

APPENDIX G

Business and Economic Applications

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In Section 2.6, you learned that one of the most common ways to measure change is with respect to time. In this section, you will study some important rates of change in economics that are not measured with respect to time. For example, economists refer to **marginal profit**, **marginal revenue**, and **marginal cost** as the rates of change of the profit, revenue, and cost with respect to the number of units produced or sold.

Summary of Business Terms and Formulas

Basic Terms

x is the number of units produced (or sold)

p is the price per unit

R is the total revenue from selling x units

C is the total cost of producing x units

\bar{C} is the average cost per unit

P is the total profit from selling x units

The **break-even point** is the number of units for which $R = C$.

Basic Formulas

$$R = xp$$

$$\bar{C} = \frac{C}{x}$$

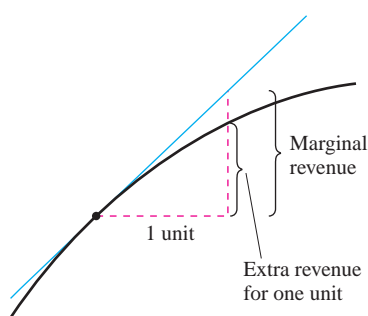
$$P = R - C$$

Marginals

$$\frac{dR}{dx} = (\text{Marginal revenue}) \approx (\text{extra revenue from selling one additional unit})$$

$$\frac{dC}{dx} = (\text{Marginal cost}) \approx (\text{extra cost of producing one additional unit})$$

$$\frac{dP}{dx} = (\text{Marginal profit}) \approx (\text{extra profit from selling one additional unit})$$



A revenue function
Figure G.1

In this summary, note that marginals can be used to approximate the *extra* revenue, cost, or profit associated with selling or producing one additional unit. This is illustrated graphically for marginal revenue in Figure G.1.

EXPLORATION

Graphs of Revenue Functions The graph of the revenue function shown in Figure 3.67 is concave down. How can that be? Shouldn't a revenue function be linear, of the form

$$R = xp$$

where x is the number of units and p is the price? Discuss this question within your group or class. Consider that the number of units sold x may itself be a function of the price per unit p . For instance, by lowering the price per unit, you may be able to increase the number of units sold.

EXAMPLE 1 Using Marginals as Approximations

A manufacturer determines that the profit derived from selling x units of a certain item is given by $P = 0.0002x^3 + 10x$.

- Find the marginal profit for a production level of 50 units.
- Compare this with the actual gain in profit obtained by increasing the production from 50 to 51 units. (See Figure G.2.)

Solution

- The marginal profit is given by

$$\frac{dP}{dx} = 0.0006x^2 + 10.$$

When $x = 50$, the marginal profit is

$$\frac{dP}{dx} = (0.0006)(50)^2 + 10 = \$11.50. \quad \text{Marginal profit}$$

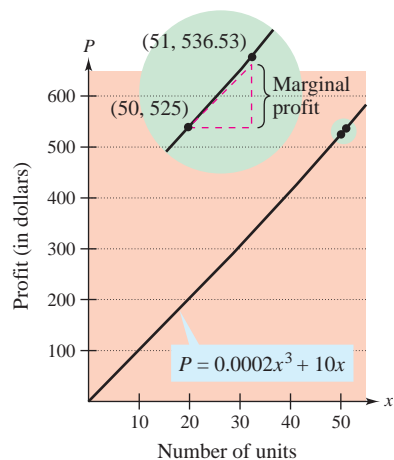
- For $x = 50$ and 51, the actual profits are

$$P = (0.0002)(50)^3 + 10(50) = 25 + 500 = \$525.00$$

$$P = (0.0002)(51)^3 + 10(51) = 26.53 + 510 = \$536.53.$$

Thus, the additional profit obtained by increasing the production level from 50 to 51 units is

$$536.53 - 525.00 = \$11.53. \quad \text{Extra profit for one unit}$$



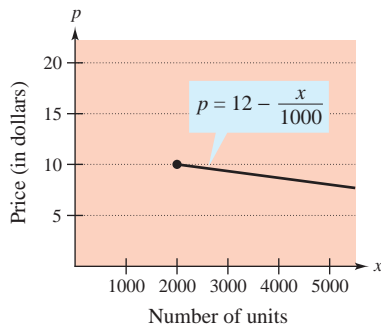
Marginal profit is the extra profit from selling one additional unit.

Figure G.2

The profit function in Example 1 is unusual in that the profit continues to increase as long as the number of units sold increases. In practice, it is more common to encounter situations in which sales can be increased only by lowering the price per item. Such reductions in price ultimately cause the profit to decline. The number of units x that consumers are willing to purchase at a given price p per unit is defined as the **demand function**

$$p = f(x).$$

Demand function



A demand function p
Figure G.3

EXAMPLE 2 Finding the Demand Function

A business sells 2000 items per month at a price of \$10 each. It is predicted that monthly sales will increase by 250 items for each \$0.25 reduction in price. Find the demand function corresponding to this prediction.

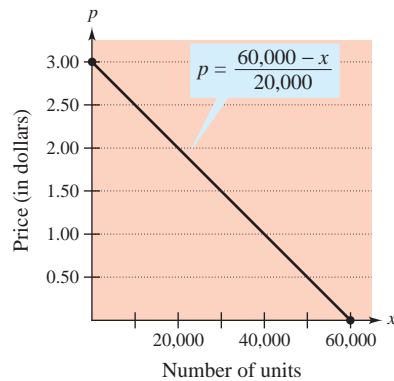
Solution From the given prediction, x increases 250 units each time p drops \$0.25 from the original cost of \$10. This is described by the equation

$$x = 2000 + 250\left(\frac{10 - p}{0.25}\right) = 12,000 - 1000p$$

or

$$p = 12 - \frac{x}{1000}, \quad x \geq 2000. \quad \text{Demand function}$$

The graph of the demand function is shown in Figure G.3.



As the price decreases, more hamburgers are sold.

Figure G.4

EXAMPLE 3 Finding the Marginal Revenue

A fast-food restaurant has determined that the monthly demand for its hamburgers is

$$p = \frac{60,000 - x}{20,000}.$$

Find the increase in revenue per hamburger (marginal revenue) for monthly sales of 20,000 hamburgers. (See Figure G.4.)

Solution Because the total revenue is given by $R = xp$, you have

$$R = xp = x\left(\frac{60,000 - x}{20,000}\right) = \frac{1}{20,000}(60,000x - x^2)$$

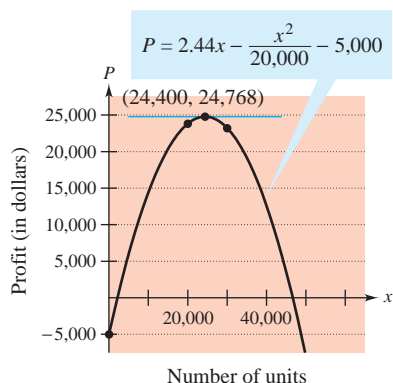
and the marginal revenue is

$$\frac{dR}{dx} = \frac{1}{20,000}(60,000 - 2x).$$

When $x = 20,000$, the marginal revenue is

$$\frac{dR}{dx} = \frac{1}{20,000}[60,000 - 2(20,000)] = \frac{20,000}{20,000} = \$1/\text{unit}.$$

NOTE The demand function in Example 3 is typical in that a high demand corresponds to a low price, as shown in Figure G.4.



The maximum profit corresponds to the point where the marginal profit is 0. When more than 24,400 hamburgers are sold, the marginal profit is negative—increasing production beyond this point will *reduce* rather than increase profit.

Figure G.5

EXAMPLE 4 Finding the Marginal Profit

Suppose that in Example 3 the cost of producing x hamburgers is

$$C = 5000 + 0.56x.$$

Find the total profit and the marginal profit for 20,000, for 24,400, and for 30,000 units.

Solution Because $P = R - C$, you can use the revenue function in Example 3 to obtain

$$\begin{aligned} P &= \frac{1}{20,000}(60,000x - x^2) - 5000 - 0.56x \\ &= 2.44x - \frac{x^2}{20,000} - 5000. \end{aligned}$$

Thus, the marginal profit is

$$\frac{dP}{dx} = 2.44 - \frac{x}{10,000}.$$

The table shows the total profit and the marginal profit for each of the three indicated demands. Figure G.5 shows the graph of the profit function.

Demand	20,000	24,400	30,000
Profit	\$23,800	\$24,768	\$23,200
Marginal profit	\$0.44	\$0.00	−\$0.56

EXAMPLE 5 Finding the Maximum Profit

In marketing a certain item, a business has discovered that the demand for the item is represented by

$$p = \frac{50}{\sqrt{x}}. \quad \text{Demand function}$$

The cost of producing x items is given by $C = 0.5x + 500$. Find the price per unit that yields a maximum profit (see Figure G.6).

Solution From the given cost function, you obtain

$$P = R - C = xp - (0.5x + 500). \quad \text{Primary equation}$$

Substituting for p (from the demand function) produces

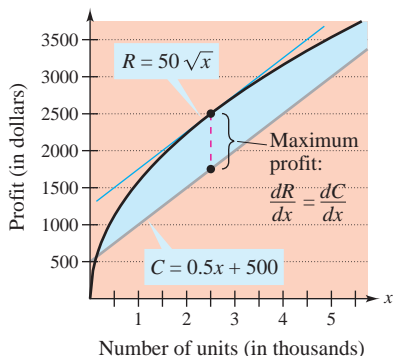
$$P = x\left(\frac{50}{\sqrt{x}}\right) - (0.5x + 500) = 50\sqrt{x} - 0.5x - 500.$$

Setting the marginal profit equal to 0

$$\frac{dP}{dx} = \frac{25}{\sqrt{x}} - 0.5 = 0$$

yields $x = 2500$. From this, you can conclude that the maximum profit occurs when the price is

$$p = \frac{50}{\sqrt{2500}} = \frac{50}{50} = \$1.00.$$



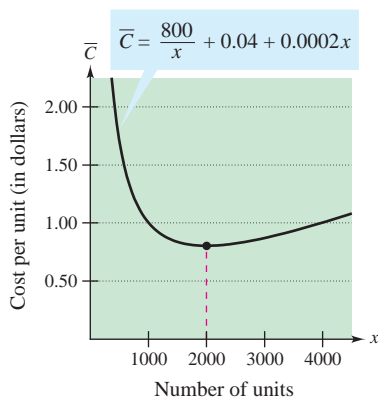
Maximum profit occurs when $\frac{dR}{dx} = \frac{dC}{dx}$.

Figure G.6

NOTE To find the maximum profit in Example 5, we differentiated the profit function, $P = R - C$, and set dP/dx equal to 0. From the equation

$$\frac{dP}{dx} = \frac{dR}{dx} - \frac{dC}{dx} = 0$$

it follows that the maximum profit occurs when the marginal revenue is equal to the marginal cost, as shown in Figure G.6.



Minimum average cost occurs when $\frac{d\bar{C}}{dx} = 0$.

Figure G.7

EXAMPLE 6 Minimizing the Average Cost

A company estimates that the cost (in dollars) of producing x units of a certain product is given by $C = 800 + 0.04x + 0.0002x^2$. Find the production level that minimizes the average cost per unit.

Solution Substituting from the given equation for C produces

$$\bar{C} = \frac{C}{x} = \frac{800 + 0.04x + 0.0002x^2}{x} = \frac{800}{x} + 0.04 + 0.0002x.$$

Setting the derivative $d\bar{C}/dx$ equal to 0 yields

$$\begin{aligned}\frac{d\bar{C}}{dx} &= -\frac{800}{x^2} + 0.0002 = 0 \\ x^2 &= \frac{800}{0.0002} = 4,000,000 \Rightarrow x = 2000 \text{ units.}\end{aligned}$$

(See Figure G.7.)

EXERCISES FOR APPENDIX G

- 1. Think About It** The figure shows the cost C of producing x units of a product.

- What is $C(0)$ called?
- Sketch a graph of the marginal cost function.
- Does the marginal cost function have an extremum? If so, describe what it means in economic terms.

- 2. Think About It** The figure shows the cost C and revenue R for producing and selling x units of a product.

- Sketch a graph of the marginal revenue function.
- Sketch a graph of the profit function. Approximate the position of the value of x for which profit is maximum.

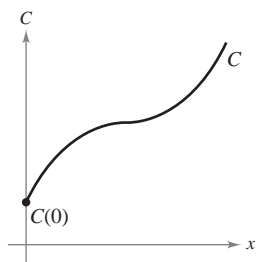


Figure for 1

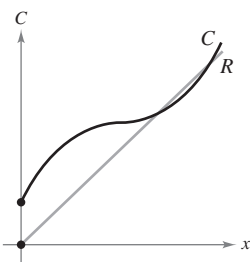


Figure for 2

In Exercises 3–6, find the number of units x that produces a maximum revenue R .

3. $R = 900x - 0.1x^2$

4. $R = 600x^2 - 0.02x^3$

5. $R = \frac{1,000,000x}{0.02x^2 + 1800}$

6. $R = 30x^{2/3} - 2x$

In Exercises 7–10, find the number of units x that produces the minimum average cost per unit \bar{C} .

7. $C = 0.125x^2 + 20x + 5000$

8. $C = 0.001x^3 - 5x + 250$

9. $C = 3000x - x^2\sqrt{300 - x}$

10. $C = \frac{2x^3 - x^2 + 5000x}{x^2 + 2500}$

In Exercises 11–14, find the price per unit p that produces the maximum profit P .

Cost Function

Demand Function

11. $C = 100 + 30x$

$p = 90 - x$

12. $C = 2400x + 5200$

$p = 6000 - 0.4x^2$

13. $C = 4000 - 40x + 0.02x^2$

$p = 50 - \frac{x}{100}$

14. $C = 35x + 2\sqrt{x-1}$

$p = 40 - \sqrt{x-1}$

Average Cost In Exercises 15 and 16, use the cost function to find the value of x at which the average cost is a minimum. For that value of x , show that the marginal cost and average cost are equal.

15. $C = 2x^2 + 5x + 18$

16. $C = x^3 - 6x^2 + 13x$

17. Prove that the average cost is a minimum at the value of x where the average cost equals the marginal cost.

18. **Maximum Profit** The profit for a certain company is

$$P = 230 + 20s - \frac{1}{2}s^2$$

where s is the amount (in hundreds of dollars) spent on advertising. What amount of advertising gives the maximum profit?



19. Numerical, Graphical, and Analytic Analysis The cost per unit for the production of a radio is \$60. The manufacturer charges \$90 per unit for orders of 100 or less. To encourage large orders, the manufacturer reduces the charge by \$0.15 per radio for each unit ordered in excess of 100 (for example, there would be a charge of \$87 per radio for an order size of 120).

(a) Analytically complete six rows of a table such as the one below. (The first two rows are shown.)

x	Price	Profit
102	$90 - 2(0.15)$	$102[90 - 2(0.15)] - 102(60) = 3029.40$
104	$90 - 4(0.15)$	$104[90 - 4(0.15)] - 104(60) = 3057.60$

(b) Use a graphing utility to generate additional rows of the table. Use the table to estimate the maximum profit. (Hint: Use the table feature of the graphing utility.)

(c) Write the profit P as a function of x .

(d) Use calculus to find the critical number of the function in part (c) and find the required order size.

(e) Use a graphing utility to graph the function in part (c) and verify the maximum profit from the graph.

20. Maximum Profit A real estate office handles 50 apartment units. When the rent is \$720 per month, all units are occupied. However, on the average, for each \$40 increase in rent, one unit becomes vacant. Each occupied unit requires an average of \$48 per month for service and repairs. What rent should be charged to obtain the maximum profit?

21. Minimum Cost A power station is on one side of a river that is $\frac{1}{2}$ mile wide, and a factory is 6 miles downstream on the other side. It costs \$12 per foot to run power lines over land and \$16 per foot to run them underwater. Find the most economical path for the transmission line from the power station to the factory.

22. Maximum Revenue When a wholesaler sold a certain product at \$25 per unit, sales were 800 units per week. After a price increase of \$5, the average number of units sold dropped to 775 per week. Assume that the demand function is linear, and find the price that will maximize the total revenue.



23. Minimum Cost The ordering and transportation cost C of the components used in manufacturing a certain product is

$$C = 100\left(\frac{200}{x^2} + \frac{x}{x+30}\right), \quad 1 \leq x$$

where C is measured in thousands of dollars and x is the order size in hundreds. Find the order size that minimizes the cost. (Hint: Use Newton's Method or the root feature of a graphing utility.)



24. Average Cost A company estimates that the cost in dollars of producing x units of a certain product is

$$C = 800 + 0.4x + 0.02x^2 + 0.0001x^3.$$

Find the production level that minimizes the average cost per unit. (Hint: Use Newton's Method or the root feature of a graphing utility.)

25. Revenue The revenue R for a company selling x units is

$$R = 900x - 0.1x^2.$$

Use differentials to approximate the change in revenue if sales increase from $x = 3000$ to $x = 3100$ units.




26. Analytic and Graphical Analysis A manufacturer of fertilizer finds that the national sales of fertilizer roughly follow the seasonal pattern

$$F = 100,000\left\{1 + \sin\left[\frac{2\pi(t-60)}{365}\right]\right\}$$

where F is measured in pounds. Time t is measured in days, with $t = 1$ corresponding to January 1.

(a) Use calculus to determine the day of the year when the maximum amount of fertilizer is sold.

(b) Use a graphing utility to graph the function and approximate the day of the year when sales are minimum.

-  **27. Modeling Data** The table shows the monthly wholesale distribution of gasoline G in billions of gallons for the year 1994 in the United States. The time in months is represented by t , with $t = 1$ corresponding to January. (Source: Federal Highway Electronic Bulletin Board)


t	1	2	3	4	5	6
G	8.91	9.18	9.79	9.83	10.37	10.16

t	7	8	9	10	11	12
G	10.37	10.81	10.03	9.97	9.85	9.51

A model for these data is

$$G = 9.90 - 0.64 \cos\left(\frac{\pi t}{6} - 0.62\right).$$


- Use a graphing utility to plot the data and graph the model.
- Use the model to approximate the month when wholesale gasoline sales were greatest.
- What factor in the model causes the seasonal variation in sales of gasoline? What part of the model gives the average monthly sales of gasoline?
- Suppose the Department of Energy added the term $0.02t$ to the model. What does the inclusion of this term mean? Use this model to estimate the maximum monthly consumption in the year 2000.

-  **28. Railroad Revenues** The annual revenue (in millions of dollars) for Union Pacific for the years 1985–1994 can be modeled by

$$R = 4.7t^4 - 193.5t^3 + 2941.7t^2 - 19,294.7t + 52,012$$

where $t = 0$ corresponds to 1980. (Source: Union Pacific Corporation)

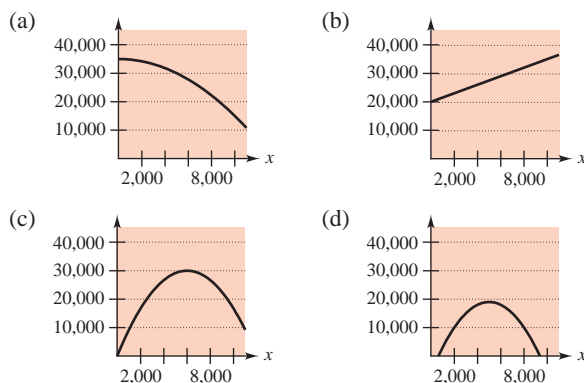
- During which year (between 1985 and 1994) was Union Pacific's revenue the least?
- During which year was the revenue the greatest?
- Find the revenues for the years in which the revenue was the least and greatest.
- Use a graphing utility to confirm the results in parts (a) and (b).

-  **29. Modeling Data** The manager of a department store recorded the quarterly sales S (in thousands of dollars) of a new seasonal product over a period of 2 years, as shown in the table, where t is the time in quarters, with $t = 1$ corresponding to the winter quarter of 1996.

t	1	2	3	4	5	6	7	8
S	7.5	6.2	5.3	7.0	9.1	7.8	6.9	8.6

- Use a graphing utility to plot the data.
- Find a model of the form $S = a + bt + c \sin \beta t$ for the data. (Hint: Start by finding β . Next, use a graphing utility to find $a + bt$. Finally, approximate c .)
- Use a graphing utility to graph the model and make any adjustments necessary to obtain a better fit.
- Use the model to predict the maximum quarterly sales in the year 2000.

- 30. Think About It** Match each graph with the function it best represents—a demand function, a revenue function, a cost function, or a profit function. Explain your reasoning. [The graphs are labeled (a), (b), (c), and (d).]



The relative responsiveness of consumers to a change in the price of an item is called the *price elasticity of demand*. If $p = f(x)$ is a differentiable demand function, the price elasticity of demand is

$$\eta = \frac{p/x}{dp/dx}.$$

For a given price, if $|\eta| < 1$, the demand is *inelastic*, and if $|\eta| > 1$, the demand is *elastic*.

Elasticity In Exercises 31–34, find η for the demand function at the indicated x -value. Is the demand elastic, inelastic, or neither at the indicated x -value?

- $p = 400 - 3x$
 $x = 20$
- $p = 5 - 0.03x$
 $x = 100$
- $p = 400 - 0.5x^2$
 $x = 20$
- $p = \frac{500}{x + 2}$
 $x = 23$