LEARNING OBJECTIVE

After completing this module, students will be able to:

1. Understand how the normal curve can be used in performing break-even analysis.
2. Compute the expected value of perfect information using the normal curve.
3. Perform marginal analysis where products have a constant marginal profit and loss.

MODULE OUTLINE

M3.1 Introduction
M3.2 Break-Even Analysis and the Normal Distribution
M3.3 Expected Value of Perfect Information and the Normal Distribution

Summary • Glossary • Key Equations • Solved Problems • Self-Test • Discussion Questions and Problems • Bibliography

Appendix M3.1: Derivation of the Break-Even Point
Appendix M3.2: Unit Normal Loss Integral
M3.1 Introduction

The normal distribution can be used when there are a large number of states and/or alternatives.

In Chapter 3 in your text we look at examples that deal with only a small number of states of nature and decision alternatives. But what if there were 50, 100, or even thousands of states and/or alternatives? If you used a decision tree or decision table, solving the problem would be virtually impossible. This module shows how decision theory can be extended to handle problems of such magnitude.

We begin with the case of a firm facing two decision alternatives under conditions of numerous states of nature. The normal probability distribution, which is widely applicable in business decision making, is first used to describe the states of nature.

M3.2 Break-Even Analysis and the Normal Distribution

Break-even analysis, often called cost-volume analysis, answers several common management questions relating the effect of a decision to overall revenues or costs. At what point will we break even, or when will revenues equal costs? At a certain sales volume or demand level, what revenues will be generated? If we add a new product line, will this action increase revenues? In this section we look at the basic concepts of break-even analysis and explore how the normal probability distribution can be used in the decision making process.

Barclay Brothers Company’s New Product Decision

Barclay Brothers Company is a large manufacturer of adult parlor games. Its marketing vice president, Rudy Barclay, must make the decision whether to introduce a new game called Strategy into the competitive market. Naturally, the company is concerned with costs, potential demand, and profit it can expect to make if it markets Strategy.

Rudy identifies the following relevant costs:

Fixed cost \( (f) \) = $36,000

Variable cost \( (v) \) per Game produced = $4

The selling price(s) per unit is set at $10.

The break-even point is the number of games at which total revenues are equal to total costs. It can be expressed as follows:

\[
\text{Break-even point (units)} = \frac{\text{Fixed cost}}{\text{Price/unit} - \text{Variable cost/unit}} = \frac{f}{s - v} \quad (M3-1)
\]

So in Barclay’s case,

\[
\text{Break-even point (games)} = \frac{\$36,000}{\$10 - \$4} = \frac{\$36,000}{\$6} = 6,000 \text{ games of Strategy}
\]

1For a detailed explanation of the break-even equation, see Appendix M3.1 at the end of this module.
Any demand for the new game that exceeds 6,000 units will result in a profit, whereas a demand less than 6,000 units will cause a loss. For example, if it turns out that demand is 11,000 games of Strategy, Barclay's profit would be $30,000:

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<td>Revenue</td>
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If demand is exactly 6,000 games (the break-even point), you should be able to compute for yourself that profit equals $0.

Rudy Barclay now has one useful piece of information that will help him make the decision about introducing the new product. If demand is less than 6,000 units, a loss will be incurred. But actual demand is not known. Rudy decides to turn to the use of a probability distribution to estimate demand.

**Probability Distribution of Demand**

Actual demand for the new game can be at any level—0 units, 1 unit, 2 units, 3 units, up to many thousands of units. Rudy needs to establish the probability of various levels of demand in order to proceed.

In many business situations the normal probability distribution is used to estimate the demand for a new product. It is appropriate when sales are symmetric around the mean expected demand and follow a bell-shaped distribution. Figure M3.1 illustrates a typical normal curve that we discussed at length in Chapter 2. Each curve has a unique shape that depends on two factors: the mean of the distribution (µ) and the standard deviation of the distribution (σ).

For Rudy Barclay to use the normal distribution in decision making, he must be able to specify values for µ and σ. This isn’t always easy for a manager to do directly, but if he or she has some idea of the spread, an analyst can determine the appropriate values. In the Barclay example, Rudy might think that the most likely sales figure is 8,000 but that demand might go as low as 5,000 or as high as 11,000. Sales could conceivably go even beyond those limits; say, there is a 15% chance of being below 5,000 and another 15% chance of being above 11,000.
Because this is a symmetric distribution, Rudy decides that a normal curve is appropriate. In Chapter 2, we demonstrate how to take the data in a normal curve such as Figure M3.2 and compute the value of the standard deviation. The formula for calculating the number of standard deviations that any value of demand is away from the mean is

$$Z = \frac{\text{Demand} - \mu}{\sigma}$$  \hspace{1cm} (M3-2)

where $Z$ is the number of standard deviations above or below the mean, $\mu$. It is provided in the table in Appendix A at the end of this text.

We see that the area under the curve to the left of 11,000 units demanded is 85% of the total area, or 0.85. From Appendix A, the $Z$ value for 0.85 is approximately 1.04. This means that a demand of 11,000 units is 1.04 standard deviations to the right of the mean, $\mu$.

With $\mu = 8,000$, $Z = 1.04$, and a demand of 11,000, we can easily compute $\sigma$:

$$Z = \frac{\text{demand} - \mu}{\sigma}$$

or

$$1.04 = \frac{11,000 - 8,000}{\sigma}$$

or

$$1.04\sigma = 3,000$$

or

$$\sigma = \frac{3,000}{1.04} = 2,885 \text{ units}$$

At last, we can state that Barclay’s demand appears to be normally distributed, with a mean of 8,000 games and a standard deviation of 2,885 games. This allows us to answer some questions of great financial interest to management, such as what the probability is of breaking even. Recalling that the break-even point is 6,000 games of Strategy, we must find the number of standard deviations from 6,000 to the mean:

$$Z = \frac{\text{break-even point} - \mu}{\sigma}$$

$$= \frac{6,000 - 8,000}{2,885} = \frac{-2,000}{2,885} = -0.69$$

This is represented in Figure M3.3. Because Appendix A is set up to handle only positive $Z$ values, we can find the $Z$ value for $+0.69$, which is 0.7549 or 75.49% of the area under the curve.
Break-Even

Profit Area = 75.49%

Loss Area = 24.51%

FIGURE M3.3
Probability of Breaking Even for Barclay’s New Game

The area under the curve for −0.69 is just 1 minus the area computed for +0.69, or 1 − 0.7549. Thus, 24.51% of the area under the curve is to the left of the break-even point of 6,000 units. Hence,

\[ P(\text{loss}) = P(\text{demand} < \text{break-even}) = 0.2451 \]
\[ = 24.51\% \]
\[ P(\text{profit}) = P(\text{demand} > \text{break-even}) = 0.7549 \]
\[ = 75.49\% \]

The fact that there is a 75% chance of making a profit is useful management information for Rudy to consider.

Before leaving the topic of break-even analysis, we should point out two caveats:

1. We have assumed that demand is normally distributed. If we find that this is not reasonable, other distributions may be applied. These distributions are beyond the scope of this book.
2. We have assumed that demand is the only random variable. If one of the other variables (price, variable cost, or fixed costs) were a random variable, a similar procedure could be followed. If two or more variables are both random, the mathematics becomes very complex. This is also beyond our level of treatment. Simulation (see Chapter 15) could be used to help with this type of situation.

Using Expected Monetary Value to Make a Decision

In addition to knowing the probability of suffering a loss with Strategy, Barclay is concerned about the expected monetary value (EMV) of producing the new game. He knows, of course, that the option of not developing Strategy has an EMV of $0. That is, if the game is not produced and marketed, his profit will be $0. If, however, the EMV of producing the game is greater than $0, he will recommend the more profitable strategy.

To compute the EMV for this strategy, Barclay uses the expected demand, \( \mu \), in the following linear profit function:

\[ \text{EMV} = (\text{Price/unit} - \text{Variable cost/unit}) \times (\text{Mean demand}) - \text{Fixed costs} \quad \text{(M3-3)} \]
\[ = (\$10 - \$4)(8,000 \text{ units}) - \$36,000 \]
\[ = 48,000 - 36,000 \]
\[ = 12,000 \]
Rudy has two choices at this point. He can recommend that the firm proceed with the new game; if so, he estimates there is a 75% chance of at least breaking even and an EMV of $12,000. Or, he might prefer to do further market research before making a decision. This brings up the subject of the expected value of perfect information.

**M3.3 Expected Value of Perfect Information and the Normal Distribution**

Let’s return to the Barclay Brothers problem to see how to compute the expected value of perfect information (EVPI) and expected opportunity loss (EOL) associated with introducing the new game. The two steps follow:

**Two Steps to Compute EVPI and EOL**

1. Determine the opportunity loss function.
2. Use the opportunity loss function and the unit normal loss integral (given in Appendix M3.2 at the end of this module) to find EOL, which is the same as EVPI.

**Opportunity Loss Function**

The opportunity loss function describes the loss that would be suffered by making the wrong decision. We saw earlier that Rudy’s break-even point is 6,000 sets of the game Strategy. If Rudy produces and markets the new game and sales are greater than 6,000 units, he has made the right decision; in this case there is no opportunity loss ($0). If, however, he introduces Strategy and sales are less than 6,000 games, he has selected the wrong alternative. The opportunity loss is just the money lost if demand is less than the break-even point; for example, if demand is 5,999 games, Barclay loses $6 (= $10 price/unit – $4 cost/unit). With a $6 loss for each unit of sales less than the break-even point, the total opportunity loss is $6 multiplied by the number of units under 6,000. If only 5,000 games are sold, the opportunity loss will be 1,000 units less than the break-even point times $6 per unit = $6,000. For any level of sales, \( X \), Barclay’s opportunity loss function can be expressed as follows:

\[
\text{Opportunity loss} = \begin{cases} 
\$6(6,000 - X) & \text{for } X \leq 6,000 \text{ games} \\
\$0 & \text{for } X > 6,000 \text{ games}
\end{cases}
\]

In general, the opportunity loss function can be computed by

\[
\text{Opportunity loss} = \begin{cases} 
K(\text{break-even point} - X) & \text{for } X \leq \text{break-even point} \\
\$0 & \text{for } X > \text{break-even point}
\end{cases} \quad (M3-4)
\]

where

\[
K = \text{loss per unit when sales are below the break-even point} \\
X = \text{sales in units}
\]

**Expected Opportunity Loss**

The second step is to find the expected opportunity loss. This is the sum of the opportunity losses multiplied by the appropriate probability values. But in Barclay’s case there are a very large number of possible sales values. If the break-even point is 6,000 games, there will be 6,000 possible sales values, from 0, 1, 2, 3, up to 6,000 units. Thus, determining the EOL would require setting 6,000 probability values that correspond to the 6,000 possible
sales values. These numbers would be multiplied and added together, a very lengthy and tedious task.

When we assume that there are an infinite (or very large) number of possible sales values that follow a normal distribution, the calculations are much easier. Indeed, when the unit normal loss integral is used, EOL can be computed as follows:

\[ EOL = K\sigma N(D) \]  

(M3-5)

where

\begin{align*}
EOL &= \text{expected opportunity loss} \\
K &= \text{loss per unit when sales are below the break-even point} \\
\sigma &= \text{standard deviation of the distribution} \\
N(D) &= \text{value for the unit normal loss integral in Appendix M3.2 for a given value of } D \\
D &= \left| \frac{\mu - \text{break-even point}}{\sigma} \right| 
\end{align*}

(M3-6)

where

\begin{align*}
|| &= \text{absolute value sign} \\
\mu &= \text{mean sales}
\end{align*}

Here is how Rudy can compute EOL for his situation:

\begin{align*}
K &= \$6 \\
\sigma &= 2,885 \\
D &= \left| \frac{8,000 - 6,000}{2,885} \right| = 0.69 = 0.60 + 0.09
\end{align*}

Now refer to the unit normal loss integral table in Appendix M3.2. Look in the “0.6” row and read over to the “0.9” column. This is \( N(0.69) \), which is 0.1453:

\[ N(0.69) = 0.1453 \]

Therefore,

\[ EOL = K\sigma N(0.69) = (\$6)(2,885)(0.1453) = \$2,515.14 \]

Because EVPI and minimum EOL are equivalent, the EVPI is also $2,515.14. This is the maximum amount that Rudy should be willing to spend on additional marketing information.

The relationship between the opportunity loss function and the normal distribution is shown in Figure M3.4. This graph shows both the opportunity loss and the normal distribution with a mean of 8,000 games and a standard deviation of 2,885. To the right of the break-even point we note that the loss function is 0. To the left of the break-even point, the opportunity loss function increases at a rate of $6 per unit, hence the slope of $\text{--}6$. The use of Appendix M3.2 and Equation M3-5 allows us to multiply the $6 unit loss times each of the probabilities between 6,000 units and 0 units and to sum these multiplications.
Summary

In this module we look at decision theory problems that involve many states of nature and alternatives. As an alternative to decision tables and decision trees, we demonstrate how to use the normal distribution to solve break-even problems and find the EMV and EVPI. We need to know the mean and standard deviation of the normal distribution and to be certain that it is the appropriate probability distribution to apply. Other continuous distributions can also be used, but they are beyond the level of this module.

Glossary

**Break-Even Analysis**  The analysis of relationships between profit, costs, and demand level.

**Opportunity Loss Function**  A function that relates opportunity loss in dollars to sales in units.

**Unit Normal Loss Integral**  A table that is used in the determination of EOL and EVPI.

Key Equations

(M3-1) Break-even point (in units)  
\[ \frac{\text{Fixed cost}}{\text{Price/unit} - \text{Variable cost/unit}} = \frac{f}{s - v} \]

The formula that provides the volume at which total revenue equals total costs.

(M3-2)  
\[ Z = \frac{\text{Demand} - \mu}{\sigma} \]

The number of standard deviations that demand is from the mean, \( \mu \).

(M3-3)  
\[ \text{EMV} = (\text{Price/unit} - \text{Variable cost/unit}) \times (\text{Mean demand}) - \text{Fixed costs} \]

The expected monetary value.

(M3-4)  
\[ \text{Opportunity loss} = \begin{cases} 
K (\text{Break-even point} - X) & \text{for } X \leq \text{Break-even point} \\
0 & \text{for } X > \text{Break-even point} 
\end{cases} \]

The opportunity loss function.

(M3-5)  
\[ EOL = K \sigma N(D) \]

The expected opportunity loss.

(M3-6)  
\[ D = \frac{\mu - \text{Break-even point}}{\sigma} \]

An intermediate value used to compute EOL.
Solved Problems

Solved Problem M3-1

Terry Wagner is considering self-publishing a book on yoga. She has been teaching yoga for more than 20 years. She believes that the fixed costs of publishing the book will be about $10,000. The variable costs are $5.50, and the price of the yoga book to bookstores is expected to be $12.50. What is the break-even point for Terry?

Solution

This problem can be solved using the break-even formulas in the module, as follows:

\[
\text{Break-even point in units} = \frac{\text{Fixed Costs}}{\text{Selling Price per Unit} - \text{Variable Cost per Unit}} = \frac{10,000}{12.50 - 5.50} = \frac{10,000}{7} = 1,429 \text{ units}
\]

Solved Problem M3-2

The annual demand for a new electric product is expected to be normally distributed with a mean of 16,000 and a standard deviation of 2,000. The break-even point is 14,000 units. For each unit less than 14,000, the company will lose $24. Find the expected opportunity loss.

Solution

The expected opportunity loss (EOL) is

\[
\text{EOL} = K \sigma N(D)
\]

We are given the following:

\[
K = \text{loss per unit} = $24 \\
\mu = 16,000 \\n\sigma = 2,000
\]

Using Equation M3-6, we find

\[
D = \left| \frac{\mu - \text{Break-even point}}{\sigma} \right| = \left| \frac{16,000 - 14,000}{2,000} \right| = 1
\]

\[
N(D) = N(1) = 0.08332 \text{ from Appendix M3.2}
\]

\[
\text{EOL} = K \sigma N(1) = 24(2,000)(0.08332) = $3,999.36
\]
Discussion Questions

M3-1 What is the purpose of conducting break-even analysis?

M3-2 Under what circumstances can the normal distribution be used in break-even analysis? What does it usually represent?

M3-3 What assumption do you have to make about the relationship between EMV and a state of nature when you are using the mean to determine the value of EMV?

M3-4 Describe how EVPI can be determined when the distribution of the states of nature follows a normal distribution.

Problems

M3-5 A publishing company is planning on developing an advanced quantitative analysis book for graduate students in doctoral programs. The company estimates that sales will be normally distributed, with mean sales of 60,000 copies and a standard deviation of 10,000 books. The book will cost $16 to produce and will sell for $24; fixed costs will be $160,000.

(a) What is the company’s break-even point?
(b) What is the EMV?

M3-6 Refer to Problem M3-5.
(a) What is the opportunity loss function?
(b) Compute the expected opportunity loss.
(c) What is the EVPI?
(d) What is the probability that the new book will be profitable?
(e) What do you recommend that the firm do?

M3-7 Barclay Brothers Company, the firm discussed in this module, thinks it underestimated the mean for its game Strategy. Rudy Barclay thinks expected sales may be 9,000 games. He also thinks that there is a 20% chance that sales will be less than 6,000 games and a 20% chance that he can sell more than 12,000 games.

(a) What is the new standard deviation of demand?
(b) What is the probability that the firm will incur a loss?
(c) What is the EMV?
(d) How much should Rudy be willing to pay now for a market research study?
M3-8 True-Lens, Inc., is considering producing long-wearing contact lenses. Fixed costs will be $24,000, with a variable cost per set of lenses of $8. The lenses will sell to optometrists for $24 per set.
(a) What is the firm’s break-even point?
(b) If expected sales are 2,000 sets, what should True-Lens do, and what are the expected profits?

M3-9 Leisure Supplies produces sinks and ranges for travel trailers and recreational vehicles. The unit price on its double sink is $28 and the unit cost is $20. The fixed cost in producing the double sink is $16,000. Mean sales for the double sinks have been 35,000 units, and the standard deviation has been estimated to be 8,000 sinks. Determine the expected monetary value for these sinks. If the standard deviation were actually 16,000 units instead of 8,000 units, what effect would this have on the expected monetary value?

M3-10 Belt Office Supplies sells desks, lamps, chairs, and other related supplies. The company’s executive lamp sells for $45, and Elizabeth Belt has determined that the break-even point for executive lamps is 30 lamps per year. If Elizabeth does not make the break-even point, she loses $10 per lamp. The mean sales for executive lamps has been 45, and the standard deviation is 30.
(a) Determine the opportunity loss function.
(b) Determine the expected opportunity loss.
(c) What is the EVPI?

M3-11 Elizabeth Belt is not completely certain that the loss per lamp is $10 if sales are below the break-even point (refer to Problem M3-10). The loss per lamp could be as low as $8 or as high as $15. What effect would these two values have on the expected opportunity loss?

M3-12 Leisure Supplies is considering the possibility of using a new process for producing sinks. This new process would increase the fixed cost by $16,000. In other words, the fixed cost would double (see Problem M3-9). This new process will improve the quality of the sinks and reduce the cost it takes to produce each sink. It will cost only $19 to produce the sinks using the new process.
(a) What do you recommend?
(b) Leisure Supplies is considering the possibility of increasing the purchase price to $32 using the old process given in Problem M3-9. It is expected that this will lower the mean sales to 26,000 units. Should Leisure Supplies increase the selling price?

M3-13 Quality Cleaners specializes in cleaning apartment units and office buildings. Although the work is not too enjoyable, Joe Boyett has been able to realize a considerable profit in the Chicago area. Joe is now thinking about opening another Quality Cleaners in Milwaukee. To break even, Joe would need to get 200 cleaning jobs per year. For every job under 200, Joe will lose $80. Joe estimates that the average sales in Milwaukee are 350 jobs per year, with a standard deviation of 150 jobs. A market research team has approached Joe with a proposition to perform a marketing study on the potential for his cleaning business in Milwaukee. What is the most that Joe would be willing to pay for the market research?

M3-14 Diane Kennedy is contemplating the possibility of going into competition with Primary Pumps, a manufacturer of industrial water pumps. Diane has gathered some interesting information from a friend of hers who works for Primary. Diane has been told that the mean sales for Primary are 5,000 units and the standard deviation is 50 units. The opportunity loss per pump is $100. Furthermore, Diane has been told that the most that Primary is willing to spend for market research for the demand potential for pumps is $500. Diane is interested in knowing the break-even point for Primary Pumps. Given this information, compute the break-even point.

M3-15 Jack Fuller estimates that the break-even point for EM5, a standard electrical motor, is 500 motors. For any motor that is not sold, there is an opportunity loss of $15. The average sales have been 700 motors, and 20% of the time sales have been between 650 and 750 motors. Jack has just been approached by Radner Research, a firm that specializes in performing marketing studies for industrial products, to perform a standard marketing study. What is the most that Jack would be willing to pay for market research?

M3-16 Jack Fuller believes that he has made a mistake in his sales figures for EM5 (see Problem M3-15 for details). He believes that the average sales are 750 instead of 700 units. Furthermore, he estimates that 20% of the time, sales will be between 700 and 800 units. What effect will these changes have on your estimate of the amount that Jack should be willing to pay for market research?

M3-17 Patrick’s Pressure Wash pays $4,000 per month to lease equipment that it uses for washing sidewalks, swimming pool decks, houses, and other things. Based on the size of a work crew, the cost of the labor used on a typical job is $80 per job. However, Patrick charges $120 per job, which results in a profit of $40 per job. How many jobs would be needed to break even each month?

M3-18 Determine the EVPI for Patrick’s Pressure Wash in Problem M3-17 if the average monthly demand is 120 jobs, with a standard deviation of 15.

M3-19 If Patrick (see Problem M3-17) charged $150 per job while his labor cost remained at $80 per job, what would be the break-even point?
Appendix M3.1: Derivation of the Break-Even Point

1. Total costs = Fixed cost + (Variable cost/unit) x (Number of units)
2. Total revenues = (Price/unit)(Number of units)
3. At break-even point, Total costs = Total revenues
4. Or, Fixed cost + (Variable cost/unit) x (Number of units) = (Price/unit)(Number of units)
5. Solving for the number of units at the break-even point, we get

\[
\text{Break-even point (units)} = \frac{\text{Fixed cost}}{\text{Price/unit} - \text{Variable cost/unit}}
\]

This equation is the same as Equation M3-1.
### Appendix M3.2: Unit Normal Loss Integral

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Example of table notation: \( .05848 = .00005848 \).
