

Ask a half dozen econometricians what econometrics is, and you could get a half dozen different answers. One might tell you that econometrics is the science of testing economic theories. A second might tell you that econometrics is the set of tools used for forecasting future values of economic variables, such as a firm's sales, the overall growth of the economy, or stock prices. Another might say that econometrics is the process of fitting mathematical economic models to real-world data. A fourth might tell you that it is the science and art of using historical data to make numerical, or quantitative, policy recommendations in government and business.

In fact, all these answers are right. At a broad level, econometrics is the science and art of using economic theory and statistical techniques to analyze economic data. Econometric methods are used in many branches of economics, including finance, labor economics, macroeconomics, microeconomics, marketing, and economic policy. Econometric methods are also commonly used in other social sciences, including political science and sociology.

This text introduces you to the core set of methods used by econometricians. We will use these methods to answer a variety of specific, quantitative questions from the worlds of business and government policy. This chapter poses four of those questions and discusses, in general terms, the econometric approach to answering them. The chapter concludes with a survey of the main types of data available to econometricians for answering these and other quantitative economic questions.

## 1.1 Economic Questions We Examine

Many decisions in economics, business, and government hinge on understanding relationships among variables in the world around us. These decisions require quantitative answers to quantitative questions.

This text examines several quantitative questions taken from current issues in economics. Four of these questions concern education policy, racial bias in mortgage lending, cigarette consumption, and macroeconomic forecasting.

### Question #1: Does Reducing Class Size Improve Elementary School Education?

Proposals for reform of the U.S. public education system generate heated debate. Many of the proposals concern the youngest students, those in elementary schools. Elementary school education has various objectives, such as developing social skills,

but for many parents and educators, the most important objective is basic academic learning: reading, writing, and basic mathematics. One prominent proposal for improving basic learning is to reduce class sizes at elementary schools. With fewer students in the classroom, the argument goes, each student gets more of the teacher's attention, there are fewer class disruptions, learning is enhanced, and grades improve.

But what, precisely, is the effect on elementary school education of reducing class size? Reducing class size costs money: It requires hiring more teachers and, if the school is already at capacity, building more classrooms. A decision maker contemplating hiring more teachers must weigh these costs against the benefits. To weigh costs and benefits, however, the decision maker must have a precise quantitative understanding of the likely benefits. Is the beneficial effect on basic learning of smaller classes large or small? Is it possible that smaller class size actually has no effect on basic learning?

Although common sense and everyday experience may suggest that more learning occurs when there are fewer students, common sense cannot provide a quantitative answer to the question of what exactly is the effect on basic learning of reducing class size. To provide such an answer, we must examine empirical evidence—that is, evidence based on data—relating class size to basic learning in elementary schools.

In this text, we examine the relationship between class size and basic learning, using data gathered from 420 California school districts in 1999. In the California data, students in districts with small class sizes tend to perform better on standardized tests than students in districts with larger classes. While this fact is consistent with the idea that smaller classes produce better test scores, it might simply reflect many other advantages that students in districts with small classes have over their counterparts in districts with large classes. For example, districts with small class sizes tend to have wealthier residents than districts with large classes, so students in small-class districts could have more opportunities for learning outside the classroom. It could be these extra learning opportunities that lead to higher test scores, not smaller class sizes. In Part II, we use multiple regression analysis to isolate the effect of changes in class size from changes in other factors, such as the economic background of the students.

## Question #2: Is There Racial Discrimination in the Market for Home Loans?

Most people buy their homes with the help of a mortgage, a large loan secured by the value of the home. By law, U.S. lending institutions cannot take race into account when deciding to grant or deny a request for a mortgage: Applicants who are identical in all ways except their race should be equally likely to have their mortgage applications approved. In theory, then, there should be no racial bias in mortgage lending.

In contrast to this theoretical conclusion, researchers at the Federal Reserve Bank of Boston found (using data from the early 1990s) that 28% of black applicants are

denied mortgages, while only 9% of white applicants are denied. Do these data indicate that, in practice, there is racial bias in mortgage lending? If so, how large is it?

The fact that more black than white applicants are denied in the Boston Fed data does not by itself provide evidence of discrimination by mortgage lenders because the black and white applicants differ in many ways other than their race. Before concluding that there is bias in the mortgage market, these data must be examined more closely to see if there is a difference in the probability of being denied for *otherwise identical* applicants and, if so, whether this difference is large or small. To do so, in Chapter 11 we introduce econometric methods that make it possible to quantify the effect of race on the chance of obtaining a mortgage, *holding constant* other applicant characteristics, notably their ability to repay the loan.

### Question #3: Does Healthcare Spending Improve Health Outcomes?

It is self-evident that no one lives forever, but avoidable deaths can be reduced and survival can be extended through the provision of healthcare. Healthcare has other beneficial effects too, like the improvement of the health-related quality of life of individuals. To these ends and more, a vast quantity of resources is devoted to the provision of healthcare worldwide. What is more there is enormous variation in the healthcare expenditures across countries both in absolute and per capita terms, as well as variations in health outcomes across countries, for example measured by life expectancy at birth.

Putting aside concerns about *iatrogenesis* (the idea that healthcare is bad for your health), basic economics says that more expenditure on healthcare should generally reduce avoidable mortality. But by how much? If the amount spent on healthcare increases by 1%, by what percentage will avoidable mortality decrease? The percentage change in avoidable mortality resulting from a 1% increase in healthcare expenditure is the *spending elasticity for mortality* (analogous to the *price elasticity of demand*, which is the percentage change in quantity demanded from a 1% increase in price). If we want to reduce avoidable mortality, say, 20% by increasing healthcare expenditure, then we need to know the spending elasticity for mortality to calculate the healthcare expenditure increase necessary to achieve this reduction in avoidable mortality.

A number of policy objectives are based on meeting targets based on avoidable mortality; for example, one of the United Nations Development Programme's sustainable development goals is that all countries should aim to reduce "under-5 mortality to at least as low as 25 per 1,000 live births."<sup>1</sup> But how should the goal be met: from expanding healthcare services or other services? And if increasing healthcare spending is to form part of the mix of policies, by how much will it need to increase? The answers to these can be obtained with estimates of the spending elasticity for mortality.

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<sup>1</sup>United Nations Development Programme (UNDP), *The Sustainable Development Goals (SDGs): Goal 3: Good health and well-being*, 2017.

While economic theory, such as the production function for health, helps us analyze the mix of inputs that may lead to improved health outcomes, it does not tell us the actual values for parameters such as the spending elasticity for mortality. To estimate the value, we must examine empirical evidence about the returns to health-care spending—either based on variations in spending across countries or within countries over time (or both). In other words, we need to analyze the data on how health outcomes and healthcare expenditures are related.

For many years economists have attempted to address this question by considering the data on healthcare expenditures and mortality rates across countries, but such empirical research is fraught with challenges. Two of the biggest challenges concern the extensive heterogeneity across countries. The first challenge is observable heterogeneity, which concerns factors that affect countries' mortality rates that may also be associated with healthcare expenditure, for example, the income per capita of each country. This can be controlled for using multiple regression analysis, as described in Part II, since these factors are observable to the analyst. The second and more troublesome challenge is the presence of unobservable heterogeneity. Unobserved factors may be important in the underlying processes determining both how decisions are made on how much money is spent on healthcare, and how the overall level of health outcome that is attained. These factors result in causality running in both directions—healthcare reduces mortality, but higher healthcare expenditure might be a response to unobserved factors, such as small natural disasters that increase mortality. Methods for handling this “simultaneous causality” are described in Chapter 12, applied to the different but conceptually similar context of estimating the price elasticity of cigarette demand.

### Question #4: By How Much Will U.S. GDP Grow Next Year?

It seems that people always want a sneak preview of the future. What will sales be next year at a firm that is considering investing in new equipment? Will the stock market go up next month, and, if it does, by how much? Will city tax receipts next year cover planned expenditures on city services? Will your microeconomics exam next week focus on externalities or monopolies? Will Saturday be a nice day to go to the beach?

One aspect of the future in which macroeconomists are particularly interested is the growth of real economic activity, as measured by real gross domestic product (GDP), during the next year. A management consulting firm might advise a manufacturing client to expand its capacity based on an upbeat forecast of economic growth. Economists at the Federal Reserve Board in Washington, D.C., are mandated to set policy to keep real GDP near its potential in order to maximize employment. If they forecast anemic GDP growth over the next year, they might expand liquidity in the economy by reducing interest rates or other measures, in an attempt to boost economic activity.

Professional economists who rely on numerical forecasts use econometric models to make those forecasts. A forecaster's job is to predict the future by using the

past, and econometricians do this by using economic theory and statistical techniques to quantify relationships in historical data.

The data we use to forecast the growth rate of GDP include past values of GDP and the so-called term spread in the United States. The *term spread* is the difference between long-term and short-term interest rates. It measures, among other things, whether investors expect short-term interest rates to rise or fall in the future. The term spread is usually positive, but it tends to fall sharply before the onset of a recession. One of the GDP growth rate forecasts we develop and evaluate in Chapter 15 is based on the term spread.

### Quantitative Questions, Quantitative Answers

Each of these four questions requires a numerical answer. Economic theory provides clues about that answer—for example, cigarette consumption ought to go down when the price goes up—but the actual value of the number must be learned empirically, that is, by analyzing data. Because we use data to answer quantitative questions, our answers always have some uncertainty: A different set of data would produce a different numerical answer. Therefore, the conceptual framework for the analysis needs to provide both a numerical answer to the question and a measure of how precise the answer is.

The conceptual framework used in this text is the multiple regression model, the mainstay of econometrics. This model, introduced in Part II, provides a mathematical way to quantify how a change in one variable affects another variable, holding other things constant. For example, what effect does a change in class size have on test scores, *holding constant* or *controlling for* student characteristics (such as family income) that a school district administrator cannot control? What effect does your race have on your chances of having a mortgage application granted, *holding constant* other factors such as your ability to repay the loan? What effect does a 1% increase in the price of cigarettes have on cigarette consumption, *holding constant* the income of smokers and potential smokers? The multiple regression model and its extensions provide a framework for answering these questions using data and for quantifying the uncertainty associated with those answers.

## 1.2 Causal Effects and Idealized Experiments

Like many other questions encountered in econometrics, the first three questions in Section 1.1 concern causal relationships among variables. In common usage, an action is said to cause an outcome if the outcome is the direct result, or consequence, of that action. Touching a hot stove causes you to get burned, drinking water causes you to be less thirsty, putting air in your tires causes them to inflate, putting fertilizer on your tomato plants causes them to produce more tomatoes. Causality means that a specific action (applying fertilizer) leads to a specific, measurable consequence (more tomatoes).

## Estimation of Causal Effects

How best might we measure the causal effect on tomato yield (measured in kilograms) of applying a certain amount of fertilizer, say, 100 grams of fertilizer per square meter?

One way to measure this causal effect is to conduct an experiment. In that experiment, a horticultural researcher plants many plots of tomatoes. Each plot is tended identically, with one exception: Some plots get 100 grams of fertilizer per square meter, while the rest get none. Whether or not a plot is fertilized is determined randomly by a computer, ensuring that any other differences between the plots are unrelated to whether they receive fertilizer. At the end of the growing season, the horticulturalist weighs the harvest from each plot. The difference between the average yield per square meter of the treated and untreated plots is the effect on tomato production of the fertilizer treatment.

This is an example of a **randomized controlled experiment**. It is controlled in the sense that there are both a **control group** that receives no treatment (no fertilizer) and a **treatment group** that receives the treatment (100 g/m<sup>2</sup> of fertilizer). It is randomized in the sense that the treatment is assigned randomly. This random assignment eliminates the possibility of a systematic relationship between, for example, how sunny the plot is and whether it receives fertilizer so that the only systematic difference between the treatment and control groups is the treatment. If this experiment is properly implemented on a large enough scale, then it will yield an estimate of the causal effect on the outcome of interest (tomato production) of the treatment (applying 100 g/m<sup>2</sup> of fertilizer).

In this text, the **causal effect** is defined to be the effect on an outcome of a given action or treatment, as measured in an ideal randomized controlled experiment. In such an experiment, the only systematic reason for differences in outcomes between the treatment and control groups is the treatment itself.

It is possible to imagine an ideal randomized controlled experiment to answer each of the first three questions in Section 1.1. For example, to study class size, one can imagine randomly assigning “treatments” of different class sizes to different groups of students. If the experiment is designed and executed so that the only systematic difference between the groups of students is their class size, then in theory this experiment would estimate the effect on test scores of reducing class size, holding all else constant.

Experiments are used increasingly widely in econometrics. In many applications, however, they are not an option because they are unethical, impossible to execute satisfactorily, too time-consuming, or prohibitively expensive. Even with non-experimental data, the concept of an ideal randomized controlled experiment is important because it provides a definition of a causal effect.

## Prediction, Forecasting, and Causality

Although the first three questions in Section 1.1, concern causal effects, the fourth—forecasting the growth rate of GDP—does not.

Forecasting is a special case of what statisticians and econometricians call **prediction**, which is using information on some variables to make a statement about the value of another variable. A **forecast** is a prediction about the value of a variable in the future, like GDP growth next year.

You do not need to know a causal relationship to make a good prediction. A good way to “predict” whether it is raining is to observe whether pedestrians are using umbrellas, but the act of using an umbrella does not cause it to rain.

When one has a small number of predictors and the data do not evolve over time, the multiple regression methods of Part II can provide reliable predictions. Predictions can often be improved, however, if there is a large number of candidate predictors. Methods for using many predictors are covered in Chapter 14.

Forecasts—that is, predictions about the future—use data on variables that evolve over time, which introduces new challenges and opportunities. As we will see in Chapter 15, multiple regression analysis allows us to quantify historical relationships, to check whether those relationships have been stable over time, to make quantitative forecasts about the future, and to assess the accuracy of those forecasts.

## 1.3 Data: Sources and Types

In econometrics, data come from one of two sources: experiments or nonexperimental observations of the world. This text examines both experimental and nonexperimental data sets.

### Experimental versus Observational Data

**Experimental data** come from experiments designed to evaluate a treatment or policy or to investigate a causal effect. For example, the state of Tennessee financed a large randomized controlled experiment examining class size in the 1980s. In that experiment, which we examine in Chapter 13, thousands of students were randomly assigned to classes of different sizes for several years and were given standardized tests annually.

The Tennessee class size experiment cost millions of dollars and required the ongoing cooperation of many administrators, parents, and teachers over several years. Because real-world experiments with human subjects are difficult to administer and to control, they have flaws relative to ideal randomized controlled experiments. Moreover, in some circumstances, experiments are not only expensive and difficult to administer but also unethical. (Would it be ethical to offer randomly selected teenagers inexpensive cigarettes to see how many they buy?) Because of these financial, practical, and ethical problems, experiments in economics are relatively rare. Instead, most economic data are obtained by observing real-world behavior.

Data obtained by observing actual behavior outside an experimental setting are called **observational data**. Observational data are collected using surveys, such as telephone surveys of consumers, and administrative records, such as historical records on mortgage applications maintained by lending institutions.



Observational data pose major challenges to econometric attempts to estimate causal effects, and the tools of econometrics are designed to tackle these challenges. In the real world, levels of “treatment” (the amount of fertilizer in the tomato example, the student–teacher ratio in the class size example) are not assigned at random, so it is difficult to sort out the effect of the “treatment” from other relevant factors. Much of econometrics, and much of this text, is devoted to methods for meeting the challenges encountered when real-world data are used to estimate causal effects.

Whether the data are experimental or observational, data sets come in three main types: cross-sectional data, time series data, and panel data. In this text, you will encounter all three types.

Cross-Sectional Data

Data on different entities—workers, consumers, firms, governmental units, and so forth—for a single time period are called **cross-sectional data**. For example, the data on test scores in California school districts are cross sectional. Those data are for 420 entities (school districts) for a single time period (1999). In general, the number of entities on which we have observations is denoted  $n$ ; so, for example, in the California data set,  $n = 420$ .

The California test score data set contains measurements of several different variables for each district. Some of these data are tabulated in Table 1.1. Each row lists data for a different district. For example, the average test score for the first district (“district 1”) is 690.8; this is the average of the math and science test scores for all fifth-graders in that district in 1999 on a standardized test (the Stanford Achievement Test). The average student–teacher ratio in that district is 17.89; that is, the number of students in district 1 divided by the number of classroom teachers in district 1

TABLE 1.1 Selected Observations on Test Scores and Other Variables for California School Districts in 1999

Observation (District) Number	District Average Test Score (fifth grade)	Student-Teacher Ratio	Expenditure per Pupil (\$)	Percentage of Students Learning English
1	690.8	17.89	\$6385	0.0%
2	661.2	21.52	5099	4.6
3	643.6	18.70	5502	30.0
4	647.7	17.36	7102	0.0
5	640.8	18.67	5236	13.9
⋮	⋮	⋮	⋮	⋮
418	645.0	21.89	4403	24.3
419	672.2	20.20	4776	3.0
420	655.8	19.04	5993	5.0

Note: The California test score data set is described in Appendix 4.1.



is 17.89. Average expenditure per pupil in district 1 is \$6385. The percentage of students in that district still learning English—that is, the percentage of students for whom English is a second language and who are not yet proficient in English—is 0%.

The remaining rows present data for other districts. The order of the rows is arbitrary, and the number of the district, which is called the **observation number**, is an arbitrarily assigned number that organizes the data. As you can see in the table, all the variables listed vary considerably.

With cross-sectional data, we can learn about relationships among variables by studying differences across people, firms, or other economic entities during a single time period.

## Time Series Data

**Time series data** are data for a single entity (person, firm, country) collected at multiple time periods. Our data set on the growth rate of GDP and the term spread in the United States is an example of a time series data set. The data set contains observations on two variables (the growth rate of GDP and the term spread) for a single entity (the United States) for 232 time periods. Each time period in this data set is a quarter of a year (the first quarter is January, February, and March; the second quarter is April, May, and June; and so forth). The observations in this data set begin in the first quarter of 1960, which is denoted 1960:Q1, and end in the fourth quarter of 2017 (2017:Q4). The number of observations (that is, time periods) in a time series data set is denoted  $T$ . Because there are 232 quarters from 1960:Q1 to 2017:Q4, this data set contains  $T = 232$  observations.

Some observations in this data set are listed in Table 1.2. The data in each row correspond to a different time period (year and quarter). In the first quarter of 1960,

**TABLE 1.2** Selected Observations on the Growth Rate of GDP and the Term Spread in the United States: Quarterly Data, 1960:Q1–2017:Q4

Observation Number	Date (year: quarter)	GDP Growth Rate (% at an annual rate)	Term Spread (percentage points)
1	1960:Q1	8.8%	0.6
2	1960:Q2	−1.5	1.3
3	1960:Q3	1.0	1.5
4	1960:Q4	−4.9	1.6
5	1961:Q1	2.7	1.4
⋮	⋮	⋮	⋮
230	2017:Q2	3.0	1.4
231	2017:Q3	3.1	1.2
232	2017:Q4	2.5	1.2

*Note:* The United States GDP and term spread data set is described in Appendix 15.1.

for example, GDP grew 8.8% at an annual rate. In other words, if GDP had continued growing for four quarters at its rate during the first quarter of 1960, the level of GDP would have increased by 8.8%. In the first quarter of 1960, the long-term interest rate was 4.5%, and the short-term interest rate was 3.9%; so their difference, the term spread, was 0.6 percentage points.

By tracking a single entity over time, time series data can be used to study the evolution of variables over time and to forecast future values of those variables.

Panel Data

**Panel data**, also called **longitudinal data**, are data for multiple entities in which each entity is observed at two or more time periods. Our data on cigarette consumption and prices are an example of a panel data set, and selected variables and observations in that data set are listed in Table 1.3. The number of entities in a panel data set is denoted  $n$ , and the number of time periods is denoted  $T$ . In the cigarette data set, we have observations on  $n = 48$  continental U.S. states (entities) for  $T = 11$  years (time periods) from 1985 to 1995. Thus, there is a total of  $n \times T = 48 \times 11 = 528$  observations.

Some data from the cigarette consumption data set are listed in Table 1.3. The first block of 48 observations lists the data for each state in 1985, organized alphabetically from Alabama to Wyoming. The next block of 48 observations lists the data for

TABLE 1.3 Selected Observations on Cigarette Sales, Prices, and Taxes, by State and Year for U.S. States, 1985–1995

Observation Number	State	Year	Cigarette Sales (packs per capita)	Average Price per Pack (including taxes)	Total Taxes (cigarette excise tax + sales tax)
1	Alabama	1985	116.5	\$1.022	\$0.333
2	Arkansas	1985	128.5	1.015	0.370
3	Arizona	1985	104.5	1.086	0.362
⋮	⋮	⋮	⋮	⋮	⋮
47	West Virginia	1985	112.8	1.089	0.382
48	Wyoming	1985	129.4	0.935	0.240
49	Alabama	1986	117.2	1.080	0.334
⋮	⋮	⋮	⋮	⋮	⋮
96	Wyoming	1986	127.8	1.007	0.240
97	Alabama	1987	115.8	1.135	0.335
⋮	⋮	⋮	⋮	⋮	⋮
528	Wyoming	1995	112.2	1.585	0.360

Note: The cigarette consumption data set is described in Appendix 12.1.

## Cross-Sectional, Time Series, and Panel Data

### KEY CONCEPT

## 1.1

- Cross-sectional data consist of multiple entities observed at a single time period.
- Time series data consist of a single entity observed at multiple time periods.
- Panel data (also known as longitudinal data) consist of multiple entities, where each entity is observed at two or more time periods.

1986, and so forth, through 1995. For example, in 1985, cigarette sales in Arkansas were 128.5 packs per capita (the total number of packs of cigarettes sold in Arkansas in 1985 divided by the total population of Arkansas in 1985 equals 128.5). The average price of a pack of cigarettes in Arkansas in 1985, including tax, was \$1.015, of which 37¢ went to federal, state, and local taxes.

Panel data can be used to learn about economic relationships from the experiences of the many different entities in the data set and from the evolution over time of the variables for each entity.

The definitions of cross-sectional data, time series data, and panel data are summarized in Key Concept 1.1.

## Summary

1. Many decisions in business and economics require quantitative estimates of how a change in one variable affects another variable.
2. Conceptually, the way to estimate a causal effect is in an ideal randomized controlled experiment, but performing experiments in economic applications can be unethical, impractical, or too expensive.
3. Econometrics provides tools for estimating causal effects using either observational (nonexperimental) data or data from real-world, imperfect experiments.
4. Econometrics also provides tools for predicting the value of a variable of interest using information in other, related variables.
5. Cross-sectional data are gathered by observing multiple entities at a single point in time; time series data are gathered by observing a single entity at multiple points in time; and panel data are gathered by observing multiple entities, each of which is observed at multiple points in time.

## Key Terms

randomized controlled experiment (48)  
control group (48)

treatment group (48)  
causal effect (48)

prediction (49)

forecast (49)

experimental data (49)

observational data (49)

cross-sectional data (50)

observation number (51)

time series data (51)

panel data (52)

longitudinal data (52)

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## Review the Concepts

- 1.1 Describe a hypothetical ideal randomized controlled experiment to study the effect of six hours of reading on the improvement of the vocabulary of high school students. Suggest some impediments to implementing this experiment in practice.
- 1.2 Describe a hypothetical ideal randomized controlled experiment to study the effect of the consumption of alcohol on long-term memory loss. Suggest some impediments to implementing this experiment in practice.
- 1.3 You are asked to study the causal effect of hours spent on employee training (measured in hours per worker per week) in a manufacturing plant on the productivity of its workers (output per worker per hour). Describe:
  - a. an ideal randomized controlled experiment to measure this causal effect;
  - b. an observational cross-sectional data set with which you could study this effect;
  - c. an observational time series data set for studying this effect; and
  - d. an observational panel data set for studying this effect.