

At the original equilibrium price of pork, \$3.30, consumers still want 220 units, but suppliers are now willing to supply only 205, so there is excess demand of 15, as panel a shows. Market pressure forces the price of pork upward until it reaches a new equilibrium at e_2, where the new equilibrium price is \$3.55 and the new equilibrium quantity is 215. Thus the increase in the price of hogs causes the equilibrium price to rise by 25¢ a pound but the equilibrium quantity to fall by 15 units. Here the increase in the price of a factor causes a *shift of the supply curve* and a *movement along the demand curve*.

We can derive the same result by using equations to solve for the equilibrium before the change and after the discrete change in the price of hogs and by comparing the two equations. We have already solved for the original equilibrium, e_1, by setting quantity in the demand function 2.3 equal to the quantity in the supply function 2.7. We obtain the new equilibrium, e_2, by equating the quantity in the demand function 2.3 to that of the new supply function 2.8: $286 - 20p = 73 + 40p$. Simplifying this expression, we find that the new equilibrium price is $p_2 = \$3.55$. Substituting that price into either the demand or the supply function, we learn that the new equilibrium quantity is $Q_2 = 215$, as panel a shows. Thus both methods show that an increase in the price of hogs causes the equilibrium price to rise and the equilibrium quantity to fall.

COMPARATIVE STATICS WITH SMALL CHANGES

Alternatively, we can use calculus to determine the effect of a small change (as opposed to the discrete change we just used) in one environmental variable, holding the other such variables constant. Until now, we have used calculus to examine how an argument of a demand function affects the quantity demanded or how an argument of a supply function affects the quantity supplied. Now, however, we want to know how an environmental variable affects the equilibrium price and quantity that are determined by the intersection of the supply and demand curves.

Our first step is to characterize the equilibrium values as functions of the relevant environmental variables. Suppose that we hold constant all the environmental variables that affect demand so that the demand function is

$$Q = D(p). \tag{2.9}$$

One environmental variable, a, in the supply function changes, causing the supply curve to shift. We write the supply function as

$$Q = S(p, a). \tag{2.10}$$

As before, we determine the equilibrium price by equating the quantities, Q, in Equations 2.9 and 2.10:

$$D(p) = S(p, a). \tag{2.11}$$

The equilibrium equation 2.11 is an example of an *identity.* As a changes, p changes so that this equation continues to hold—the market remains in equilibrium. Thus based on this equation, we can write the equilibrium price as an implicit function of the environmental variable: $p = p(a)$. That is, we can write the equilibrium condition 2.11 as

$$D(p(a)) = S(p(a), a). \tag{2.12}$$

We can characterize how the equilibrium price changes with a by differentiating the equilibrium condition 2.12 with respect to a using the chain rule at the original equilibrium,[9]

$$\frac{\mathrm{d}D(p(a))}{\mathrm{d}p}\frac{\mathrm{d}p}{\mathrm{d}a} = \frac{\partial S(p(a), a)}{\partial p}\frac{\mathrm{d}p}{\mathrm{d}a} + \frac{\partial S(p(a), a)}{\partial a}. \tag{2.13}$$

Using algebra, we can rearrange Equation 2.13 as

$$\frac{\mathrm{d}p}{\mathrm{d}a} = \frac{\dfrac{\partial S}{\partial a}}{\dfrac{\mathrm{d}D}{\mathrm{d}p} - \dfrac{\partial S}{\partial p}}, \tag{2.14}$$

where we suppress the arguments of the functions for notational simplicity. Equation 2.14 shows the derivative of $p(a)$ with respect to a.

[9]The chain rule is a formula for the derivative of the composite of two functions, such as $f(g(x))$. According to this rule, $df/dx = (\mathrm{d}f/\mathrm{d}g)(\mathrm{d}g/\mathrm{d}x)$. See the Calculus Appendix.

We know that $dD/dp < 0$ by the Law of Demand. If the supply curve is upward sloping, then $\partial S/\partial p$ is positive, so the denominator of Equation 2.14, $dD/dp - \partial S/\partial p$, is negative. Thus dp/da has the same sign as the numerator of Equation 2.14. If $\partial S/\partial a$ is negative, then dp/da is positive: As a increases, the equilibrium price rises. If $\partial S/\partial a$ is positive, an increase in a causes the equilibrium price to fall.

By using either the demand function or the supply function, we can use this result concerning the effect of a on the equilibrium price to determine the effect of a on the equilibrium quantity. For example, we can rewrite the demand function 2.9 as

$$Q = D(p(a)). \tag{2.15}$$

Differentiating the demand function 2.15 with respect to a using the chain rule, we find that

$$\frac{dQ}{da} = \frac{dD}{dp}\frac{dp}{da}. \tag{2.16}$$

Because $\partial D/\partial p < 0$ by the Law of Demand, the sign of dQ/da is the opposite of that of dp/da. That is, as a increases, the equilibrium price moves in the opposite direction of the equilibrium quantity. In Solved Problem 2.1, we use the pork example to illustrate this type of analysis.

SOLVED PROBLEM 2.1

How do the equilibrium price and quantity of pork vary as the price of hogs changes if the variables that affect demand are held constant at their typical values? Answer this comparative statics question using calculus. (*Hint:* This problem is of the same form as the more general one we just analyzed. In the pork market, the environmental variable that shifts supply, a, is p_h.)

Answer

1. *Solve for the equilibrium price of pork in terms of the price of hogs*: To obtain an expression for the equilibrium similar to Equation 2.14, we equate the right-hand sides of the demand function 2.3 and the supply function 2.6 to obtain

$$286 - 20p = 178 + 40p - 60p_h,$$

or

$$p = 1.8 + p_h. \tag{2.17}$$

(As a check, when p_h equals its typical value, \$1.50, the equilibrium price of pork is p = \$3.30 according to Equation 2.17, which is consistent with our earlier calculations.)

2. *Use this equilibrium price equation to show how the equilibrium price changes as the price of hogs changes*: Differentiating the equilibrium price expression 2.17 with respect to p_h gives an expression of the form of Equation 2.16:

$$\frac{dp}{dp_h} = 1. \tag{2.18}$$

That is, as the price of hogs increases by 1¢, the equilibrium price of pork increases by 1¢. Because this condition holds for any value of p_h, it also holds for larger changes in the price of hogs. Thus a 25¢ increase in the price of hogs causes a 25¢ increase in the equilibrium price of pork.

3. *Write the pork demand function as in Equation 2.15, and then differentiate it with respect to the price of hogs to show how the equilibrium quantity of pork varies with the price of hogs*: From the pork demand function, Equation 2.3, we can write the quantity demanded as

$$Q = D(p(p_h)) = 286 - 20p(p_h).$$

Differentiating this expression with respect to p_h using the chain rule, we obtain an equation of the form of Equation 2.16 with respect to p_h:

$$\frac{dQ}{dp_h} = \frac{dD}{dp}\frac{dp}{dp_h} = -20 \times 1 = -20. \quad (2.19)$$

That is, as the price of hogs increases by \$1, the equilibrium quantity falls by 20 units.

HOW SHAPES OF DEMAND AND SUPPLY CURVES MATTER

The shapes and positions of the demand and supply curves determine by how much a shock affects the equilibrium price and quantity. We illustrate the importance of the shape of the demand curve by showing how our comparative statics results would change if the processed pork demand curve had a different shape. We continue to use the estimated supply curve of pork and examine what happens if the price of hogs increases by 25¢, causing the supply curve of pork to shift to the left from S^1 to S^2 in panel a of Figure 2.8. In the actual market, the *shift of the supply curve* causes a *movement along the downward-sloping demand curve*, D^1, so the equilibrium quantity falls from 220 to 215 million kg per year, and the equilibrium price rises from \$3.30 to \$3.55 per kg. Thus this supply shock—an increase in the price of hogs—hurts consumers by raising the equilibrium price of pork 25¢ per kg, so customers buy less: 215 instead of 220.

A supply shock would have different effects if the demand curve had a different shape. Suppose that the quantity demanded were not sensitive to a change in the price,

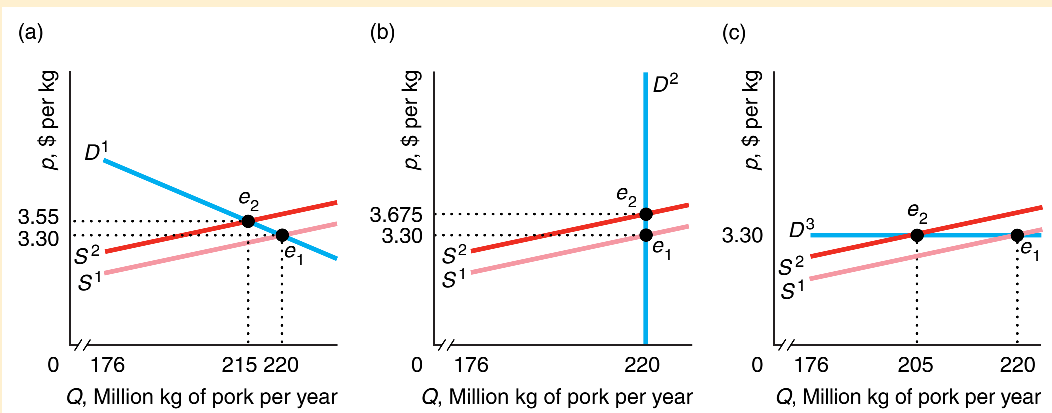


Figure 2.8 The Effect of a Shift of the Supply Curve Depends on the Shape of the Demand Curve. A 25¢ increase in the price of hogs causes the supply curve for processed pork to shift to the left from S^1 to S^2. (a) Given the actual downward-sloping linear demand curve, the equilibrium price rises from \$3.30 to \$3.55 and the equilibrium quantity falls from 220 to 215. (b) If the demand curve were vertical, the supply shock would cause price to rise to \$3.675 while quantity would remain unchanged. (c) If the demand curve were horizontal, the supply shock would not affect price but would cause quantity to fall to 205.

so the same amount is demanded no matter what the price is, as in vertical demand curve D^2 in panel b. A 25¢ increase in the price of hogs again shifts the supply curve from S^1 to S^2. Equilibrium quantity does not change, but the price consumers pay rises by 37.5¢ to \$3.675. Thus the amount consumers spend rises by more when the demand curve is vertical instead of downward sloping.

Now suppose that consumers are very sensitive to price, as in the horizontal demand curve, D^3, in panel c. Consumers will buy virtually unlimited quantities of pork at \$3.30 per kg (or less), but if the price rises even slightly, they will stop buying pork. Here an increase in the price of hogs has *no* effect on the price consumers pay; however, the equilibrium quantity drops substantially to 205 million kg per year. Thus how much the equilibrium quantity falls and how much the equilibrium price of processed pork rises when the price of hogs increases depend on the shape of the demand curve.

2.5 Elasticities

It is convenient to be able to summarize the responsiveness of one variable to a change in another variable using a summary statistic. In our last example, we wanted to know whether an increase in the price causes a large or a small change in the quantity demanded (that is, whether the demand curve is relatively vertical or relatively horizontal at the current price). We can use summary statistics of the responsiveness of the quantity demanded and the quantity supplied to determine comparative statics properties of the equilibrium. Often, we have reasonable estimates of these summary statistics and can use them to predict what will happen to the equilibrium in a market—that is, to make comparative statistics predictions. Later in this chapter, we will examine how the government can use these summary measures for demand and supply to predict, before it institutes the tax, the effect of a new sales tax on the equilibrium price, firms' revenues, and tax receipts.

Suppose that a variable z (for example, the quantity demanded or the quantity supplied) is a function of a variable x (say, the price of z) and possibly other variables such as y: $z = f(x, y)$. For example, f could be the demand function, where z is the quantity demanded, x is the price, and y is income. We want a summary statistic that describes how much z changes as x changes, holding y constant. An **elasticity** is the percentage change in one variable (here, z) in response to a given percentage change in another variable (here, y), holding other relevant variables (here, y) constant. The elasticity, E, of z with respect to x is

$$E = \frac{\text{percentage change in } z}{\text{percentage change in } x} = \frac{\Delta z/z}{\Delta x/x} = \frac{\partial z}{\partial x}\frac{x}{z}, \tag{2.20}$$

where Δz is the change in z, so $\Delta z/z$ is the percentage change in z. If z changes by 3% when x changes by 1%, then the elasticity E is 3. Thus the elasticity is a pure number (it has no units of measure).[10] As Δx goes to zero, $\Delta z/\Delta x$ goes to the partial derivative $\partial z/\partial x$. Economists usually calculate elasticities only at this limit—that is, for infinitesimal changes in x.

[10]Economists use the elasticity rather than the slope, $\partial z/\partial x$, as a summary statistic because the elasticity is a pure number, whereas the slope depends on the units of measurement. For example, if x is a price measured in pennies and we switch to measuring price using dollars, the slope changes, but the elasticity remains unchanged.

DEMAND ELASTICITY

The **price elasticity of demand** (or simply the *demand elasticity* or *elasticity of demand*) is the percentage change in the quantity demanded, Q, in response to a given percentage change in the price, p, at a particular point on the demand curve. The price elasticity of demand (represented by ε, the Greek letter epsilon) is

$$\varepsilon = \frac{\text{percentage change in quantity demanded}}{\text{percentage change in price}} = \frac{\Delta Q/Q}{\Delta p/p} = \frac{\partial Q}{\partial p}\frac{p}{Q}, \tag{2.21}$$

where $\partial Q/\partial p$ is the partial derivative of the demand function with respect to p (that is, holding constant other variables that affect the quantity demanded). For example, if $\varepsilon = -2$, then a 1% increase in the price results in a 2% decrease in the quantity demanded.

We can use Equation 2.12 to calculate the elasticity of demand for a linear demand function (holding fixed other variables that affect demand),

$$Q = a - bp,$$

where a is the quantity demanded when price is zero, $Q = a - (b \times 0) = a$, and $-b$ is the ratio of the fall in quantity to the rise in price: the derivative $\mathrm{d}Q/\mathrm{d}p$. The elasticity of demand is

$$\varepsilon = \frac{\mathrm{d}Q}{\mathrm{d}p}\frac{p}{Q} = -b\frac{p}{Q}. \tag{2.22}$$

For the linear demand function for pork, $Q = a - bp = 286 - 20p$, at the initial equilibrium where $p = \$3.30$ and $Q = 220$, the elasticity of demand is

$$\varepsilon = b\frac{p}{Q} = -20 \times \frac{3.30}{220} = -0.3.$$

The negative sign on the elasticity of demand of pork illustrates the Law of Demand: Less quantity is demanded as the price rises. The elasticity of demand concisely answers the question "How much does quantity demanded fall in response to a 1% increase in price?" A 1% increase in price leads to an ε% change in the quantity demanded. At the equilibrium, a 1% increase in the price of pork leads to a -0.3% fall in the quantity of pork demanded: A price increase causes a less than proportionate fall in the quantity of pork demanded.

APPLICATION

Willingness to Surf

Do you surf the Net for hours and download billions of bits of music? Would you cut back if the price of your Internet service increased? At what price would you give up using the Internet?

Varian (2002) estimated demand curves for connection time by people at a university who paid for access by the minute. He found that the price elasticity of demand was -2.0 for those who used a 128 kilobits per second (Kbps) service and -2.9 for people who connected at 64 Kbps. That is, a 1% increase in the price per minute reduced the connection time used by those with high-speed access by 2% but decreased the connection time by nearly 3% for those with slow phone-line access. Thus high-speed users are less sensitive to connection prices than slow-speed users.

Some recent studies have found that residential users who pay a flat rate (no per-minute charge) for service have a very inelastic demand for dial-up service. That is, few dial-up users will give up their service if the flat fee rises. Residential customers are more sensitive to the flat-fee price of broadband service, with elasticities ranging from −0.75 to −1.5 (Duffy-Deno, 2003). That is, if the price of broadband service increases 10%, between 7.5% and 15% fewer households will use a broadband service.

Elasticities Along the Demand Curve. The elasticity of demand varies along most demand curves. The elasticity of demand is different at every point along a downward-sloping linear demand curve; however, the elasticities are constant along horizontal, vertical, and log-linear demand curves.

On strictly downward-sloping linear demand curves—those that are neither vertical nor horizontal—the elasticity of demand is a more negative number the higher the price. Consequently, even though the slope of the linear demand curve is constant, the elasticity varies along the curve. A 1% increase in price causes a larger percentage fall in quantity near the top (left) of the demand curve than near the bottom (right).

Where a linear demand curve hits the quantity axis ($p = 0$ and $Q = a$), the elasticity of demand is $\varepsilon = -b(0/a) = 0$, according to Equation 2.22. The linear pork demand curve in Figure 2.9 illustrates this pattern. Where the price is zero, a 1% increase in price does not raise the price, so quantity does not change. At a point where the elasticity of demand is zero, the demand curve is said to be *perfectly inelastic.* As a physical analogy, if you try to stretch an inelastic steel rod, the length does not change. The change in the price is the force pulling at demand; if the quantity demanded does not change in response to this pulling, the demand curve is perfectly inelastic.

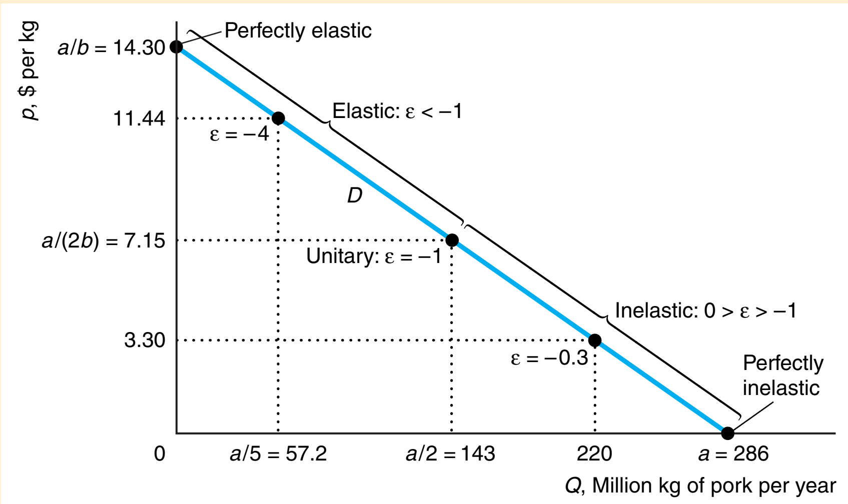


Figure 2.9 Elasticity Along the Linear Pork Demand Curve. With a linear demand curve such as the pork demand curve, the higher the price, the more elastic the demand curve (ε is larger in absolute value—a larger negative number). The demand curve is perfectly inelastic ($\varepsilon = 0$) where the demand curve hits the horizontal axis, is perfectly elastic where the demand curve hits the vertical axis, and has unitary elasticity ($\varepsilon = -1$) at the midpoint of the demand curve.

For quantities between the midpoint of the linear demand curve and the lower end where $Q = a$, the demand elasticity lies between 0 and −1: $0 \varepsilon > -1$. A point along the demand curve where the elasticity is between 0 and −1 is *inelastic* (but not perfectly inelastic): A 1% increase in price leads to a fall in quantity of less than 1%. For example, at the original pork equilibrium, $\varepsilon = -0.3$, so a 1% increase in price causes quantity to fall by −0.3%.

At the midpoint of the linear demand curve, $p = a/(2b)$ and $Q = a/2$, so $\varepsilon = -bp/Q = -b[a/(2b)]/(a/2) = -1$.[11] Such an elasticity of demand is called a *unitary elasticity*.

At prices higher than at the midpoint of the demand curve, the elasticity of demand is less than negative one, $\varepsilon < -1$. In this range, the demand curve is called *elastic*: A 1% increase in price causes a more than 1% fall in quantity. A physical analogy is a rubber band that stretches substantially when you pull on it. In the figure where $Q = a/5$, the elasticity is −4, so a 1% increase in price causes a 4% drop in quantity.

As the price rises, the elasticity gets more and more negative, approaching negative infinity. Where the demand curve hits the price axis, it is *perfectly elastic*.[12] At the price a/b where $Q = 0$, a 1% decrease in p causes the quantity demanded to become positive, which is an infinite increase in quantity.

The elasticity of demand varies along most demand curves, not just downward-sloping linear ones. Along a special type of demand curve, called a *constant-elasticity demand curve*, however, the elasticity is the same at every point along the curve. Constant-elasticity demand curves all have the exponential form

$$Q = Ap^{\varepsilon}, \tag{2.23}$$

where A is a positive constant and ε, a negative constant, is the elasticity at every point along this demand curve. By taking natural logarithms of both sides of Equation 2.23, we can rewrite this exponential demand curve as a log-linear demand curve:

$$\ln Q = \ln A + \varepsilon \ln p. \tag{2.24}$$

For example, in the application "Aggregating the Demand for Broadband Service," the estimated demand function for broadband services by large firms is $Q = 16p^{-0.296}$. Here $A = 16$ and $\varepsilon = -0.296$ is the constant elasticity of demand. That is, their demand is inelastic ($0 > \varepsilon > -1$). We can equivalently write the demand function for broadband services by large firms as $\ln Q = \ln 16 - 0.296 \ln p \approx 2.773 - 0.296 \ln p$.

Figure 2.10 shows several constant-elasticity demand curves with different elasticities. Except for the two extreme cases, these curves are convex to the origin. The two extreme cases of these constant-elasticity demand curves are the strictly vertical and the strictly horizontal demand curves. Along the horizontal demand curve, which is horizontal at p^* in Figure 2.10, the elasticity is infinite everywhere. It is also a special case of a linear demand curve with a zero slope ($b = 0$). Along this demand curve, people are willing to buy as much as firms sell at any price less than or equal to p^*. If the price increases even

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[11]The linear demand curve hits the price axis at $p = a/b$ and the quantity axis at $p = 0$. The midpoint occurs at $p = (a/b - 0)/2 = a/(2b)$. The corresponding quantity is $Q = a - b[a/(2b)] = a/2$.

[12]The linear demand curve hits the price axis at $p = a/b$ and $Q = 0$, so the elasticity is $-bp/0$. As the price approaches a/b, the elasticity approaches negative infinity. An intuition for this convention is provided by looking at a sequence where −1 divided by 1/10 is −10, −1 divided by 1/100 is −100, and so on. The smaller the number we divide by, the more negative the result, which goes to $-\infty$ (negative infinity) in the limit.

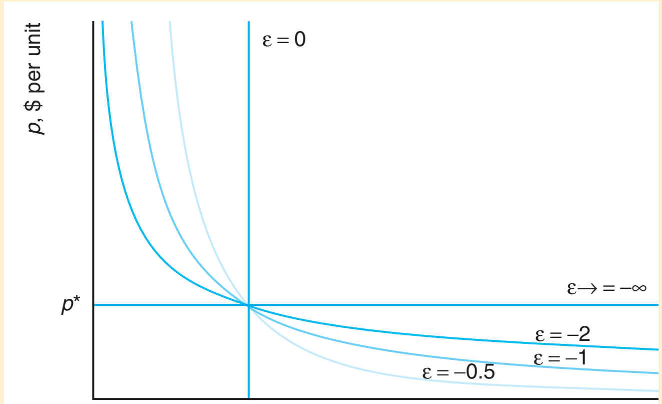

Figure 2.10 Constant Elasticity Demand Curves. These constant elasticity demand curves, $Q = Ap^{\varepsilon}$, vary with respect to their elasticities. Curves with negative, finite elasticities are convex to the origin. The vertical constant elasticity demand is perfectly inelastic, while the horizontal curve is perfectly elastic.

slightly above p^*, however, demand falls to zero. Thus a small increase in price causes an infinite drop in quantity, which means that the demand curve is perfectly elastic.

Why would a demand curve be horizontal? One reason is that consumers view a good as identical to another good and do not care which one they buy. Suppose that consumers view Washington State apples and Oregon apples as identical. They won't buy Washington apples if these apples sell for more than Oregon apples. Similarly, they won't buy Oregon apples if their price is higher than that of Washington apples. If the two prices are equal, consumers do not care which type of apple they buy. Thus the demand curve for Oregon apples is horizontal at the price of Washington apples.

The other extreme case is a vertical demand curve, which is perfectly inelastic everywhere. Such a demand curve is an extreme case of the linear demand curve with an infinite (vertical) slope. If the price goes up, the quantity demanded is unchanged, $dQ/dp = 0$, so the elasticity of demand must be zero: $(dQ/dp)(p/Q) = 0(p/Q) = 0$.

A demand curve is vertical for *essential goods*—goods that people feel they must have and will pay anything to get. Because Sydney is a diabetic, his demand curve for insulin could be vertical at a day's dose, Q^*. More realistically, he may have a maximum price, p^*, that he can pay, whereupon his demand curve becomes perfectly elastic at that price. Thus his demand curve is vertical at Q^* up to p^* and horizontal at p^*.

SOLVED PROBLEM 2.2

Show that the elasticity of demand is a constant ε if the demand function is exponential, $Q = Ap^{\varepsilon}$, or, equivalently, log-linear: $\ln Q = \ln A + \varepsilon \ln p$.

Answer

1. *Differentiate the exponential demand curve with respect to price to determine dQ/dp, and substitute that expression into the definition of the elasticity of demand:* Differentiating the demand curve $Q = Ap^{\varepsilon}$, we find that $dQ/dp = \varepsilon A p^{\varepsilon - 1}$.

Substituting that expression into the elasticity definition, we learn that the elasticity is

$$\frac{dQ}{dp}\frac{p}{Q} = \varepsilon A p^{\varepsilon-1}\frac{p}{Q} = \varepsilon A p^{\varepsilon-1}\frac{p}{Ap^{\varepsilon}} = \varepsilon.$$

Because the elasticity is a constant that does not depend on the particular value of p, it is the same at every point along the demand curve.

2. *Differentiate the log-linear demand curve to determine* dQ/dp, *and substitute that expression into the definition of the elasticity of demand*: Differentiating the log-linear demand curve, $\ln Q = \ln A + \varepsilon \ln p$, with respect to p, we find that $(dQ/dp)/Q = \varepsilon/p$. Multiplying both sides of this equation by p, we again discover that the elasticity is constant:

$$\frac{dQ}{dp}\frac{p}{Q} = \varepsilon\frac{Q}{p}\frac{p}{Q} = \varepsilon.$$

Other Demand Elasticities. We refer to the price elasticity of demand as *the* elasticity of demand. However, there are other demand elasticities that show how the quantity demanded changes in response to changes in variables other than price that affect the quantity demanded. Two such demand elasticities are the income elasticity of demand and the cross-price elasticity of demand.

As income increases, the demand curve shifts. If the demand curve shifts to the right, a larger quantity is demanded at any given price. If instead the demand curve shifts to the left, a smaller quantity is demanded at any given price.

We can measure how sensitive the quantity demanded at a given price is to income by using the **income elasticity of demand** (or *income elasticity*), which is the percentage change in the quantity demanded in response to a given percentage change in income, Y. The income elasticity of demand is

$$\xi = \frac{\text{percentage change in quantity demanded}}{\text{percentage change in income}} = \frac{\Delta Q/Q}{\Delta Y/Y} = \frac{\partial Q}{\partial Y}\frac{Y}{Q},$$

where ξ is the Greek letter xi. If the quantity demanded increases as income rises, the income elasticity of demand is positive. If the quantity demanded does not change as income rises, the income elasticity is zero. Finally, if the quantity demanded falls as income rises, the income elasticity is negative.

By partially differentiating the pork demand function 2.2, $Q = 171 - 20p + 20p_b + 3p_c + 2Y$, with respect to Y, we find that $\partial Q/\partial Y = 2$, so the income elasticity of demand for pork is $\xi = 2Y/Q$. At our original equilibrium, quantity $Q = 220$ and income $Y = 12.5$, so the income elasticity is $2 \times (12.5/220) \approx 0.114$, or about one-ninth. The positive income elasticity shows that an increase in income causes the pork demand curve to shift to the right.

Income elasticities play an important role in our analysis of consumer behavior in Chapter 5. Typically, goods that consumers view as necessities, such as food, have income elasticities near zero. Goods that they consider to be luxuries generally have income elasticities greater than one.

The **cross-price elasticity of demand** is the percentage change in the quantity demanded in response to a given percentage change in the price of another good, p_o. The cross-price elasticity may be calculated as

$$\frac{\text{percentage change in quantity demanded}}{\text{percentage change in price of another good}} = \frac{\Delta Q/Q}{\Delta p_o/p_o} = \frac{\partial Q}{\partial p_o}\frac{p_o}{Q}.$$

When the cross-price elasticity is negative, the goods are complements. If the cross-price elasticity is negative, people buy less of one good when the price of the other, second good increases: The demand curve for the first good shifts to the left. For example, if people like cream in their coffee, as the price of cream rises, they consume less coffee, so the cross-price elasticity of the quantity of coffee with respect to the price of cream is negative.

If the cross-price elasticity is positive, the goods are substitutes.[13] As the price of the second good increases, people buy more of the first good. For example, the quantity demanded of pork increases when the price of beef, p_b, rises. By partially differentiating the pork demand function 2.2, $Q = 171 - 20p + 20p_b + 3p_c + 2Y$, with respect to the price of beef, we find that $\partial Q/\partial p_b = 20$. As a result, the cross-price elasticity between the price of beef and the quantity of pork is $20p_b/Q$. At the original equilibrium where $Q = 220$ million kg per year, and $p_b = \$4$ per kg, the cross-price elasticity is $20 \times (4/220) \approx 0.364$. As the price of beef rises by 1%, the quantity of pork demanded rises by a little more than one-third of 1%.

APPLICATION

Substitution May Save Endangered Species

One reason that many species—including tigers, rhinoceroses, pinnipeds, green turtles, geckos, sea horses, pipefish, and sea cucumbers—are endangered, threatened, or vulnerable to extinction is that certain of their body parts are used as aphrodisiacs in traditional Chinese medicine. Is it possible that consumers will switch from such potions to Viagra, a less expensive and almost certainly more effective alternative treatment, and thereby help save these endangered species?

We cannot directly calculate the cross-price elasticity of demand between Viagra and these endangered species because their trade is illicit and not reported. However, in Asia, harp seal and hooded seal genitalia are also used as aphrodisiacs, and they may be legally traded. Before 1998, Viagra was unavailable (effectively, it had an infinite price). When it became available at about \$15 to \$20 Canadian per pill, the demand curve for seal sex organs shifted substantially to the left. According to von Hippel and von Hippel (2002, 2004), 30,000 to 50,000 seal organs were sold at between \$70 and \$100 Canadian in the years just before 1998. In 1998, the price per unit fell to between \$15 and \$20, and only 20,000 organs were sold. By 1999–2000 (and thereafter), virtually none were sold. This evidence suggests a strong willingness to substitute at current prices: a positive cross-price elasticity between seal organs and the price of Viagra. Thus Viagra can perhaps save more than marriages.

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[13] *Jargon alert*: Graduate-level textbooks generally call these goods *gross substitutes* (and the goods in the previous example would be called *gross complements*).

SUPPLY ELASTICITY

Just as we can use the elasticity of demand to summarize information about the responsiveness of the quantity demanded to price or other variables, we can use the elasticity of supply to summarize information about the responsiveness of the quantity demanded. The **price elasticity of supply** (or *supply elasticity*) is the percentage change in the quantity supplied in response to a given percentage change in the price. The price elasticity of supply (η, the Greek letter eta) is

$$\eta = \frac{\text{percentage change in quantity supplied}}{\text{percentage change in price}} = \frac{\Delta Q/Q}{\Delta p/p} = \frac{\partial Q}{\partial p}\frac{p}{Q}, \tag{2.25}$$

where Q is the *quantity supplied*. If $\eta = 2$, a 1% increase in price leads to a 2% increase in the quantity supplied.

The definition of the elasticity of supply, Equation 2.25, is very similar to the definition of the elasticity of demand, Equation 2.21. The key distinction is that the elasticity of supply describes the movement along the *supply* curve as price changes, whereas the elasticity of demand describes the movement along the *demand* curve as price changes. That is, in the numerator, supply elasticity depends on the percentage change in the *quantity supplied*, whereas demand elasticity depends on the percentage change in the *quantity demanded*.

If the supply curve is upward sloping, $\partial p/\partial Q > 0$, the supply elasticity is positive: $\eta > 0$. If the supply curve slopes downward, the supply elasticity is negative: $\eta < 0$. For the pork supply function 2.7, $Q = 88 + 40p$, the elasticity of supply of pork at the original equilibrium, where $p = \$3.30$ and $Q = 220$, is

$$\eta = \frac{dQ}{dp}\frac{p}{Q} = 40 \times \frac{3.30}{220} = 0.6.$$

As the price of pork increases by 1%, the quantity supplied rises by slightly less than two-thirds of a percent.

The elasticity of supply varies along an upward-sloping supply curve. For example, because the elasticity of supply for the pork is $\eta = 40p/Q$, as the ratio p/Q rises, the supply elasticity rises.

At a point on a supply curve where the elasticity of supply is $\eta = 0$, we say that the supply curve is *perfectly inelastic*: The supply does not change as the price rises. If $0 < \eta < 1$, the supply curve is *inelastic* (but not perfectly inelastic): A 1% increase in price causes a less than 1% rise in the quantity supplied. If $\eta > 1$, the supply curve is *elastic*. If η is infinite, the supply curve is *perfectly elastic*.

The supply elasticity does not vary along constant-elasticity supply functions, which are exponential or (equivalently) log-linear: $Q = Bp^{\eta}$ or $\ln Q = \ln B + \eta \ln p$. If η is a positive, finite number, the constant-elasticity supply curve starts at the origin, as Figure 2.11 shows. Two extreme examples of both constant-elasticity of supply curves and linear supply curves are the vertical supply curve and the horizontal supply curve.

A supply curve that is vertical at a quantity, Q^*, is perfectly inelastic. No matter what the price is, firms supply Q^*. An example of inelastic supply is a perishable item such as already picked fresh fruit. If the perishable good is not sold, it quickly becomes worthless. Thus the seller will accept any market price for the good.

A supply curve that is horizontal at a price, p^*, is perfectly elastic. Firms supply as much as the market wants—a potentially unlimited amount—if the price is p^* or

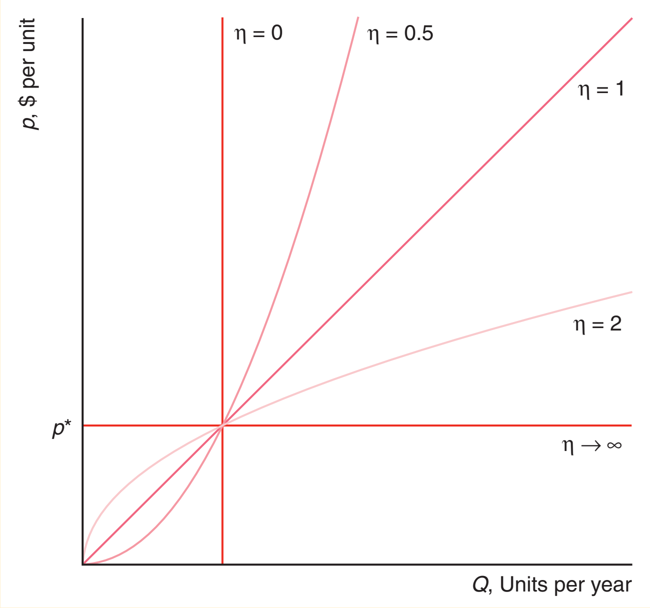


Figure 2.11 Constant Elasticity Supply Curves. Constant elasticity supply curves, $Q = Bp^{\eta}$, with positive, finite elasticities start at the origin. They are concave to the horizontal axis if $1 < \eta < \infty$ and convex if $0 < \eta < 1$. The unitary elasticity supply curve is a straight line through the origin. The vertical constant elasticity supply curve is perfectly inelastic, while the horizontal curve is perfectly elastic.

above. Firms supply nothing at a price below p^*, which does not cover their cost of production.

LONG RUN VERSUS SHORT RUN

Typically, short-run demand or supply elasticities differ substantially from long-run elasticities. The duration of the *short run* depends on the planning horizon—how long it takes consumers or firms to adjust for a particular good.

Demand Elasticities over Time. Two factors that determine whether short-run demand elasticities are larger or smaller than long-run elasticities are ease of substitution and storage opportunities. Often one can substitute between products in the long run but not in the short run.

When oil prices rose rapidly in the 1970s and 1980s because of actions by the Organization of Petroleum Exporting Countries (OPEC), most Western consumers did not greatly alter the amount of oil they demanded. Someone who drove 27 miles to and from work every day in a 1969 Chevy could not easily reduce the amount of gasoline purchased. In the long run, however, this person could buy a smaller car, get a job closer to home, join a car pool, or in other ways reduce the amount of gasoline purchased.

Gallini (1983) estimated long-run demand elasticities that are more elastic than the short-run elasticity for gasoline in Canada. She found that the short-run elasticity is −0.35; the 5-year intermediate-run elasticity is nearly twice as elastic, −0.7; and the 10-year, long-run elasticity is approximately −0.8, which is slightly more elastic. Thus a 1% increase in price lowers the quantity demanded by only about 0.35% in the short run but by more than twice as much, 0.8%, in the long run. Similarly, Grossman and Chaloupka (1998) estimated that a rise in the street price of cocaine has a larger long-run effect than its short-run effect on cocaine consumption by young adults (aged 17–29). The long-run demand elasticity is −1.35, whereas the short-run elasticity is −0.96.

For goods that can be stored easily, short-run demand curves may be more elastic than long-run curves. If frozen orange juice goes on sale this week at your local supermarket, you may buy large quantities and store the extra in your freezer. As a result, you may be more sensitive to price changes for frozen orange juice in the short run than in the long run.

Supply Elasticities over Time. Supply curves too may have different elasticities in the short run than in the long run. If a manufacturing firm wants to increase production in the short run, it can do so by hiring workers to use its machines around the clock, but how much it can expand its output is limited by the fixed size of its manufacturing plant and the number of machines it has. In the long run, however, the firm can build another plant and buy or build more equipment. Thus we would expect this firm's long-run supply elasticity to be greater than its short-run elasticity.

Adelaja (1991) found that the short-run supply elasticity of milk is 0.36, whereas the long-run supply elasticity is 0.51. Thus the long-run quantity response to a 1% increase in price is about 42% [= (0.51 − 0.36)/0.36] more than in the short run.

APPLICATION

Oil Drilling in the Arctic National Wildlife Refuge

We can use information about demand and supply elasticities to answer an important public policy question: Would selling oil from the Arctic National Wildlife Refuge (ANWR) substantially affect the price of oil? Established in 1980, the ANWR covers 20 million acres and is the largest of Alaska's 16 national wildlife refuges. It is believed to contain massive deposits of petroleum. For decades, a debate has raged over whether the ANWR's owners—the citizens of the United States—should keep it undeveloped or permit oil drilling.[14]

In the simplest form of this complex debate, environmentalists stress that drilling would harm the wildlife refuge and pollute the environment, while President George W. Bush and other drilling proponents argue that extracting this oil would substantially reduce the price of petroleum (as well as decrease U.S. dependence on foreign oil and bring in large royalties). Recent spurts in the price of gasoline and the war in Iraq have heightened this intense debate.

The effect of the sale of ANWR oil on the world price of oil is a key element in this debate. We can combine oil production information with supply and demand elasticities to make a "back of the envelope" estimate of the price effects.

[14] I am grateful to Robert Whaples, who wrote an earlier version of this analysis. In the following discussion, we assume for simplicity that the oil market is competitive, and use current values of price and quantities even though drilling in the ANWR would not take place for at least a decade.

A number of studies estimate that the long-run elasticity of demand, ε, for oil is about -0.4 and the long-run supply elasticity, η, is about 0.3. Analysts agree less about how much ANWR oil will be produced. The Department of Energy's Energy Information Service (EIS) predicts that production from the ANWR would average about 800,000 barrels per day (the EIS estimates that the ANWR's oil would increase the volume of production by about 0.7% in 2020). That production would be about 1% of the worldwide oil production, which averaged about 82 million barrels per day in 2004 (and was only slightly higher in 2005 and 2006).

A report of the U.S. Department of Energy predicted that ANWR drilling could lower the price of oil by about 50¢ a barrel or 1%, given that the price of a barrel of oil was slightly above $50 at the beginning of 2007. Severin Borenstein, an economist who is the director of the U.C. Energy Institute, concluded that the ANWR might reduce oil prices by up to a few percentage points but that "drilling in ANWR will never noticeably affect gasoline prices."

In the following solved problem, we can make our own calculations of the price effect of drilling in the ANWR. Here and in many of the solved problems in this book, you are asked to determine how a change in a variable or policy affects one or more variables. In this problem, the policy changes from not allowing to permitting drilling in the ANWR, which affects the world's equilibrium price of oil.

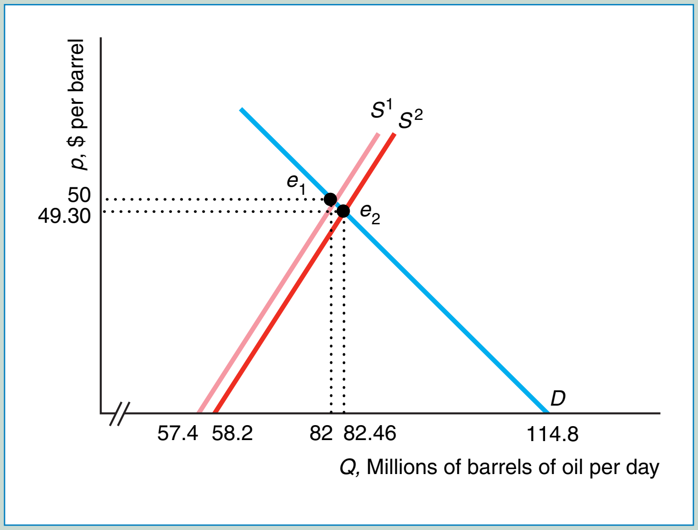
SOLVED PROBLEM 2.3

What would be the effect of ANWR production on the world equilibrium price of oil given that $\varepsilon = -0.4$, $\eta = 0.3$, the pre-ANWR daily world production of oil is $Q_1 = 82$ million barrels per day, the pre-ANWR world price is $p_1 = \$50$ per barrel, and daily ANWR production would be 0.8 million barrels per day? For specificity, assume that the supply and demand curves are linear and that the introduction of ANWR oil would cause a parallel shift in the world supply curve to the right by 0.8 million barrels per day.

Answer

1. *Determine the long-run linear demand function that is consistent with pre-ANWR world output and price*: At the original equilibrium, e_1 in the figure, $p_1 = \$50$ and $Q_1 = 82$. There the elasticity of demand is $\varepsilon = (dQ/dp)(p_1/Q_1) = (dQ/dp)(50/82) = -0.4$. Using algebra, we find that dQ/dp equals $-0.4(82/50) = -0.656$, which is the inverse of the slope of the demand curve, D, in the figure. Knowing this slope and that demand equals 82 at $50 per barrel, we can solve for the intercept, because the quantity demanded rises by 0.656 for each dollar by which the price falls. The demand when the price is zero is $82 + (0.656 \times 50) = 114.8$. Thus the equation for the demand curve is $Q = 114.8 - 0.656p$.

2. *Determine the long-run linear supply function that is consistent with pre-ANWR world output and price*: Where S^1 intercepts D at the original equilibrium, e_1, the elasticity of supply is $\eta = (dQ/dp)(p_1/Q_1) = (dQ/dp)(50/82) = 0.3$. Solving, we find that $dQ/dp = 0.3(82/50) = 0.492$. Because the quantity supplied falls by



0.492 for each dollar by which the price drops, the quantity supplied when the price is zero is $82 - (0.492 \times 50) = 57.4$. Thus the equation for the pre-ANWR supply curve, S^1 in the figure, is $Q = 57.4 + 0.492p$.

3. *Determine the post-ANWR long-run linear supply function*: The oil pumped from the ANWR would cause a parallel shift in the supply curve, moving S^1 to the right by 0.8 to S^2. That is, the slope remains the same, but the intercept on the quantity axis increases by 0.8. Thus the supply function for S^2 is $Q = 58.2 + 0.492p$.

4. *Use the demand curve and the post-ANWR supply function to calculate the new equilibrium price and quantity*: The new equilibrium, e_2, occurs where S^2 intersects D. Setting the right-hand sides of the demand function and the post-ANWR supply function equal, we obtain an expression in the new price, p_2:

$$58.2 + 0.492p_2 = 114.8 - 0.656p_2.$$

We can solve this expression for the new equilibrium price: $p_2 \approx \$49.30$. That is, the price drops about 70¢, or approximately 1.4%. If we substitute this new price into either the demand curve or the post-ANWR supply curve, we find that the new equilibrium quantity is 82.46 million barrels per day. That is, equilibrium output rises by 0.46 million barrels per day (0.56%), which is only a little more than half of the predicted daily ANWR supply, because other suppliers will decrease their output slightly in response to the lower price.

Comment: Our estimate of a small drop in the world oil price if ANWR oil is sold would not change substantially if our estimates of the elasticities of supply and demand were moderately larger or smaller. The main reason for this result is that the ANWR output would be a very small portion of worldwide supply—the new supply curve is only slightly to the right of the initial supply curve. Thus drilling in the ANWR cannot insulate the American market from international events that roil the oil market. A new war in the Persian Gulf could shift the worldwide supply curve to the left by 3 million barrels a day or more (nearly four times the ANWR production). Such a shock would cause the price of oil to soar whether or not we drill in the ANWR.

2.6 Effects of a Sales Tax

How much a tax affects the equilibrium price and quantity and how much of the tax falls on consumers depends on the elasticities of demand and supply. Knowing only the elasticities of demand and supply, we can make accurate predictions about the effects of a new tax and determine how much of the tax falls on consumers.

In this section, we examine three questions about the effects of a sales tax:

1. What effect does a sales tax have on equilibrium prices and quantity?
2. Is it true, as many people claim, that taxes assessed on producers are *passed along* to consumers? That is, do consumers pay for the entire tax, or do producers pay part of it?
3. Do the equilibrium price and quantity depend on whether the tax is assessed on consumers or on producers?

TWO TYPES OF SALES TAXES

Governments use two types of sales taxes. The most common sales tax is called an *ad valorem* tax by economists and *the* sales tax by real people. For every dollar the consumer spends, the government keeps a fraction, α, which is the *ad valorem* tax rate. Japan's national sales tax is $\alpha = 5\%$. If a consumer in Japan buys a Nintendo Wii for \$500, the government collects $\alpha \times \$500 = 5\% \times \$500 = \$25$ in taxes, and the seller receives $(1 - \alpha) \times \$500 = \$475$.[15]

The other type of sales tax is a *specific* or *unit* tax, where a specified dollar amount, τ, is collected per unit of output. The federal government collects $\tau = 18.4¢$ on each gallon of gas sold in the United States.

EQUILIBRIUM EFFECTS OF A SPECIFIC TAX

To answer our three questions, we must extend the standard supply-and-demand analysis to take taxes into account. Let's start by assuming that the specific tax is assessed on firms at the time of sale. If the consumer pays p for a good, the government takes τ and the seller receives $p - \tau$.

Suppose that the government collects a specific tax of $\tau = \$1.05$ per kg of processed pork from pork producers. Because of the tax, suppliers keep only $p - \tau$ of price p that consumers pay. Thus at every possible price paid by consumers, firms are willing to supply less than when they received the full amount consumers paid. Before the tax, firms were willing to supply 206 million kg per year at a price of \$2.95 as the pretax supply curve S^1 in Figure 2.12 shows. After the tax, firms receive only \$1.90 if consumers pay \$2.95, so they are not willing to supply 206. For firms to be willing to supply 206, they must receive \$2.95 after the tax, so consumers must pay \$4. As a result, the after-tax supply curve, S^2, is $\tau = \$1.05$ above the original supply curve S^1 at every quantity, as the figure shows.

[15]For specificity, we assume that the price firms receive is $p = (1 - \alpha)p^*$, where p^* is the price consumers pay and α is the *ad valorem* tax rate on the price consumers pay. However, many governments (including U.S. and Japanese governments) set the *ad valorem* sales tax, β, as an amount added to the price sellers charge, so consumers pay $p^* = (1 + \beta)p$. By setting α and β appropriately, the taxes are equivalent. Here $p = p^*/(1 + \beta)$, so $(1 - \alpha) = 1/(1 + \beta)$. For example, if $\beta = 1/3$, then $\alpha = 1/4$.

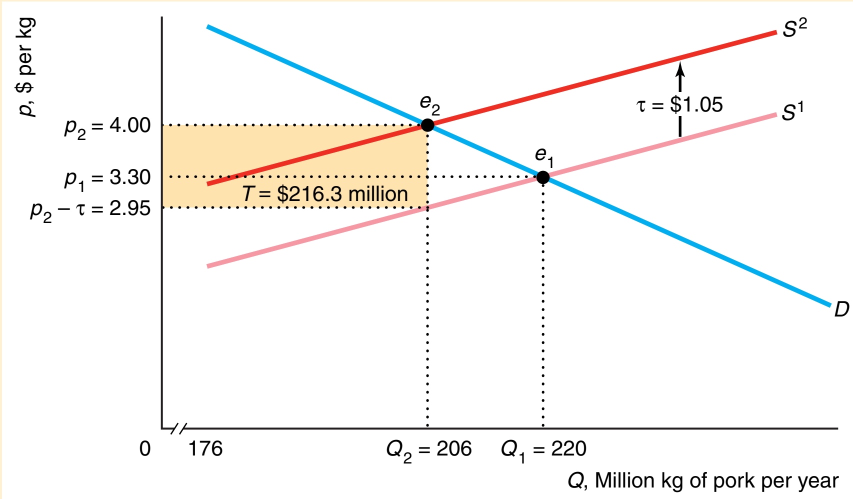


Figure 2.12 Effect of a $1.05 Specific Tax on the Pork Market Collected from Producers. The specific tax of τ = \$1.05 per kg collected from producers shifts the pretax pork supply curve from S^1 to the posttax supply curve, S^2. The tax causes the equilibrium to shift from e_1 (determined by the intersection of S^1 and D) to e_2 (intersection of S^2 with D). The equilibrium price increases from \$3.30 to \$4.00. Two-thirds of the incidence of the tax falls on consumers, who spend 70¢ more per unit. Producers receive 35¢ less per unit after the tax. The government collects tax revenues of $T = \tau Q_2$ = \$216.3 million per year.

We can use this figure to illustrate the answer to our first question concerning the effects of the tax on the pork market equilibrium. *The specific tax causes the equilibrium price consumers pay to rise, the equilibrium quantity to fall, and the tax revenue to rise.*

The intersection of the pretax pork supply curve S^1 and the pork demand curve D in Figure 2.12 determines the pretax equilibrium, e_1. The equilibrium price is p_1 = \$3.30, and the equilibrium quantity is $Q_1 = 220$. The tax shifts the supply curve to S^2, so the after-tax equilibrium is e_2, where consumers pay p_2 = \$4, firms receive p_2 − \$1.05 = \$2.95, and $Q_2 = 206$. Thus the tax causes the price that consumers pay to increase, $\Delta p = p_2 - p_1$ = \$4 − \$3.30 = 70¢, and the quantity to fall, $\Delta Q = Q_2 - Q_1 = 206 - 220 = -14$.

Although consumers and producers are worse off because of the tax, the government acquires new tax revenue of $T = \tau Q$ = \$1.05 per kg × 206 million kg per year = \$216.3 million per year. The length of the shaded rectangle in the figure is $Q_2 = 206$ million kg per year, and its height is τ = \$1.05 per kg, so the area of the rectangle equals the tax revenue. (The figure shows only part of the length of the rectangle because the horizontal axis starts at 176.)

HOW SPECIFIC TAX EFFECTS DEPEND ON ELASTICITIES

We now turn to our second question: Who is hurt by the tax? To answer this comparative static question, we want to determine how the price that consumers pay and firms receive changes after the tax is imposed.

The government collects a specific or unit tax, τ, from sellers, so sellers receive $p - \tau$ when consumers pay p. We now determine the effect of the tax on the equilibrium.

In the new equilibrium, the price that consumers pay is determined by equality between the demand function and the after-tax supply function,

$$D(p) = S(p - \tau) = 0.$$

Thus the equilibrium price is an implicit function of the specific tax: $p = p(\tau)$. Consequently, the equilibrium condition is

$$D(p(\tau)) = S(p(\tau) - \tau). \tag{2.26}$$

We determine the effect of a small tax on price by differentiating Equation 2.26 with respect to τ:

$$\frac{dD}{dp}\frac{dp}{d\tau} = \frac{dS}{dp}\frac{d(p(\tau) - \tau)}{d\tau} = \frac{dS}{dp}\left(\frac{dp}{d\tau} - 1\right).$$

Rearranging terms, it follows that the change in the price that consumers pay with respect to a change in the tax is

$$\frac{dp}{d\tau} = \frac{\frac{dS}{dp}}{\frac{dS}{dp} - \frac{dD}{dp}}. \tag{2.27}$$

We know that $dD/dp < 0$ from the Law of Demand. If the supply curve slopes upward so that $dS/dp > 0$, then $dp/d\tau > 0$, as Figure 2.12 illustrates. The higher the tax, the greater the price consumers pay. If $dS/dp < 0$, the direction of change is ambiguous: It depends on the relative slopes of the supply and demand curves (the denominator).

By multiplying both the numerator and denominator of the right-hand side of Equation 2.27 by p/Q, we can express this derivative in terms of elasticities,

$$\frac{dp}{d\tau} = \frac{\frac{dS}{dp}\frac{p}{Q}}{\frac{dS}{dp}\frac{p}{Q} - \frac{dD}{dp}\frac{p}{Q}} = \frac{\eta}{\eta - \varepsilon}, \tag{2.28}$$

where the last equality follows because dS/dp and dD/dp are the changes in the quantities supplied and demanded as price changes and the consumer and producer prices are identical when $\tau = 0$.[16] This expression holds for any size change in τ if both the demand and supply curves are linear. For most other shaped curves, the expression holds only for small changes.

We can now answer our second question: Who is hurt by the tax? The **incidence of a tax on consumers** is the share of the tax that falls on consumers. The incidence of the tax that falls on consumers is $dp/d\tau$, the amount by which the price to consumers rises as a fraction of the amount the tax increases. Firms receive $p - \tau$, so the change in the price that firms receive as the tax changes is $d(p - \tau)/d\tau = dp/d\tau - 1$. The *incidence*

[16] To determine the effect on quantity, we can combine the price result from Equation 2.28 with information from either the demand or the supply function. Differentiating the demand function with respect to τ, we know that

$$\frac{dD}{dp}\frac{dp}{d\tau} = \frac{dD}{dp}\tau\frac{h}{h - e},$$

which is negative if the supply curve is upward sloping so that $\eta > 0$.

of the tax on firms is the amount by which the price to firms falls: $1 - dp/d\tau$. The sum of the incidence of the tax to consumers and firms is $dp/d\tau + 1 - dp/d\tau = 1$. That is, the increase in price to consumers plus the drop in price to firms equals the tax.

The demand elasticity for pork is $\varepsilon = -0.3$ and the supply elasticity is $\eta = 0.6$, so the incidence of a specific tax on consumers is $dp/d\tau = \eta/(\eta - \varepsilon) = 0.6/[0.6 - (-0.3)] = 0.6/0.9 = 2/3$, and the incidence of the tax on firms is $1 - 2/3 = 1/3$.

Thus a discrete change in the tax of $\Delta\tau = \tau - 0 = \$1.05$ causes the price that consumers pay to rise by $\Delta p = p_2 - p_1 = \$4.00 - \$3.30 = [\eta/(\eta - \varepsilon)]\Delta\tau = 2/3 \times \$1.05 =$ 70¢ and the price to firms to fall by $1/3 \times \$1.05 =$ 35¢, as Figure 2.2 shows. The sum of the increase to consumers plus the loss to firms is 70¢ + 35¢ = $1.05 = τ.

Equation 2.28 shows that, for a given supply elasticity, the more elastic the demand, the less the equilibrium price rises when a tax is imposed. Similarly, for a given demand elasticity, the smaller the supply elasticity, the smaller the increase in the equilibrium price that consumers pay when a tax is imposed. For example, in the pork example, if the supply elasticity were $\eta = 0$ (a perfectly inelastic vertical supply curve), $dp/d\tau = 0/[0 - (-0.3)] = 0$, so none of the incidence of the tax falls on consumers, and the entire incidence of the tax falls on firms.[17]

THE SAME EQUILIBRIUM NO MATTER WHO IS TAXED

Our third question is, "Does the equilibrium or the incidence of the tax depend on whether the tax is collected from producers or consumers?" Surprisingly, in the supply-and-demand model, the equilibrium and the incidence of the tax are the same regardless of whether the government collects the tax from producers or from consumers.

We've already seen that firms are able to pass on some or all of the tax collected from them to consumers. We now show that, if the tax is collected from consumers, they can pass the producers' share back to the firms.

Suppose the specific tax $\tau = \$1.05$ on pork is collected from consumers rather than from producers. Because the government takes τ from each p that consumers spend, producers receive only $p - \tau$. Thus the demand curve as seen by firms shifts downward by $1.05 from D to D^s in Figure 2.13.

The intersection of D^2 and S determines the after-tax equilibrium, where the equilibrium quantity is Q_2 and the price received by producers is $p_2 - \tau$. The price paid by consumers, p_2 (on the original demand curve D at Q_2), is τ above the price received by producers. We place the after-tax equilibrium, e_2, bullet on the market demand D in Figure 2.11 to show that it is the same as the e_2 in Figure 2.12.

Comparing Figure 2.13 to Figure 2.12, we see that the after-tax equilibrium is the same regardless of whether the tax is imposed on consumers or producers. The price to consumers rises by the same amount, $\Delta p =$ 70¢, and the incidence of the tax, $\Delta p/\Delta\tau = 2/3$, is the same.

A specific tax, regardless of whether the tax is collected from consumers or producers, creates a *wedge* equal to the per-unit tax of τ between the price consumers pay, p, and the price producers receive, $p - \tau$. In short, regardless of whether firms or consumers pay the tax to the government, you can solve tax problems by shifting the supply curve, shifting the demand curve, or inserting a wedge between the supply and demand curves. All three approaches give the same answer.

[17]See **www.aw-bc.com/perloff,** Chapter 2, "Incidence of a Tax on Restaurant Meals," for another application.

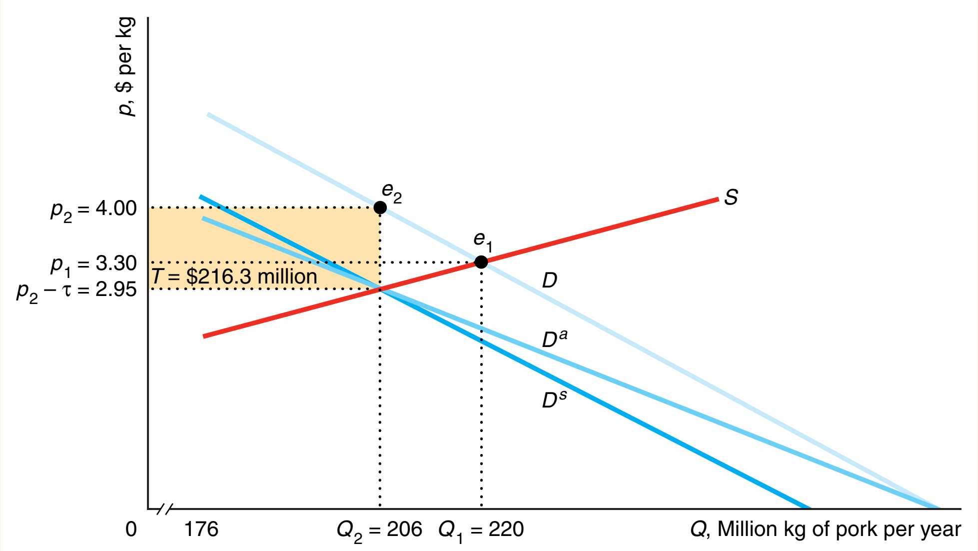


Figure 2.13 Effects of a Specific Tax and of an *Ad Valorem* Tax on Consumers. Without a tax, the demand curve is D and the supply curve is S. A specific tax of $\tau = \$1.05$ per kg collected from consumers shifts the demand curve to D^s, which is parallel to D. The new equilibrium is e_2 on the original demand curve D. If instead an *ad valorem* tax of $\alpha = 26.25\%$ is imposed, the demand curve facing firms is D^a. The gap between D and D^a, the per-unit tax, is larger at higher prices. The after-tax equilibrium is the same with both of these taxes.

THE SIMILAR EFFECTS OF *AD VALOREM* AND SPECIFIC TAXES

In contrast to specific sales taxes, which are applied to relatively few goods, governments levy *ad valorem* taxes on a wide variety of goods. Most states apply an *ad valorem* sales tax to most goods and services, exempting only a few staples such as food and medicine. There are 6,400 different *ad valorem* sales tax rates across the United States, which can go as high as 8.5% (Besley and Rosen, 1999).

Suppose that the government imposes an *ad valorem* tax of α, instead of a specific tax, on the price that consumers pay for processed pork. We already know that the equilibrium price is \$4 with a specific tax of \$1.05 per kg. At that price, an *ad valorem* tax of $\alpha = \$1.05/\$4 = 26.25\%$ raises the same amount of tax per unit as a \$1.05 specific tax.

It is usually easiest to analyze the effects of an *ad valorem* tax by shifting the demand curve. Figure 2.13 shows how an *ad valorem* tax shifts the processed pork demand curve. The *ad valorem* tax shifts the demand curve to D^a. At any given price p, the gap between D and D^a is αp, which is greater at high prices than at low prices. The gap is \$1.05 (= 0.2625 × \$4) per unit when the price is \$4, and \$2.10 when the price is \$8.

Imposing an *ad valorem* tax causes the after-tax equilibrium quantity, Q_2, to fall below the original quantity, Q_1, and the after-tax price, p_2, to rise above the original price, p_1. The tax collected per unit of output is $\tau = \alpha p_2$. The incidence of the tax that falls on consumers is the change in price, $\Delta p = (p_2 - p_1)$, divided by the change in the per-unit tax, $\Delta\tau = \alpha p_2 - 0$, that is collected, $\Delta p/(\alpha p_2)$. The incidence of an *ad valorem* tax is generally shared between consumers and producers. Because the *ad valorem* tax of $\alpha = 26.25\%$ has exactly the same impact on the equilibrium pork price and raises the same amount of tax per unit as the \$1.05 specific tax, the incidence is the same for both types of taxes.

(As with specific taxes, the incidence of the *ad valorem* tax depends on the elasticities of supply and demand, but we'll spare your having to go through that in detail.)

2.7 Quantity Supplied Need Not Equal Quantity Demanded

In a supply-and-demand model, the quantity supplied does not necessarily equal the quantity demanded because of the way we defined these two concepts. We defined the quantity supplied as the amount firms *want to sell* at a given price, holding constant other factors that affect supply, such as the price of inputs. We defined the quantity demanded as the quantity that consumers *want to buy* at a given price, if other factors that affect demand are held constant. The quantity that firms want to sell and the quantity that consumers want to buy at a given price need not equal the *actual* quantity that is bought and sold.

We could have defined the quantity supplied and the quantity demanded so that they must be equal. If we had defined the quantity supplied as the amount firms *actually* sell at a given price and the quantity demanded as the amount consumers *actually* buy, supply would have to equal demand in all markets because we *defined* the quantity demanded and the quantity supplied as the same quantity.

It is worth emphasizing this distinction because politicians, pundits, and the press are so often confused on this point. Someone insisting that "demand *must* equal supply" must be defining demand and supply as the *actual* quantities sold. Because we define the quantities supplied and demanded in terms of people's *wants* and not *actual* quantities bought and sold, the statement that "supply equals demand" is a theory, not merely a definition.

This theory says that the quantity supplied equals the quantity demanded at the intersection of the supply and demand curves if the government does not intervene. Not all government interventions prevent markets from *clearing* by equilibrating the quantity supplied and the quantity demanded. For example, as we've seen, a government tax affects the equilibrium but does not cause a gap between the quantity demanded and the quantity supplied. However, some government policies do more than merely shift the supply or demand curve.

For example, a government may control price directly. This policy leads to either excess supply or excess demand if the price the government sets differs from the market clearing price. We illustrate this result with two types of price control programs. The government may set a *price ceiling* at $\underline{p}$ so that the price at which goods are sold may be no higher than $\underline{p}$. When the government sets a *price floor* at $\underline{p}$, the price at which goods are sold may not fall below $\underline{p}$.

We can study the effects of such regulations using the supply-and-demand model. Despite the lack of equality between the quantity supplied and the quantity demanded, the supply-and-demand model is useful in analyzing this market because it predicts the excess demand or excess supply that is observed.

PRICE CEILING

Price ceilings have no effect if they are set above the equilibrium price that would be observed in the absence of the price controls. If the government says that firms may charge no more than $\bar{p} = \$5$ per gallon of gas and firms are actually charging $p = \$1$, the government's price control policy is irrelevant. However, if the equilibrium price, p, is above the price ceiling $\bar{p}$, the price that is actually observed in the market is the price ceiling.

The U.S. experience with gasoline illustrates the effects of price controls. In the 1970s, OPEC reduced supplies of oil—which is converted into gasoline—to Western countries. As a result, the total supply curve for gasoline in the United States—the hor-

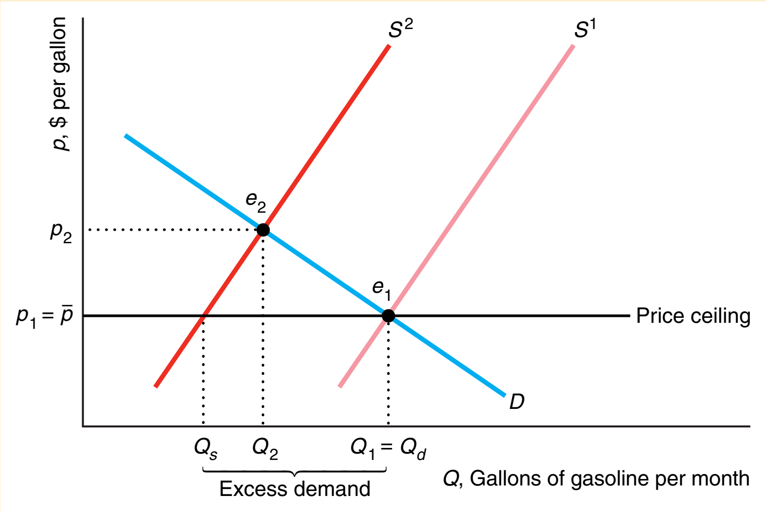


Figure 2.14 Price Ceiling on Gasoline. Supply shifts from S^1 to S^2. Under the government's price control program, gasoline stations may not charge a price above the price ceiling $p = p_1$. At that price, producers are willing to supply only Q_s, which is less than the amount $Q_1 = Q_d$ that consumers want to buy. The result is excessive demand, or a shortage of $Q_d - Q_s$.

izontal sum of domestic and OPEC supply curves—shifted to the left from S^1 to S^2 in Figure 2.14. Because of this shift, the equilibrium price of gasoline would have risen substantially, from p_1 to p_2. In an attempt to protect consumers by keeping gasoline prices from rising, the U.S. government set price ceilings on gasoline in 1973 and 1979.

The government told gas stations that they could charge no more than $\bar{p} = p_1$. Figure 2.14 shows the price ceiling as a solid horizontal line extending from the price axis at $\bar{p}$. The price control is binding because $p_2 > \bar{p}$. The observed price is the price ceiling. At $\bar{p}$, consumers *want* to buy $Q_d = Q_1$ gallons of gasoline, which is the equilibrium quantity they bought before OPEC acted. However, firms supply only Q_s gallons, which is determined by the intersection of the price control line with S^2. As a result of the binding price control, there is excess demand of $Q_d - Q_s$.

Were it not for the price controls, market forces would drive up the market price to p_2, where the excess demand would be eliminated. The government price ceiling prevents this adjustment from occurring. As a result, an enforced price ceiling causes a **shortage:** a persistent excess demand.

At the time of the controls, some government officials falsely contended that the shortages were caused by OPEC's cutting off its supply of oil to the United States. Without the price controls, the new equilibrium would be e_2. In this equilibrium, the price, p_2, is much higher than before, p_1; however, there is no shortage. Moreover, without controls, the quantity sold, Q_2, is greater than the quantity sold under the control program, Q_s.

With a binding price ceiling, the supply-and-demand model predicts an *equilibrium with a shortage*. In this equilibrium, the quantity demanded does not equal the quantity supplied. The reason that we call this situation an equilibrium even though a shortage exists is that no consumers or firms want to act differently, given the law. Without the price controls, consumers facing a shortage would try to get more output by offering to pay more, or firms would raise prices. With effective government price controls, they know that they can't drive up the price, so they live with the shortage.

What happens? Some lucky consumers get to buy Q_s units at the low price of $\bar{p}$. Other potential customers are disappointed: They would like to buy at that price, but they cannot find anyone willing to sell gas to them. With enforced price controls, sellers use criteria other than price to allocate the scarce commodity. They may supply their friends, long-term customers, or people of a certain race, gender, age, or religion. They may sell their goods on a first-come, first-served basis. Or they may limit everyone to only a few gallons.

Another possibility is for firms and customers to evade the price controls. A consumer could go to a gas station owner and say, "Let's not tell anyone, but I'll pay you twice the price the government sets if you'll sell me as much gas as I want." If enough customers and gas station owners behaved that way, no shortage would occur. A study of 92 major U.S. cities during the 1973 gasoline price controls found no gasoline lines in 52 of them. However, in cities such as Chicago, Hartford, New York, Portland, and Tucson, potential customers waited in line at the pump for an hour or more.[18] Deacon and Sonstelie (1989) calculated that for every dollar consumers saved during the 1980 gasoline price controls, they lost $1.16 in waiting time and other factors. This experience may be of importance in Hawaii, which recently suspended gasoline price controls that the state had imposed starting in 2005.

APPLICATION

Zimbabwe Price Controls

During the 2001 presidential campaign, Zimbabwe's government imposed price controls on many basic commodities, including various foods (about a third of citizens' daily consumption), soap, and cement. The controls led to shortages of these goods at retail outlets. Consequently, as the minister of finance and economic development acknowledged, a thriving *black market* or *parallel market* developed, where controls were ignored. Prices on the black market were two to three times higher than the controlled prices.

Cement manufacturers stopped accepting new orders when the price controls were imposed. Dealers quickly shifted existing supplies to the parallel market. Lack of cement crippled the construction industry. By May 2002, the government had nearly doubled the control price of cement in an effort to induce firms to resume selling cement.

In Zimbabwe's sugar industry, as the price controls made sugar significantly cheaper than in the surrounding regions, smuggling to other countries increased. Meanwhile, Zimbabwe suffered from a sugar shortage. Similarly, there was a critical maize shortage—which was exacerbated by other shortsighted policies that caused the quantity of maize produced to fall by 30%. Major supermarkets had no maize meal, sugar, and cooking oil on many days. Bakers scaled back their operations because they could obtain only half as much flour as before the controls. These dire shortages pushed many people to the verge of starvation.

[18]See **www.aw-bc.com/perloff,** Chapter 2, "Gas Lines," for a more detailed discussion of the effects of the 1973 and 1979 gasoline price controls.

In 2005, the government announced new price controls on basic food commodities. Food shortages grew worse. More than a third of the populace is malnourished. Only international food aid has kept millions of these people alive. In 2006, the inflation rate (largely prices of non-controlled goods) exceeded 1,000% and the government introduced a new watchdog agency to monitor prices and incomes—a combination likely to exacerbate the situation.

PRICE FLOOR

Governments also commonly use price floors. One of the most important examples of a price floor is the minimum wage in labor markets.

The minimum wage law forbids employers from paying less than a minimum wage, $\underline{w}$. Minimum wage laws date from 1894 in New Zealand, 1909 in the United Kingdom, and 1912 in Massachusetts. The Fair Labor Standards Act of 1938 set a federal U.S. minimum wage of 25¢. The U.S. federal minimum wage is currently $5.15 an hour, but Congress is debating a substantial increase. The statutory monthly minimum wage ranges from the equivalent of 19 in the Russian Federation to 375 in Portugal, 1,154 in France, and 1,466 in Luxembourg. If the minimum wage binds—exceeds the equilibrium wage, w^*—the minimum wage may cause *unemployment,* which is a persistent excess supply of labor.[19]

For simplicity, suppose that there is a single labor market in which everyone is paid the same wage. Figure 2.15 shows the supply and demand curves for labor services (hours worked). Firms buy hours of labor service—they hire workers. The quantity measure on the horizontal axis is hours worked per year, and the price measure on the vertical axis is the wage per hour.

With no government intervention, the market equilibrium is e, where the wage is w^* and the number of hours worked is L^*. The minimum wage creates a price floor, a horizontal line, at $\underline{w}$. At that wage, the quantity demanded falls to L_d and the quantity supplied rises to L_s. As a result, there is an excess supply or unemployment of $L_s - L_d$. The minimum wage prevents market forces from eliminating this excess supply, so it leads to an equilibrium with unemployment. The original 1938 U.S. minimum wage law caused massive unemployment in Puerto Rico (see **www.aw-bc.com/perloff**, Chapter 2, "Minimum Wage Law in Puerto Rico").

It is ironic that a law designed to help workers by raising their wages may harm some of them by causing them to become unemployed. Such a minimum wage law benefits only those who remain employed.[20]

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[19]The U.S. Department of Labor maintains at its Web site (**www.dol.gov**) an extensive history of the federal minimum wage law, labor markets, state minimum wage laws, and other information. For European minimum wages, see **www.fedee.com/minwage.html**. Where the minimum wage applies to only some labor markets (Chapter 10) or where only a single firm hires all the workers in a market (Chapter 15), a minimum wage might not cause unemployment. Card and Krueger (1997) provide evidence that recent rises in the minimum wage had negligible (at most) effects on employment in certain low-skill labor markets.

[20]The minimum wage could raise the wage enough that total wage payments, wL, rise despite the fall in demand for labor services. If workers could share the unemployment—everybody works fewer hours than he or she wants—all workers could benefit from the minimum wage. See Problem 40.

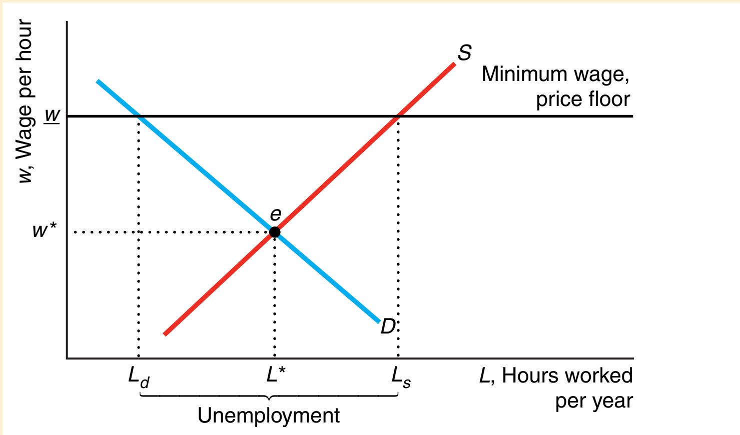

Figure 2.15 Minimum Wage. In the absence of a minimum wage, the equilibrium wage is w^* and the equilibrium number of hours worked is L^*. A minimum wage, $\underline{w}$, set above w^*, leads to unemployment—persistent excess supply—because the quantity demanded, L_d, is less than the quantity supplied, L_s.

2.8 When to Use the Supply-and-Demand Model

As we've seen, supply-and-demand theory can help us to understand and predict real-world events in many markets. Through Chapter 10, we discuss competitive markets in which the supply-and-demand model is a powerful tool for predicting what will happen to market equilibrium if underlying conditions—tastes, incomes, and prices of inputs—change. The types of markets for which the supply-and-demand model is useful are described at length in these chapters, particularly Chapter 8. Briefly, this model is applicable in markets in which:

- **Everyone is a price taker:** Because no consumer or firm is a very large part of the market, no one can affect the market price. Easy entry of firms into the market, which leads to a large number of firms, is usually necessary to ensure that firms are price takers.
- **Firms sell identical products:** Consumers do not prefer one firm's good to another.
- **Everyone has full information about the price and quality of goods:** Consumers know if a firm is charging a price higher than the price others set, and they know if a firm tries to sell them inferior-quality goods.
- **Costs of trading are low:** It is not time consuming, difficult, or expensive for a buyer to find a seller and make a trade or for a seller to find and trade with a buyer.

Markets with these properties are called *perfectly competitive markets*.

Where there are many firms and consumers, no single firm or consumer is a large enough part of the market to affect the price. If you stop buying bread or if one of the many thousands of wheat farmers stops selling the wheat used to make the bread, the price of bread will not change. Consumers and firms are *price takers*: They cannot affect the market price.

In contrast, if there is only one seller of a good or service—a *monopoly* (Chapter 11)—that seller is a *price setter* and can affect the market price. Because demand curves slope downward, a monopoly can increase the price it receives by reducing the amount of a good it supplies. Firms are also price setters in an *oligopoly*—a market with only a small number of firms—or in markets where they sell differentiated products and a consumer prefers one product to another (Chapter 13). In markets with price setters, the market price is usually higher than that predicted by the supply-and-demand model. That doesn't make the model generally wrong. It means only that the supply-and-demand model does not apply to markets with a small number of sellers or buyers. In such markets, we use other models.

If consumers have less information than a firm, the firm can take advantage of consumers by selling them inferior-quality goods or by charging a much higher price than that charged by other firms. In such a market, the observed price is usually higher than that predicted by the supply-and-demand model, the market may not exist at all (consumers and firms cannot reach agreements), or different firms may charge different prices for the same good (Chapter 18).

The supply-and-demand model is also not entirely appropriate in markets in which it is costly to trade with others because the costs of a buyer's finding a seller or of a seller's finding a buyer are high. **Transaction costs** are the expenses of finding a trading partner and making a trade for a good or service other than the price paid for that good or service. These costs include the time and money spent to find someone with whom to trade. When transaction costs are high, trades may not occur; or if they do occur, individual trades may occur at a variety of prices (Chapter 18).

Thus the supply-and-demand model is not appropriate in markets in which there are only one or a few sellers (such as electricity), firms produce differentiated products (such as music CDs), consumers know less than sellers about quality or price (such as used cars), or there are high transaction costs (such as nuclear turbine engines). Markets in which the supply-and-demand model has proved useful include agriculture, finance, labor, construction, services, wholesale, and retail—markets with many firms and consumers and where firms sell identical products.

Summary

1. **Demand:** The quantity of a good or service demanded by consumers depends on their tastes, the price of a good, the price of goods that are substitutes and complements, consumers' income, information, government regulations, and other factors. The *Law of Demand*—which is based on observation—says that *demand curves slope downward*. The higher the price, the less quantity is demanded, holding constant other factors that affect demand. A change in price causes a *movement along the demand curve*. A change in income, tastes, or another factor that affects demand other than price causes a *shift of the demand curve*. To get a total demand curve, we horizontally sum the demand curves of individuals or types of consumers or countries. That is, we add the quantities demanded by each individual at a given price to get the total demanded.
2. **Supply:** The quantity of a good or service supplied by firms depends on the price, the firm's costs, government regulations, and other factors. The market supply curve need not slope upward but usually does. A change in price causes a *movement along the supply curve*. A change in the price of an input or government regulation causes a *shift of the supply curve*. The total supply curve is the horizontal sum of the supply curves for individual firms.
3. **Market Equilibrium:** The intersection of the demand curve and the supply curve determines the equilibrium price and quantity in a market. Market forces—actions of consumers and firms—drive the price and quantity to the equilibrium levels if they are initially too low or too high.
4. **Shocking the Equilibrium: Comparative Statics:** A change in an underlying factor other than price causes a shift of the supply curve or the demand curve, which alters the equilibrium. Comparative statics is the method that economists use to analyze how variables controlled by consumers and firms—such as price and quantity—react to a change in *environmental variables* such as prices of substitutes and complements, income, and prices of inputs.
5. **Elasticities:** An elasticity is the percentage change in a variable in response to a given percentage change in another variable, holding all other relevant variables constant. The elasticity of demand, ε, is the percentage change

in the quantity demanded in response to a given percentage change in price: A 1% increase in price causes the quantity demanded to fall by ε%. Because demand curves slope downward according to the Law of Demand, the elasticity of demand is always negative. The elasticity of supply, η, is the percentage change in the quantity supplied in response to a given percentage change in price. Given estimated elasticities, we can forecast the comparative statics effects of a change in taxes or other variables that affect the equilibrium.

6. **Effects of a Sales Tax:** The two common types of sales taxes are *ad valorem* taxes, by which the government collects a fixed percentage of the price paid per unit, and specific taxes, by which the government collects a fixed amount of money per unit sold. Both types of sales taxes typically raise the equilibrium price and lower the equilibrium quantity. Both usually also raise the price consumers pay and lower the price suppliers receive, so consumers do not bear the full burden or incidence of the tax. The effects on quantity, price, and the incidence of the tax that falls on consumers depend on the demand and supply elasticities. In competitive markets, the effect of a tax on equilibrium quantities, prices, and the incidence of the tax is unaffected by whether the tax is collected from consumers or producers.

7. **Quantity Supplied Need Not Equal Quantity Demanded:** The quantity supplied equals the quantity demanded in a competitive market if the government does not intervene. However, some government policies—such as price floors or ceilings—cause the quantity supplied to be greater or less than the quantity demanded, leading to persistent excesses or shortages.

8. **When to Use the Supply-and-Demand Model:** The supply-and-demand model is a powerful tool to explain what happens in a market or to make predictions about what will happen if an underlying factor in a market changes. However, this model is applicable only in competitive markets, which are markets with many buyers and sellers; identical goods; certainty and full information about price, quantity, quality, incomes, costs, and other market characteristics; and low transaction costs.

Questions

If you ask me anything I don't know, I'm not going to answer. —Yogi Berra

* = *answer at the back of this book;* **W** = *audio-slide show answers by James Dearden at* **www.aw-bc.com/perloff**.

*1. Use a supply-and-demand diagram to explain the statement "Talk is cheap because supply exceeds demand." At what price is this comparison being made?

2. The 9/11 terrorist attacks caused the U.S. airline travel demand curve to shift left by an estimated 30% (Ito and Lee, 2005). Use a supply-and-demand diagram to show the likely effect on price and quantity (assuming that the market is competitive). Indicate the magnitude of the likely equilibrium price and quantity effects—for example, would you expect equilibrium quantity to change by about 30%? Show how the answer depends on the shape and location of the supply and demand curves.

3. In 1970, virtually every U.S. funeral involved a casket; however, only 71% did in 2005 as many consumers switched to cremations (Ashley M. Heher, "Rise in Cremations is Forcing Changes," *San Diego Union-Tribune*, March 11, 2006). Government regulations, increasing prices of wood, and other factors drove up the price of burials. Use supply and demand curves to illustrate what happened in the cremation industry. Explain your figure.

4. The Federation of Vegetable Farmers Association of Malaysia reported that a lack of workers caused a 25% drop in production that drove up vegetable prices by 50% to 100% in 2005 ("Vegetable Price Control Sought," **thestar.com.my**, June 6, 2005). Consumers called for price controls on vegetables. Show why the price increased, and predict the effects of a binding price control. **W**

*5. In 2004, as soon as the United States revealed the discovery of a single mad cow in December 2003, more than 40 countries slapped an embargo on U.S. beef. In addition, a few U.S. consumers stopped eating beef. In the three weeks after the discovery, the U.S. price in January 2004 fell by about 15% and the quantity sold increased by 43% over the last week in October 2003. Use supply-and-demand diagrams to explain why these events occurred.

6. The application "Substitution May Save Endangered Species" describes how the equilibrium changed in the market for seal genitalia (used as an aphrodisiac in Asia) when Viagra was introduced. Use a supply-and-demand diagram to illustrate what happened. Show whether the following is possible: A positive quantity is demanded at various prices, yet nothing is sold in the market.

7. In 2002, the U.S. Fish and Wildlife Service proposed banning imports of beluga caviar to protect the beluga sturgeon in the Caspian and Black Seas, whose sturgeon population had fallen 90% in the last two decades. The United States imports 60% of the world's beluga caviar. On the world's legal wholesale market, a kilogram of caviar costs an average of $500, and about $100 million worth is sold per year. What effect would the U.S. ban have

on world prices and quantities? Would such a ban help protect the beluga sturgeon? (In 2005, the service decided not to ban imports.)

8. The prices received by soybean farmers in Brazil, the world's second-largest soybean producer and exporter, tumbled 30%, in part because of China's decision to cut back on imports and in part because of a bumper soybean crop in the United States, the world's leading exporter (Todd Benson, "A Harvest at Peril," *New York Times*, January 6, 2005, C6). In addition, Asian soy rust, a deadly crop fungus, is destroying large quantities of the Brazilian crops.
   a. Use a supply-and-demand diagram to illustrate why Brazilian farmers are receiving lower prices.
   b. If you knew only the *direction* of the shifts in both the supply and the demand curves, could you predict that prices would fall? Why or why not? **W**

9. According to one forecast, half of the country's corn crop in 2008 may be used in producing ethanol (John Donnelly, "Ethanol's Success Story May Have Downside," *Boston Globe*, January 5, 2007). Ethanol production doubled from 2001 to 2005 and may double again by 2008. What effect will this increased use of corn for producing ethanol have on the price of corn and the consumption of corn as food?

10. On January 1, 2005, a three-decades-old system of global quotas that had limited how much China and other countries could ship to the United States and other wealthy nations ended. Over the next four months, U.S. imports of Chinese-made cotton trousers rose by more than 1,505% and their price fell 21% in the first quarter of the year (Tracie Rozhon, "A Tangle in Textiles," *New York Times*, April 21, 2005, C1). The U.S. textile industry demanded quick action, saying that 18 plants had already been forced to close that year and that 16,600 textile and apparel jobs had been lost. The Bush administration reacted to the industry pressure. The United States (and Europe, which faced similar large increases in imports) pressed China to cut back its textile exports, threatening to restore quotas on Chinese exports or to take other actions. Illustrate what happened, and show how the U.S. quota reimposed in May 2005 affected the equilibrium price and quantity in the United States.

11. After Hurricane Katrina damaged a substantial portion of the nation's oil-refining capacity in 2005, the price of gasoline shot up around the country. In 2006, many state and federal elected officials called for price controls. Had they been imposed, what effect would price controls have had? Who would have benefited, and who would have been harmed by the controls? Use a supply-and-demand diagram to illustrate your answers.

*12. Between 1971 and 2006, the United States from time to time imposed quotas or other restrictions on importing steel. Suppose both the domestic supply curve of steel, S^d, and the foreign supply curve of steel for sale in the United States, S^f, are upward-sloping straight lines. How did a quota set by the United States on foreign steel imports of $\bar{Q} > 0$ affect the total American supply curve for steel (domestic and foreign supply combined)?

*13. Given the answer to Question 12, what is the effect of a U.S. quota on steel of $\bar{Q} > 0$ on the equilibrium in the U.S. steel market? (*Hint:* The answer depends on whether the quota binds [is low enough to affect the equilibrium]).

14. Suppose that the demand curve for wheat in each country is inelastic up to some "choke" price p^*—a price so high that nothing is bought—so that the demand curve is vertical at Q^* at prices below p^* and horizontal at p^* (that is, the demand curve forms a box with the axes). If p^* and Q^* vary across countries, what does the world's demand curve look like? Discuss how the elasticity of demand varies with price along the world's demand curve.

15. According to Borjas (2003), immigration into the United States increased the labor supply of working men by 11.0% from 1980 to 2000 and reduced the wage of the average native worker by 3.2%. From these results, can we make any inferences about the elasticity of supply or demand? Which curve (or curves) changed, and why? Draw a supply-and-demand diagram and label the axes to illustrate what happened.

16. The U.S. Bureau of Labor Statistics reports that the average salary for postsecondary economics teachers in the Raleigh-Durham-Chapel Hill metropolitan area, which has many top universities, rose to $105,200 (based on a 52-week work year) in 2003. According to the *Wall Street Journal* (Timothy Aeppel, "Economists Gain Star Power," February 22, 2005, A2), the salary increase resulted from an outward shift in the demand curve for academic economists due to the increased popularity of the economics major, while the supply curve of Ph.D. economists did not shift and the quantity supplied did not change.
    a. If this explanation is correct, what is the short-run price elasticity of supply of academic economists?
    b. If these salaries are expected to remain high, will more people enter doctoral programs in economics? How would such entry affect the long-run price elasticity of supply? **W**

17. According to Agcaoli-Sombilla (1991), the elasticity of demand for rice is −0.47 in Austria; −0.8 in Bangladesh, China, India, Indonesia, and Thailand; −0.25 in Japan; −0.55 in the European Union and the United States; and −0.15 in Vietnam. In which countries is the demand for rice inelastic? In which country is it the least elastic?

18. What effect does a $1 specific tax have on equilibrium price and quantity, and what is the incidence on consumers, if

a. the demand curve is perfectly inelastic?
b. the demand curve is perfectly elastic?
c. the supply curve is perfectly inelastic?
d. the supply curve is perfect elastic?
e. the demand curve is perfectly elastic and the supply curve is perfectly inelastic?

Use graphs and math to explain your answers.

19. On July 1, 1965, the federal *ad valorem* taxes on many goods and services were eliminated. Comparing prices before and after this change, we can determine how much the price fell in response to the tax's elimination. When the tax was in place, the tax per unit on a good that sold for p was αp. If the price fell by αp when the tax was eliminated, consumers must have been bearing the full incidence of the tax. Consequently, consumers got the full benefit of removing the tax from those goods. The entire amount of the tax cut was passed on to consumers for all commodities and services that were studied for which the taxes were collected at the retail level (except admissions and club dues) and for most commodities for which excise taxes were imposed at the manufacturer level, including face powder, sterling silverware, wristwatches, and handbags (Brownlee and Perry, 1967). List the conditions (in terms of the elasticities or shapes of supply or demand curves) that are consistent with 100% pass-through of the taxes. Use graphs to illustrate your answer.

20. Essentially none of the savings from removing the federal *ad valorem* tax were passed on to consumers for motion picture admissions and club dues (Brownlee and Perry, 1967; see Question 19). List the conditions (in terms of the elasticities or shapes of supply or demand curves) that are consistent with 0% pass-through of the taxes. Use graphs to illustrate your answer.

*21. Do you care whether a 15¢ tax per gallon of milk is collected from milk producers or from consumers at the store? Why or why not?

*22. Usury laws place a ceiling on interest rates that lenders such as banks can charge borrowers. Low-income households in states with usury laws have significantly lower levels of consumer credit (loans) than comparable households in states without usury laws (Villegas, 1989). Why? (*Hint:* The interest rate is the price of a loan, and the amount of the loan is the quantity.)

Problems

*23. Using the estimated demand function for processed pork in Canada, Equation 2.2, show how the quantity demanded, Q, at a given price changes as per capita income, Y, increases slightly (that is, calculate the partial derivative of quantity demanded with respect to income). How much does Q change if income rises by $100 a year?

*24. Suppose that the inverse demand function for movies is $p = 120 - Q_1$ for college students and $p = 120 - 2Q_2$ for other town residents. What is the town's total demand function ($Q = Q_1 + Q_2$ as a function of p)? Use a diagram to illustrate your answer.

25. The demand function for movies is $Q_1 = 120 - p$ for college students and $Q_2 = 120 - 2p$ for other town residents. What is the total demand function? Use a diagram to illustrate your answer. (*Hint:* By looking at your diagram, you'll see that some care must be used in writing the demand function.)

26. In the application "Aggregating the Demand for Broadband Service" (based on Duffy-Deno, 2003), the demand function is $Q_s = 15.6p - 0.563$ for small firms and $Q_l = 16.0p - 0.296$ for larger firms, where price is in cents per kilobyte per second and quantity is in millions of kilobytes per second (Kbps).

    a. What is the total demand function for all firms? Suppose that the supply curve for broadband service is horizontal at 40¢ per Kbps (firms will supply as much service as desired at that price).
    b. What is the quantity demanded by small firms, large firms, and all firms?

27. In the application "Aggregating the Demand for Broadband Service" (based on Duffy-Deno, 2003), the demand function is $Q_s = 15.6p^{-0.563}$ for small firms and $Q_l = 16.0p^{-0.296}$ for larger ones. As the graph in the application shows, the two demand functions cross. What are the elasticities of demand for small and large firms? Explain.

*28. Green, Howitt, and Russo (2005) estimate the supply and demand curves for California processing tomatoes. The supply function is $\ln Q = 0.2 + 0.55 \ln p$, where Q is the quantity of processing tomatoes in millions of tons per year and p is the price in dollars per ton. The demand function is $\ln Q = 2.6 - 0.2 \ln p + 0.15 \ln p_t$, where p_t is the price of tomato paste (which is what processing tomatoes are used to produce) in dollars per ton. In 2002, $p_t = 110$. What is the demand function for processing tomatoes, where the quantity is solely a function of the price of processing tomatoes? Solve for the equilibrium price and the quantity of processing tomatoes (rounded to two digits after the decimal point). Draw the supply and demand curves (note that they are not straight lines), and label the equilibrium and axes appropriately.

29. The U.S. Tobacco Settlement between the major tobacco companies and 46 states caused the price of cigarettes to jump 45¢ (21%) in November 1998. Levy and Meara

(2005) find only a 2.65% drop in prenatal smoking 15 months later. What is the elasticity of demand for prenatal smokers?

*30. Calculate the price and cross-price elasticities of demand for coconut oil. The coconut oil demand function (Buschena and Perloff, 1991) is $Q = 1{,}200 - 9.5p + 16.2p_p + 0.2Y$, where Q is the quantity of coconut oil demanded in thousands of metric tons per year, p is the price of coconut oil in cents per pound, p_p is the price of palm oil in cents per pound, and Y is the income of consumers. Assume that p is initially 45¢ per pound, p_p is 31¢ per pound, and Q is 1,275 thousand metric tons per year.

31. When the U.S. government announced that a domestic mad cow was found in December 2003, analysts estimated that domestic supplies would increase in the short run by 10.4% as many other countries barred U.S. beef. An estimate of the price elasticity of beef demand is −1.6 (Henderson, 2003). Assuming that only the domestic supply curve shifted, how much would you expect the price to change? (*Note*: The U.S. price fell by about 15% in the first month, but that probably reflected shifts in both supply and demand curves.)

32. Keeler et al. (2004) estimate that the U.S. Tobacco Settlement between major tobacco companies and 46 states caused the price of cigarettes to jump by 45¢ per pack (21%) and overall per capita cigarette consumption to fall by 8.3%. What is the elasticity of demand for cigarettes? Is cigarette demand elastic or inelastic?

33. In a commentary piece on the rising cost of health insurance ("Healthy, Wealthy, and Wise, *Wall Street Journal*, May 4, 2004, A20), economists John Cogan, Glenn Hubbard, and Daniel Kessler state, "Each percentage-point rise in health-insurance costs increases the number of uninsured by 300,000 people." Assuming that their claim is correct, demonstrate that the price elasticity of demand for health insurance depends on the number of people who are insured. What is the price elasticity if 200 million people are insured? What is the price elasticity if 220 million people are insured? **W**

34. Using calculus, determine the effect of an increase in the price of beef, p_b, from \$4 to \$4.60 on the equilibrium price and quantity in the Canadian pork example. (*Hint*: Conduct an analysis that differs from that in Solved Problem 2.1 in that the shock is to the demand curve rather than to the supply curve.) Illustrate your comparative statics analysis in a figure.

35. Solved Problem 2.3 claims that a new war in the Persian Gulf could shift the world oil supply curve to the left by 3 million barrels a day or more, causing the world price of oil to soar regardless of whether we drill in the ANWR. How accurate is that claim? Use the same type of analysis as in the solved problem to calculate how much such a shock would cause the price to rise with and without the ANWR production.

36. A subsidy is a negative tax in which the government gives people money instead of taking it from them. If the government applied a \$1.05 specific subsidy instead of a specific tax in Figure 2.12, what would happen to the equilibrium price and quantity? Use the demand function and the after-subsidy supply function to solve for the new equilibrium values. What is the incidence of the subsidy on consumers?

37. Besley and Rosen (1998) find that a 10¢ increase in the federal tax on a pack of cigarettes leads to an average 2.8¢ increase in state cigarette taxes. What implications does their result have for calculating the effects of an increase in the federal cigarette tax on the quantity demanded? As of 2005, the U.S. federal cigarette tax was 39¢ per pack, and the federal tax plus the average state tax was 84.5¢ per pack. Given the current federal tax and an estimated elasticity of demand for the U.S. population of −0.3, what is the effect of a 10¢ increase in the federal tax? How would your answer change if the state tax does not change?

38. Green et al. (2005) estimate that the demand elasticity is −0.47 and the long-run supply elasticity is 12.0 for almonds. The corresponding elasticities are −0.68 and 0.73 for cotton and −0.26 and 0.64 for processing tomatoes. If the government were to apply a specific tax to each of these commodities, what would be the consumer tax incidence for each of these commodities?

*39. Use calculus to show that an increase in a specific sales tax τ reduces quantity by less and tax revenue more, the less elastic the demand curve. [*Hint:* The quantity demanded depends on its price, which in turn depends on the specific tax, $Q(p(\tau))$, and tax revenue is $R = p(\tau)Q(p(\tau))$.]

40. An increase in the minimum wage could raise the total wage payment, $W = wL(w)$, where w is the minimum wage and $L(w)$ is the demand function for labor, despite the fall in demand for labor services. Show that whether the wage payments rise or fall depends on the elasticity of demand of labor.

41. Lewit and Coate (1982) estimate that the price elasticity of demand for cigarettes is −0.42. Suppose that the daily market demand for cigarettes in New York City is $Q = 20{,}000p^{-0.42}$ and that the inverse market supply curve of cigarettes in the city is $p = 1.5p_w$, where p_w is the wholesale price of cigarettes. (That is, the inverse market supply curve is a horizontal line at a price, p, equal to $1.5p_w$. Retailers sell cigarettes if they receive a price that is 50% higher than what they pay for the cigarettes so as to cover their other costs.)

a. Assume that the New York retail market for cigarettes is competitive. Calculate the equilibrium price and quantity of cigarettes as a function of the wholesale price. Let Q^* represent the equilibrium quantity. Find dQ^*/dp_w.

b. Now suppose that New York City and State each impose a \$1.50 specific tax on each pack of cigarettes, for a total of \$3.00 per pack on all cigarettes possessed for sale or use in New York City. The tax is paid by the retailers. Show using both math and a graph how the introduction of the tax shifts the market supply curve. How does the introduction of the tax affect the equilibrium retail price and quantity of cigarettes?

c. With the quantity tax in place, calculate the equilibrium price and quantity of cigarettes as a function of wholesale price. How does the presence of the quantity tax affect dQ^*/dp_w? **W**

42. Due to a recession that lowered incomes, the 2002 market prices for last-minute rentals of U.S. beachfront properties were lower than usual (June Fletcher, "Last-Minute Beach Rentals Offer Summer's Best Deals," *Wall Street Journal*, June 21, 2002, D1). Suppose that the inverse demand function for renting a beachfront property in Ocean City, New Jersey, during the first week of August is $p = 1{,}000 - Q + Y/20$, where Y is the median annual income of the people involved in this market, Q is quantity, and p is the rental price. The inverse supply function is $p = Q/2 + Y/40$.

a. Derive the equilibrium price, p^*, and quantity, Q^*, in terms of Y.

b. Use a supply-and-demand analysis to show the effect of decreased income on the equilibrium price of rental homes. That is, find dp^*/dY. Does a decrease in median income lead to a decrease in the equilibrium rental price? **W**

Appendix 2

Economists use a *regression* to estimate economic relationships such as demand curves and supply curves. A regression analysis allows us to answer three types of questions:

- How can we best fit an economic relationship to actual data?
- How confident are we in our results?
- How can we determine the effect of a change in one variable on another if many other variables are changing at the same time?

ESTIMATING ECONOMIC RELATIONS

We use a demand curve example to illustrate how regressions can answer these questions. The points in Figure 2A.1 show eight years of data on Nancy's annual purchases of candy bars, q, and the prices, p, she paid.[21] For example, in the year when candy bars cost 20¢, Nancy bought q_2 candy bars.

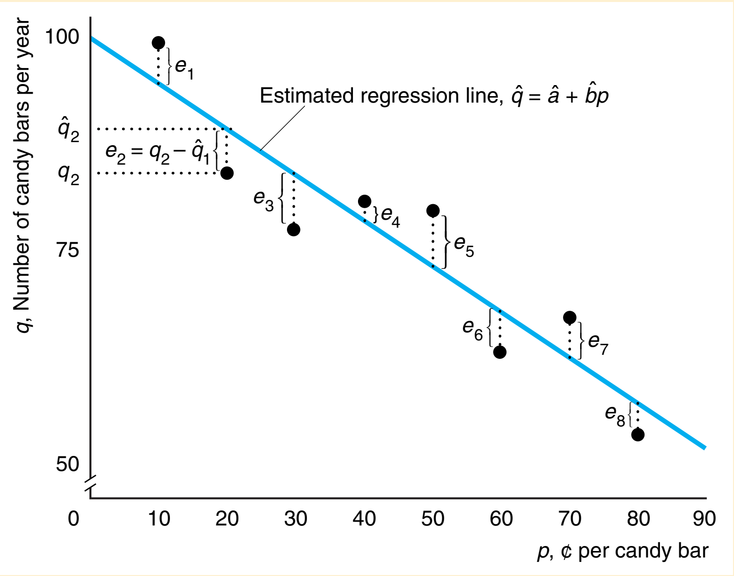

Figure 2A.1

[21]We use a lowercase q for the quantity demanded for an individual instead of the uppercase Q that we use for a market. Notice that we violated the rule economists usually follow of putting quantity on the horizontal axis and price on the vertical axis. We are now looking at this relationship as statisticians who put the independent or explanatory variable, price, on the horizontal axis and the dependent variable, quantity, on the vertical axis.

Because we assume that Nancy's tastes and income did not change during this period, we write her demand for candy bars as a function of the price of candy bars and unobservable random effects. We believe that her demand curve is linear and want to estimate the demand function:

$$q = a + bp + e,$$

where a and b are the coefficients we want to determine and e is an error term. This *error term* captures random effects that are not otherwise reflected in our function. For instance, in one year, Nancy took an economics course that raised her anxiety level, causing her to eat more candy bars than usual, resulting in a relatively large positive error term for that year.

The data points in the figure exhibit a generally downward-sloping relationship between quantity and price, but the points do not lie strictly on a line because of the error terms. There are many possible ways in which we could draw a line through these data points.

The way we fit the line in the figure is to use the standard criterion that our estimates *minimize the sum of squared residuals*, where a residual, $e = q - \hat{q}$, is the difference between an actual quantity, q, and the fitted or predicted quantity on the estimated line, $\hat{q}$. That is, we choose estimated coefficients $\hat{a}$ and $\hat{b}$ so that the estimated quantities from the regression line,

$$\hat{q} = \hat{a} + \hat{b}p,$$

make the sum of the squared residuals, $e_1^2 + e_2^2 + \cdots + e_8^2$, as small as possible. By summing the square of the residuals instead of the residuals themselves, we treat the effects of a positive or negative error symmetrically and give greater weight to large errors than to small ones.[22] In the figure, the regression line is

$$\hat{q} = 99.4 - 0.49p,$$

where $\hat{a} = 99.4$ is the intercept of the estimated line and $\hat{b} = -0.49$ is the slope of the line.

CONFIDENCE IN OUR ESTIMATES

Because the data reflect random errors, so do the estimated coefficients. Our estimate of Nancy's demand curve depends on the *sample* of data we use. If we were to use data from a different set of years, our estimates, $\hat{a}$ and $\hat{b}$ of the true coefficients, a and b, would differ.

If we had many estimates of the true parameter based on many samples, the estimates would be distributed around the true coefficient. These estimates are *unbiased* in the sense that the average of the estimates would equal the true coefficients.

[22]Using calculus, we can derive the $\hat{a}$ and $\hat{b}$ that minimize the sum of squared residuals. The estimate of the slope coefficient is a weighted average of the observed quantities, $\hat{b} = \Sigma_i w_i q_i$, where $w_i = (p_i - p)/\Sigma_i(p_i - p)^2$, p is the average of the observed prices, and Σ_i indicates the sum over each observation i. The estimate of the intercept, $\hat{a}$, is the average of the observed quantities.

Computer programs that calculate regression lines report a *standard error* for each coefficient, which is an estimate of the dispersion of the estimated coefficients around the true coefficient. In our example, a computer program reports

$$\underset{}{\hat{q}} = \underset{(3.99)}{99.4} - \underset{(0.08)}{0.49p},$$

where below each estimated coefficient is its estimated standard error between parentheses.

The smaller the estimated standard error, the more precise the estimate, and the more likely it is to be close to the true value. As a rough rule of thumb, there is a 95% probability that the interval that is within two standard errors of the estimated coefficient contains the true coefficient.[23] Using this rule, the *confidence interval* for the slope coefficient, $\hat{b}$, ranges from $-0.49 - (2 \times 0.08) = -0.65$ to $-0.49 + (2 \times 0.08) = -0.33$. If zero were to lie within the confidence interval for $\hat{b}$, we would conclude that we cannot reject the hypothesis that the price has no effect on the quantity demanded. In our case, however, the entire confidence interval contains negative values, so we are reasonably sure that the higher the price, the less Nancy demands.

MULTIPLE REGRESSION

We can also estimate relationships involving more than one explanatory variable using a *multiple regression*. For example, Moschini and Meilke (1992) estimate a pork demand function, Equation 2.2, in which the quantity demanded is a function of income, Y, and the prices of pork, p, beef, p_b, and chicken, p_c:

$$Q = 171 - 20p + 20p_b + 3p_c + 2Y.$$

The multiple regression is able to separate the effects of the various explanatory variables. The coefficient 20 on the p variable indicates that an increase in the price of pork by $1 per kg lowers the quantity demanded by 20 million kg per year, holding the effects of the other prices and income constant.

[23] The confidence interval is the coefficient plus or minus 1.96 times its standard error for large samples (at least hundreds of observations) in which the coefficients are normally distributed. For smaller samples, the confidence interval tends to be larger.