The procedure that McFadden developed forms the conceptual basis for all sophisticated travel demand forecasting done today. The details of McFadden's procedure and how it has been adapted to forecast the effects of alternative congestion pricing schemes, in one study on a private toll road in Orange County and in another on the San Francisco Bay bridges, is the topic of "Urban Passenger Travel Demand," by André de Palma, Robin Lindsey, and Nathalie Picard.

It was mentioned in the Preface that one of the major developments that led to the creation of urban economics as a field was the transportation and land-use studies of the 1950s and 1960s. Interest in the relationship between urban transportation and land use has continued unabated. Transportation availability strongly affects land use, but land use also strongly affects transportation demand. Forecasting land use is the weakest link in urban traffic demand forecasting, and has been made more difficult by the suburbanization of employment and the increased importance of noncommuting trips. John McDonald's essay, "Urban Transportation and Land Use," examines how economists go about forecasting the effects of urban transportation improvements on land use.

Urban transport policy generates heated debate. One reason is that it so directly affects people's lives, another that winners and losers are usually clearly identifiable, and yet another that professional cultures collide. Economists favor market-based, pricing solutions; planners, bureaucrats, and regulators instinctively want to regulate; and engineers incline toward technology- and infrastructure-based solutions. In "Urban Transport Policies: The Dutch Struggle with Market Failures and Policy Failures," Piet Rietveld surveys the landscape of urban transport policy in the Netherlands, which has the highest density of population among developed countries.

Scarcity is central to economics. We – economists and students of economics – need to continually remind ourselves that a situation that is unpleasant or even morally offensive may, because of scarcity, nonetheless be efficient or even socially optimal. Traffic congestion is an example. The spatial concentration of economic activity that is the defining characteristic of cities generates agglomeration benefits but also traffic congestion. While our instincts may tell us that long delays in traffic are "outrageous," as economists we should aim not to eliminate traffic congestion but to insure that its level is socially optimal.

CHAPTER FIFTEEN

Urban Transport Economic Theory

Yoshitsugu Kanemoto

15.1 INTRODUCTION

Although the transportation sector constitutes a small share of total production (about 3 percent of GDP in the United States), transportation costs play a critical role in the formation and workings of cities. For example, the introduction of urban transit such as trolley lines and subways in the nineteenth century was the key to the emergence of giant cities such as New York (Mills & Hamilton 1989). In the twentieth century, the internal combustion engine caused another revolution in urban structure, leading to more decentralized metropolitan areas. The striking difference in urban form between Tokyo and Los Angeles is clear evidence of the importance of transportation. Tokyo is a mass-transit-based city and the population density of the metropolitan area is about 3,424 per km^2. Los Angeles, an automobile-based city, has a much lower density: the population density of Los Angeles – Riverside – Orange County CMSA is 188 per km^2 and even for the core area (Los Angeles – Long Beach PMSA) the density is 916 per km^2.

Urban transportation is associated with a variety of externalities, and for technological and political reasons it is difficult to "price" them properly. Most important among them, quantitatively, is traffic congestion. Traffic jams during morning and evening rush hours are common in most cities in the world. The magnitude of congestion externalities varies enormously depending on location and time. The Federal Highway Administration in the USA estimates the average congestion cost for passenger cars to be 7.7 cents per mile for urban interstate highways, compared with 0.78 cents for their rural counterparts (Federal Highway Administration 2000). According to Newbery (1990), "Urban central areas at the peak have an average congestion cost of 10 times the average over all roads, and more than 100 times that of the average motorway or rural road." Economists have advocated the adoption of congestion tolls for road transportation for a long time, but – except for a very small number of places, such as Singapore – they have not been instituted. Even where congestion tolls have been introduced, they are rather crude and do not fully reflect wide variations over time and space.

Environmental pollution and accident externalities also involve substantial social costs. The Federal Highway Administration estimates the air pollution costs of passenger cars to be 1.33 cents per mile for urban interstate highways (Federal Highway Administration 2000). Their estimate of crash costs is 1.19 cents per mile. Although these figures are lower than the congestion cost estimates, they are still quite substantial.

Mass transit is not immune from significant externalities either. When demand is low relative to capacity, positive externalities between passengers exist because an increase in demand enables more frequent services. When demand is high, the externalities turn negative, as observed on commuter railways in Tokyo. According to Yamazaki and Asada, optimal congestion tolls can be close to three times as large as the current fares (Yamazaki & Asada 1999).

This chapter examines pricing and investment decisions in the presence of these urban externalities. In particular, we focus on second-best problems under the constraint that many of the externalities are improperly priced.

15.2 Pricing and Investment Decisions: The Basics

15.2.1 Private and social costs

The cost structure of urban transportation is complicated for two reasons. First, because of the high density of activities and interactions in a city, urban transportation causes a variety of externalities such as traffic congestion, air pollution, noise, and that part of accident costs not borne by drivers. Second, consumers incur many different types of user costs in addition to user fees (tolls and fares). For example, automobile users incur motor vehicle running costs (the cost of fuel, tires, engine oil, maintenance, and the value of vehicle wear-and-tear), the opportunity cost of travel time, and traffic accident costs. Users must also pay taxes. Taxes on gasoline are especially heavy in Europe and Japan, where more than half of the retail price is tax. Even in the USA, where the tax rate is much lower, it was about 35 percent of the retail price in 2003. Because taxes are transfers of wealth and do not represent social resource costs, we treat them separately from other cost categories.

We denote the *user cost* per trip by p. This user cost corresponds to the "price" in standard textbook microeconomics. The user cost contains *user fees* such as fuel tax, tolls, and fares. The rest of the user cost is the resource cost, such as *vehicle running costs* and the *value of travel time*. The suppliers of transport services, such as highway authorities and mass transit operators, incur *production costs* of these services. These costs are at least partly covered by user fees. *External costs*, such as air pollution costs, constitute part of the social cost. The social cost does not, however, include user fees because these are simply transfers of income.

Among external costs of transportation, congestion costs have special characteristics because they are externalities imposed by users on users. Each user is simultaneously causing and suffering the congestion externality. Other externalities, such as air pollution, are externalities imposed by the transportation sector on others. Let us briefly explain the congestion externality by taking an example of automobile users. Vehicle running costs depend critically on the speed of traffic. Time and fuel costs are clear examples, but other costs such as tires and maintenance costs also increase when the speed becomes slower. With a small number of vehicles on a road, an increase in traffic does not significantly affect traffic speed. As more and more vehicles enter the road, the speed gets slower, which raises the user costs of all drivers on the same road at that time. The externality arises because an additional vehicle raises the costs of other vehicles.

Let $TSC(Q,K)$ denote total social cost when transport demand is Q and capacity is K. The total social cost is divided into the variable-cost component, $C(Q,K)$, with $C(0,K) = 0$, and the fixed-cost component, $F(K)$. *Marginal social cost* (MSC) is the increase in the total social cost caused by a small increase in transport demand. Mathematically, it can be written as follows:

$$MSC(Q) = \partial TSC(Q,K)/\partial Q = \partial C(Q,K)/\partial Q. \qquad (15.1)$$

Since fixed cost does not depend on demand, the marginal social cost equals the marginal social variable cost. Noting that integrating a derivative brings us back the original function, we have

$$C(Q,K) = \int_0^Q MSC(q,K)dq. \qquad (15.2)$$

Average social cost (ASC) is $ASC(Q,K) = TSC(Q,K)/Q$ and the *average variable social cost* ($AVSC$) is $c(Q,K) = C(Q,K)/Q$. The relationship between the total, average, and marginal cost curves is shown in Figure 15.1, where the total variable social cost equals the area below the marginal social cost curve – that is, the hatched area $IHQO$ – as well as the average variable cost times transport demand; that is, rectangle $cGQO$ with thick borders. In the rest of this chapter, we shall repeatedly use the fact that these two areas are equal.

15.2.2 The consumer's surplus

Because of fuel and other taxes, a consumer is faced with a "price" that is different from the resource cost. If the price is denoted by p, the demand curve can be written as $Q = D(p)$. The *consumer's surplus* (CS) is the triangle between the demand curve and the price; that is, the hatched area in Figure 15.2. The *social benefit* (SB) is defined as the area below the demand curve (trapezoid $EGQO$), which includes the expenditure on transportation in addition to the consumer's

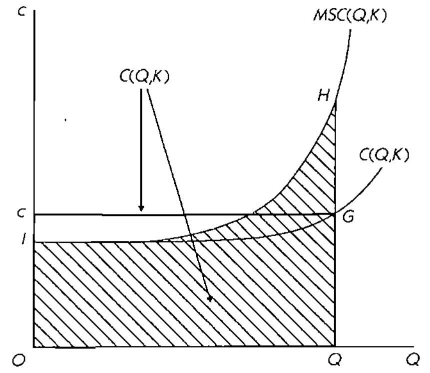

Figure 15.1 The total, marginal, and average cost curves.

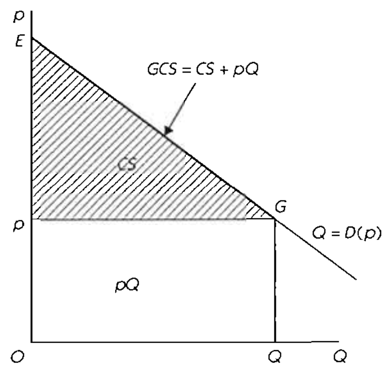

Figure 15.2 The demand curve and the consumer's surplus.

surplus. In Figure 15.2, the hatched area is the consumer's surplus and the rectangle *pGQO* shows the revenue.

15.2.3 A mass transit example

Let us take an example of a hypothetical mass transit line in a city where heavy subsidies are necessary for it to compete with automobile transportation. Most American and European cities fit this category. The largest Japanese cities, such as Tokyo and Osaka, are in a very different situation where many of the commuter railways are financially self-sufficient and congestion externalities are significant. The analyses of those cases are left to the reader.

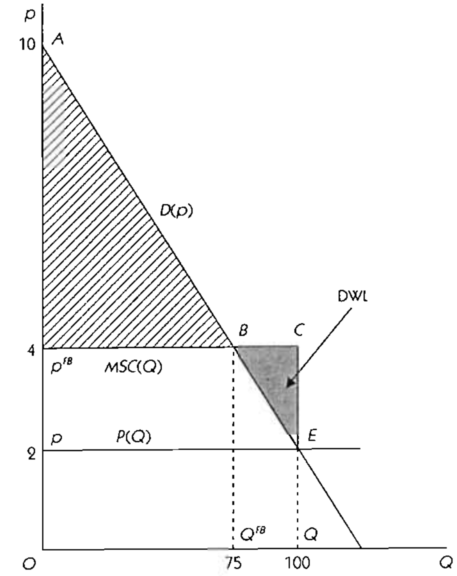

Figure 15.3 The net surplus and the deadweight loss: a mass transit example.

The marginal social cost of the transit system is $4 per trip, where the average trip length is 10 miles. We examine a subsidy to lower the fare to $2 per trip. For simplicity, we assume that the *MSC* curve is horizontal. The *AVSC* then equals the *MSC*. The number of trips is 100,000 per day.

Figure 15.3 shows the net social surplus for this example. With the subsidized fare of $2, the equilibrium is point $E = (p,Q) = (2,100)$, and the *SB* is trapezoid *AEQO*. Since the area below the *MSC* curve (area $p^{FB}CQO$) gives the total variable cost, the net surplus is area ABp^{FB} minus area *BCE*. Raising the price to the level of the *MSC* increases the net surplus by area *BCE*. By checking whether any other point along the demand curve has a smaller surplus, one can see that the net surplus is maximized at this point. The optimal solution therefore requires that the price equal the *MSC*:

$$p^{FB} = MSC(Q,K), \tag{15.3}$$

where the superscript *FB* denotes the first-best solution. The difference in net surplus from the first best is called the *deadweight loss*, which is indicated by DWL in Figure 15.3.

Figure 15.3 assumes that lowering the fare from $4 to $2 increases demand by 25,000 (from 75,000 to 100,000). In this case, the revenue of the transit operator decreases by \$100,000 per day (from \$300,000 to \$200,000), and the deadweight loss is \$25,000. If transit demand is more responsive to the fare, the revenue decrease becomes smaller and the deadweight loss larger. For example, if halving the fare increases demand by 75,000, then the revenue remains the same and the deadweight loss is \$75,000.

15.2.4 Optimal pricing and capacity investment

The net surplus maximization can be reformulated as social welfare maximization with an aggregate utility function. Let us represent the welfare of society by a quasi-linear utility function, $U(z,Q) = z + u(Q)$, where z is a composite consumer good. This functional form is restrictive, but we can extend our results to a general utility function if we choose an appropriate welfare measure (Kanemoto & Mera 1985).

The budget constraint for the consumer is $Y = z + pQ + T$, where Y is income and T is the lump-sum tax to finance the transportation sector deficit. Maximization of the utility function subject to the budget constraint yields the first-order condition that marginal utility (MU) equals price, $u'(Q) = p$. This condition gives the inverse demand function: the height of the demand curve equals marginal utility. The usual demand function, $Q = D(p)$, is the inverse of the marginal utility function.

Now, without loss of generality, we can normalize the utility function so that $u(0) = 0$. Then, we can show that the transportation component of the utility function coincides with the social benefit: $u(Q) = SB$. SB is the area below the demand curve and the integration of the marginal utility function from 0 to Q yields the SB; that is,

$$u(Q) = \int_0^Q u'(q)\mathrm{d}q = SB. \tag{15.4}$$

Substituting into the budget constraint the tax to finance the transportation-sector deficit, $T = -[pQ - C(Q,K) - F(K)]$, we can rewrite the utility function as

$$SW = u(Q) - C(Q,K) - F(K) + Y. \tag{15.5}$$

We call this *social welfare*. Maximization of this social welfare with respect to Q yields the first-order condition that marginal utility equals the MSC: $u'(Q) = \partial C/\partial Q$. Since the consumer's utility maximization requires that marginal utility equal price, we obtain the same optimality condition as before: $p^{FB} = MSC$, as in equation (15.3).

Maximizing social welfare with respect to capacity yields $-\partial C/\partial K = F(K)$. The left-hand side is the reduction in the total variable social cost by a marginal increase in capacity. We call this the *marginal direct benefit of capacity expansion* (MBK). The right-hand side is the *marginal cost of capacity expansion* (MCK), and optimality requires that they be equal ($MBK = MCK$).

15.3 Pricing and Investment with Distortion in Other Sectors

So far, we have implicitly assumed that there is no price distortion in other sectors of the economy. This is simply not true in the real world, where taxes, monopoly power, and improper congestion pricing make market prices diverge from corresponding marginal social costs. For example, it is almost impossible to raise tax revenue in a nondistortionary fashion, and the deadweight loss associated with tax distortion needs to be considered in evaluating any public policy. We take a simple example of mass transit that competes with a highway whose pricing is distorted. The same framework can be applied to other situations, such as two competing highway routes, off-peak pricing with underpriced peak hours, and transportation investment under the presence of urban agglomeration economies.

We use similar notation as in the preceding section and indicate mass transit by subscript 1 and the highway by subscript 2. For example, the prices of mass transit and the highway are p_1 and p_2, respectively. We suppress the capacity of the highway, K_2, because it is taken as exogenous.

In order to represent distortion in highway pricing, we assume a general pricing rule: $p_2 = P_2(Q_2)$. This formulation includes, as its special cases, those with a zero congestion toll and optimal congestion pricing.

We continue to assume a quasi-linear form for the aggregate utility function, $U(z,Q_1,Q_2) = z + u(Q_1,Q_2)$, which now includes two transportation modes. The consumer's utility maximization yields the first-order condition that marginal utilities equal prices: that is, $\partial u(Q_1,Q_2)/\partial Q_1 = p_1$ and $\partial u(Q_1,Q_2)/\partial Q_2 = p_2$. By solving these two equations for Q_1 and Q_2, we obtain demand functions for mass transit and the highway: $Q_1 = D_1(p_1,p_2)$ and $Q_2 = D_2(p_2,p_1)$. Because of the quasi-linear form, the demand functions do not depend on the income of the consumer.

15.3.1 General equilibrium demand functions

Let us now examine the effect of changing the mass transit price, p_1. A change in the transit price changes the demand for the highway and causes a change in its price. This in turn affects demand for the transit system. We obtain the effect of a transit price change on each of these two modes, taking into account the repercussions on the other mode.

Note that the pricing rule, $p_2 = P_2(Q_2)$, and the highway demand function, $Q_2 = D_2(p_2,p_1)$, have only three variables including the transit price. Given the transit price, p_1, therefore, these two equations determine the remaining two variables, Q_2 and p_2. In particular, the highway price is determined as a function of the transit price, which we write as $p_2 = p_2^*(p_1)$. By substituting this relationship into the demand function for mass transit, we obtain the demand for mass transit as a function of its price only:

$$Q_1 = D_1(p_1,p_2^*(p_1)) \equiv d_1(p_1). \tag{15.6}$$

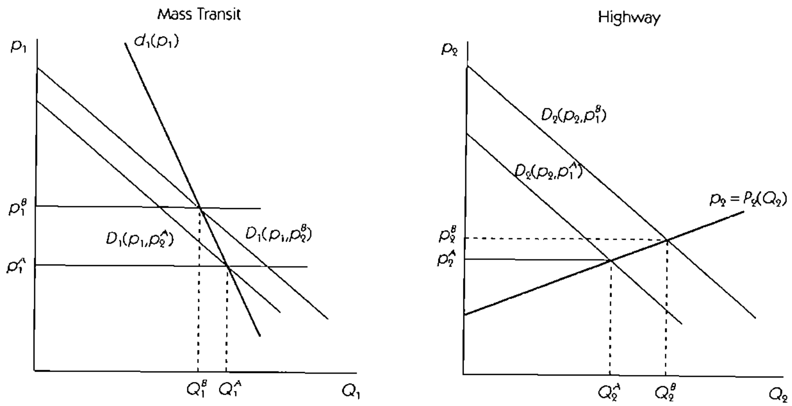

Figure 15.4 Partial and general equilibrium demand curves.

We call $Q_1 = d_1(p_1)$ the *general equilibrium demand function* for mass transit, since it depicts the relationship between its price and demand, taking into account general equilibrium repercussions on other sectors of the economy.

Figure 15.4 illustrates the derivation of the general equilibrium demand function. Let us start with the transit price, p_1^B. Given this price level, we can draw the (partial equilibrium) demand curve for the highway sector, $Q_2 = D_2(p_2,p_1^B)$. The intersection of this demand curve with the pricing rule curve, $p_2 = P_2(Q_2)$, gives the equilibrium highway price, p_2^B. Coming back to the mass transit sector, this highway price, coupled with the transit price that we set earlier, determines demand for mass transit, $Q_1^B = D_1(p_1^B,p_2^B)$. If the transit price falls to p_1^A, then some of the highway users shift to the transit system, and the highway demand curve moves down to $Q_2 = D_2(p_2,p_1^A)$. This lowers the highway price to p_2^A, which in turn shifts down the demand curve for mass transit. Demand for mass transit is then $Q_1^A = D_1(p_1^A,p_2^A)$. Connecting points such as (Q_1^B,p_1^B) and (Q_1^A,p_1^A), we obtain the general equilibrium demand curve, $Q_1 = d_1(p_1)$.

The general equilibrium demand function for the highway is defined by

$$Q_2 = D_2[p_2^*(p_1),p_1] \equiv d_2(p_1). \tag{15.7}$$

This demand function gives demand for the highway as a function of the transit price. We can change the argument of the demand function to the highway price, p_2, using the relationship between the two prices, $p_2 = p_2^*(p_1)$, obtained above. Note however that, since the pricing rule uniquely determines the relationship between Q_2 and p_2, this demand function must coincide with the pricing rule.

15.3.2 The consumer's surplus with general equilibrium demand functions

Next, let us examine how to measure the consumer's surplus in our multi-market situation. The difficulty we face is that the consumer's utility, $U(z,Q_1,Q_2) = z + u(Q_1,Q_2)$, is not separable between the two markets. We have to find a way to divide the utility between the two markets. The trick is to evaluate small changes and sum them to obtain a welfare measure for a large change.

In the single-market case, we have seen that the *SB* coincides with the transportation component of the utility function, $u(Q)$, if the utility function is normalized so that $u(0) = 0$. Here, we also assume that $u(0,0) = 0$. Figure 15.5 shows the effect of lowering the transit price from p_1^B to p_1^A. This change increases demand for transit from Q_1^B to Q_1^A and reduces demand for the highway from Q_2^B to Q_2^A. We divide these changes into small changes and evaluate them separately.

A small change in the mass transit price, Δp_1, changes demands for mass transit and the highway by $\Delta Q_1 = d_1'(p_1)\Delta p_1$ and $\Delta Q_2 = d_2'(p_1)\Delta p_1$. The induced change in utility is obtained by multiplying these demand changes by marginal utilities of the transportation services: $\Delta u = (\partial u/\partial Q_1)\Delta Q_1 + (\partial u/\partial Q_2)\Delta Q_2$. Since the consumer's utility maximization insures that marginal utility equal price, this utility change can be rewritten as $\Delta u = p_1\Delta Q_1 + p_2\Delta Q_2$. We can therefore obtain a change in utility by multiplying a change in quantity demanded by the price. In Figure 15.5, these are represented by narrow hatched rectangles in the transit market and shaded ones in the highway market. The sum of these areas yields the utility change. By reducing the size of Δp_1 to zero, we obtain the exact estimates. Thus, the area under a general equilibrium demand curve gives the social benefit.

The general equilibrium demand curve in the highway market coincides with the pricing rule. The pricing rule is typically based on supply-side conditions. For example, in the case of road transportation, it is determined mainly by time costs, operating costs, and fuel taxes. The reader may have difficulty in understanding why this supply-side relationship determines the consumer's surplus. We can offer the following intuitive explanation. The height of the partial equilibrium demand curve shows the consumer's willingness to pay, but the demand curve shifts when the mass transit price changes. For example, p_2^B in Figures 15.4 and 15.5 gives willingness to pay at quantity Q_2^B when the transit price is p_1^B. If the transit price becomes lower, the partial equilibrium demand curve shifts leftward and demand for the highway decreases. Since the new equilibrium point must be on the pricing rule curve, the highway price falls to a level such as p_2'. Willingness to pay at this new point given by the new partial equilibrium demand curve is p_2'. Since the equilibrium point moves along the pricing rule curve, the area below the curve gives the *SB*.

15.3.3 A mass transit example: a fare subsidy

We now extend the earlier numerical example in Figure 15.3 to allow for price distortion in the highway market. Recall that we examined the effects of lowering

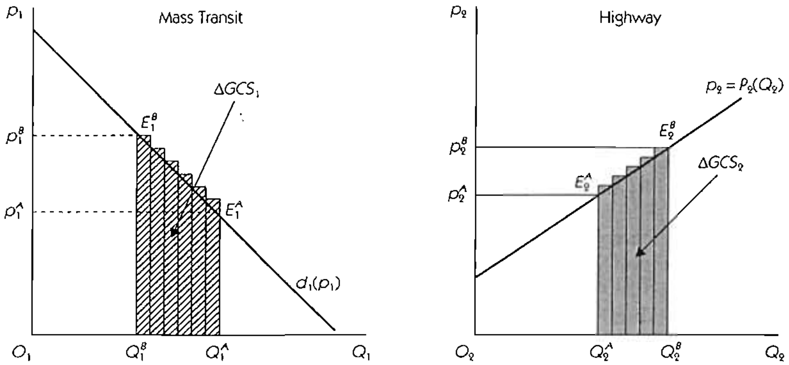

Figure 15.5 The social benefit.

the fare from the *MSC* of \$4 per trip to the subsidized fare of \$2. Mass transit demand is 75,000 per day if the fare is \$4, and becomes 100,000 if it is lowered to \$2. On the highway side, we assume that demand is 225,000 trips in the \$4 case and 200,000 in the \$2 case. Total demand is then the same at 300,000 in both cases. We assume moderate congestion on the highway so that traffic congestion there is slightly mitigated if the transit fare is reduced to \$2. The user cost per trip is \$3.20 if the fare is \$4, and it becomes \$3 if the fare is lowered to \$2. These user costs include time costs, operating costs, and fuel taxes. In order to obtain the social cost, we have to subtract the fuel tax and add external costs such as air pollution costs. The fuel tax is assumed to be \$0.20 and external costs to be \$0.50 per trip in both cases. The social costs are then \$3.30 and \$3.50. Note that these costs are not marginal costs, but average costs. The external costs of \$0.30 do not include the congestion externality, because this is implicit in the increase in user cost from \$3 to \$3.20. Average costs per trip are summarized in Table 15.1.

Table 15.1 Average costs per trip

	\$4 fare case		*\$2 fare case*	
	Mass transit	*Highway*	*Mass transit*	*Highway*
Traffic (1,000 trips)	75	225	100	200
User cost	\$4.00	\$3.20	\$2.00	\$3.00
Fuel tax or fare	\$4.00	\$0.20	\$2.00	\$0.20
Supplier cost	\$4.00	\$0.00	\$2.00	\$0.00
External costs	\$0.00	\$0.50	\$0.00	\$0.50

Note: External costs in the last row do not include a congestion externality.

Panel (a) in Figure 15.6 shows changes in the *SB*s caused by lowering the fare from \$4 to \$2. The hatched area on the left shows the increase in the *SB* in the mass transit market and the shaded area on the right is the decrease in the *SB* in the highway market. Henceforth, we adopt the convention that a hatched area indicates an increase in benefits (or a decrease in costs) and a shaded area a decrease in benefits. The increase in the *SB* in the mass transit market is \$75,000 and the decrease in the highway is \$77,500. In order to obtain the benefit of the price change, we have to subtract the increase in total social cost from the increase in the *SB*. As shown in panel (b) of Figure 15.6, the increase in demand for mass transit raises the social cost by \$100,000 per day, which is indicated by the shaded area. The induced decrease in highway traffic from 225,000 to 200,000 lowers the social cost by \$127,500. By subtracting these from the changes in the *SB*, we can see that the social surplus decreases by \$25,000 in the mass transit market and increases by \$50,000 in the highway market. The net benefit is then \$25,000. Even though we assume fairly mild congestion on the highway, subsidizing mass transit to reduce its fare is socially beneficial.

15.3.4 The second-best price and capacity for mass transit

Next, we derive the condition for the second-best optimum when the highway price is distorted. The budget constraint for the consumer is $z + p_1Q_1 + p_2Q_2 = Y - T$, where, as before, T is the tax to finance the deficit of the transportation sector and satisfies

$$T = -[p_1Q_1 - C_1(Q_1,K_1) - F_1(K_1)] - [p_2Q_2 - C_2(Q_2) - F_2]. \tag{15.8}$$

Substituting the budget constraint and the general equilibrium demand functions into the utility function yields

$$U^*(p_1,K_1) = u[d_1(p_1),d_2(p_1)] - C_1[d_1(p_1),K_1] - F_1(K_1) - C_2[D_2(p_1)] - F_2 + Y. \tag{15.9}$$

The first-order conditions for optimal price, p_1, and capacity, K_1, are as follows:

$$\frac{\partial U^*}{\partial p_1} = \left[\frac{\partial U}{\partial Q_1} - MSC_1\right] d_1'(p_1) + \left[\frac{\partial U}{\partial Q_2} - MSC_2\right] d_2'(p_1) - 0, \tag{15.10}$$

$$\frac{\partial U^*}{\partial K_1} = -\frac{\partial C_1}{\partial K_1} - F_1'(K_1) = 0. \tag{15.11}$$

As seen before, utility maximization of the consumer yields $p_i = MU_i$ for both sectors. Substituting these relationships into equation (15.10) and rearranging terms, we obtain

$$p_1 - MSC_1 = -\frac{d_2'(p_1)}{d_1'(p_1)}[P_2(Q_2) - MSC_2]. \tag{15.12}$$

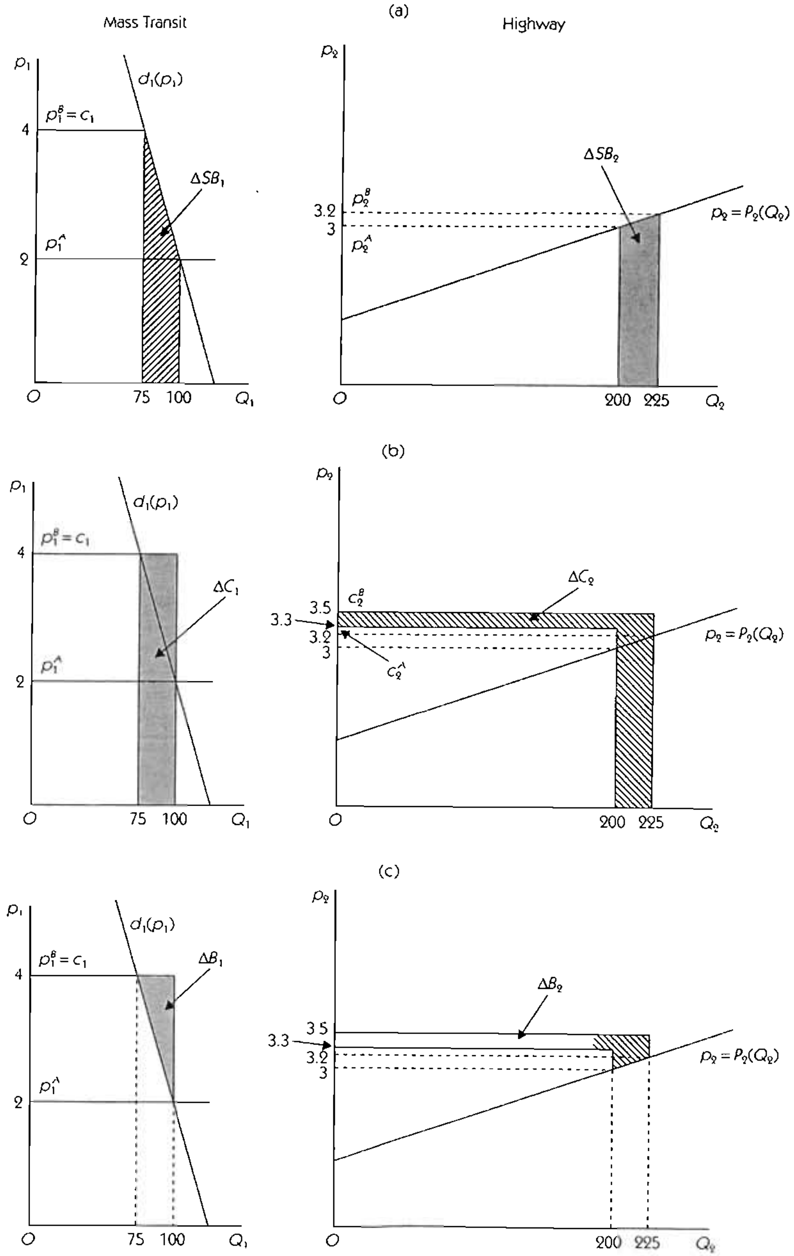

Figure 15.6 The effects of a reduction in transit price: (a) the social benefit; (b) the total social costs; (c) the social surplus.

It is usually the case that general equilibrium demand for mass transit is downward sloping: $d_1'(p_1) < 0$. If there is sufficient substitutability between mass transit and the highway, a rise in the price of mass transit will increase demand for the highway: $d_2'(p_1) > 0$. In such a case, when the highway is underpriced – that is, $p_2 < MSC_2(Q_2)$ – the mass transit price must also be lower than the *MSC*.

In a special case where the total demand for the two modes is fixed, we have $d_1(p_1) + d_2(p_1) = \text{const}$. In this case, the decrease in demand for mass transit equals the increase in demand for the highway – that is, $d_1'(p_1) = -d_2'(p_1)$ – and we obtain

$$p_1 - MSC_1 = P_2(Q_2) - MSC_2; \tag{15.13}$$

that is, the price–*MSC* margins for the two modes must be equal. Arnott and Kraus (2003) offer more general and detailed discussions on this special case.

Linear demand and pricing rule functions consistent with our numerical example are as follows:

$$d_1(p_1) = -12.5p_1 + 125, \tag{15.14}$$

$$d_2(p_2) = 12.5p_1 + 175, \tag{15.15}$$

$$P_2(Q_2) = \frac{1}{125}Q_2 + 1.4, \tag{15.16}$$

and the marginal social costs are

$$MSC_1 = 4, \tag{15.17}$$

$$MSC_2 = 0.2p_1 + 4.5. \tag{15.18}$$

Since the sum of the demands in the two markets is constant, the differences between the prices (user costs) and the *MSC*s are equal in the two markets, as in equation (15.13). Substituting equations (15.14)–(15.18) into equation (15.13), we obtain the second-best prices, $p_1^{SB} = 23/11 \cong 2.0909$ and $p_2^{SB} \cong 3.0909$. In this example, a heavy subsidy to make the transit fare almost a half of the *MSC* is second-best optimal.

We have examined an example with mild congestion on a highway. In large metropolitan areas such as Tokyo and New York City, with more acute congestion, the price–*MSC* margin in road transportation is much larger. In downtown Tokyo, it is estimated to be about 27 yen per km per vehicle. Mass transit fares per person are somewhere around 12–20 yen per km. If the two modes are substitutes and the total demand for the two modes is inelastic, the second-best optimal transit fares could be significantly negative. In Tokyo, however, congestion in mass transit is also severe in peak hours. Furthermore, most of the commuters are already using mass transit and it is not clear how much traffic will shift from automobiles to mass transit. Rigorous empirical studies are necessary to determine the optimal subsidies to mass transit. Unfortunately, in many countries substantial subsidies are given to mass transit without rigorous economic analysis to justify them.

The condition for optimal capacity given in equation (15.11) is the same as the single-market case: the marginal direct benefit of capacity expansion, $MBK_1 = -\partial C_1/\partial K_1$, must equal its marginal cost, $MCK_1 = F_1'(K_1)$. Note that this condition is obtained because the price of mass transit is chosen (second-best) optimally. Otherwise, a change in the price caused by capacity investment induces a change in the deadweight loss.

15.3.5 Cost–benefit analysis of transportation investment

The framework that we have used in analyzing a fare subsidy can be applied to transportation investment. The only addition is the effect of the investment on the social cost. Let us take the example in Figure 15.6 and examine the investment in mass transit to reduce its operating costs from \$4 per trip to \$2. In the fare subsidy case, the same reduction in the mass transit price was not accompanied by a decrease in the social cost. We now have to add this element. The effects on the *SB* are the same as in Figure 15.6. Because of the cost reduction in mass transit, the effects on total social costs are different from those of Figure 15.6. In panel (a) of Figure 15.7, the hatched area on the mass transit side shows the reduction in social costs due to the operating cost reduction. The shaded area represents the increase in costs due to the demand increase. Adding Figure 15.6 and panel (a) of Figure 15.7, we obtain the benefit of investment shown in panel (b) of Figure 15.7.

Although the figures look somewhat complicated, the calculation of the benefit is quite simple. First, based on demand forecasts, we estimate the general equilibrium demand functions. In practice, demand curves are assumed to be straight lines connecting equilibrium points with and without the investment project. Second, we compute the areas below the demand curves to obtain *SBs*. Third, given the demand forecasts, we estimate the changes in total social costs. Finally, we subtract the sum of the latter from that of the former to yield the benefit of the project. This process is the same as cost–benefit analysis in a first-best world. So long as we use the right prices and costs, no change is necessary even in a second-best world with distorted prices.

If we make the usual assumption that the demand curves are straight lines, we have a simple cost–benefit formula. If demand changes from Q_i^B to Q_i^A in market i, and if prices and total social costs change from p_i^B and C_i^B to p_i^A and C_i^A, respectively, the increase in the *SB* is as follows:

$$\Delta SB_i = \frac{1}{2}(p_i^A + p_i^B)(Q_i^A - Q_i^B), \qquad (15.19)$$

and the increase in social costs is

$$\Delta C_i = C_i^A - C_i^B \qquad (15.20)$$

in market i. Summing the difference between these two over all markets yields the social surplus of investment:

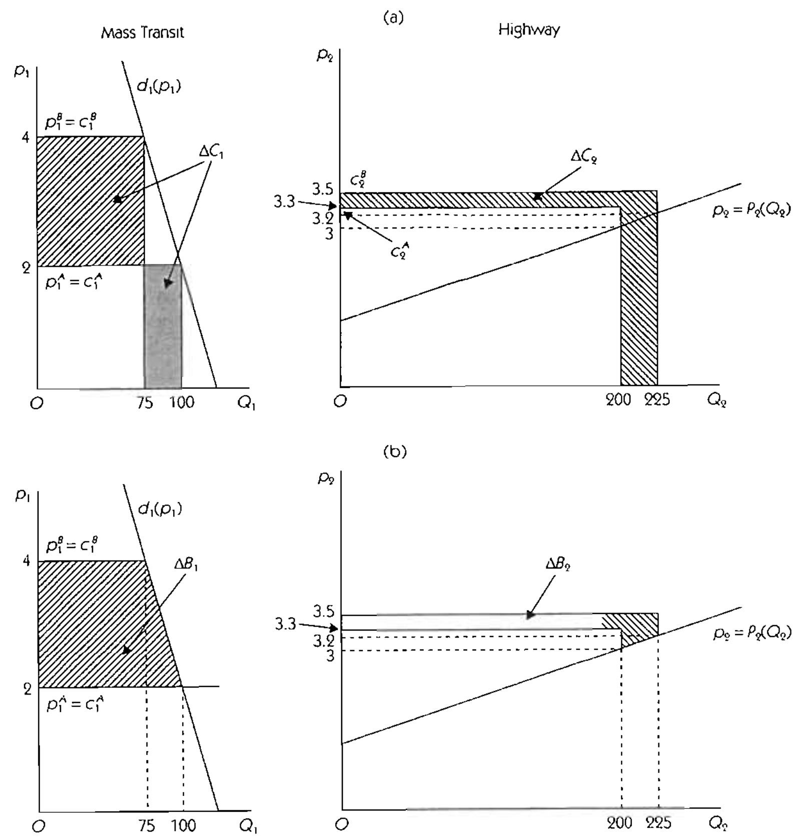

Figure 15.7 The effects of investment in mass transit on total social costs and the social surplus: (a) the total social costs; (b) the benefits.

$$\Delta B = \sum_i \left\{ \frac{1}{2}(p_i^A + p_i^B)(Q_i^A - Q_i^B) - (C_i^A - C_i^B) \right\} \qquad (15.21)$$

In cost–benefit analysis, we compare this benefit with the cost of the investment.

15.4 CONCLUSION

We have seen how to analyze the welfare impact of pricing and investment policies in urban transportation. The fact that cities inevitably have many externalities that are not properly priced makes the analysis somewhat complicated. Furthermore, tax revenue to finance a public project is almost always raised in a distortionary fashion, and the deadweight loss associated with this needs to be taken into account. What you have to do in evaluating real-world problems, however, is quite simple, as long as you assume convenient functional forms such as linear demand functions.

It would be a rewarding exercise to pick an example in the city in which you live and conduct a cost–benefit analysis of a change of some aspect of transportation policies. What you have to obtain, or estimate, are prices, costs, and quantities demanded in the cases with and without the proposed change. With these numbers, you should be able to apply the methodologies explained in this chapter to calculate the benefits of the proposal. For detailed explanations of techniques used in cost–benefit analysis, we refer readers to Boardman, Greenberg, Vining, and Weimer (2001).

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Bibliography

Arnott, R. and Kraus, M. 2003: Principles of transport economics. In R. W. Hall (ed.), *Handbook of Transportation Science*, 2nd edn. Norwell, MA: Kluwer, 689–726.
Boardman, A. E., Greenberg, D. H., Vining, A. R., and Weimer, D. L. 2001: *Cost–Benefit Analysis: Concepts and Practice*, 2nd edn. Upper Saddle River, NJ: Prentice Hall.
Federal Highway Administration 2000: *Addendum to the 1997 Federal Highway Cost Allocation Study Final Report*. Washington, DC: US Department of Transportation, Federal Highway Administration.
Kanemoto, Y. and Mera, K. 1985: General equilibrium analysis of the benefits of large transportation improvements. *Regional Science and Urban Economics*, 15(3), 343–63
Mills, E. S. and Hamilton, B. W. 1989: *Urban Economics*, 4th edn. Glenview, IL: Scott, Foresman.
Mohring, H. 1976: *Transportation Economics*. Cambridge, MA: Ballinger.
Newbery, D. M. 1990: Pricing and congestion: economic principles relevant to pricing roads. *Oxford Review of Economic Policy*, 6(2), 22–38.
Yamazaki, F. and Asada, Y. 1999: The estimation of social costs of railway congestion and optimal fares. *The Quarterly Journal of Housing and Land Economics* (*Jutaku Tochi Keizai*), 34, 4–11 (in Japanese).

CHAPTER SIXTEEN

Urban Passenger Travel Demand

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16.1 Introduction

The idea of tolling roads to reduce traffic congestion was suggested back in 1920. For several decades, road pricing was largely dismissed as impractical and publicly unacceptable, and early attempts to introduce tolls on urban roads foundered because of poor marketing strategies and political opposition. But a number of road-pricing projects are now in operation or planned around the world, and in the 1990s the US federal government introduced a Value Pricing program to fund innovative road and parking pricing schemes.

This essay reviews two econometric studies of road pricing in the United States. One, by Lam and Small (2001), concerns a toll-lanes project on State Route 91 in Orange County, California, which was the first Value Pricing project to be implemented. Lam and Small use data obtained from users of the freeway to estimate individual choice models of whether to drive on the toll lanes and related travel decisions. The second study, by Bhat and Castelar (2002), investigates the effects of hypothetical congestion-pricing initiatives in the San Francisco Bay Area. Their study illustrates how traveler responses to policies that have yet to be implemented can be estimated.

The two studies focus on the role of road pricing to alleviate traffic congestion, which is a rising scourge in large urban areas. In part, support for road pricing derives from the basic economic principle of efficient pricing that motorists should pay the full marginal costs of driving – including congestion, air pollution, and other external costs. Support for road pricing also stems from the fact that more traditional policies to improve personal mobility have not been particularly