

## CHAPTER 11

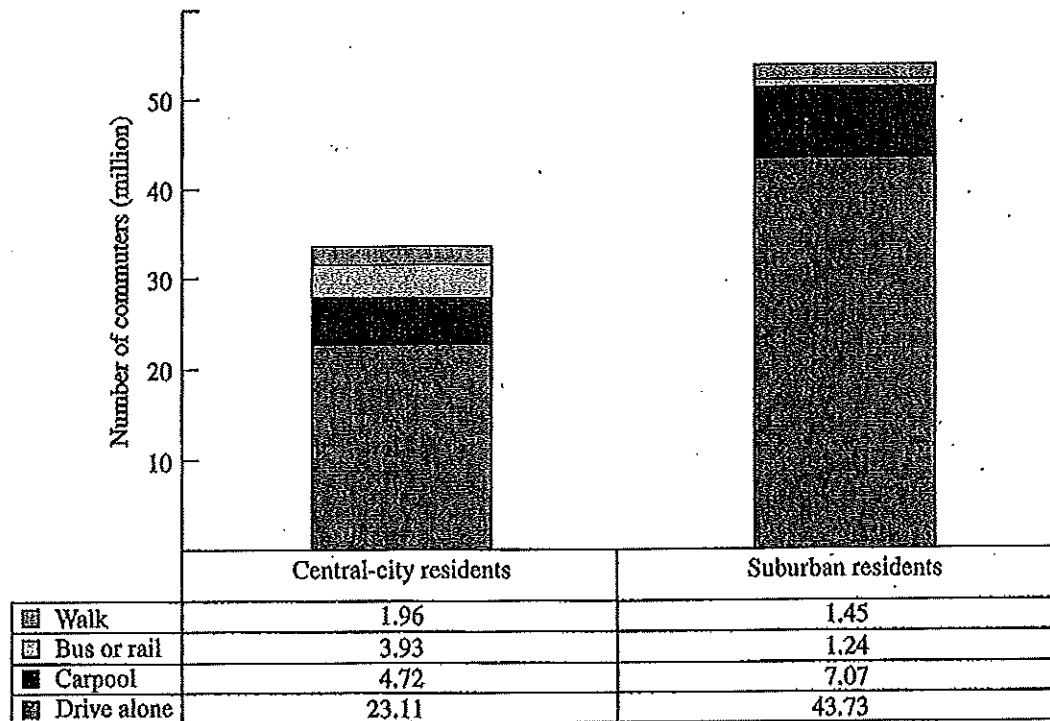
# *Autos and Highways*

*The home is where part of the family waits until the others are through with the car.*

—HERBERT PROCHNOW

**T**his is the first of two chapters on urban transportation. It discusses the most popular travel mode, the automobile, which is used by almost 90 percent of U.S. commuters. It examines three transportation problems caused by the automobile: congestion, air pollution, and highway accidents. Congestion during rush hours is inevitable, and a certain level of congestion is actually efficient. Just as it would be inefficient to eliminate all air pollution, it would be inefficient to eliminate all congestion. The question is whether congestion is at the optimum level. If not, there are a number of policies that could decrease congestion, including various taxes on auto travel, subsidies for mass transit, and highway construction. The second problem, air pollution, is controlled by the federal government through its auto emissions policies. The question is whether other pollution-control policies such as pollution taxes or gas taxes might be more efficient in controlling pollution. The third transportation problem is auto safety. Traffic accidents injure and kill people, and also disrupt traffic flow, contributing to the congestion problem. The policy question is: how do government policies affect highway death rates and accident rates? Figure 11-1 shows the modal choices of commuters in U.S. metropolitan areas.

About 77 percent of central-city residents commute by automobile (car, truck, or van) with about four of five of these commuters driving alone, and the rest riding in carpools. Suburban residents are more numerous, and a larger fraction of them (93 percent) commute by automobile. As we saw in Chapter 9, about 40 percent of metropolitan workers commute from one suburb to another. Over 97 percent of these commuters use automobiles. In contrast, among the 33 percent of metropolitan workers who commute within the central city, only 72 percent use automobiles.

**FIGURE 11-1** Modal Choice of Central-City and Suburban Commuters

Source: U.S. Bureau of the Census, *1990 Census of Population and Housing, SSTF20, Journey to Work in the United States*, (Washington, D.C.: U.S. Government Printing Office, 1994).

### CONGESTION: EQUILIBRIUM VERSUS OPTIMUM TRAFFIC VOLUME

Most cities suffer from traffic congestion during the morning and evening rush hours. In recent years, congestion has become worse in most metropolitan areas in the United States, Western Europe, and Japan (Giuliano and Small, 1998). During the 1970s and 1980s, vehicle traffic per capita increased at a rate of about 2.5 percent per year in the United States. Highway capacity hasn't kept pace with rising traffic volume; the ratio of traffic volume to road capacity increased in 47 of the 50 largest metropolitan areas, with an average increase of 16 percent. The result is more congestion. For example, on the San Francisco–Oakland Bay Bridge, the aggregate time loss resulting from congestion delays more than doubled between 1984 and 1991. The annual cost of congestion (for extra time and fuel consumption) in the 50 largest metropolitan areas is about \$35 billion (Small, 1997).

We'll use a simple model to explain the congestion phenomenon and evaluate some alternative public policies to deal with it. Consider a city with the following characteristics:

1. **Radial highway.** There is a two-lane highway from the suburbs to the city center (a distance of 10 miles).

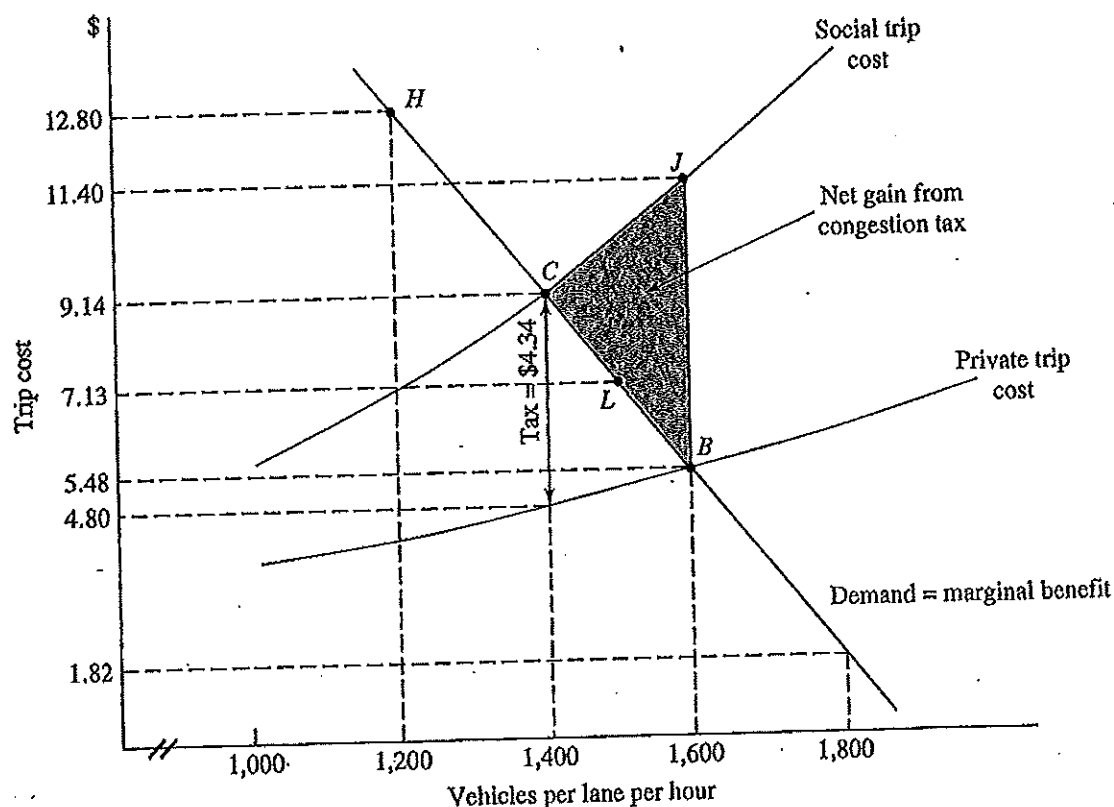
2. **Monetary travel cost.** The monetary cost of auto travel is 20 cents per mile.
3. **Time cost.** The opportunity cost of travel time is 10 cents per minute.

The total cost of a commuting trip is the sum of the monetary and time costs of the 10-mile trip. The monetary cost is \$2 (10 miles times 20 cents per mile). The time cost depends on travel time: A trip that takes 30 minutes has a time cost of \$3 (30 minutes times 10 cents per minute); a 20-minute trip has a time cost of only \$2. Therefore, the total cost of a 30-minute trip is \$5 (\$2 plus \$3), and the total cost of a 20-minute trip is \$4.

### The Demand for Urban Travel

Consider first the demand side of the urban travel market. Figure 11-2 shows the demand curve for travel along the radial highway. The horizontal axis measures the number of vehicles per lane per hour. The vertical axis measures the cost of the commuting trip, the sum of the monetary and time costs of the 10-mile trip.

FIGURE 11-2 Congestion Externalities and the Congestion Tax



Drivers use the highway as long as the marginal benefit (shown by the demand curve) exceeds the private trip cost, so the equilibrium traffic volume is 1,600 vehicles per lane per hour. At the optimum, the marginal benefit equals the marginal social cost (the social trip cost). The equilibrium volume (1,600) exceeds the optimum volume (1,400) because drivers ignore the external costs of their trips. A congestion tax of \$4.34 internalizes the congestion externality, generating the optimum traffic volume.

The demand curve shows, for each trip cost, how many travelers use the highway. For example, if the trip cost is \$12.80, there are 1,200 people for whom the benefit of the trip exceeds the cost, so the traffic volume is 1,200 vehicles per lane per hour. As the cost of the trip decreases, there are more people for whom the benefit exceeds the cost, so the city moves downward along the travel demand curve: there are 1,400 vehicles at a cost of \$9.14, and 1,600 vehicles at a cost of \$5.48.

The demand curve is a **marginal-benefit curve**. For each traffic volume, it shows how much the marginal traveler is willing to pay for the highway trip. Suppose that the city starts with a trip cost of \$9.15 and a traffic volume of 1,399. If the trip cost decreases to \$9.14, traffic volume increases to 1,400, meaning that the 1,400th driver is willing to pay \$9.14 to make the trip; at any cost above \$9.14, the trip would not be worthwhile. The demand curve shows that the marginal benefit of the 10-mile trip decreases from \$12.80 for the 1,200th driver to \$1.82 for the 1,800th driver.

### The Private and Social Costs of Travel

Table 11-1 shows the relationships between traffic volume and travel time. Column B lists the trip time (the travel time per driver) for different traffic volumes. For traffic volumes up to 400 vehicles per lane per hour, there is no congestion: everyone travels at the legal speed limit of 50 miles per hour, and the 10-mile trip takes 12 minutes. For traffic volume above 400 vehicles, the computations are based on the following formula:

$$\text{Trip time} = 12.0 + 0.001 \cdot (\text{Volume} - 400) + 0.000015 \cdot (\text{Volume} - 400)^2$$

When the 401st driver enters the highway, the congestion threshold is crossed. As the highway becomes crowded, the space between vehicles decreases and drivers slow down to maintain safe distances between cars. As more and more drivers enter the highway, travel speeds decrease and travel times increase; the trip takes 12.8 minutes

**TABLE 11-1** Traffic Volume, Travel Time, Travel Cost, and Congestion Externalities

A	B	C	D	E	F	G	H
Traffic Volume (vehicles)	Trip Time (minutes)	Increase in Travel Time per Driver (minutes)	Increase in Total Travel Time (minutes)	External Trip Cost (\$)	Private Trip Cost (\$)	Social Trip Cost (\$)	Marginal Benefit (demand)
200	12.0	0	0	0	3.20	3.20	31.10
400	12.0	0	0	0	3.20	3.20	27.44
600	12.8	0.007	4.2	0.42	3.28	3.70	23.78
800	14.8	0.013	10.4	1.04	3.48	4.52	20.12
1,000	18.0	0.019	19.0	1.90	3.80	5.70	16.46
1,200	22.4	0.025	30.0	3.00	4.24	7.24	12.80
1,400	28.0	0.031	43.4	4.34	4.80	9.14	9.14
1,600	34.8	0.037	59.2	5.92	5.48	11.40	5.48
1,800	42.8	0.043	77.4	7.74	6.28	14.02	1.82
2,000	52.0	0.049	98.0	9.80	7.20	17.00	

if there are 600 vehicles, 22.4 minutes for 1,200 vehicles, and 52.0 minutes for 2,000 vehicles.

Columns C and D show the effects of the marginal driver on the travel times of other drivers. For low traffic volumes (below 400 vehicles), an additional driver does not affect speeds or travel times. For volumes above 400 vehicles, however, an additional driver slows traffic and increases travel times. For example, the 600th driver increases the travel time per driver by 0.007 minutes (column C); when the driver enters the highway, the trip time increases from 12.793 to 12.80. The increase in total travel time is simply the extra time per driver (0.007) times the number of other drivers (599), or 4.2 minutes (column D). This is the **congestion externality**: The marginal driver slows traffic and increases travel time, forcing other drivers to spend more time on the road. The congestion externality increases with traffic volume; the 1,200th driver increases travel time by 30 minutes (0.025 minutes times 1,199), and the 1,600th driver increases travel time by 59.2 minutes (0.037 times 1,599).

The **external trip cost** equals the monetary value of the congestion externality. The figures in column E are based on the assumption that the opportunity cost of travel time is 10 cents per minute. For the 600th driver, the external trip cost equals the increase in total travel time (4.2 minutes) times 10 cents per minute, or 42 cents. The external trip cost increases with traffic volume, rising to \$3.00 for the 1,200th driver, \$5.92 for the 1,600th driver, and \$9.80 for the 2,000th driver.

Columns F and G show the private and social costs of travel. The **private trip cost** is the travel cost incurred by the individual commuter, defined as the sum of the monetary cost (\$2.00) and the private time cost. To compute the private time cost, multiply the trip time by the opportunity cost of travel time. The opportunity cost is 10 cents per minute, so the private time cost is \$1.20 for a volume of 200 vehicles, \$1.28 for 600 vehicles, and so on. Therefore, the private trip cost is \$3.20 for 200 vehicles, \$3.28 for 600 vehicles, and so on. The **social trip cost** is the sum of the private trip cost (column F) and the external trip cost (column E). Figure 11-2 shows the cost curves for private trip cost and social trip cost. The social-cost curve lies above the private-cost curve, with the gap between the two curves equal to the external trip cost.

There are some alternative labels for private and social trip costs. An alternative label for private trip cost is **average travel cost**, defined as total travel cost divided by the number of drivers. Since each driver travels at the same speed and thus has the same travel cost, the average travel cost equals the private trip cost. An alternative label for social trip cost is **marginal travel cost**, defined as the increase in the total cost of travel resulting from adding one more traveler. Since the social trip cost equals the trip cost incurred by the marginal driver plus the external cost he imposes on other drivers, the social trip cost is the same as the marginal travel cost.

### Equilibrium versus Optimum Traffic Volume

What is the equilibrium number of drivers? A driver uses the highway if the marginal benefit of a trip (from the demand curve) exceeds the private trip cost. In Figure 11-2,

the demand curve intersects the private-trip-cost curve at 1,600, so the equilibrium number of vehicles is 1,600 and the equilibrium private trip cost is \$5.48. The 1,601st driver does not use the highway because the marginal benefit of using the highway is less than the trip cost.

What is the optimum number of drivers? The basic efficiency rule is that an activity should be increased as long as the marginal social benefit exceeds the marginal social cost; at the optimum level, the marginal benefit equals the marginal cost. In Figure 11-2, the marginal social benefit is shown by the demand curve, and the marginal social cost is shown by the social-trip-cost curve. The demand curve intersects the social-trip-cost curve at a volume of 1,400, so the optimum traffic volume is 1,400 vehicles. For the first 1,400 drivers, the social benefit of travel exceeds the social cost, so their use of the highway is efficient. For the 1,401st driver, the social cost exceeds the benefit, so her use of the highway is inefficient.

The equilibrium volume exceeds the optimum volume because drivers ignore the costs they impose on other drivers. An additional driver slows traffic, forcing other drivers to spend more time on the road. Suppose that Carla, the 1,599th driver, has a private benefit of \$5.49. From column F in Table 11-1, the private trip cost for 1,599 vehicles is about \$5.48, so Carla uses the highway. Her use of the highway is inefficient because the benefit of the trip (\$5.49) is less than the social cost of the trip (\$11.40, equal to the sum of Carla's private cost of \$5.48 and the external trip cost of \$5.92). Because Carla ignores the \$5.92 external cost, she makes an inefficient choice.

### THE POLICY RESPONSE: CONGESTION TAX

The government could use a congestion tax to generate the optimum traffic volume. A tax equal to the external trip cost would internalize the congestion externality, generating the optimum number of drivers. In Figure 11-2, a congestion tax of \$4.34 per trip would shift the private-trip-cost curve upward by \$4.34, decreasing the equilibrium number of drivers from 1,600 to 1,400. The 1,401st driver would not use the road because the benefit of the trip (\$9.13) would be less than the full cost of the trip (\$9.14, the sum of the \$4.80 private cost and the \$4.34 congestion tax). Because the congestion tax closes the gap between private and social costs, the individual driver bases his travel decision on the social cost of travel. Therefore, the highway is used efficiently.

### Benefits and Costs of Congestion Taxes

From the perspective of the individual traveler, the imposition of congestion taxes generates good news and bad news. People who continue to use the highway after the tax is imposed pay the tax, but also have a lower time cost; the tax decreases traffic volume, which decreases travel times. People who stop using the highway avoid the tax, but forgo the benefits associated with using the highway. In other words, there are costs and benefits for both types of people. Do the benefits outweigh the costs?

TABLE 11-2 Benefits and Costs of Congestion Taxes

	Congestion Tax	Tax Refund	Net Transfer	Time Savings	Consumer Surplus Lost	Net Benefit
Helen (H)	\$4.34	\$3.79	-\$0.55	\$0.68	—	+\$0.13
Louis (L)	—	3.79	+ 3.79	—	\$1.65	+ 2.14

## Definitions

1. Total tax revenue = Tax per driver  $\times$  Volume:  $1,400 \times \$4.34 = \$6,076$ .
2. Transfer payment = Total tax revenue  $\div$  Number of citizens:  $\$6,076/1,600 = \$3.79$ .
3. Net transfer = Refund - Congestion tax (if any).
4. Consumer surplus lost = Willingness to pay (from demand curve) - Private trip cost (before congestion tax).

A key consideration in the evaluation of the congestion tax is the disposition of the revenue it generates. The government does not throw the tax revenue away, but presumably uses it to finance public services or to decrease other local taxes. In fact, as explained later in the chapter, the total revenue from the congestion tax is just enough to pay for the optimum highway. Therefore, the government could substitute congestion taxes for the gasoline tax, which is currently used to finance highways.

To simplify matters, suppose that the government redistributes the tax revenue in equal shares to all of the households who use the highway before the congestion tax is imposed. In Figure 11-2, the pretax traffic volume is 1,600, so there are 1,600 highway users. The total tax revenue is \$6,076 (1,400 vehicles at \$4.34 per vehicle), so the transfer per household is \$3.79 (\$6,076/1,600).

Table 11-2 shows the costs and benefits for two travelers. Helen has a relatively large willingness to pay for highway use, so she uses the highway even after the congestion tax is imposed. In Figure 11-2, her position on the demand curve is shown by point *H*. Louis has a relatively small willingness to pay, so he stops using the highway after the tax is imposed (point *L* in Figure 11-2). What are the benefits and costs for the two travelers?

- Helen pays a tax of \$4.34 and receives a refund of \$3.79, for a 55-cent net increase in taxes. The congestion tax decreases the private trip cost from \$5.48 (at a volume of 1,600) to \$4.80 (at a volume of 1,400), for a savings of 68 cents. The net benefit is 13 cents: a benefit of 68 cents less the tax increase of 55 cents.
- Louis doesn't use the highway after the congestion tax is imposed. Before the tax, his benefit from using the highway equaled the gap between his willingness to pay (from the demand curve) and the private trip cost. This gap is his **consumer surplus** from using the highway. From Figure 11-2, Louis was willing to pay \$7.13 for a trip with a private trip cost of \$5.48, so his consumer surplus was \$1.65 (\$7.13 - \$5.48). After the congestion tax, Louis does not use the highway, so he loses this surplus. Because the tax also provides a transfer payment of \$3.79, Louis is better off after the congestion tax by \$2.14; the transfer payment more than offsets his loss of consumer surplus.

In this example, both citizens benefit from the imposition of congestion taxes. A more rigorous analysis of the benefits and costs would show that some people

in the city would be harmed by the congestion tax policy. For some travelers, the savings in travel costs and the transfer payment would not be large enough to offset the congestion tax or the loss in consumer surplus.

A more rigorous analysis would also show that the winners' benefits exceed the losers' costs. In other words, the move from the equilibrium to the optimum generates a net gain for society. In Figure 11-2, the net gain is shown by the shaded area, the area between the demand curve (the marginal-benefit curve) and the social-trip-cost curve.

To explain the computation of the net gain from moving to the optimum, consider a small move toward the optimum. Specifically, suppose the city starts with the equilibrium volume (1,600 vehicles) and somehow persuades the 1,600th driver to not use the road. What are the benefits and costs of diverting the driver?

- **Benefit:** The total travel cost decreases by the social trip cost for the 1,600th driver (about \$11.40 at point *J*).
- **Cost:** The driver loses the benefits of the highway trip; the willingness to pay for the trip is shown by the demand curve (about \$5.48 at point *B*).

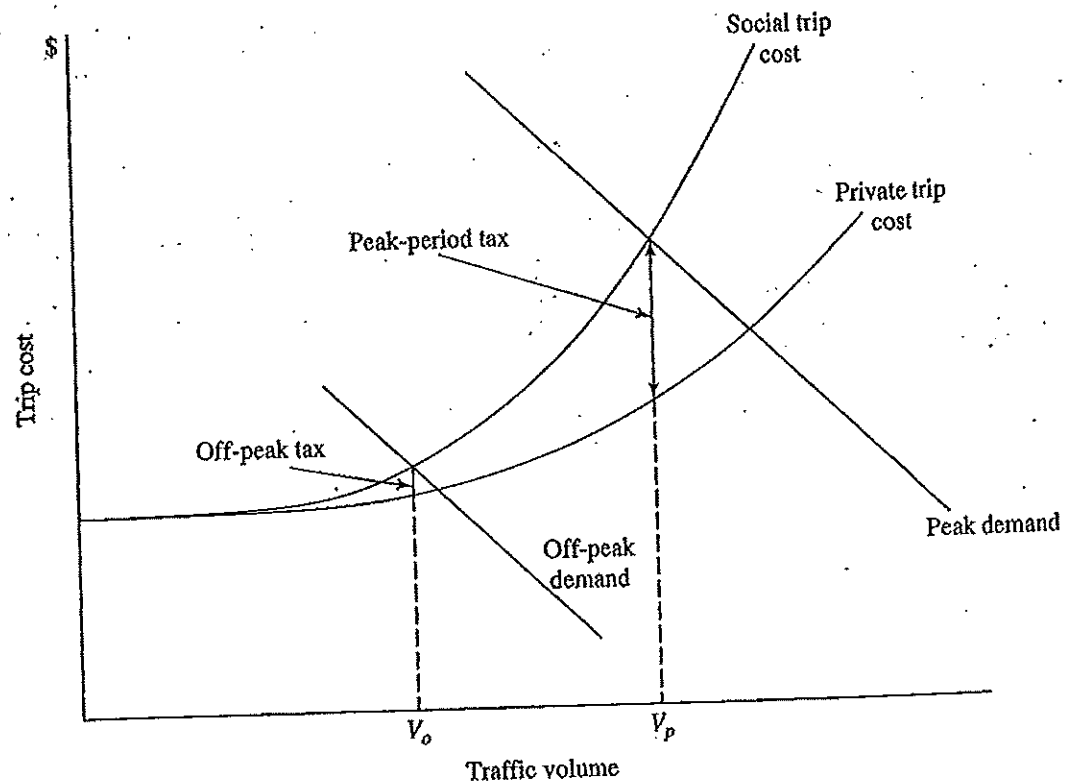
The net benefit from diverting the 1,600th driver is the difference between the social trip cost (a benefit of \$11.40) and the willingness to pay (a cost of \$5.48), or \$5.92.

To compute the net gain to society from moving to the optimum, we repeat this thought experiment for the 1,401st through the 1,599th driver. The social gain from diverting the 1,599th driver is slightly lower than the gain from diverting the 1,600th driver because the social trip cost is lower (the city starts lower on the cost curve) and the willingness to pay is higher (the city starts further up the demand curve). The net gain to society from moving from the equilibrium (point *B*) to the optimum (point *C*) is the sum of the differences between the social trip cost and the willingness to pay (from the demand curve) for the 1,600th through the 1,401st drivers. In other words, it is the area between the two curves, shown by the area of triangle *CJB*. Because there is a net gain from the move to the optimum point, the government could, in principle, redistribute income from the winners to the losers to ensure that everyone is made better off by the congestion tax.

### Peak versus Off-Peak Travel

To be efficient, the congestion tax must vary across time and space. The tax should be higher on congested highways. The most congested highways are the ones leading to and from employment centers. Most congestion occurs during the morning and evening rush hours. According to Straszheim (1979), about a quarter of all trips are made during the rush hours. McConnell-Pay (1986) reports that 64 percent of the trips from homes to workplaces in the San Francisco Bay area occur between 6:30 and 8:30 A.M., and 57 percent of the workplace-home trips occur between 4:30 and 6:30 P.M. Figure 11-3 shows the demand curves and congestion tolls for the peak period and the off-peak period. Given the high volume of traffic during the peak period ( $V_p$ , compared to  $V_o$  during the off-peak period), the peak-period congestion toll is higher.



**FIGURE 11-3** Congestion Tax during Peak and Off-Peak Periods

During the off-peak period, the demand for travel is relatively low, generating a low traffic volume ( $V_o$ , compared to  $V_p$  during the peak period), so the optimum congestion tax is relatively low.

### Estimates of Congestion Taxes

What is the optimum congestion tax? In a study of the San Francisco Bay area, Keeler and Small (1977) estimate congestion taxes for different locations and times. Pozdena (1988) updated the Keeler and Small estimates, and he estimated that during the peak travel periods, the congestion tax would be 65 cents per mile on central urban highways, 21 cents per mile on suburban highways, and 17 cents per mile on fringe highways. During the off-peak periods, the taxes would be between 3 and 5 cents per mile at all locations.

Mohring (1999) recently computed the appropriate congestion taxes for the Twin Cities (Minneapolis and St. Paul) metropolitan area. Of the 9,700 miles of roads in the area, about 2,000 miles are congested during the peak hours. The congestion tax would vary with the volume of traffic, averaging about 9 cents per mile, with a tax as high as 21 cents per mile on the most congested roads. The imposition of congestion taxes would decrease traffic volume by 12 percent on average and by 25 percent on the most congested roads.

Small explores the features of a potential congestion pricing system for Los Angeles (Small, 1993). In the Los Angeles region congestion occurs for about 28 percent of the total vehicle miles traveled. The peak-period congestion tax would average

about 15 cents per mile, with higher taxes on the most congested roads. The average peak-period trip is 10 miles long, so the typical peak-period commuter would pay about \$1.50 per one-way trip, or \$3.00 per day. The congestion tax would decrease traffic volume during the peak period by about 26 percent, increasing travel speeds and reducing delays.

### **Implementing the Congestion Tax**

How would the government collect the congestion tax? One possibility is to install toll booths on every road and collect the tax directly from drivers. This option is impractical because the collection process slows traffic, causing more congestion. The high-technology version of toll booths is a vehicle-identification system (VIS). Under a VIS, every car is equipped with a transponder—an electronic device that allows sensors along the road to identify the car as it passes. The system records the number of times a vehicle uses the congested highway and sends a congestion bill to the driver at the end of the month. For example, a driver who travels 10 miles along a congested highway 20 times per month would pay a monthly congestion bill of \$86.80 (20 times \$4.34 as shown in Figure 11-2). The alternative approach is to install a device in each car that decreases the value of a cash card or a debit card: when the car passes a checkpoint, the value of the card (inserted into the device in the car) is reduced by an amount equal to the toll.

### **Experiences with Congestion Pricing**

Singapore was the first city to use prices to control the volume of traffic. Under the Area Licensing System (ALS) implemented in 1975, drivers were charged about \$2 per day to travel in a restricted zone in the central area of the city. Initially, ALS applied only to the morning rush hour, but later was extended for the entire day. The system decreased traffic volume by about 44 percent and increased travel speeds.

In 1998, Singapore's ALS was replaced with Electronic Road Pricing (ERP). Under ERP, drivers pay fees for passing different points en route to the central business district. The fees vary by location and time of day, with the highest fees for the most congested areas during rush hours. The collection system uses an in-vehicle electronic device that accepts a stored-value cash card (purchased at local banks). The in-vehicle device deducts the appropriate fee from the cash card every time the vehicle passes through an ERP gantry (a structure spanning the roads at each collection point). Vehicles that do not have an in-vehicle unit or sufficient value on their cash cards are photographed by gantry cameras for what Singapore officials call "subsequent enforcement action." The fee for the private cars entering the central district between 8:30 A.M. and 9:00 A.M. is \$2, compared to \$1 for the period 9:30 A.M. to 3:00 P.M. Motorcycles pay half as much as private cars, and taxis pay one-third as much.

In Toronto, the users of the 407 Express Toll Road pay tolls that depend on the distance traveled and time of day. The per-kilometer toll is 10 cents during rush hours (10 cents Canadian, equal to 7 cents U.S.), 7 cents during other weekday times,

and 4 cents on the weekend. The system uses a trip-toll method that, with the help of a transponder in each car, determines when and where a vehicle enters and exits the tollway; a central system matches entry and exit registrations and computes the vehicle's toll for the trip. The toll road is open to occasional users without in-vehicle transponders: the system photographs license plates and sends bills to the registered owners.

One approach that is gaining popularity involves changing the rules for high-occupancy vehicle (HOV) lanes. An HOV lane—sometimes known as a “diamond” lane or an express lane—is a lane designated for use by high-occupancy vehicles, typically defined as a vehicle with at least three passengers. A HOT lane is a lane that can be used both by high-occupancy vehicles and other vehicles that pay a toll (HOT stands for “high occupancy and toll”).

The first HOT project was along Riverside Freeway (California State Route 91), which connects employment centers in Los Angeles and Orange Counties with rapidly growing areas to the east. Two HOV lanes that had been added in the median strip of the freeway were switched to HOT lanes. The toll varies by time of day, with the highest toll (\$2.75 per trip) between 5 A.M. and 9 A.M. on weekdays. Each car has a transponder in its windshield for identification purposes and a corresponding account that is billed each time the vehicle uses the HOT lane. Changing to a HOT lane increased traffic volume on the old HOV lanes, with about 80 percent of users paying the toll. The change also decreased traffic volume and increased speeds along the regular lanes on Route 91, generating benefits for commuters who did not pay the toll.

Another HOT project is along Interstate 15 in San Diego. The reversible facility consists of an eight-mile stretch of two lanes in the freeway median, which are accessible only at the endpoints of the facility. A fee is charged for each trip, with the toll varying in “real time” from \$0.50 to \$4.00, depending on the level of congestion. Each vehicle has a transponder and a prepaid account that is billed each time the vehicle uses the HOT lane. The toll is highest between 7 A.M. and 8 A.M., and 4 P.M. and 5 P.M.

These recent experiences with congestion pricing are promising. Travelers respond to higher prices by changing their travel behavior in ways that decrease traffic volume and improve the efficiency of travel. The most frequent responses are: (1) forming carpools, (2) switching to mass transit, (3) switching to off-peak travel, (4) picking alternative routes, and (5) combining two or more trips into a single trip (Small and Gomez-Ibanez, 1998). In many other cities in the United States, Europe, and Asia, policymakers are evaluating the merits of congestion pricing.

## ALTERNATIVES TO A CONGESTION TAX

A number of alternative congestion policies have been proposed. One set of policies discourages auto use by increasing the cost of auto travel. Three of the pricing options are gasoline taxes, parking taxes, and congestion-zone taxes. How effective are these policies compared to a congestion tax? To set the stage for a discussion of

the efficacy of the alternative policies, it will be useful to list the four ways that the congestion tax decreases traffic volume:

1. **Modal substitution.** The tax increases the cost of auto travel relative to carpooling and mass transit (buses, subways, light rail), causing some travelers to switch to these other travel modes.
2. **Time of travel.** The tax is highest during the peak travel periods, causing some travelers to travel at different times. Because work and study schedules are relatively inflexible, commuters and students would be less likely to change their travel times than other travelers (e.g., shoppers). Nonetheless, firms would have a greater incentive to change work schedules to allow their workers to avoid costly travel during the peak period. The institution of flextime and the rearrangement of shift times would cause some workers to change their travel times.
3. **Travel route.** The congestion tax is highest on the most congested routes, causing some travelers to switch to alternative routes.
4. **Location choices.** The congestion tax increases the unit cost of travel (travel cost per mile), causing some commuters to decrease their commuting distances. Some workers may move closer to their jobs, and others may switch to jobs closer to their residences.

These four changes cause the city to move up the travel-demand curve as the cost of travel increases. In Figure 11-2, the congestion tax decreases traffic volume from 1,600 to 1,400 because it changes travel modes, times, routes, and distances.

### Gasoline Tax

One alternative to the congestion tax is a gasoline tax. The simple idea is that if travel is more expensive, traffic volume decreases. The problem is that the gas tax increases the costs of all automobile travel, not just travel along congested routes during peak periods. In contrast with the congestion tax, which changes travel times and routes, the gas tax does not encourage drivers to switch to other travel times or routes. Suppose the government wants to use the gasoline tax to decrease the peak period traffic volume to its optimum level. What is the required gasoline tax? To have the same effect as the congestion tax in Figure 11-2, the gas tax must increase the cost of travel by 43.4 cents per mile (\$4.34 per 10-mile trip). If the typical car gets 22 miles per gallon of gasoline (the average mileage in 1992), the required gas tax is \$9.55 per gallon (43.4 cents times 22); if gas mileage is only 10 miles per gallon, the tax is \$4.34 per gallon. Even if a gas tax at this level were feasible, it would be inefficient because it would also increase the cost of off-peak travel by 43.4 cents per mile.

### Parking Tax

A number of cities use parking taxes to discourage driving to central business district jobs. In an experiment in Madison, Wisconsin, a tax surcharge of \$1 was imposed

on drivers who arrived at parking garages during the peak travel period (7 A.M. to 9 A.M.) and left their cars for more than three hours. As explained by Parody (1984), the surcharge decreased traffic volume because (1) some commuters switched to carpools and mass transit and (2) some changed their travel times. In Washington, D.C., the government increased parking costs for its employees, causing some workers to switch to carpools and mass transit (Miller and Everett, 1982).

In Ottawa, Canada, the government increased parking rates for government employees from zero to 70 percent of the commercial rate, causing (1) a 23 percent decrease in the number of workers driving to work, (2) a 6 percent increase in the auto occupancy rate (from 1.33 to 1.41), and (3) a 16 percent increase in bus ridership (DiRenzo, Cima, and Barber, 1981). In a series of experiments in Los Angeles, the elimination of free parking decreased the number of solo drivers by between 18 percent and 83 percent. When one Los Angeles firm increased its parking fee from zero to \$28.75 per month, the number of solo drivers dropped by 44 percent; when the firm increased the monthly fee to \$57.50, solo driving decreased 81 percent (Small, 1992).

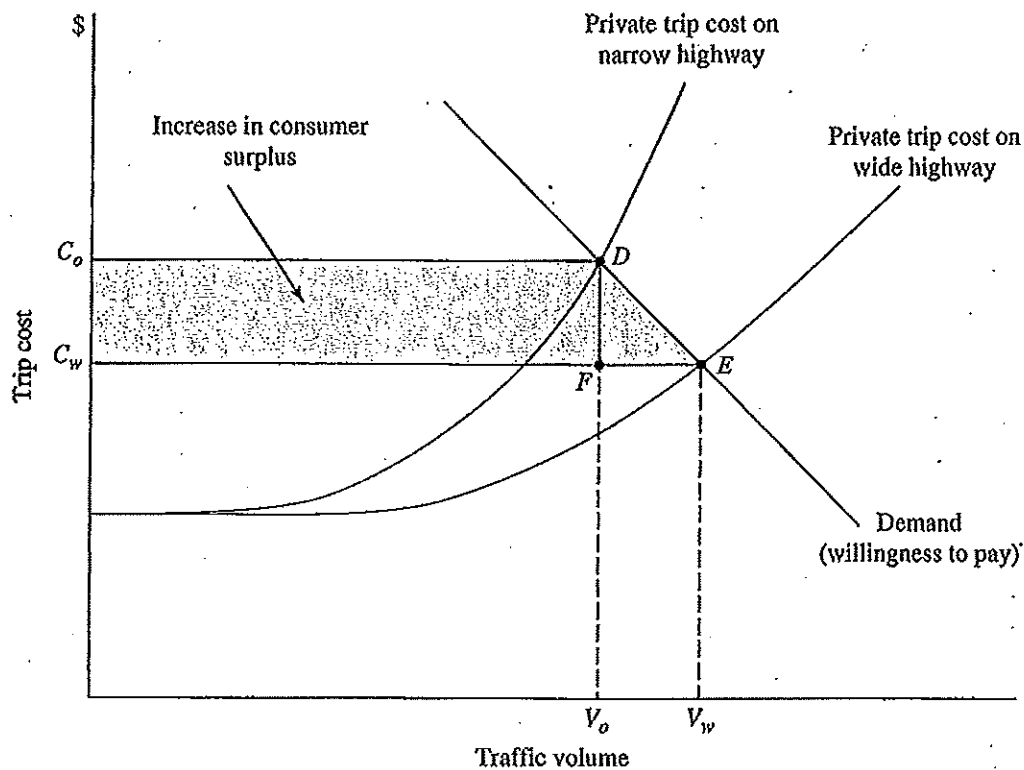
There are three potential problems with using parking taxes to decrease congestion. The first is that the taxes must be imposed only on peak-period commuters; drivers who travel during the off-peak periods should be exempt from the tax. As shown by the Madison experiment, this problem can be solved by imposing a surcharge for drivers who arrive at parking garages during the peak travel periods. Second, in contrast with the congestion tax, which increases the unit cost of travel and decreases travel distances, the parking tax does not depend on the distance traveled. Therefore, there is less incentive for commuters to economize on travel cost by living closer to their workplaces. Third, because much of the congestion problem is caused by cars that do not park in congested areas, the tax does not force all peak-period travelers to pay for the congestion they cause.

Shoup (1993) suggests that the subsidization of parking by employers contributes to the congestion problem. In 1990, about 95 percent of American commuters who drove to work benefited from free parking at their place of work. In Los Angeles, the average subsidy from free parking provided by employers is \$3.87 per day. Shoup estimates that employer-paid parking shifts 25 percent of all commuters into solo driving and increases the number of cars driven to work by 19 percent. One possible response to this problem is to "cash out" the parking subsidy. An employer that provides free parking worth, say, \$150 per month, would give its workers the option of free parking or \$150 in cash. When faced with the cash option, many workers would take the cash and make other arrangements for getting to work, thus decreasing traffic volume.

### Capacity Expansion and Traffic Design

A third response to the congestion problem is to widen the highway to increase its carrying capacity. Figure 11-4 shows the effects of such a policy on travel times and traffic volume. The wider road reaches the congestion threshold at a higher traffic volume and has a lower private trip cost at all volumes above the original congestion

FIGURE 11-4 Effects of Widening the Highway



The widening of the highway shifts the private trip cost to the right: the congestion threshold increases, and trip cost is lower at every traffic volume above the original threshold volume. The decrease in trip cost increases traffic volume from  $V_o$  to  $V_w$ . The benefit of the widening is the increase in consumer surplus (the shaded area).

threshold. The decrease in trip costs increases traffic volume as the city moves down the demand curve from point  $D$  to  $E$ .

Under what conditions would the widening of the highway be efficient? One way to measure the total benefit is with consumer surplus. As explained earlier, consumer surplus equals the excess of the willingness to pay (from the demand curve) over the actual cost of travel. Widening the highway decreases the trip costs of all drivers, so it increases consumer surplus.

In Figure 11-4, the increase in consumer surplus is shown as the shaded area. For the original drivers (Volume =  $V_o$ ), the consumer surplus per driver increases by the savings in private trip cost ( $C_o - C_w$ ). The increase in consumer surplus is the rectangular area with a width of  $(C_o - C_w)$  and a length of  $V_o$ . The decrease in trip cost also increases traffic volume from  $V_o$  to  $V_w$ . The consumer surplus of the new drivers equals the area of the triangle  $DEF$ . The benefit of widening the highway exceeds the cost if the increase in consumer surplus (the sum of the rectangle and the triangle) exceeds the cost of widening the highway. This analysis ignores pollution cost, which is discussed later in the chapter.

There are many anecdotes about increases in highway capacity that did not result in less congestion and faster travel during the rush hour. The reason is that

the demand for rush-hour travel is highly elastic, with many commuters initially deterred from using the congested highway because of slow travel speeds. This is the phenomenon of "latent demand." In the language of Small (1993), there is a "reserve army of the unfulfilled" that will switch to a previously congested highway as soon as an increase in capacity increases travel speeds. This latent demand will fill most or all of the new capacity during peak periods. Many of the new users have switched from other routes or other times, so we must look beyond the rush hour along the widened highway to see the effects of the increase in capacity.

The city could also improve the flow of traffic on the existing highway. Street lights can be synchronized to keep traffic flowing at a steady speed. Designating one-way streets and restricting on-street parking increase the carrying capacity of streets. Some cities have placed stoplights on expressway on-ramps, thus smoothing the flow of vehicles onto expressways. In the language of transportation engineers, the ramp lights decrease the "turbulence" caused by entering vehicles, thus increasing travel speeds. In Los Angeles, the installation of such a system on the Harbor Freeway increased average travel speeds from 15 miles per hour to 40 miles per hour. A similar system in Dallas increased travel speeds from 14 miles per hour to 30 miles per hour.

### Subsidies for Transit

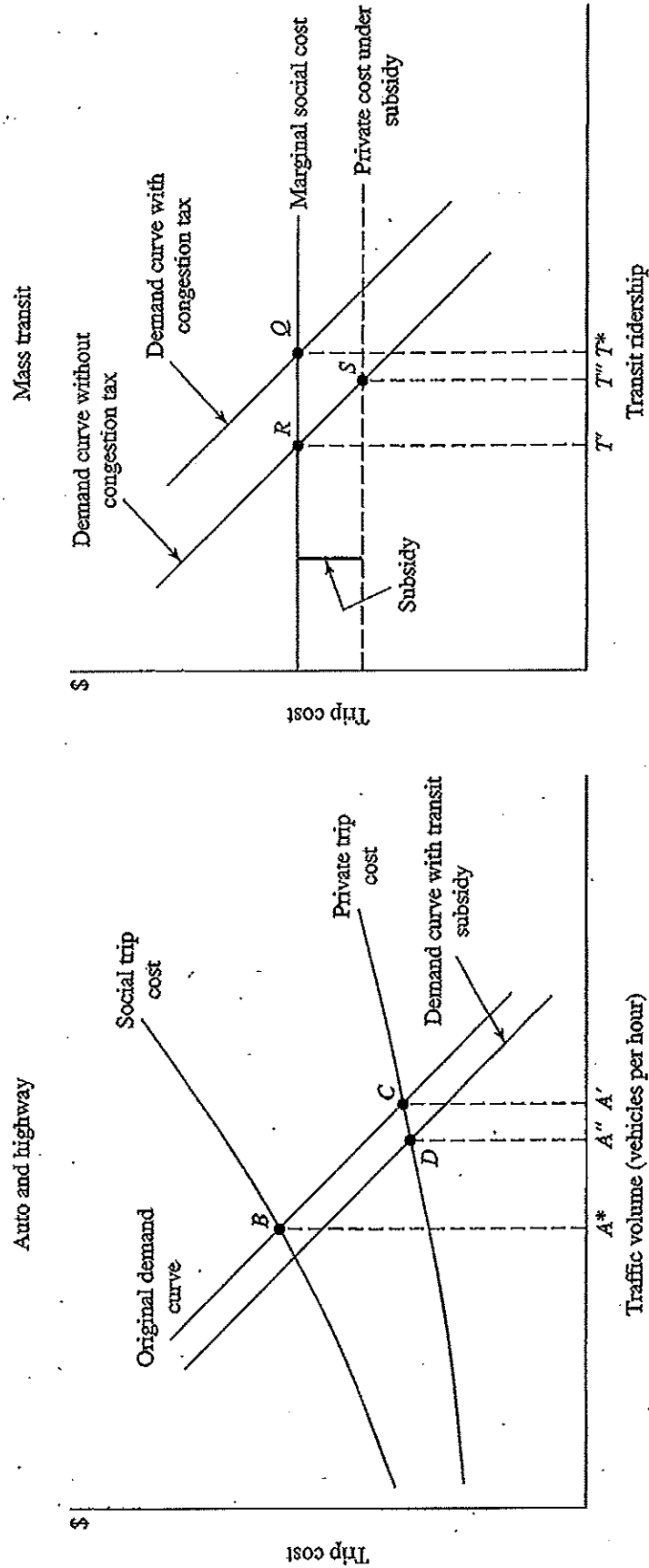
Another alternative to congestion taxes is the subsidization of mass transit (buses, subways, commuter trains, light rail). Transit and autos are substitute travel modes, so a decrease in the cost of transit causes some consumers to switch from autos to transit. In other words, a transit subsidy decreases the auto volume, narrowing the gap between the equilibrium and optimum traffic volumes.

Figure 11-5 shows the interactions between the auto and transit markets. Under a system of optimum congestion taxes, the auto market reaches point *B*, with traffic volume of  $A^*$  (where the demand curve intersects the social-trip-cost curve), and the transit market reaches point *Q*, with ridership of  $T^*$  (where the demand curve intersects the marginal-social-cost curve). In the presence of congestion taxes, both markets are at their optimum points, defined as the points at which the marginal social benefit (from the demand curve) equals the marginal social cost.

What if there are no congestion taxes? The auto market reaches point *C*, where the demand curve intersects the private-trip-cost curve, generating an equilibrium traffic volume of *A*. The underpricing of auto travel shifts the demand curve for transit (a substitute good) downward. The equilibrium is shown by point *R*, with ridership of  $T'$ . If auto travel is underpriced, the auto volume exceeds the optimum volume and transit ridership is less than the optimum ridership.

A small transit subsidy moves both markets closer to their optimum points. In the transit market, the subsidy decreases the cost of transit, causing movement down the demand curve to point *S*; ridership increases to  $T''$ , closing about two-thirds of the gap between the equilibrium and the optimum volume. In the auto market, the decrease in the price of transit shifts the auto-demand curve downward, moving the market from point *C* to point *D*. The equilibrium volume decreases

FIGURE 11-5 Effects of Transit Subsidies on Auto Volume and Transit Ridership



In the optimum situation, auto drivers pay a congestion tax, so auto volume is  $A^*$  and transit ridership is  $T^*$ . If there is no congestion tax, the auto volume is  $A'$  and the transit ridership is  $T'$  (the underpricing of auto travel shifts the demand curve for transit downward). A transit subsidy increases transit ridership to  $T''$  and decreases auto volume to  $A''$  (the subsidy shifts the auto-demand curve downward). The subsidy narrows the transit gap faster than it narrows the auto gap.



from  $A'$  to  $A''$ , closing about one-quarter of the gap between the equilibrium and the optimum volume. The subsidy narrows—but does not eliminate—the gaps between the optimum and equilibrium volumes:  $A''$  is still less than  $A^*$ , and  $T''$  is still less than  $T^*$ .

Would it be possible to eliminate both the auto gap and the transit gap? In Figure 11-5, the transit gap is closing faster than the auto gap; the subsidy closes two-thirds of the transit gap, but only one-quarter of the auto gap. In other words, the subsidy increases transit ridership by more than it decreases auto volume. This occurs because in addition to diverting some drivers from cars to transit, the subsidy also attracts new travelers to transit. For example, suppose that the subsidy causes 250 drivers to switch from autos to transit ( $A' - A'' = 250$ ) and also generates 280 new travelers. The total increase in transit ridership is 530 ( $T'' - T' = 530$ ), the sum of the diverted auto drivers and the new transit riders. Because the transit gap is closing faster than the auto gap, if the city decides to eliminate the transit gap, the city will be left with an auto gap. Alternatively, if it decides to eliminate the auto gap, the city will overshoot the transit gap: transit ridership will exceed the optimum ridership. The city can close one—but not both—gaps.

The fundamental problem of the transit subsidy is that it underprices transit, increasing ridership above its optimum level. In the absence of congestion taxes, a transit subsidy may improve the efficiency of the transportation system, but the subsidy will never be as efficient as a system of congestion taxes. The policy question is whether the benefit of the transit subsidy (the diversion of drivers from underpriced and congested roads) is larger or smaller than the cost (excessive transit ridership).

## HIGHWAY PRICING AND TRAFFIC VOLUME IN THE LONG RUN

This section shows how the government could pick both the optimum traffic volume and the optimum road width. The long-run analysis of highway pricing and investment has four steps:

1. Derive the average total-cost curves for different highway widths.
2. Derive the long-run-cost curves (average and marginal).
3. Pick the optimum traffic volume and road width.
4. Pick the congestion tax that generates the optimum traffic volume on the optimum road.

### Average Total Cost for Two-Lane and Four-Lane Highways

The average total cost of travel is the sum of the trip cost and the average road cost. Figure 11-6 shows the trip-cost curves for both the two-lane and the four-lane highways; the cost curves are horizontal up to the point at which congestion sets in; the congestion threshold is  $V_2$  vehicles per hour for the two-lane highway and  $V_4$  vehicles for the four-lane highway. The average road cost equals the total cost of building the highway divided by the number of trips.