Breaks in the Axes The graph in Fig. A1.4(a) has breaks in its axes, as shown by the small gaps. The breaks indicate that there are jumps from the origin, 0, to the first values recorded.

The breaks are used because the lowest values of income and expenditure exceed $20,000. If we made this graph with no breaks in its axes, there would be a lot of empty space, all the points would be crowded into the top right corner, and it would be difficult to see whether a relationship exists between these two variables. By breaking the axes, we are able to bring the relationship into view.

Putting a break in one or both axes is like using a zoom lens to bring the relationship into the center of the graph and magnify it so that the relationship fills the graph.

Misleading Graphs Breaks can be used to highlight a relationship, but they can also be used to mislead—to make a graph that lies. The most common way of making a graph lie is to put a break in the axis and either to stretch or compress the scale. For example, suppose that in Fig. A1.4(a), the *y*-axis that measures expenditure ran from zero to $35,000 while the *x*-axis was the same as the one shown. The graph would now create the impression that despite a huge increase in income, expenditure had barely changed.

To avoid being misled, it is a good idea to get into the habit of always looking closely at the values and the labels on the axes of a graph before you start to interpret it.

Correlation and Causation A scatter diagram that shows a clear relationship between two variables, such as Fig. A1.4(a), tells us that the two variables have a high correlation. When a high correlation is present, we can predict the value of one variable from the value of the other variable. But correlation does not imply causation.

Sometimes a high correlation is a coincidence, but sometimes it does arise from a causal relationship. It is likely, for example, that rising income causes rising expenditure (Fig. A1.4a) and that high unemployment makes for a slack economy in which prices don't rise quickly, so the inflation rate is low (Fig. A1.4b).

You've now seen how we can use graphs in economics to show economic data and to reveal relationships. Next, we'll learn how economists use graphs to construct and display economic models.

Graphs Used in Economic Models

The graphs used in economics are not always designed to show real-world data. Often they are used to show general relationships among the variables in an economic model.

An *economic model* is a stripped-down, simplified description of an economy or of a component of an economy such as a business or a household. It consists of statements about economic behavior that can be expressed as equations or as curves in a graph. Economists use models to explore the effects of different policies or other influences on the economy in ways that are similar to the use of model airplanes in wind tunnels and models of the climate.

You will encounter many different kinds of graphs in economic models, but there are some repeating patterns. Once you've learned to recognize these patterns, you will instantly understand the meaning of a graph. Here, we'll look at the different types of curves that are used in economic models, and we'll see some everyday examples of each type of curve. The patterns to look for in graphs are the four cases in which

- Variables move in the same direction.
- Variables move in opposite directions.
- Variables have a maximum or a minimum.
- Variables are unrelated.

Let's look at these four cases.

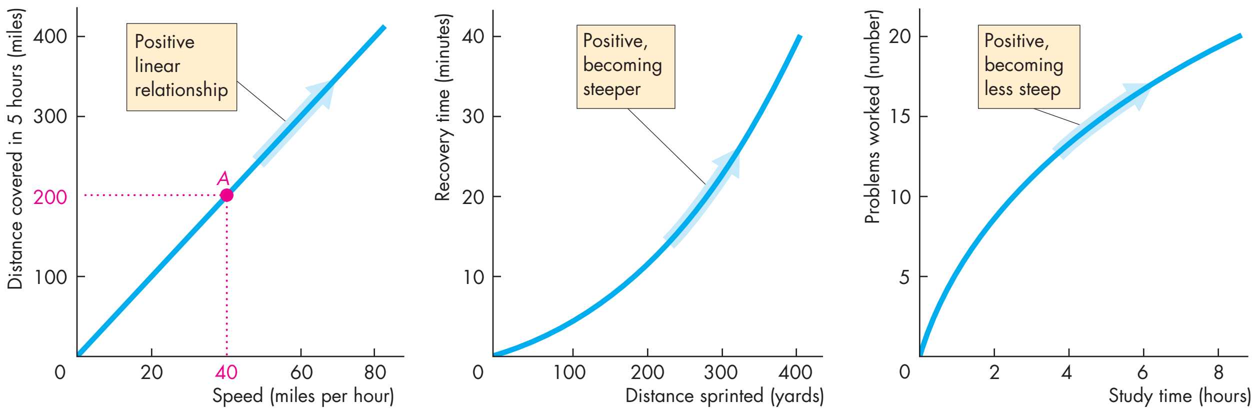
Variables That Move in the Same Direction

Figure A1.5 shows graphs of the relationships between two variables that move up and down together. A relationship between two variables that move in the same direction is called a **positive relationship** or a **direct relationship**. A line that slopes upward shows such a relationship.

Figure A1.5 shows three types of relationships: one that has a straight line and two that have curved lines. All the lines in these three graphs are called curves. Any line on a graph—no matter whether it is straight or curved—is called a *curve*.

A relationship shown by a straight line is called a **linear relationship**. Figure A1.5(a) shows a linear relationship between the number of miles traveled in

FIGURE A1.5 Positive (Direct) Relationships



(a) Positive linear relationship **(b) Positive, becoming steeper** **(c) Positive, becoming less steep**

Each part shows a positive (direct) relationship between two variables. That is, as the value of the variable measured on the *x*-axis increases, so does the value of the variable measured on the *y*-axis. Part (a) shows a linear positive relationship—as the two variables increase together, we move along a straight line.

Part (b) shows a positive relationship such that as the two variables increase together, we move along a curve that becomes steeper.

Part (c) shows a positive relationship such that as the two variables increase together, we move along a curve that becomes flatter.

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5 hours and speed. For example, point *A* shows that we will travel 200 miles in 5 hours if our speed is 40 miles an hour. If we double our speed to 80 miles an hour, we will travel 400 miles in 5 hours.

Figure A1.5(b) shows the relationship between distance sprinted and recovery time (the time it takes the heart rate to return to its normal resting rate). This relationship is an upward-sloping one that starts out quite flat but then becomes steeper as we move along the curve away from the origin. The reason this curve becomes steeper is that the additional recovery time needed from sprinting an additional 100 yards increases. It takes less than 5 minutes to recover from sprinting 100 yards but more than 10 minutes to recover from 200 yards.

Figure A1.5(c) shows the relationship between the number of problems worked by a student and the amount of study time. This relationship is an upward-sloping one that starts out quite steep and becomes flatter as we move along the curve away from the origin. Study time becomes less productive as the student spends more hours studying and becomes more tired.

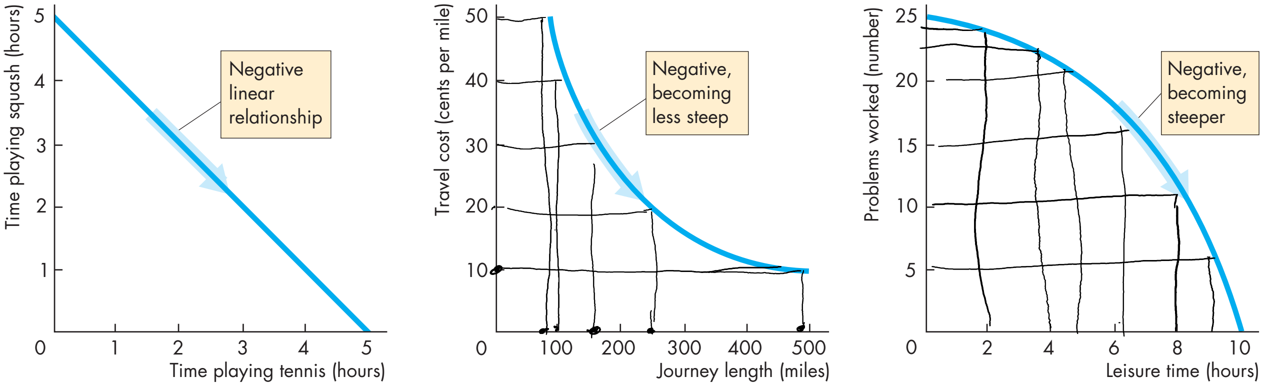
Variables That Move in Opposite Directions

Figure A1.6 shows relationships between things that move in opposite directions. A relationship between variables that move in opposite directions is called a **negative relationship** or an **inverse relationship**.

Figure A1.6(a) shows the relationship between the hours spent playing squash and the hours spent playing tennis when the total time available is 5 hours. One extra hour spent playing tennis means one hour less spent playing squash and vice versa. This relationship is negative and linear.

Figure A1.6(b) shows the relationship between the cost per mile traveled and the length of a journey. The longer the journey, the lower is the cost per mile. But as the journey length increases, even though the cost per mile decreases, the fall in the cost is smaller the longer the journey. This feature of the relationship is shown by the fact that the curve slopes downward, starting out steep at a short journey length and then becoming flatter as the journey length increases. This relationship arises because some of the costs are fixed, such as auto insurance, and the fixed costs are spread over a longer journey.

FIGURE A1.6 Negative (Inverse) Relationships



(a) Negative linear relationship **(b) Negative, becoming less steep** **(c) Negative, becoming steeper**

Each part shows a negative (inverse) relationship between two variables. Part (a) shows a linear negative relationship. The total time spent playing tennis and squash is 5 hours. As the time spent playing tennis increases, the time spent playing squash decreases, and we move along a straight line.

Part (b) shows a negative relationship such that as the journey length increases, the travel cost decreases as we move along a curve that becomes less steep.

Part (c) shows a negative relationship such that as leisure time increases, the number of problems worked decreases as we move along a curve that becomes steeper.

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Figure A1.6(c) shows the relationship between the amount of leisure time and the number of problems worked by a student. Increasing leisure time produces an increasingly large reduction in the number of problems worked. This relationship is a negative one that starts out with a gentle slope at a small number of leisure hours and becomes steeper as the number of leisure hours increases. This relationship is a different view of the idea shown in Fig. A1.5(c).

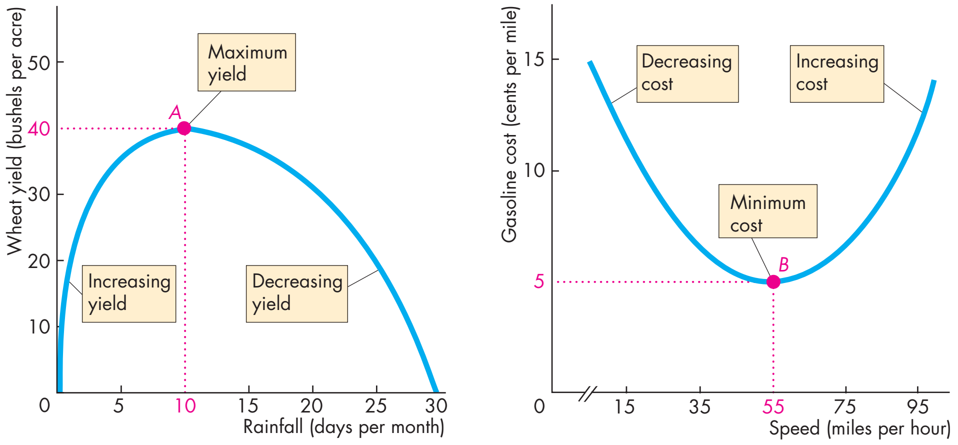
Variables That Have a Maximum or a Minimum

Many relationships in economic models have a maximum or a minimum. For example, firms try to make the maximum possible profit and to produce at the lowest possible cost. Figure A1.7 shows relationships that have a maximum or a minimum.

Figure A1.7(a) shows the relationship between rainfall and wheat yield. When there is no rainfall, wheat will not grow, so the yield is zero. As the rainfall increases up to 10 days a month, the wheat yield increases. With 10 rainy days each month, the wheat yield reaches its maximum at 40 bushels an acre (point *A*). Rain in excess of 10 days a month starts to lower the yield of wheat. If every day is rainy, the wheat suffers from a lack of sunshine and the yield decreases to zero. This relationship is one that starts out sloping upward, reaches a maximum, and then slopes downward.

Figure A1.7(b) shows the reverse case—a relationship that begins sloping downward, falls to a minimum, and then slopes upward. Most economic costs are like this relationship. An example is the relationship between the cost per mile and speed for a car trip. At low speeds, the car is creeping in a traffic snarl-up. The number of miles per gallon is low, so the cost per mile is high. At high speeds, the car is traveling faster than its efficient speed, using a large quantity of gasoline, and again the number of miles per gallon is low and the cost per mile is high. At a speed of 55 miles an hour, the cost per mile is at its minimum (point *B*). This relationship is one that starts out sloping downward, reaches a minimum, and then slopes upward.

FIGURE A1.7 Maximum and Minimum Points



(a) Relationship with a maximum **(b) Relationship with a minimum**

Part (a) shows a relationship that has a maximum point, *A*. The curve slopes upward as it rises to its maximum point, is flat at its maximum, and then slopes downward.

Part (b) shows a relationship with a minimum point, *B*. The curve slopes downward as it falls to its minimum, is flat at its minimum, and then slopes upward.

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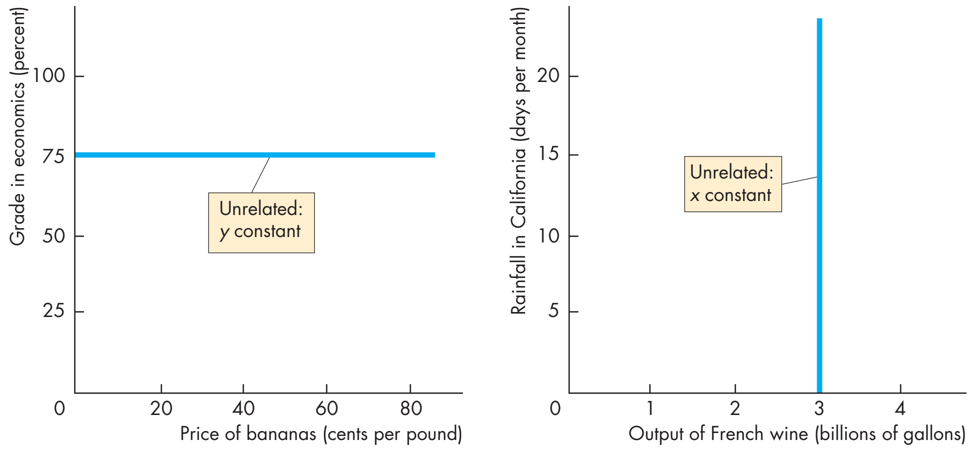
Variables That Are Unrelated

There are many situations in which no matter what happens to the value of one variable, the other variable remains constant. Sometimes we want to show the independence between two variables in a graph, and Fig. A1.8 shows two ways of achieving this.

In describing the graphs in Fig. A1.5 through Fig. A1.7, we have talked about curves that slope upward or slope downward, and curves that become less steep or steeper. Let's spend a little time discussing exactly what we mean by *slope* and how we measure the slope of a curve.

FIGURE A1.8 Variables That Are Unrelated



(a) Unrelated: *y* constant **(b) Unrelated: *x* constant**

This figure shows how we can graph two variables that are unrelated. In part (a), a student's grade in economics is plotted at 75 percent on the *y*-axis regardless of the price of bananas on the *x*-axis. The curve is horizontal.

In part (b), the output of the vineyards of France on the *x*-axis does not vary with the rainfall in California on the *y*-axis. The curve is vertical.

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The Slope of a Relationship

We can measure the influence of one variable on another by the slope of the relationship. The **slope** of a relationship is the change in the value of the variable measured on the *y*-axis divided by the change in the value of the variable measured on the *x*-axis. We use the Greek letter Δ (*delta*) to represent "change in." Thus Δy means the change in the value of the variable measured on the *y*-axis, and Δx means the change in the value of the variable measured on the *x*-axis. Therefore the slope of the relationship is

$$\text{Slope} = \frac{\Delta y}{\Delta x}.$$

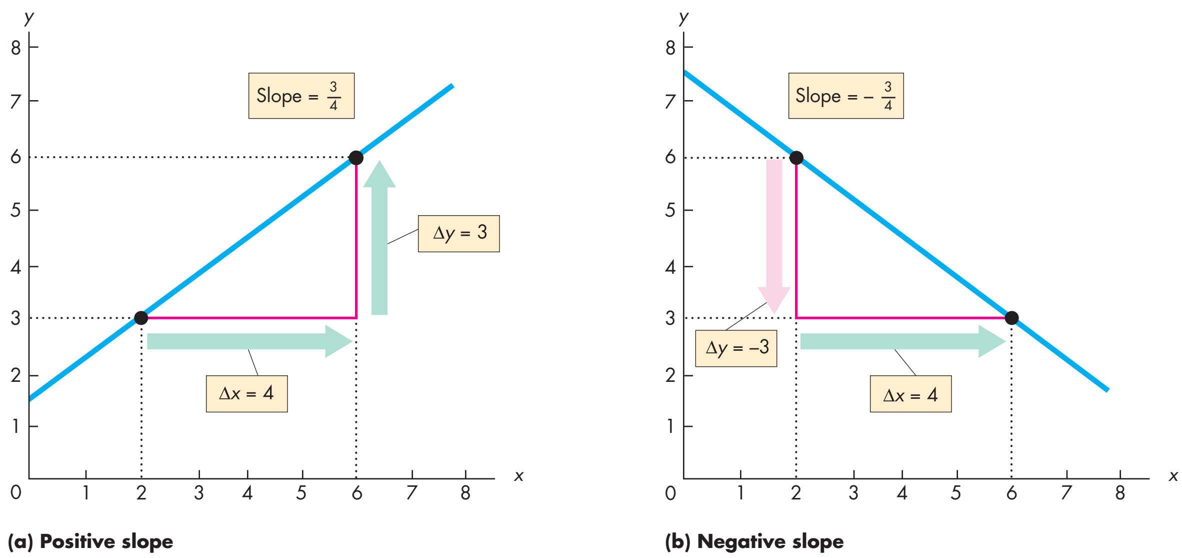
If a large change in the variable measured on the *y*-axis (Δy) is associated with a small change in the variable measured on the *x*-axis (Δx), the slope is large and the curve is steep. If a small change in the variable measured on the *y*-axis (Δy) is associated with a large change in the variable measured on the *x*-axis (Δx), the slope is small and the curve is flat.

We can make the idea of slope clearer by doing some calculations.

The Slope of a Straight Line

The slope of a straight line is the same regardless of where on the line you calculate it. The slope of a straight line is constant. Let's calculate the slope of the positive relationship in Fig. A1.9. In part (a),

FIGURE A1.9 The Slope of a Straight Line



To calculate the slope of a straight line, we divide the change in the value of the variable measured on the *y*-axis (Δy) by the change in the value of the variable measured on the *x*-axis (Δx) as we move along the line.

Part (a) shows the calculation of a positive slope. When *x* increases from 2 to 6, Δx equals 4. That change in *x* brings about an increase in *y* from 3 to 6, so Δy equals 3. The slope ($\Delta y/\Delta x$) equals 3/4.

Part (b) shows the calculation of a negative slope. When *x* increases from 2 to 6, Δx equals 4. That increase in *x* brings about a decrease in *y* from 6 to 3, so Δy equals –3. The slope ($\Delta y/\Delta x$) equals –3/4.

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when x increases from 2 to 6, y increases from 3 to 6. The change in x is +4—that is, Δx is 4. The change in y is +3—that is, Δy is 3. The slope of that line is

$$\frac{\Delta y}{\Delta x} = \frac{3}{4}.$$

In part (b), when x increases from 2 to 6, y decreases from 6 to 3. The change in y is *minus* 3—that is, Δy is –3. The change in x is *plus* 4—that is, Δx is 4. The slope of the curve is

$$\frac{\Delta y}{\Delta x} = \frac{-3}{4}.$$

Notice that the two slopes have the same magnitude (3/4), but the slope of the line in part (a) is positive (+3/+4 = 3/4) while that in part (b) is negative (–3/+4 = –3/4). The slope of a positive relationship is positive; the slope of a negative relationship is negative.

The Slope of a Curved Line

The slope of a curved line is trickier. The slope of a curved line is not constant, so the slope depends on where on the curved line we calculate it. There are two ways to calculate the slope of a curved line: You can calculate the slope at a point, or you can calculate the slope across an arc of the curve. Let's look at the two alternatives.

Slope at a Point To calculate the slope at a point on a curve, you need to construct a straight line that has the same slope as the curve at the point in question. Figure A1.10 shows how this is done. Suppose you want to calculate the slope of the curve at point *A*. Place a ruler on the graph so that the ruler touches point *A* and no other point on the curve, then draw a straight line along the edge of the ruler. The straight red line is this line, and it is the tangent to the curve at point *A*. If the ruler touches the curve only at point *A*, then the slope of the curve at point *A* must be the same as the slope of the edge of the ruler. If the curve and the ruler do not have the same slope, the line along the edge of the ruler will cut the curve instead of just touching it.

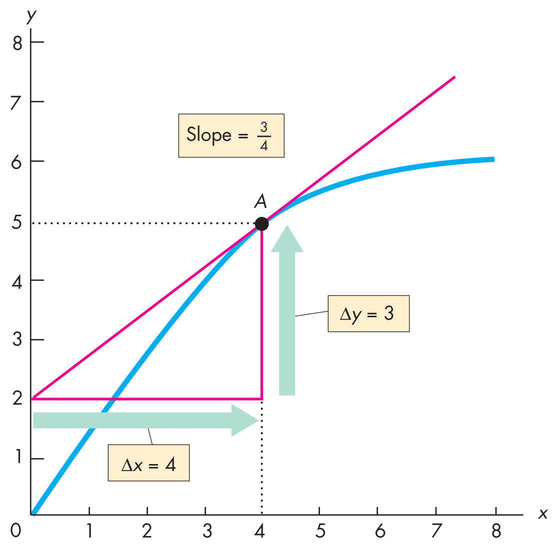
Now that you have found a straight line with the same slope as the curve at point *A*, you can calculate the slope of the curve at point *A* by calculating the slope of the straight line. Along the straight line, as x increases from 0 to 4 (Δx is 4) y increases from 2 to 5 (Δy is 3). Therefore the slope of the straight line is

$$\frac{\Delta y}{\Delta x} = \frac{3}{4}.$$

So the slope of the curve at point *A* is 3/4.

Slope Across an Arc An arc of a curve is a piece of a curve. Fig. A1.11shows the same curve as in Fig. A1.10, but instead of calculating the slope at point *A*, we are now going to calculate the slope across the arc from point *B* to point *C*. You can see that the slope of the curve at point *B* is greater than at point *C*. When we calculate the slope across an arc, we are calculating the average slope between two points. As we move along the arc from *B* to *C*, x increases from 3 to 5 and y increases from 4.0 to 5.5. The change in x is 2 (Δx is 2), and the change in y is 1.5 (Δy is 1.5).

FIGURE A1.10 Slope at a Point



To calculate the slope of the curve at point *A*, draw the red line that just touches the curve at *A*—the tangent. The slope of this straight line is calculated by dividing the change in y by the change in x along the red line. When x increases from 0 to 4, Δx equals 4. That change in x is associated with an increase in y from 2 to 5, so Δy equals 3. The slope of the red line is 3/4, so the slope of the curve at point *A* is 3/4.

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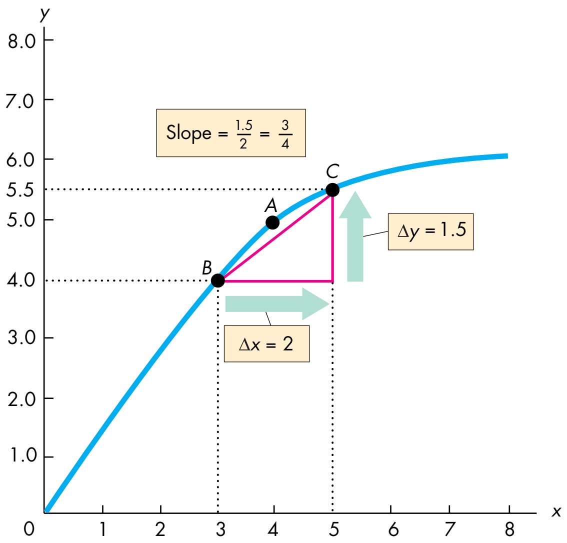
FIGURE A1.11 Slope Across an Arc



To calculate the average slope of the curve along the arc *BC*, draw a straight line from point *B* to point *C*. The slope of the line *BC* is calculated by dividing the change in *y* by the change in *x*. In moving from *B* to *C*, the increase in x is 2 (Δx equals 2) and the change in y is 1.5 (Δy equals 1.5). The slope of the line *BC* is 1.5 divided by 2, or 3/4. So the slope of the curve across the arc *BC* is 3/4.

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Therefore the slope is

$$\frac{\Delta y}{\Delta x} = \frac{1.5}{2} = \frac{3}{4}.$$

So the slope of the curve across the arc *BC* is 3/4.

This calculation gives us the slope of the curve between points *B* and *C*. The actual slope calculated is the slope of the straight line from *B* to *C*. This slope approximates the average slope of the curve along the arc *BC*. In this particular example, the slope across the arc *BC* is identical to the slope of the curve at point *A*, but the calculation of the slope of a curve does not always work out so neatly. You might have fun constructing some more examples and a few counter examples.

You now know how to make and interpret a graph. So far, we've limited our attention to graphs of two variables. We're now going to learn how to graph more than two variables.

Graphing Relationships Among More Than Two Variables

We have seen that we can graph the relationship between two variables as a point formed by the *x*- and *y*-coordinates in a two-dimensional graph. You might be thinking that although a two-dimensional graph is informative, most of the things in which you are likely to be interested involve relationships among many variables, not just two. For example, the amount of ice cream consumed depends on the price of ice cream and the temperature. If ice cream is expensive and the temperature is low, people eat much less ice cream than when ice cream is inexpensive and the temperature is high. For any given price of ice cream, the quantity consumed varies with the temperature; and for any given temperature, the quantity of ice cream consumed varies with its price.

Figure A1.12 shows a relationship among three variables. The table shows the number of gallons of ice cream consumed each day at two different temperatures and at a number of different prices of ice cream. How can we graph these numbers?

To graph a relationship that involves more than two variables, we use the *ceteris paribus* assumption.

Ceteris Paribus

Ceteris paribus (often shortened to *cet par*) means "if all other relevant things remain the same." To isolate the relationship of interest in a laboratory experiment, a scientist holds everything constant except for the variable whose effect is being studied. Economists use the same method to graph a relationship that has more than two variables.

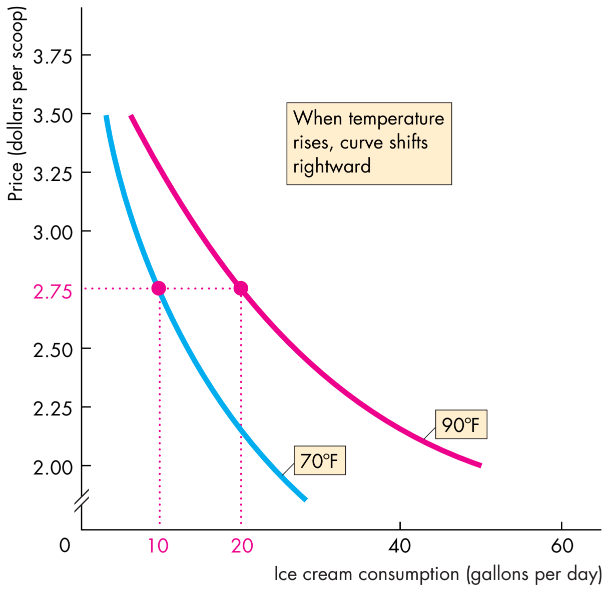
Figure A1.12 shows an example. There, you can see what happens to the quantity of ice cream consumed when the price of ice cream varies but the temperature is held constant.

The curve labeled 70°F shows the relationship between ice cream consumption and the price of ice cream if the temperature remains at 70°F. The numbers used to plot that curve are those in the first two columns of the table. For example, if the temperature is 70°F, 10 gallons are consumed when the price is \$2.75 a scoop and 18 gallons are consumed when the price is \$2.25 a scoop.

The curve labeled 90°F shows the relationship between ice cream consumption and the price of ice cream if the temperature remains at 90°F. The

FIGURE A1.12 Graphing a Relationship Among Three Variables

Price (dollars per scoop)	Ice cream consumption (gallons per day) 70°F	90°F
2.00	25	50
2.25	18	36
2.50	13	26
2.75	**10**	**20**
3.00	7	14
3.25	5	10
3.50	3	6



Ice cream consumption depends on its price and the temperature. The table tells us how many gallons of ice cream are consumed each day at different prices and two different temperatures. For example, if the price is $2.75 a scoop and the temperature is 70°F, 10 gallons of ice cream are consumed.

To graph a relationship among three variables, the value of one variable is held constant. The graph shows the relationship between price and consumption when temperature is held constant. One curve holds temperature at 70°F and the other holds it at 90°F.

A change in the price of ice cream brings a movement along one of the curves—along the blue curve at 70°F and along the red curve at 90°F.

When the temperature *rises* from 70°F to 90°F, the curve that shows the relationship between consumption and price *shifts* rightward from the blue curve to the red curve.

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numbers used to plot that curve are those in the first and third columns of the table. For example, if the temperature is 90°F, 20 gallons are consumed when the price is $2.75 a scoop and 36 gallons are consumed when the price is $2.25 a scoop.

When the price of ice cream changes but the temperature is constant, you can think of what happens in the graph as a movement along one of the curves. At 70°F there is a movement along the blue curve and at 90°F there is a movement along the red curve.

When Other Things Change

The temperature is held constant along each of the curves in Fig. A1.12, but in reality the temperature changes. When that event occurs, you can think of what happens in the graph as a shift of the curve. When the temperature rises from 70°F to 90°F, the curve that shows the relationship between ice cream consumption and the price of ice cream shifts rightward from the blue curve to the red curve.

You will encounter these ideas of movements along and shifts of curves at many points in your study of economics. Think carefully about what you've just learned and make up some examples (with assumed numbers) about other relationships.

With what you have learned about graphs, you can move forward with your study of economics. There are no graphs in this book that are more complicated than those that have been explained in this appendix.