Chapter 1

The Foundations of Statistics: Theory, Methods, and Measurement

Learning Objectives

- Understand the difference between statistics and math.
- Explain the role of statistics in the process of scientific inquiry.
- Discuss the relationship among theory, research methods, and statistics.
- Identify the steps in the research process.
- Understand the relationship among primary questions, research questions, null hypotheses, and research hypotheses.
- Explain the differences among nominal, ordinal, interval, and ratio level data.
- Determine the level of measurement for data in exercises.

Key Terms

bivariate statistics
concept
descriptive statistics
discovery
inferential statistics
interval
level of measurement
multivariate statistics
nominal
null hypothesis
observation
operationalization
ordinal
primary question

process of inquiry
ratio
research
research design
research hypothesis
research methods
research question
scientific inquiry
statistical analysis
statistics
theory
true zero
univariate statistics
variable

People often think statistics is a math class. It is true that statistics involves math—sometimes a lot of math. But statistics is more than just getting the right answer to a problem. Statistics is about *discovery*—discovery of something previously unknown or something we thought we knew but were not sure. For example, it is commonly believed that poverty causes crime. While there may be some relationship between the two, research has shown that poverty by itself does not cause crime. So what does?

Statistics, as a part of a research project, could help us figure this out—or at least know more about it. The process of *scientific inquiry* provides a method of examining things that interest us in a systematic manner. This process generally requires evidence to support an argument. One of the clearest methods of establishing evidence is by examining numbers associated with the objects being studied. That examination takes place through *statistical analysis*.

The purpose of this book is to further your knowledge of statistical analysis—and to do it in a way that makes sense and calms the fears of those who hate math. We will walk you through commonsense discussions of statistical procedures, introduce you to how to talk about statistics and the results of statistical analyses, and show you how to do statistical analyses in ways that are not as math heavy as many think necessary. We also want to give you some background on statistics so you may better understand where it came from and why it is important. It is to that history that we now turn.

1-1 Some Statistical History

The earliest form of what is now considered statistical analysis was developed by Pythagoras in the 6th century B.C. This was the forerunner of *descriptive statistics.* The other type of statistical analysis—*inferential statistics*—is thought to have first developed in the Orient around 200 B.C. in attempts to predict whether an expected child was likely to be male or female. Probability theory, as it would come to be known, was born in the form of gambling mathematics in the works of people such as Pascal (1623–1662). Many of the other descriptive statistics were developed in the late 1800s and early 1900s by mathematicians and scientists such as Galton (1883) and Pearson (1895).

Statistics moved beyond gambling and purely mathematical concepts through what was called political arithmetic, developed by John Graunt in 1662 to study London's death rates. Although there is fierce debate concerning the original use of the term *statistics*, the greatest support is that it was coined by Eberhard August Wilhelm von Zimmerman in 1787.

1-2   Statistics and the Process of Scientific Inquiry

Statistics as you will come to know them are methods used to examine data collected in the process of scientific inquiry. These methods allow researchers to think logically about the data and to do one of two things:

- To come to some succinct and meaningful conclusions about the data (descriptive statistics), or
- To determine—or infer—characteristics of large groups based on the data collected on small parts (samples) of the group (inferential statistics).

For example, data could be gathered on all children in all middle schools in the state for a research project to determine their breakdown according to sex and race. This would be a descriptive analysis. Alternatively, data from a sample of middle school students from one school district could be collected and the data from the sample used to make statements about all middle school children in the state. This would be drawing conclusions (inferences) about a large group based on information about a sample of the group.

But *statistics* is just one part of the process of scientific inquiry. The other two critical components are *theory* and *research methods*. Let's talk about these two briefly before we get into the concept of statistical analysis.

Theory

At the most basic level, theory consists of statements concerning the relationship among the characteristics of people or things. For example, in criminology, there are theories addressing how people learn to be criminal. In these theories, statements are constructed that deal with the role of peers in a person's learning of criminal behavior, how the rewards from a crime can influence behavior, and what influence punishment can have on the decision to commit a crime. The goal of these statements is to develop explanations of why things are as they appear and to try to explain their meaning.

We often have ideas about the causes of events and why things work the way that they do. The problem with these explanations, however, is that they are often too simplistic to be of any real value. Theory attempts to provide a stronger foundation for these ideas by asking questions such as:

- What is the point of all this?
- What does it mean?
- Why are things this way?

Without theory, there is often only conjecture and war stories. With theory, we may begin to develop statements or ideas that are based on sound observation and thought.

Research Methods

Theory cannot stand alone, however. Theory must also have research methods to give structure to the inquiry and *statistical analysis* to back it up. Theory without research and statistical analysis to back it up is little more than fable. Research methods without *theory* are like a house without plans. And research without statistical analysis is like building a house without nails.

Research methods are a scientific, systematic way of examining and testing theory. They are a systematic way of turning observation and statistical analysis into theory (induction) or testing theory through statistical analysis (deduction). Although there are no exact, cookbook steps that must be followed in conducting a study, there are some general guidelines that should be followed to ensure nothing is left out or done improperly. These are discussed next.

The Process of Conducting Research

The process of scientific inquiry (using a deductive method) is shown in **Figure 1-1**. This is a typical process of research, and it shows where statistics fits into the process. As shown in this diagram, theory and methods are at the starting point of the process. Many steps flow from theory and methods and where they meet. Each part of this figure and where it fits within the process of conducting research are discussed in the sections that follow.

Observation and Inquisitiveness

The first step in the process of scientific inquiry, and one of the most important, is often overlooked: *observation* and inquisitiveness. Many research projects are never begun because the researcher was not aware of his or her surroundings or did not recognize something as a topic worthy of research. As you go through school and read research and material you find interesting, you will sometimes think you have a better way to do something, or what you read may stimulate you to further examine a topic. This observation and curiosity is what starts the scientific process.

Primary Question

A *primary question* is the one driving thought behind a research project. It should represent the entire reason for the study. The primary question should be a carefully worded phrase that states exactly the focus of the study. For example, in research on
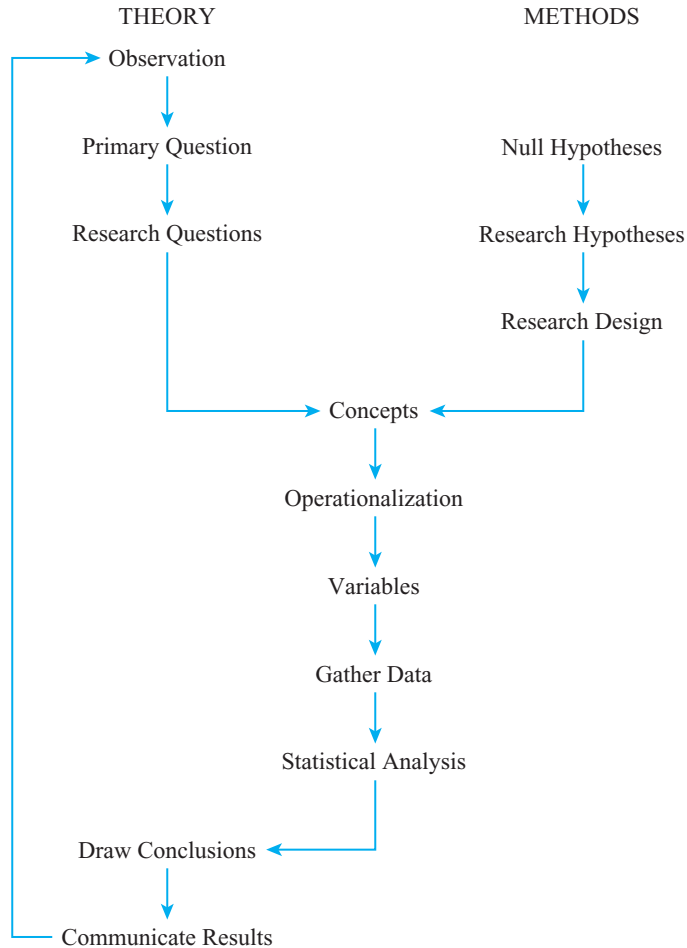
THEORY   METHODS

Observation

Primary Question   Null Hypotheses

Research Questions   Research Hypotheses

                                                   Research Design

                        Concepts

                     Operationalization

                         Variables

                        Gather Data

                    Statistical Analysis

Draw Conclusions

Communicate Results

Figure 1–1   Process of Scientific Inquiry Using a Deductive Method

what political parties people become involved in, a possible *primary question* might be, What factors most influence a person to participate in a specific political party?

Often, the primary question will be theoretical, vague, and perhaps not directly addressable through research. For that reason, *research questions* are the next step in the research process.

Research Questions

Research questions break down the primary question into subproblems that are more manageable and make the primary question testable through research. If the primary

question establishes the goal of the research, the research questions suggest ways of achieving that goal. In our earlier example concerning people participating in political parties, some possible *research questions* might include the following:

- What is the relationship between a person's family background and whether she or he is active in her or his political party?
- What is the relationship between a person's educational level and whether he or she is more likely to be a Republican or a Democrat?
- How does the economy influence both which political party a person belongs to and how active the person is in the party?

These research questions break down the primary question into smaller parts that can be examined more easily. The answers to these questions are derived from the research process and statistical analysis and allow the researcher to answer the primary question.

Hypotheses

Once the research questions have been developed, you must decide what the research is attempting to determine. This moves into the process of methods on the right side of Figure 1-1. Hypotheses are questions or statements whose answers will support or refute the theoretical questions of the research. Hypotheses are generally broken down into *null hypotheses* and *research hypotheses*. These match to the primary question and the research questions on the theory side of Figure 1-1. Null and research hypotheses are introduced here and discussed more fully in Chapters 9 and 10.

One of the often difficult to understand but vital aspects of research is that research alone cannot prove anything. Even when researchers find a great deal of support for an association between two variables, these results may occur because information is missing or the research is somehow flawed. Other researchers may be able to disprove these findings by conducting additional research. If research cannot *prove* anything, what can it do?

Research can be used to disprove something or to eliminate alternatives. For example, even though research cannot prove that more-educated people will be active in their political parties, it may disprove that there is no relationship between education and political activism. This is accomplished with a null hypothesis, which generally takes the form of one of the following examples:

- There is no statistically significant difference between the groups being compared.
- There is no statistically significant difference between a group being studied and the population.
- The differences between the groups are due to random errors.

This is an example of a null hypothesis:

There is no statistically significant difference between a person's education level and his or her probability of being active in a political party.

The null hypothesis is a broad hypothesis covering all of the research, much as a primary question does.

Like the primary question, the null hypothesis should be broken down into a number of research hypotheses. A research hypothesis is a statement, similar to a research question, that indicates the expected outcome of a part of a research project. If a research question in a project asks, "What is the relationship between a person's educational level and whether the person is more likely to be a Republican or Democrat?" then the research hypothesis might be, "There is a statistically significant correlation between a person's educational level and whether the person is more likely to be a Democrat."

In using research hypotheses, the researcher turns the relatively abstract wording of theory development into a more concrete, testable form appropriate for statistical analysis. Only after a clear picture of the theory to be tested has been developed through questions and hypotheses should the way of testing the theory be developed. This is critical. Many people want to first develop a survey and then determine what they can find out from it. Surveys should be developed far into the process of research, after a complete understanding of the theory and methods is developed.

Research Design

Once a decision is made of what will be studied, planning the research may begin. As a researcher, you should be cautious not to jump ahead of this step to other steps in the research process. You would not start building a house without first looking at other houses and thinking about what you want your house to look like; why would you start a research project without thorough consideration of what you want to do and find?

Activities in developing the *research design* include determining the method to be used (experiment, survey, or other method) and generally deciding how to approach the research. If the researcher has to collect the data, decisions must be made concerning how to collect it, what group it will be collected from, and other parameters.

Concepts

Once research questions and hypotheses have been developed, they must be broken down into more manageable parts. This is accomplished by drawing out the *concepts* from the questions and hypotheses. Concepts are terms that are generally agreed upon as representing a characteristic or a phenomenon. For example, *poverty* and *prejudice* are fairly abstract concepts. You know immediately what each of these means, but it

would probably be difficult for you to write a concise description of what they mean and even more difficult to get a consensus among the class members of what the terms mean.

The use of concepts allows researchers to break down questions and hypotheses but to retain the flexibility, for now, of not having to describe specifically what is being studied. In the example above concerning political activism, the concepts to be addressed are person, educational level, economic conditions, and party affiliation.

Operationalization and Variables

To be able to address concepts in terms of statistical analysis, the concepts must be placed in a form that can be analyzed mathematically. This is accomplished through *operationalization*. This is a process of translating a concept, which is abstract and verbal, into a *variable*, which can be seen and tested, by describing how the concept can be measured. The process of converting the abstract to the concrete can be seen in the example of political activism. In cases like this, the difference between a concept and a variable may be determined by asking if the word is specific enough to be able to find data on it. *Democrat* is a fairly clear term, but for the purposes of research it is still a concept that needs to be operationalized. Questions to be answered include the following:

- ■ Will all people who have registered to vote as a Democrat be used, or just people who voted in the last election?
- ■ Will people who only vote Democrat be selected, or will people who generally vote Democrat but sometimes vote Republican be included?

The answers to these questions and others will operationalize the somewhat vague concept of a Democrat into someone who can be classified as an object of the research.

The process of transforming concepts into variables demonstrates a critical point in operationalization: Operationalized definitions used in research are the researcher's definitions and do not have to match the definitions others might use or definitions the same researcher might use in other research. For example, in this research project, the term *Democrats* might be operationalized as only people who voted strictly Democrat in the last election. Others could define the term *Democrat* differently by including people who self-identify themselves as Democrats, even if they did not vote in the last election.

Gathering Data

Gathering the data is the step in the research process where most people want to begin, and it is nearly the last place they should begin. Returning to the example of building a house, to begin by gathering data would be like deciding to build a house and,

without developing any plans, ordering a truckload of 2×4s, 1,000 lbs of nails, and five bags of concrete and then going to work. You might actually get the house built this way, especially if you are an expert, but it would be better to begin with carefully developed plans.

Gathering the data should be a simple process if it is done properly. All you have to do is to look at the variables that have been operationalized from the concepts and gather the data you said you needed, following the rest of the research design created in that step.

Statistical Analysis

The next step in the research process is statistical analysis. Statistical analysis is the nuts-and-bolts work that gives researchers the information needed to determine the success or failure of the research. Statistical analysis deals specifically with the art of making comparisons, and it will be the focus of the rest of the chapters, so the discussion of statistical analysis is abbreviated here.

Drawing Conclusions

Mistakenly, many people believe the process of statistical analysis, and even scientific inquiry, stops at the end of the analysis. Nothing could be further from the truth. Statisticians and researchers distinguish themselves in the interpretation of analyses and in the conclusions that can be drawn. This is also generally the most difficult part of research.

This step involves determining if the results of the statistical analysis support the hypotheses developed at the beginning of the research process. At this step, the research process leaves statistical analysis and methodological issues and returns to theory. If the researcher is using a deductive process, this is the point at which the theory outlined in the first steps is compared to the results and a decision is made concerning whether the theory is supported or refuted.

Communicating Results

The final step in the process of scientific inquiry is to communicate the results of the research. This step is also often overlooked. Beyond just making sure people know of the findings of the research, it can also aid in the process of scientific inquiry, as discussed at the beginning of the chapter, by stimulating others to undertake research.

This concludes the research process. There is one more topic of research methods that needs to be addressed before we get completely into the art of statistics: levels of measurement of data.

1-3   Levels of Measurement

To be able to discuss the characteristics of our surroundings in terms of statistics, these characteristics must be in a form suitable for statistical analysis. A critical component of examining data is to determine the proper *level of measurement* of the data that has been (or will be) collected. This is important because the level of measurement of data is a determining factor in the type of statistical analyses that can be used. Incorrectly identifying the level of measurement of a variable can be disastrous to research because statistical analyses that are not appropriate for the data could mistakenly be used, which would give erroneous results.

Measurement itself is a way of assigning numbers, or numbered symbols, to characteristics (people, social phenomena, etc.), using certain rules and in such a way that the relationships between the numbers reflect the relationships between the characteristics or variables being studied. In fields such as physics or engineering, determining the level of measurement is easy. A person conducting research on the Space Shuttle can operate in terms of the speed of the Space Shuttle, height above Earth, and so on, which are already in the form of numbers. In social sciences, determining the level of measurement is not always so simple.

Every variable can be put into one of four categories: *nominal*, *ordinal*, *interval*, and *ratio*. Each of these levels of measurement has different characteristics that must be considered when deciding on a statistical procedure. Let's look at the different levels of measurement and what makes them special for certain types of statistical analysis.

Nominal Level Data

The lowest level of data in terms of levels of measurement is *nominal*. Nominal level data is purely qualitative in nature, meaning that the variables are typically found as words, as opposed to quantitative data, which is number-oriented. Variables in this category might include race, occupation, and hair color.

By assigning numbers to these characteristics, thereby making them useful for statistical analysis, we are doing nothing more than renaming them in a numeric format, and words or letters would serve just as well. For example, the categories of the variable "gender" could be classified as either male or female; or these categories could be abbreviated as M or F; or numbers could be substituted for these classifications, making them 1 and 2. The numbers are simply labels or names that can indicate how the groups differ; but the numbers have no real numeric significance that can tell magnitudes of differences or how the numbers are ordered. Additionally, they could be switched around such that female/male, F/M, and 2/1 also mean the same as in

the first three instances. The only reason to use numbers rather than letters is to make mathematical operations possible.

The primary difference between nominal level data and other levels of measurement is that nominal level data cannot be ordered. Since values are arbitrarily assigned, it cannot be argued that one value is greater than or less than another value. For example, coding blue eyes as 2 and brown eyes as 1 does not mean that blue eyes are better than brown eyes, and we could just as easily label blue eyes as 1 and brown eyes as 2. The variable *eye color* cannot be ordered on the characteristic being studied. It is very important, then, to establish the ordering (or lack thereof) of the categories. You should be very specific as to why the categories can or cannot be ordered. Failure to be very clear concerning the ability to order categories will almost always result in misclassification of the level of measurement. For example, you may have data such as patrol district number, which you obtained from the local police agency. These patrol district numbers may look as follows:

1
2
3
4
5

These are certainly ordered, right? Wrong. If you examined them closely, you would see that the numbers can be ordered but what they represent (patrol districts) is not ordered. You could just as easily have labeled them patrol districts A, B, C, D, E.

Ordinal Level Data

Ordinal level data is similar to nominal level data in that it is often made up of words that we place with numbers to use in math. For example, you might say a shirt comes in small, medium, and large. To use shirt size in research, however, you would need to assign it numbers; so you could assign them as small = 1, medium = 2, and large = 3.

The difference between nominal and ordinal level data is that ordinal level data can be ordered. In ordinal level data, the order of the numbers reflects the order of the relationship between the characteristics being studied. This order in the categories is such that one may be said to be less than or greater than another, but it cannot be said by how much. This ordering is similar to having a footrace without a stopwatch. It is possible to determine who finished first, but it is difficult to determine exactly by how much that runner won. In the example above, it is easy to see that a medium shirt is larger than a small shirt and smaller than a large shirt. But it is not possible to determine by how much each is different, and there may be differences between different

types of shirts. So the best we can do is to order the shirt sizes here. More precise measurement requires a higher level of data, as discussed next.

Interval Level Data

Interval level data builds on ordinal level data because the data may be ranked or ordered; but with interval level data, there are also equal intervals between categories. With ordinal level data it is not possible to know exactly what the interval is between, for example, shirt sizes of small, medium, and large; but with interval level data it can be established that there are equal intervals between, for example, miles per gallon in fuel economy (where the interval between each point is 1 mi/gal).

Ratio Level Data

Ratio level data is considered the highest order of data. It is interval level data with a *true zero*, where there is the possibility of a true absence of the characteristic in the variable. For example, income is generally considered to be a ratio level variable. You can certainly have zero income! Ratio data includes things that can be counted such as dollars, eggs, and people. Anything that is present and can be counted generally can have an absence of that item, so the data is ratio.

A very important thing to remember about levels of measurement is that a set of data has to meet *all* of the characteristics of the level of measurement, not just some of them. For example, it is possible to have something with a true zero. Suppose you are measuring social security numbers. It is possible for a person to not have a social security number, so there is the possibility of an absence of the number. However, social security numbers are not ordered in a meaningful way; so since they cannot be ordered, they are nominal even though they may have a true zero.

Practical Process for Determining Level of Measurement

As discussed above, properly identifying data and classifying it into its correct level of measurement are a vital part of the research process. A practical process for determining the level of measurement is shown in **Figure 1-2**.

The first step in this process is to determine if the data can be ordered. If the data cannot be ordered, or if the categories can be switched around such that the ordering does not matter, then the data is considered nominal level. If the data can be ordered, it is at least ordinal level and requires further examination. The next step in this process is to determine if there are equal intervals between data points. Note here that equal intervals need not be present—just the possibility of equal intervals. For example, when people are surveyed about their age, there are definite gaps in the data. This is so because there are usually not enough people surveyed to have someone at every possible
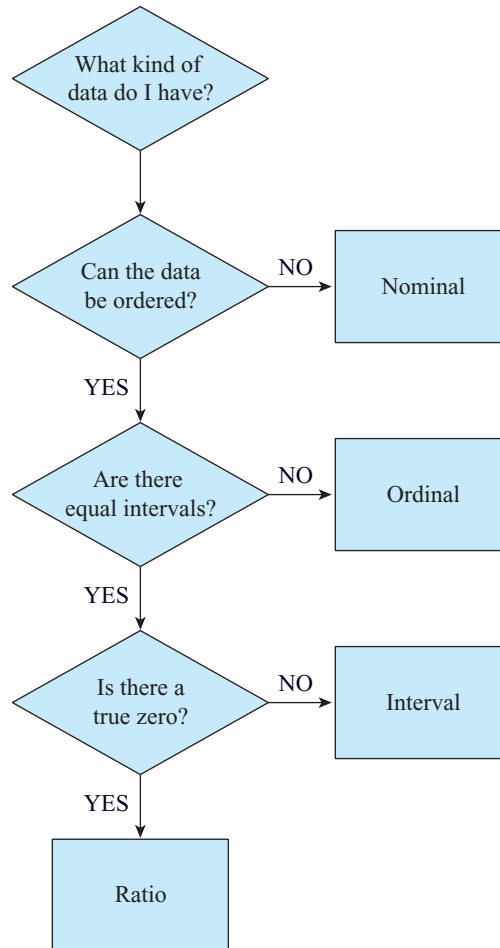
Figure 1–2   Process for Determining Level of Measurement

age. This does not mean the data is not interval, though, simply because there are not perfect intervals in the collected data. If there is no possibility of equal intervals but the data is ordered, then the data is ordinal. If there is the possibility of equal intervals between the data points, such as age in years or months (where the interval between each data point is one year or one month, respectively), then the data is at least interval level and requires further examination. The final step in this process is to determine if there is a true zero, whether clearly identifiable or implied. If there is no true zero, the data is interval; otherwise, the data is ratio level.

   There are a few important points to remember when you use this process to de-termine the level of measurement. These will not make the process of determining the

level of measurement easier, but they will make it more accurate. First, it is important to be specific about the data. It is not enough to think abstractly about the variable. You have to ask how the data is arranged *in this case*. This is particularly important in establishing whether the data is ordered. It is not sufficient simply to state that the data can be ordered. How can it be ordered? What specifically supports an argument that it can be ordered?

In addition, look at how the data is being used in the research. Age, for example, can be used in a number of ways in the research process—ways that can change the level of measurement. If age is categorized into groups (0–10, 11–20, etc.), it is probably ordinal level, whereas someone's age in years is probably interval level. Do not simply assume that all variables are measured at the same level all the time. Check the specifics of the research before you jump to conclusions about the level of measurement.

It is also imperative that you look beyond the numbers in a frequency distribution and look at the underlying dimension to understand whether there are equal intervals. For example, if you are examining how long in months prisoners have been incarcerated, the underlying dimension is time in prison in months. In this case, the interval is always months, regardless of what actually is displayed in a frequency distribution. In measuring the taste of doughnuts on a scale of 1 to 10, however, the underlying dimension is taste. The interval is how one doughnut tastes compared to another. Here, the interval will probably be different. For example, the difference between a 5 and a 6 may be quite different from that between a 1 and a 2, because when you move from a 5 to a 6, you are saying that the doughnut tastes good rather than just okay; thus the interval that may take a doughnut from a 5 to a 6 is probably larger than that to get from a 1 to a 2. The jump to get from a 9 to a perfect 10 may be the largest of all because it takes a great doughnut to be perfect. The bottom line here is that the intervals between different categories of taste are not the same, even though the difference in the numbers is 1.

Finally, it is imperative to work through the process outlined in Figure 1-2 until a "no" answer is reached. Ordering must be shown for a variable before equal intervals matter. There are many variables that have a true zero but cannot be ordered. Having a true zero does not matter if the data cannot be ordered; it is still nominal level data. To state that a variable is measured at the ratio level, it is necessary to show all of the following:

1. The data can be ordered.
2. There are equal intervals.
3. There is a true zero.

Also, do not succumb to the temptation to find that a variable can be ordered and then quit, stating that it is ordinal. Find out first if there are equal intervals. If there

are no equal intervals, the variable is ordinal; if there are equal intervals, the process continues.

1-4   For Further Reading

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