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Road Pricing for Congestion Management: The Transition from Theory to Policy

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10. Road pricing for congestion management: the transition from theory to policy

Kenneth A. Small and José A. Gomez-Ibañez

10.1 INTRODUCTION

Traffic congestion is a classic externality, especially pervasive in urban areas. The theoretical and empirical relationships governing it have been thoroughly studied. As a result, most urban economists and a growing number of other policy analysts agree that the best policy to deal with it would be some form of congestion pricing. Such a policy involves charging a substantial fee for operating a motor vehicle at times and places where there is insufficient road capacity to easily accommodate demand. The intention is to alter people's travel behavior enough to reduce congestion.

Researchers have long speculated about how to overcome the practical barriers to implementing some form of congestion pricing. The work of William Vickrey (1955, 1963, 1965, 1973) stands out, but is by no means alone: other notable contributions addressing policy design and evaluation include Walters (1961), UK Ministry of Transport (1964), Mohring (1965), May (1975), Gomez-Ibañez and Fauth (1980), Kraus (1989), and Small (1992). A comprehensive two-year study by the US National Research Council (1994) is almost entirely concerned with implementation. Additional recent policy evaluations include Grieco and Jones (1994) and Emmerink *et al.* (1995). Together, these works address technology and institutions for implementation, relationship to road investment, welfare evaluation of ideal and not-so-ideal policies, financial policies for using revenues, and practical steps that could take us from current policies toward congestion pricing.

Public officials have recently become more interested in congestion pricing and other schemes for charging for road use, such as toll roads or parking taxes. This broader group of policies is often called road pricing. The interest in road pricing has been stimulated by the desire to find new revenue sources for transportation investments, and by the failure of alternative policies to significantly stem the growth of traffic congestion.

As a result, practical experience with road pricing has been increasing worldwide. For many years, the only example of congestion pricing was Singapore, a case that has received mixed reviews. Today there is considerably more experience to draw from, as well as several quite detailed plans that made considerable progress towards political approval. These cases cover a wide range of sites, objectives, and details of implementation. Many are described by Hau (1992), Lewis (1993), and Gomez-Ibañez and Small (1994).

This chapter summarizes 13 such cases, including Singapore, and draws lessons about implementation from them. In particular, we examine how well the theoretical advantages of congestion pricing hold up in the transition to practical and politically acceptable policies. The cases are divided into four broad categories: congestion pricing of a center city, center-city toll rings designed primarily to raise revenue, congestion pricing of a single facility, and comprehensive area-wide congestion pricing. Table 10.1 lists our cases according to these categories, and shows whether each case is already implemented, is under study, or, as in one case, is a limited-time experiment.

Table 10.1 Cases of road pricing studied

Type of road pricing	Degree of implementation		
	In place (starting date)	Behavioral experiment (dates)	Under study
City center: congestion pricing	Singapore (1975)		Hong Kong Cambridge, UK
City center: toll ring	Bergen (1986) Oslo (1990) Trondheim (1991)	Stuttgart (1994–95)	Stockholm
Single facility: congestion pricing	Autoroute A1, France (1992) State Route 91, California (1995) Interstate 15, San Diego (1996)		
Area-wide: congestion pricing			Randstad London

10.2 PIONEERS: CONGESTION PRICING OF CITY CENTERS

Three cities have seriously considered congestion pricing of a city center, each pioneering a different method of applying or implementing the concept. Singapore was the first to design and implement a practical, low-tech scheme for congestion pricing. Singapore's initial system was very simple: the priced area is defined by a single cordon line surrounding the city center, the technology consists of paper windshield stickers, and enforcement is through visual inspection by traffic officers. Hong Kong was the pioneer in fully-automated charging; its electronic road pricing (ERP) scheme was a flexible and comprehensive system involving multiple cordons. For Cambridge, England, the new concept was congestion-specific charging, an attempt to more closely approximate the theoretical ideal of congestion pricing by making the charge vary in real time in a manner reflecting the severity of congestion actually encountered while inside the priced area.

Only one of these systems is operational. Singapore's Area License Scheme (ALS) was inaugurated in 1975 and still operates today; the city has recently inaugurated an electronic system to replace its manual charging and enforcement. Hong Kong's ERP scheme was subjected to extensive technological field trials as well as exhaustive desk studies for prediction and evaluation, but was withdrawn due to public opposition. Cambridge has also been the site of a technological field trial but the scheme was abandoned when a new and unsupportive council came to power in 1993.

10.2.1 Singapore's Area License Scheme

Singapore's ALS is part of an extremely stringent set of policies designed to restrict automobile ownership and use in this crowded island city-state of three million people. The national government chose the ALS over conventional road tolls and higher parking charges because space for toll stations was lacking in the city center and it thought higher parking charges would be ineffective in the face of heavy through traffic and numerous chauffeur-driven cars.

The size and structure of the fee has varied over the years. When first implemented in 1975, the fee was imposed only on vehicles entering the restricted area during the morning peak period. Carpools and taxis carrying four or more people were exempted, as were motorcycles and commercial trucks. For cars, the fee has ranged from approximately $1.50 to $2.50 per day in US currency equivalent.[1] In 1989, the charging hours were extended to the afternoon peak (but still in the inbound direction, since that produced the desired effect on through traffic) and the exemptions were eliminated for all vehicles except public transit. In 1994, the hours were extended to include the time between the morning and afternoon peaks. Collection costs have been modest, amounting to about 11 percent of revenue in the early years.

The effects on traffic have been dramatic. Among commuters to jobs in the restricted zone, the share commuting in cars with less than four passengers dropped from 48 percent to 27 percent during the first few months of operation, while the combined modal shares of carpool and bus rose from 41 percent to 62 percent (Watson and Holland, 1978, p. 85). As shown in Table 10.2, the numbers of vehicles of all types entering the zone during restricted

Table 10.2 Effects of the Singapore area license scheme

	1975 initiation: morning only		1989 changes: morning and afternoon	
	Before (Mar. 1975)	After (Sept.–Oct. 1975)	Before (May (1989)	After (May 1990)
Daily traffic entering restricted zone (1000s):				
7:00–7:30	9.8	11.1	9.7	9.7
7:30–10:15[a,b]	74.0	41.2	51.8	44.8
10:15–11:00	NA	NA	22.1	21.8
4:00–4:30	NA	NA	12.9	12.4
4:30–6:30[b]	NA	NA	51.5	23.8
6:30–7:30	NA	NA	22.3	24.1
Average commute time to jobs in restricted zone for those not changing mode (minutes):				
Solo driver	26.8	27.9	NA	NA
Carpool[c]	28.2	31.5	NA	NA
Bus rider	40.4	41.0	NA	NA

Notes:
a Restraint hours in effect August 1975–May 1989.
b Restraint hours in effect February 1990–December 1993.
c Average for carpool drivers, carpool passengers, and other car passengers, weighted by number in sample.
NA = data not available

Sources Watson and Holland (1978), pp. 41, 133, Menon and Lam (1993), p 29.

hours declined by 44 percent. During the half-hour preceding the restraint period, in contrast, traffic rose 13 percent, and it probably rose also during the hours after the peak. (In fact, the original restraint hours of 7:30–9:30 had to be extended by 45 minutes after the first month of operation because so many people were postponing trips until just after the restraint period.)

Some of the road space originally released during the restraint hours was taken by trucks, whose peak-period entries increased by 124 percent during the first few months of operation (Watson and Holland, 1978, p. 48). Their use declined markedly after the fee was extended to trucks in 1989. Furthermore, afternoon traffic failed to decline significantly until afternoon restraint hours were established in 1989; before that, many people with destinations on the far side of the zone apparently avoided the zone during the morning but traveled through it during the afternoon. Both truck traffic and afternoon peak traffic illustrate that very specific responses occur to pricing incentives, and any loopholes in the charging scheme are likely to be heavily exploited.

While traffic speeds rose dramatically in the zone itself, a large portion of the resulting time savings appears to have been dissipated by increased congestion outside the zone. As shown in Table 10.2, average commuting time to jobs in the zone increased for each mode of travel from May to October, 1975. We suspect that subsequent road improvements outside the zone have modified this pessimistic finding, but data are lacking.

In 1994 the ALS was extended to a two-tiered structure covering a longer period of the day, with one charge for a weekday permit valid for the midday hours (10:15–16:30) and a higher charge for a permit that also covers the morning and afternoon peak (valid 7:30–18:30). In March 1998, the current paper permit system was replaced by an electronic 'smart card' system; initially it will merely duplicate the current pricing structure but later it may be used to introduce refinements.[2]

The Singapore experience demonstrates that travelers respond dramatically to sufficiently high pricing incentives. However, it does not necessarily prove that a scheme as simple as a single cordon and a single time period is a good idea. Problems of spillover across spatial and time boundaries may make this scheme too crude an approximation of marginal-cost pricing to provide the net economic benefits achievable in theory. On the other hand, the problem could be simply that the fee was set too high, as argued by Watson and Holland (1978), Wilson (1988), Toh (1992), and McCarthy and Tay (1993).

10.2.2 Hong Kong's Electronic Road Pricing Trial

Nearly a decade after the inauguration of the Singapore area license scheme, Hong Kong, a slightly larger city with population 4 million, proceeded with plans for a more complex system using electronic charging and video enforcement. Hong Kong's field trial proved the ability of electronic charging mechanisms to operate with very high degrees of accuracy. The system, now technologically outdated, used radio-frequency communications through loop antennas buried in the pavement, and required vehicles to be channeled into lanes when they passed the charging points. Systems for automatic charging, billing, and enforcement through closed-circuit television all performed extremely well (Catling and Harbord, 1985).

Alternative pricing structures and charging locations were evaluated using a simulation model designed by the MVA Consultancy in London (Harrison, 1986). Three different schemes were studied (see Table 10.3), each including at least five charging zones in contrast to Singapore's single zone. (Hong Kong has two dense commercial districts, one on the tip of the Kowloon Peninsula and the other on the north shore of Hong Kong Island, making a single cordon like Singapore's less practical.) Scheme A had five zones and several cordon 'tails' extending the zonal boundaries to discourage travel along the outer edge of the zones; 130 distinct charging points would have had to be equipped, each imposing an identical charge which varied by time

Table 10.3 Predicted effects of Hong Kong electronic road pricing schemes

	ERP scheme		
	A	B	C
Design of restraint scheme:			
Number of zones	5	5	13
Number of charging points	130	115	185
Peak direction more expensive?	no	yes	yes
Average monthly payment (US$ equivalents, 1985)[a]	15.60	18.20	20.80
Predicted effect on travel:			
Change in peak-period car trips	–20%	–21%	–24%
Economic evaluation:			
Gross revenue (US$ millions/year)[a]	51	60	70
Net benefits before collection costs (US$ millions/year)[a]	95	113	119

Note: a The 1985 exchange rate was HK$1 = US$0 13 (International Monetary Fund, 1992).

Source Transpotech, Ltd. (1985), pp 2 69, 2.70, 2.74, 2.79.

of day. Schemes B and C imposed higher charges for crossing in the direction of peak flow than for crossing in the opposite direction. Scheme C also had more zones and more charging points than either A or B. In all three schemes, two levels of charges were to be assessed: a higher one during the morning and afternoon peaks and a lower one before, between, and after the peaks. No charge would be assessed at other times.

Peak travel was predicted to decline by 20 to 24 percent (Table 10.3). Total daily car trips would be reduced by 9–13 percent. In the case of Scheme B, for example, about 41 percent of all daily trip makers would be unaffected by the charging scheme, another 42 percent would pay the charge, and the remaining 17 percent would alter their trips, two-thirds by changing mode and one-third by changing time of day of travel (Transpotech, 1985, pp. 2.69–2.79).

Projected net benefits, ignoring collection costs, are shown in the last row of Table 10.3. Taking the most complex scheme (C) as the benchmark, the simplest scheme (A) achieves 80 percent of the possible net benefits, while Scheme B achieves 95 percent. This suggests that five zones and two charging levels are sufficient to approximate marginal-cost pricing reasonably well; charging more in the peak direction (Scheme B) seems to be more important than further refining the geography (Scheme C).

Ultimately none of the schemes were adopted for a number of reasons. The field trials took place during the early stages of a transfer of power from the British colonial government to popularly elected officials; the government was slow to consult newly elected members of local district boards, giving them an issue on which to assert their independence. A weak economy in the early 1980s had lowered automobile ownership, moreover, and thus relieved some of the urgency for strict policies to reduce congestion. Many people objected to the potential invasion of privacy made possible by the electronic monitoring equipment. Finally, many did not perceive that the revenues from the project would benefit them; only belatedly did the government propose to use these revenues to reduce Hong Kong's high annual vehicle registration fees.

Analysts have debated the extent to which Hong Kong's failure to implement any of the proposed schemes represented tactical errors, bad luck, or an inherent political weakness of congestion pricing.[3] What seems clear is that any successful implementation in a democracy will require anticipating and resolving likely objections early in the planning process, including making clear just how the revenues will be used to benefit the population.

10.2.3 Congestion-Specific Charging for Cambridge, England

Cambridge, a historic city of 100 000 people located 100 kilometers north of London, was the site for a unique proposal that would carry congestion pricing close to its theoretical extreme. Within a ring encompassing the congested city center, charges would vary in real time in accordance with the amount of congestion actually experienced by the individual vehicle (Sharpe, 1993). The rationale was that the amount of congestion experienced by a vehicle is probably closely related to the externalities it imposes on others. (This proposition is debatable given the dynamics of congestion formation.) The proposal, put forth in 1990 by Brian Oldridge, then Director of Transportation for Cambridgeshire, won preliminary approval of the Cambridgeshire County Council.

Real-time pricing was to be implemented by means of an in-vehicle meter, which contains a clock and is connected to the car's odometer. Under one suggested charging regime, for example, the meter would assess a charge of US$0.36 (at the 1990 exchange rate) whenever a distance of 0.5 km was traversed either (a) at a speed less than 25 km per hour or (b) with more than four stops.[4] These criteria were intended to make the charge on a vehicle approximate the externality that vehicle imposes on others. Charges would be deducted from the balance contained in a prepaid 'smart card' or 'electronic purse', thereby preserving the user's anonymity and overcoming one source of resistance encountered in Hong Kong.

When Oldridge retired in 1993 his replacement, J. Michael Sharpe, decided to focus on more conventional forms of road pricing, such as cordon charges or zone fees, as alternatives to congestion metering. Sharpe was concerned about the potential for public outrage when charges are unpredictable. From the user's point of view, real-time charging would have meant that on those very days when travel conditions were unexpectedly poor, a financial penalty would be added to the aggravation already experienced. Many citizens might blame politicians or traffic planners for incidents of severe congestion rather than accepting the principle that they should pay more because they are imposing higher marginal costs on others. In addition, drivers might drive unsafely to avoid triggering the meter (Ison, 1996).

The metering technology was tested in October 1993 as part of the ADEPT project within the European Union's DRIVE-II program (Clark *et al.*, Blythe, 1994). Implementation efforts ended, however, with a change in the shire government earlier that year. Surveys in summer 1994 found that the road pricing concept was viewed as 'acceptable' by only one-third of respondents, a larger proportion than for car bans or parking controls but far less than for public transport improvements (Ison, 1996, p. 120). Modeling studies of road pricing alternatives for Cambridge have continued; preliminary results suggest that the use of congestion-specific charges does significantly increase the benefits beyond those achievable from a cordon-type pricing system (Milne *et al.*, 1994), presumably by increasing the precision with which prices approximate marginal costs.

Cambridge demonstrated the technical feasibility of more sophisticated forms of road pricing. But it also demonstrated the need to develop grass roots support simultaneously with concrete proposals, especially ones as radical as the original Cambridge plan. It seems unlikely that any locality would accept a pricing scheme with unpredictable charges, at least in the absence of lengthy prior experience with less elaborate schemes.

10.3 THE SCANDINAVIAN TOLL RINGS

While Singapore, Hong Kong, and Cambridge have been experimenting with increasingly sophisticated proposals for congestion pricing, Scandinavian cities have developed a more modest type of road pricing which has emerged as an important tool for highway finance. Toll rings now surround three Norwegian cities, and one was planned for Stockholm, Sweden.

The Scandinavian toll rings do not represent congestion pricing. They are designed primarily to generate revenue to finance desired transportation infrastructure improvements; furthermore, congestion management is not among the objectives in Norway, and was only secondary in Sweden. As a result, Norway's tolls are low, ranging from approximately \$0.70 to \$1.75 per entry,[5] and do not vary much by time of day. Furthermore, the locations of toll stations were chosen not to optimize traffic management, but to achieve a politically acceptable balance between the financial contributions of city and suburban residents while altering trip-making behavior as little as possible. In Stockholm, revenue generation was also the dominant motive for the proposed toll ring, although the reduction in vehicle air pollution was a secondary objective. Congestion management was only a third priority, so tolls were not planned to vary by time of day.

The Scandinavian toll rings may evolve into a system of congestion pricing, despite their modest beginnings. The toll rings are virtually identical to a cordon scheme for congestion pricing except that toll rates are low and do not vary much with congestion. Furthermore, each Scandinavian toll ring is more technologically sophisticated than its predecessor. Two of the three Norwegian toll rings offer electronic toll collection as an option. The Swedes planned to develop electronic collection still further by collecting the tolls from free-flowing traffic on multilane roads without physical lane barriers. This gradual progression of technological sophistication offers the opportunity for local planners to examine a number of practical issues that anyone planning a large scale urban congestion pricing scheme would face.

10.3.1 Norway's Three Urban Toll Rings

Norway has long used tolls to finance individual tunnels and bridges; the toll rings extend the concept of toll finance to entire urban road networks. Each toll ring is part of a financial package of major regional road improvements. In each case it is facilitated by the existence of natural barriers created by mountains and fjords. An operational and financial summary of these rings is contained in Table 10.4.

Bergen, with an urban area population of 300 000, instituted in 1986 a manual system operating 16 hours per day on weekdays. It initially used just six toll stations, with a seventh added following completion of a new highway link. Oslo, the nation's capital with area population 700 000, followed four years later with a system of 19 toll stations charging at all times. The imposition of the tolls was timed to coincide with the opening of the Oslo Tunnel, an express bypass for congested downtown arterials that is one of the road projects to be financed by toll revenues. An electronic charging option, available by subscription at reduced daily or monthly rates, uses a microwave technology pioneered in 1987 at the Ålesund tunnel on the western coast; subscribers are billed monthly and enforcement is by video camera.

Trondheim instituted a more complex system in 1991. It operates 11 hours per day on weekdays. Electronic subscribers, who now account for 95 percent of all tolled crossings, benefit from a discount for trips entering after 10:00 and from ceilings on their charge liabilities in any given hour or month. No seasonal pass is available in Trondheim. These features could enable Trondheim's system to approximate congestion pricing, and public literature from the municipality and the Public Roads Administration even touts this feature.[6] At present, the charges per crossing are only $1.12 for prepaid subscribers and the off-peak discount is only $0.32, so the scheme does not accomplish much congestion management.

One drawback of the Trondheim toll ring as a financing mechanism is that about one-third of the region's drivers live inside the ring and therefore seldom pay charges, yet they benefit from some of the road improvements. In order to better distribute the burden as well as to increase revenues, several changes were approved by the city council in June 1996, to be implemented in 1997 pending approval by the Parliament. The most important is the imposition of new charges for crossing three newly defined screenlines inside the ring. Hence there will be three central zones instead of one. At the same time the existing fee for crossing the ring is to be increased by $0.15 and its period of operation will be extended one hour later in the afternoon (to 18:00). The fee for crossing the internal screenlines has not yet been decided, but will be considerably lower than the fee for crossing the ring, with the goal of achieving overall a 50 percent increase in toll revenues.[7]

Table 10.4 Overview of Norway's toll rings

	Bergen	Oslo	Trondheim[a]
Urban area population, '000s	300	700	136
% inside toll ring	10	28	40
Starting date of toll ring	Jan. 1986	Feb. 1990	Oct. 1991
Number of stations	7	19	11
Entry fee for cars (NOK)[b]			
Single trip (manual or coin)[c]	5	11	10
Per trip (subscription):[d]			
With prepayment[e]	4.50	7.43	7
Off-peak discount (after 10:00)	NA	NA	2
Monthly pass[f]	100	250	NA
Times charges are in effect:			
Days	Mon–Fri	all days	Mon–Fri
Hours	6:00–22:00	all hours	6:00–17:00
Average daily crossings during toll hours ('000s)	68	204.4	40.5
% by subscription	59	63	85
1992 gross revenue, NOK millions	63	628	70.7

Notes:

a Figures exclude the pre-existing Ranheim toll station, which has higher rates (not shown) applicable in both directions and at all times

b For 1992. Exchange rate: NOK 1 = $0 16

c Bergen: all stations manned Oslo: all stations manned, 8 also have coin lanes. Trondheim 1 station manned, others coin or magnetic card only.

d In Trondheim, subscribers are charged for no more than one trip per hour, and no more than 75 per month. Trondheim subscription rates rose in 1994 for people making 10 or fewer crossing per month.

e Charges shown are for the following prepayment quantities Bergen: booklets of 20 Oslo: 350 trips. Trondheim: NOK 1500 prepayment. A postpayment option is also available in Trondheim.

f Six- and twelve-month passes are also available, at lower rates.

NA: not applicable.

Sources: Larsen (1988), Waersted (1992), Tretvik (1992), and personal communications with E. Backer-Rød (Bro- og Tunnelselskapet A/S, Bergen), K. Waersted (Directorate of Public Roads), G Fredriksen (Trøndelag Toll Road Company, Trondheim), and T. Tretvik (SINTEF, Trondheim).

Video license plate enforcement in Norway is effective except in Bergen, which lacks electronic collection and still allows non-stop passage by seasonal pass holders. Privacy for electronic subscribers is protected by the Data Inspectorate, an agency which strictly regulates all government data registers containing personal information. Use of electronic billing information for law enforcement, for example, would require a court order.

As expected, the impact of these pricing systems on traffic has been modest, reducing vehicle crossings by no more than 5–10 percent (Ramjerdi, 1994). The Trondheim system does seem to have induced some afternoon peak spreading, as people delay inbound trips until the end of the charging period at 17:00 (the normal work day ends at 16:00); downtown shop owners have even extended their hours of operation to accommodate this response. There was also a small shift in trip making from weekdays to weekends (Meland, 1994, pp. 16–17, 43–44). The small price reduction at 10:00 in Trondheim appears to have little or no effect on travel.

As shown in Table 10.5, attitudes toward the toll rings in both Oslo and Trondheim were strongly negative, although less so after the systems opened than before. Attitudes toward the entire package of tolls and road improvements in Trondheim, however, are more evenly balanced.

Table 10.5 Public attitudes toward toll rings

	Percentage of respondents		
	Positive	Negative	Unsure
Oslo toll ring:			
Before (1989)	29	65	6
After (1992)	39	56	5
Trondheim toll ring:			
Before (April/May 1991)	7	72	21
After (Dec. 1991)	20	48	32
Trondheim package:			
Before (April/May 1991)	28	28	44
After (Dec. 1991)	32	23	45

Sources A/S Fjellingjen (Oslo); surveys by NOREAKTA (Trondheim) as reported by Tretvik (1992), p 7 and fig 4.

10.3.2 The Dennis Package for Stockholm

Sweden's interest in road pricing has arisen in a quite different political context than Norway's. Its capital city, Stockholm, is more than twice the size of Oslo, with a regional population of 1.64 million. Sweden has little history of toll finance of roads, bridges, tunnels, or even ferries. But it does have a strong environmental movement, and the Swedish program has stressed environmental problems associated with traffic, especially in inner cities.

Since the late 1980s, city politicians have been floating various proposals to restrain automobile traffic in order to reduce congestion, pollution, accidents, and noise, and to increase the speed of transit buses. In 1990 the national government convened negotiations among local leaders of the three chief political parties; the appointed negotiator for the Stockholm negotiations was Bengt Dennis, Governor of the Bank of Sweden. In 1991 the negotiators agreed to invest approximately $6.9 billion over 15 years in urban transportation improvements, to be financed primarily by road pricing (Swedish National Rail Administration *et al.*, 1994). The program, known as the Dennis package, devotes slightly more than half of the funds to road improvements and the balance to public transit, primarily rail.

The road investments include two controversial elements, both designed to divert through traffic from the inner city: completion of an inner ring road within the city limits, and construction of a tolled north–south bypass route west of the city. A third controversial element, designed in part to reduce all forms of inner-city traffic, is the toll ring. It would lie just outside the ring road, charging inbound vehicles, and would require about 28 toll stations. The ring toll was expected to be set initially at $2.55 (1992 prices) and would be adjusted to automatically for inflation. Discounts of an undetermined structure could be offered (Cewers, 1994).

The final package required compromise by each of the three main political parties. The feature most pertinent here is that the Moderate Party (a conservative party) objected to the toll ring, desiring instead to finance the inner ring road as a conventional toll road. The compromise was to place the cordon line just outside the ring road. In this way the toll would help limit traffic coming into the inner city, while still serving partly as a toll on the ring road itself, since most people using the road would come from outside the cordon.

The Dennis agreement stated that toll collection initially would allow for either cash or electronic payment. However, the agreement also directed the Swedish National Road Administration to undertake technical development of a fully automated electronic fee-collection system for eventual use. The system was to allow fees to be varied by time of day and by type of emission control on the vehicle (Social Democratic Party *et al.*, 1991, p. 30). It was eventually to operate in a free-flow multilane environment with video enforcement, and to permit a single smart card to pay for the toll ring, public transport, and parking.

Modeling studies suggest that the toll ring would complement the bypass routes' goal of reducing motor-vehicle travel in inner Stockholm, and would mitigate the effects of additional traffic caused by construction of the new roads (Johansson and Mattsson, 1994). The package therefore offers both improved travel conditions and a limitation on congestion and adverse environmental effects of road traffic.

Construction of the inner ring road and imposition of the ring toll were originally scheduled for 1997, but were subsequently delayed indefinitely.[8] Public opposition to part of the inner-ring construction proved so severe that the entire agreement is in jeopardy.

10.3.3 Lessons from the Scandinavian Toll Rings

Norway and Sweden have adopted a pragmatic approach to road pricing, with limited though gradually expanding objectives. While Bergen's and Oslo's schemes are strictly meant to raise revenue, Trondheim's applies a mild incentive to spread the afternoon rush hour, and Stockholm's was designed to significantly reduce inner-city traffic and pollution.

This pragmatism has produced pricing schemes of impressive scope. Each surrounds an entire large city center, affecting many of the region's motorists. Oslo handles 200 000 crossings per day, while Stockholm anticipated more than 350 000 (Cewers, 1994). This large scale spreads the burden of financing road improvements widely. The use of seasonal passes or ceilings on the number of charges incurred further limits the burden on any one household.

The evolution of these toll rings highlights the benefits of building on others' experience. Each project was carefully planned and used methods and equipment that were sufficiently simple and well tested to promote a smooth, relatively problem-free introduction. At the same time, each has taken advantage of the experience of its predecessors by adding new features that increase the convenience to users and the effectiveness of congestion management. Public confidence has developed through experience, so long as the schemes remained closely tied to well articulated and widely shared objectives.

10.4 CONGESTION PRICING OF A SINGLE FACILITY

Three examples of congestion pricing appeared during the 1990s. In each case, the operator of a crowded expressway has adopted an innovative tolling scheme for a particular limited purpose.

10.4.1 Autoroute A1 in Northern France: Weekend Peak Spreading

Autoroute A1 is an expressway connecting Paris to Lille, about 200 km to the north. It is part of a network of toll expressways operated by the Société des Autoroutes du Nord et de l'Est de la France (SANEF), one of seven government-owned but quasi-commercial toll road operators. As with many state turnpikes in the United States, vehicles receive a ticket upon entering the expressway and pay at a toll booth upon exiting, the amount depending on the length of the trip.

The A1 is subject to heavy inbound peaking near Paris on Sunday afternoons and evenings. In April 1992, after a period of extensive public consultation and publicity, SANEF confronted this congestion problem by implementing a time-varying toll scheme for Sundays only. A special 'red tariff' is charged during the Sunday peak period (16:30–20:30), with toll rates 25 to 56 percent higher than the normal toll. Before and after the peak there is a 'green tariff' with rates 25 to 56 percent lower than the normal toll. For example, the tariff from Lille to Paris is normally $9.88;[9] but on Sunday it falls to $7.41 at 14:30, then rises to $12.35 between 16:30 to 20:30, then falls again to $7.41 before returning to its normal value at 23:30. These hours and rates were designed so that total revenues are nearly identical to those collected with the normal tariff. This property was believed essential for public acceptance, which in fact has been largely favorable.

The impact of the scheme is mainly on the timing of trips. Comparisons of traffic counts show that southbound traffic at the last mainline toll barrier near Paris declined approximately 4 percent during the red period and rose approximately 7 percent during the green period, relative to a six-year trend for comparable Sundays. The most pronounced shift was from the last hour of the red period to the later green period (Groupe SEEE, 1993, pp. 11, 18). A survey in November 1992 confirmed that many people – about one-fifth of those traveling during the green period – sought to lower their toll by shifting the timing of their trips, sometimes by stopping for meals at service areas along the highway (Centre d'Etudes Techniques de l'Equipement Nord-Picardie, 1993).

Although many people traveling during the early green period (14:30–16:30) said that they had advanced their trips, traffic levels during these two hours grew little if at all. A likely explanation is that as congestion during the red period lessened, some people who previously had traveled early in order to avoid congestion now found it more convenient to travel during the peak and were willing to pay the higher toll to do so. This is an example of the kind of efficient reallocation of peak traffic, to those for whom timing is most important, that is predicted by the theory of congestion pricing (Arnott *et al.*, 1988).

The experiment on Autoroute A1 appears to be successful, and is being imitated by a fully private toll road company, Cofiroute, at other toll booths near Paris.

10.4.2 California's Private Toll Lanes: 91 Express Lanes

The first site of congestion pricing in the United States is a section of highway in southern California which opened to traffic in December 1995. Designed and operated by a private corporation, the project is far more complex than the Paris scheme.

Its history goes back to 1989, when new California legislation authorized four transportation projects to be selected from proposals by private firms. The four selected projects are all for toll expressways, including two on which tolls would vary by time of day.[10]

One of these projects (the only one to be built as of early 1998) is located in the median strip of the existing Riverside Freeway (State Route 91). This is an extremely congested commuter route connecting the employment centers of Orange and Los Angeles Counties with rapidly growing eastern suburbs, primarily in Riverside County. The original four lanes in each direction carried over 200 000 vehicles per day with one-way delays as much as 50 minutes including time in queues at metered entrance ramps. The project added two lanes in each direction in the median along a 16-km stretch in Orange County, for a capital cost of approximately $126 million. While the original freeway lanes remain untolled, users of the new '91 Express Lanes' must pay a fee, except for motorcycles and high-occupancy vehicles (HOVs) with three or more passengers. Profits are constrained by a flexible ceiling on rate of return, negotiated with the State in a franchise agreement; otherwise the toll rates and structure are freely determined by the company. This flexibility was crucial to the project's viability and, in particular, to the builders' ability to apply time-varying tolls.

The project was controversial in Riverside County, whose residents will pay most of the tolls, even though it adds new capacity and the original lanes remain free of charge. The reason is that it substitutes for an originally planned single HOV lane in each direction, which was expected to be funded by Orange County. Riverside County had already built HOV lanes on its side of the border, and many of its leaders felt that its residents should not be contributing toward the cost of Orange County's lanes. This objection is partially ameliorated by the stipulation that the new lanes are free to vehicles with three or more occupants, subject to some financial conditions,[11] and the fact that they provide twice the capacity increment of the original HOV plan. In any event, the project has received generally favorable ratings in opinion surveys, with 60–70 percent approving toll finance and 50–60 percent (up from 40–50 percent before it opened) approving time-varying tolls (Sullivan and Mastako, 1997).

The scheme used by this project has come to be known as 'HOV buy-in' or high occupancy toll (HOT) lanes (Fielding and Klein, 1993). In essence, the unused capacity in HOV lanes is auctioned off to lower-occupancy vehicles. Some proponents of HOT lanes argue that one should later incorporate adjacent free lanes, one by one, into the HOT lane facility if there is adequate demand for faster service at a price. Such a scheme was proposed for the Seattle area and accepted by the Washington State Transportation Commission (WSDOT, 1994), although public opposition soon stymied that particular initiative.

The existence of free parallel lanes just a few feet away greatly constrains the tolls that can be charged on HOT lanes. As a result, the company which operates the 91 express lanes is using a complex toll structure. The initial structure, shown for the inbound direction in Table 10.6, had a maximum toll of $2.50. The price is announced on electronic message signs visible prior to the point where motorists must decide whether to opt for the priced or unpriced lanes. The toll schedule was revised in January 1997, primarily by raising the toll $0.25 during the peak and night periods while leaving the shoulder of the peak the same, thereby creating a slightly steeper gradient. At the same time an optional two-part tariff was introduced, by which a flat fee of $15 per month

Table 10.6 Initial toll rates, Route 91 express lanes inbound

Weekdays:	Mon.–Thurs.	Friday
0:00–4:00	$0.25	$0.25
4:00–5:00	1.50	1.50
5:00–9:00	2.50	2.50
9:00–10:00	1.50	1.50
10:00–11:00	1.00	1.00
11:00–15:00	0.50	0.50
15:00–19:00	0.50	1.00
19:00–24:00	0.25	0.25
Weekend:	Saturday	Sunday
0:00–8:00	$0.25	$0.25
8:00–10:00	0.50	0.50
10:00–15:00	1.00	1.00
15:00–18:00	0.50	1.00
18:00–21:00	0.50	0.50
21:00–24:00	0.25	0.25

Source. California Private Transportation Company, Corona, Calif entitles the user to a \$0.50 reduction on every toll. Later revisions raised tolls further and introduced some toll variation within the four-hour peak periods.

For the longer term, the operator is considering toll rates that would vary in fine increments in response to real-time measurements of congestion levels. Information about delays on the free lanes would be added to the price information that is already provided on variable-message signs. The fact that users would know the price in advance is an important difference between this scheme and the real-time pricing plan proposed earlier in Cambridge.

The complexity of the pricing structure is made possible by restricting entry to cars equipped for electronic charging. Each car carries a transponder in its windshield with a corresponding account maintained off-site by the operator. The operator claims that only a few percent of users are violators, and they are detected by video monitoring of license plates.

The company reported that over 75 000 users established prepaid accounts and received transponders during the first year of operation. Traffic in the express lanes has grown steadily and was about 26 000 per weekday after a year of operation, with about 20 percent consisting of exempt HOVs.[12] Average one-way peak hour volume appears to have reached around 2400 vehicles,[13] somewhat over half the capacity, after one year.

Delays on the adjacent free lanes have diminished dramatically, often to about 10–20 minutes. One would expect this to release considerable latent demand for the corridor, either through newly generated traffic or diversions from parallel routes. Preliminary findings of a monitoring study showed few such demand effects during the first six months of operation (Sullivan and Mastako, 1997). In part this reflects the mountainous terrain and the consequent absence of close substitutes for the route.

The reduction in traffic delays on the adjacent lanes is good for public relations, but of course tends to undermine the incentive to use the new lanes. Conditions for a successful pricing strategy on a HOT lane are more delicate than in most applications, because the quality differential between the express lanes and the free alternative tends to automatically erode as traffic shifts. A crucial parameter is the extent to which latent demand will permit the expanded peak-hour capacity to be filled while still maintaining some congestion on the free portion of the highway. In a sense the delicacy of the pricing conditions is the price paid for the politically expedient bundling of the pricing concept with the simultaneous provision of new capacity.

10.4.3 Buying Space on Existing Carpool Lanes: I-15 Express Lanes in San Diego

Another HOT lane project, also in southern California, has been proceeding along a completely different path.[14] An existing pair of 13-km-long reversible carpool lanes on a major commuter route into San Diego was underutilized, with peak-hour volumes below 1000 vehicles per lane. Meanwhile a local mayor, subsequently a state legislator, was pressuring the regional transportation planning agency to find a way to finance public transit services to his suburban community located on the same route. The result was a scheme to sell off vacant capacity on the reversible lanes to single occupant vehicles, with the revenue targeted for public transit.

The project has been proceeding in steps. Starting in December 1996, a limited number of monthly permits were sold at $50 each, the permit allowing unlimited use of the reversible lanes during that month. The permits were colored decals for the windshield, with police enforcement by visual inspection (as in Singapore's scheme twenty years earlier). To ensure free-flow conditions, only 500 permits were sold during the first month, and in fact were all sold on the first day they were offered. As of early 1997, officials planned to sell additional permits as they gained experience, and to gradually increase the fee to a projected $110 later that year.[15]

Although a flat monthly fee may not appear to be congestion pricing, there is little incentive for anyone to purchase a permit except for use during peak hours. Thus the price of the monthly permit serves as a somewhat crudely targeted congestion toll.

Officials planned to substitute transponders for decals as the enforcement mechanism in 1997. Later, the monthly pass is to be replaced by an electronically collected fee per trip. The fee schedule will vary in real time with the degree of congestion, subject to stated limits.

The project is managed by the San Diego Association of Governments, in close cooperation with the California Department of Transportation. It has been remarkably free of controversy both because of extensive public participation and consultation and because the HOT lane concept produces few losers. Carpoolers may lose if speeds drop in the former HOV lanes, but these losses can be kept small by strictly limiting the number of paying users. Environmentalists sometimes oppose HOT lanes on the grounds that they might dilute the incentive to carpool.

10.4.4 Lessons and Future Prospects for Congestion Pricing on Single Facilities

France and California have produced the first three instances of true congestion pricing other than Singapore's. Each is a narrowly targeted response to specific problems. Each turned to pricing as a common-sense adaptation of more conventional policies – ordinary toll financing or HOV lanes – to the specific needs of the situation. In France, political considerations called for revenue neutrality and so an intuitive (though non-optimal) three-tiered toll structure was developed. On California's 91 Express Lanes, financial viability in the face of parallel free lanes required a fine-tuned system of time-of-day pricing. On California's Interstate 15, the existence of underutilized HOV lanes permitted even a very rough pricing scheme to raise new revenue and provide travelers with a new option.

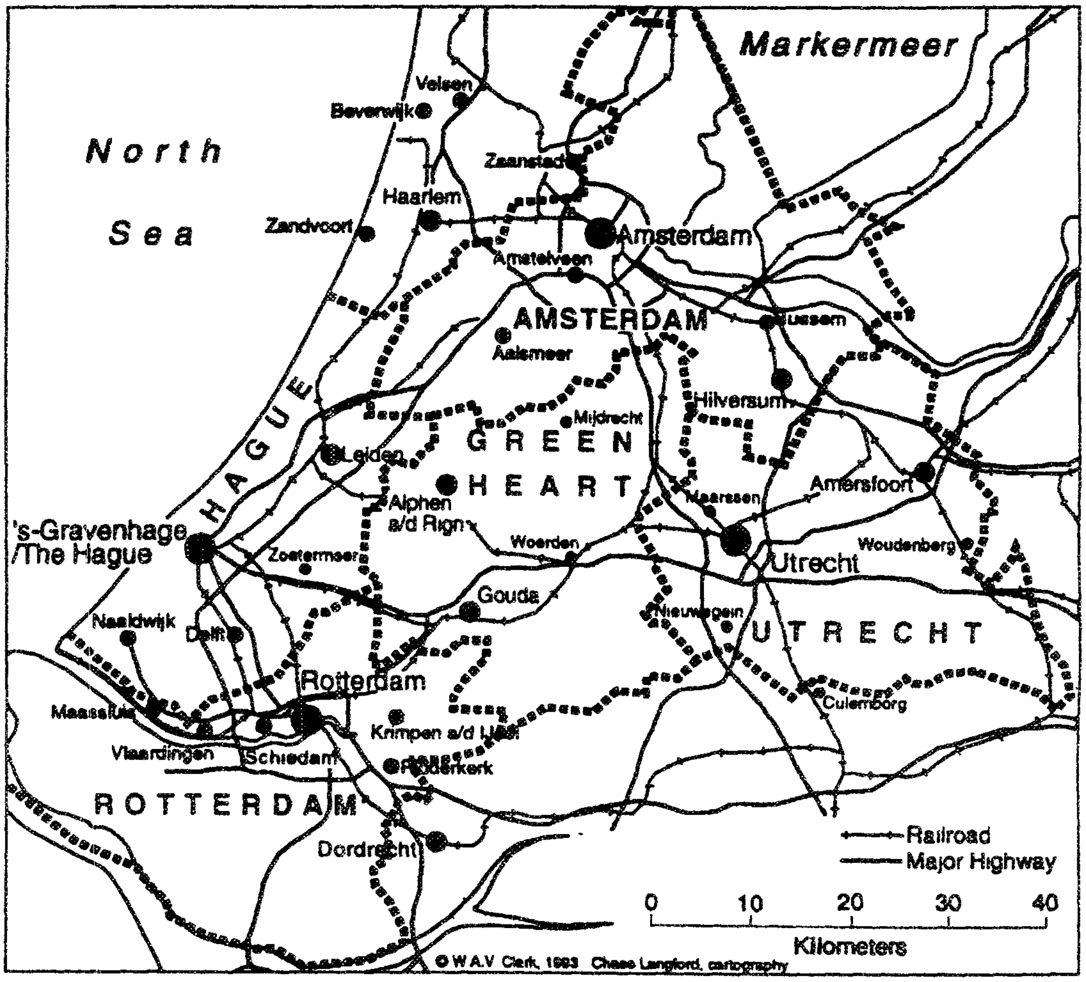
A number of other single-facility congestion pricing projects are under consideration in the United States. The New York State Thruway Authority announced plans early in 1997 to collect time-varying tolls on trucks crossing the Tappan Zee Bridge north of New York City. Detailed planning is underway to convert the Katy Expressway's HOV lane, a 21-km reversible single lane in western Houston, into a HOT lane. The Maine Turnpike experimented with time-of-day pricing in the summer of 1995 by offering a discount during certain off-peak hours on Fridays and Sundays (Colgan *et al.*, 1996). Another of the approved private projects in California, thus far held up by environmental and financial considerations, would extend State Route 57 as an all-new elevated expressway along the Santa Ana River channel in Orange County; 18 kilometers in length, it would charge tolls tentatively proposed to vary between $1 at night and $5 during the peak (Gomez-Ibañez and Meyer, 1993, p. 173). Initial planning for congestion pricing on the San Francisco Bay Bridge (Dittmar *et al.*, 1994) was overturned by political opposition, as was the far-reaching HOT lane proposal for the Seattle area mentioned earlier. Preliminary studies of HOT lanes and other congestion pricing schemes are underway in New York, Los Angeles, Minneapolis, Portland (Oregon), Boulder (Colorado), and Lee County (Florida).

10.5 BIG PLANS FOR THE RANDSTAD AND LONDON

Two very large metropolitan areas, in The Netherlands and England, have been the sites of proposals, plans, and studies of comprehensive congestion pricing. The scale and scope of these potential pricing schemes make them qualitatively different from the schemes discussed earlier. Their political history is like the proverbial cat with many lives: each time the concept is defeated, it resurfaces for serious consideration in a new form. Thus, the prospects for implementation are quite uncertain.

10.5.1 The Netherlands' Randstad Region[16]

The Randstad region of The Netherlands, shown in Figure 10.1, is a sprawling urban agglomeration that covers more than 2000 square miles and is home to some 6 million people. It includes the nation's four largest urban areas: Rotterdam and Amsterdam, with one million people each, and The



Regions of the Randstad

Source Clark and Kuijpers-Linde (1994) reprinted by permission

Figure 10.1 Randstad, Holland

Hague and Utrecht, each with over half a million. The Randstad resembles the Los Angeles region in the United States in both its urban form and its degree of road congestion.[17] Both areas are polycentric with multi-directional peak flows, both contain vital international ports and airports, and both have turned to congestion management strategies to cope with growing traffic.

During the late 1980s, the government of the Netherlands developed a proposal called *rekening rijden* ('road pricing') for the region. It involved a multiple cordon system with 140 charging points and time-varying tolls, and was expected to reduce vehicle travel by 17 percent during peak hours. Considerable development work was undertaken on the technology and on models to predict traffic impacts. However, critics questioned its technical feasibility, its security against invasions of privacy, and its ability to prevent traffic from spilling over to local streets. Publicity had focused on technical aspects rather than explaining the benefits to a doubtful public (Grieco and Jones, 1994, p. 1526; Emmerink *et al.*, 1995, p. 598). Unable to obtain support in Parliament, the government in 1990 substituted a more modest plan calling for conventional road tolls.

The Ministry of Transport and Public Works revived the proposal in 1992, however, after it determined that conventional tolls would require too much land for toll plazas and would cause even more traffic congestion. The Ministry's new proposal, called 'peak charging', again incorporated congestion pricing, this time in the form of a daily supplementary license for travel on the main arterial system during the morning peak. The fee would be about $2.85 per day[18] applied during the morning hours 6:00–10:00. The purchase of a daily, seasonal, or annual pass would be recorded by license plate and enforcement would be by random video pictures.

The proposal was set back temporarily in 1994, when a new government was elected. By 1995, however, the new Minister of Transport issued a letter to Parliament strongly proposing *rekening rijden*, this time translated as 'congestion charging', for implementation in the Randstad starting in the year 2001 (Dutch Minister of Transport, 1995). While details remained open, the letter suggested that a substantial charge would be levied on national motorways during the morning rush hour, for the sole purpose of congestion management. The scheme 'has no purpose in terms of financing, as earnings will be returned ... where possible ... [to] the categories of road users who will pay' (p. 2). The letter stated that the Cabinet considered congestion charging essential, and that it 'could lead to a more than fifty per cent reduction of congestion during the morning rush hour on the main road network in urban Holland'. Consultations with local officials would determine whether or not charges would be imposed on parallel local roads in order to limit undesirable diversion of through traffic. An automatic system using anonymous debit cards was envisioned, with technology compatible with emerging European standards.

The Minister's letter gave considerable attention to the need to build public support, acknowledging that 'civilian opposition forms a major and detrimental risk'. Accordingly, the Ministry surveyed peak-period road users about the project in June 1995 (Verhoef, 1996, chapter 10). Half the sample said road pricing was a bad idea, a quarter that it was a good idea. An overwhelming majority – 85 percent – said their opinion would depend on the allocation of revenues. The most favored policies for such allocation were road investments and reductions of vehicle-related taxes, followed closely by public transport investments. About one-third said they would respond to congestion charging in part by rescheduling trips, an option that dominated all other responses (other than no change). As of late 1996, the Ministry of Transport was still committed to implementing congestion charging starting in the year 2001.[19]

10.5.2 Greater London

Greater London, with seven million people and nearly four million jobs, has been the site of a series of comprehensive studies of congestion pricing over the last 30 years. The resulting proposals have garnered considerable political support, but not enough as yet to be adopted.

During the 1970s, the Greater London Council became interested in restraining traffic through a form of 'supplementary licensing' in which a daily license would be required to drive within a defined area during peak hours. The favored options all involved a daily charge of around \$2.00 (1973 prices)[20] to drive in Central London between 8:00 and 18:00 on weekdays; in some variations, an additional charge would apply in Inner London (a larger area surrounding Central London) during the morning peak only. Because Central London is only 3.4 miles in diameter and has extensive transit service, these charges were expected to reduce downtown traffic dramatically and to raise peak-hour speeds by as much as 40 percent (May, 1975).

In 1985, the Greater London Council was abolished and its planning functions devolved to the newly created London Planning Advisory Committee, composed of representatives of local boroughs and other authorities. This group in 1988 proposed a transportation strategy with considerably less road building than was planned by the national government. The strategy relied heavily on traffic restraint, including pricing measures. This time the pricing proposal was for three concentric cordon rings, the innermost surrounding Central London and the outermost surrounding Inner London. In addition, screenlines would divide Central London into six cells. A charge of \$0.89 (1988 prices) would be assessed for crossing a cordon or screenline; for Central London this would apply all day in both directions, whereas for the outer two cordons it would apply only during the peak period and in the peak direction (London Planning Advisory Committee, 1988).

Analysis suggested that the proposed charges would have reduced inbound traffic by 15 percent into Inner London and 25 percent into Central London (May *et al.*, 1990). More recent analysis shows that the financial burden of the scheme would have been borne primarily by suburban car-owning households. Restricting the charges just to Central London would have lowered total benefits and shifted the adverse impacts more toward poorer households

(Fowkes *et al.*, 1993); it would also have made the benefits more sensitive to the charging level, thus raising the danger of setting the price too high, as apparently happened in Singapore.

The most recent study of congestion pricing in London was a three-year program sponsored by the UK Department of Transport. Concluded in 1994, the study encompassed technology, public attitudes, changes in travel behavior, effects on reliability of travel times, effects on goods vehicles, cost–benefit appraisal, and many other issues. A sophisticated modeling scheme, named APRIL, was developed to distinguish seven time periods and allow for several types of mode, route, and time-of-day shifts. The methods and results were described in a published report and in a series of articles in *Traffic Engineering and Control*.[21] All calculations were based on hypothetical implementation in 1991 and results stated at 1991 price levels.

The simplest pricing scheme investigated was a single cordon charge for Central London, involving 130 charge points. Three charge levels (ranging from approximately $3.50 to $14.00 for an inbound crossing) were considered. This scheme was predicted to achieve substantial traffic reductions for Central London (8 to 22 percent), with correspondingly large improvements in average speed (10 to 32 percent). Annual revenues of $285 to $825 million would be partially offset by annual operating costs of the charging system (including in-vehicle units) of $97 million, as well as by modest changes in parking and public transport revenues.[22] In addition there would be a one-time implementation cost of $150 million for the simplest charging system (read–write tags with central accounting). After taking into account user time savings, lost consumer surplus, accident cost savings, and annualized implementation costs, the net benefits were estimated to be about $60 million (at the low charge) to $105 million (at the high charge). These did not account for any user benefits from increased bus frequency. A charge level about three-fourths of the highest one considered appeared to generate the highest net benefits.[23]

Successively more complex schemes provided significant additional net benefits only when charge levels were high. Adding a more outlying cordon around Inner London and charging outbound trips at half the level of inbound trips would more than double net benefits at the high charge level. A further increase, to $345 million annually, could be attained by adding a third cordon and four radial screenlines, with charges varying in several steps over time. Compared to a single inbound cordon, this scheme has a slightly smaller effect on traffic in Central London but a much larger effect on traffic in the larger Inner London area. The charge levels that maximize net benefits would also be higher. However, this scheme also would be considerably more complex than a single cordon, with nearly three times the implementation and operating costs.

These studies generally verify the behavioral responses expected from theory. However, the technology was sufficiently expensive that charging costs used up an uncomfortable portion of revenues and benefits unless charges were set at levels that the public might consider very high. The technology investigated offered very high reliability, virtually no intrusion on traffic flow, and a high level of convenience and protection of privacy for drivers, however, characteristics considered essential for acceptance of a system affecting so many people.

At the conclusion of the study the Minister of Transport declared that no congestion pricing would be undertaken in London at least for the remainder of the decade. However, results of the study were being considered for application to other British metropolitan areas such as Bristol (Collis and Inwood, 1996).

10.5.3 Assessment

Despite the commitment of some important political figures, neither The Netherlands nor the United Kingdom has put in place any of the ambitious schemes for congestion pricing that have been proposed. The magnitude of the operation has been so large, the technical and operational details so numerous, the effects so far-reaching, and the interest groups so many, that it has proven exceedingly difficult to introduce comprehensive pricing all at once. Nevertheless, much has been learned about how road pricing might be administered and what its effects might be.

10.6 A REAL-LIFE BEHAVIORAL EXPERIMENT: STUTTGART

A unique experiment was undertaken in Stuttgart, Germany, between May 1994 and February 1995.[24] A cordon line was established around the southern entrance to the city center, with three charging points controlling access. Some 400 volunteer motorists agreed not only to test the charging equipment but to subject themselves to actual charges and to participate in a number of interviews and surveys. In return, they received a block allocation of funds that was intended to more than cover expected charges. At the margin, then, these volunteers paid fully for any trip taken, even though they made money from the experiment as a whole. To be sure they realistically perceived the trips as costing them money, they were required to recharge their debit cards each month (for an amount specified by the experimenters) using their own funds, and the block allocation (of the same amount) was paid three weeks later.[25] The charging equipment consisted of an on-board charging unit and a rechargeable debit card. A variable message sign outside the cordon informed participants what the charge was at that particular time.

This scheme cannot test system-wide responses to congestion pricing, but it is ideal for testing individual behavioral responses. Not only did the participants agree to take part in extensive monitoring, but the charging scheme was varied extensively over the course of the experiment, in five distinct phases each lasting two months.

The most dramatic behavioral shifts occurred in response to charging patterns specifically designed to elicit them. When one route was charged a differential of up to $2.50 compared to the other two, for example, about one in eight drivers switched from their usual route to a cheaper one. Similarly, about one in eight switched to cheaper times of day when faced with large price differentials over time. The weekday pricing schedule for this phase of the experiment is shown in Table 10.7.

Table 10.7 Stuttgart weekday fee schedule, September–October 1994

Time	Fee (US$)[a]
0:00–6:00	0.00
6:00–6:45	1.25
6:45–7:15	5.00
7:15–7:45	3.75
7:45–8:15	5.00
8:15–9:00	2.50
9:00–17:00	1.25
17:00–19:00	2.50
19:00–21:00	1.25
21:00–24:00	0.00

Note: Using the 1994 average exchange rate of approximately 1 mark = US$0 625.

Source. Hug *et al.* (1997), fig. 4.

The next most common responses were to shift to public transport or to carpool. Public transport was facilitated by a park-and-ride lot located just outside the cordon and providing frequent subway service to the city center. The shift to public transport varied over the five different phases from 3.4 to 5.9 percent of participants' total weekday trips, the amount depending sensitively on the magnitude of the automobile charges. (Weekend shifts were much larger, up to 15 percent.) Carpooling was a small but steadily increasing response, with participants reporting by the end of the experiment that about 7 percent of their trips were in newly formed carpools.

A less common response was to combine two or more trips into a single tour. Such tours increased in frequency by about 3 percent of all participants' trips on weekdays and 6 percent on Saturdays. Destination shifts were reported to be less than 1 percent of trips. Of course, a permanent system might elicit some additional responses that a limited-duration experiment does not.

The lesson of this experiment was that people will respond to pricing incentives, especially when they are finely targeted. Charging patterns can induce substantial shifts of route and time of day if designed to do so. Significant though somewhat smaller shifts to public transport can also be induced in a situation where good transport service is available.

The city and county of Leicester, England, were planning a similar trial for 1997 on the A47 corridor.[26]

10.7 CONCLUSION

Both studies and actual experience have shown that congestion pricing can substantially affect behavior and reduce traffic congestion. At the risk of over-generalizing, it appears that charges of $2 to $3 per day for entry to a restricted area during peak periods can reduce traffic by 20 percent or more. Charges can be targeted to divert traffic around certain areas or to shift it from one time period to another. In most cases it is feasible to offer customers a choice of collection options. Operating costs can be kept to reasonable levels, around 10–12 percent of revenues.

Careful attention to the details of design and implementation is important. The level of fee, the potential for evasion or diversion, the security of information about people's travel, and the degree of public understanding all greatly influence the project's viability.

Winning political approval for any congestion pricing project is difficult in a democracy, even with careful planning. The most fundamental reason is that many motorists stand to lose, especially if they do not perceive that they are benefitting from the uses of toll revenues. One obvious solution is to use toll receipts to finance widely desired transportation improvements, to lower other taxes paid by motorists, or to reduce other toll charges. When the tolled facility is new and is financed directly by the revenues, people are more likely to understand the relationship between their payments and tangible benefits.

Another reason is that people are suspicious of plans to change arrangements they are comfortable with. In this case, a strategy of incremental change may hold the answer. The Norwegian toll rings began as means of financing transportation infrastructure, but have gradually incorporated traffic management as a subsidiary goal. The accumulated experience has enabled Stockholm to design a conscious traffic management strategy in a city considerably larger than any in Norway, while still giving prominence to the objective of financing infrastructure. It seems likely that similar spillovers from the projects in France and California could easily occur, giving pricing mechanisms the degree of credibility needed for other toll road operators to adapt them to their needs. These considerations increase the importance of demonstration projects.

There is always the danger that an ill-advised project will focus attention on the potential drawbacks of congestion pricing without revealing its potential benefits, and thereby provide ammunition to opponents. One advantage of the comprehensive studies in The Netherlands and Britain is that they enable the essential elements of a successful program to be identified in advance, thereby reducing the likelihood of unexpected problems arising during the course of implementation.

Finally, an experimental approach as in Stuttgart offers the triple advantages of testing the equipment, demonstrating the system to the public, and collecting valuable data on how travelers respond to a variety of pricing schedules.

In sum, the international experience with congestion pricing is both cautionary and encouraging. While suggesting important pitfalls and political limitations, it also demonstrates that pricing can be practical and effective at managing congestion, and that political problems, while difficult, may be soluble.

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NOTES

1. The exchange rate between the Singapore dollar and the US dollar was approximately S$1=US$0.48 in 1975, US$0.55 in 1992, and US$0.70 in 1996. For a complete account of changes in fee structure and level over the years, see Gomez-Ibañez and Small (1994), especially Table A-4. For other reviews see Toh (1992) and Menon *et al.* (1993).
2. Expected cost is about US$140 million (at the 1996 exchange rate), including equipment for about 60 charging locations and 700 000 in-vehicle units. Personal communication, Senior Manager for Traffic and Road Management, Land Transport Authority, 25 June 1996.
3. See Ho (1986), Fong (1986), Borins (1988), and Hau (1989).
4. See 'SERC Funds Research' (1990) or Oldridge (1994).
5. We use the average exchange rates for 1992: NOK 1 = US$0.16 for Norway, and SEK 1 = US$0.17 for Sweden.
6. See Norwegian Public Roads Administration and Trondheim Municipality (undated), pp. 14–15.
7. Private communication from Tore Hoven, toll ring project manager, Public Roads Administration, 21 Jan. 1997. Annual revenues as of early 1997 were running about NOK 80 million, or $12 million at the January 1997 exchange rate
8. Press release by Ulf Lundin, Ministry of Transport and Communications, 2 February 1997.
9. Using the 1992 exchange rate of 1 franc = $0.19.
10. Gomez-Ibañez and Meyer (1993), pp 172–93.
11. See California Department of Transportation and California Private Transportation Corporation (1992), p. 2, or Fielding (1994), p. 392. In 1998 HOVs began paying half price.
12. The figure for total traffic is from a presentation by Edward Sullivan, Transportation Research Board, Jan. 14, 1997. Of that traffic, 22 percent was exempt HOVs at an unspecified time late in 1996 (Williams, 1996, p. 23); that percentage was steadily declining throughout 1996 as new SOVs were signed up, so it was probably close to 20 percent in early 1997.
13. See Fine (1996).
14. See Duve (1994) and Oropeza and Orso (1996).
15. Presentation by Mario Oropeza to the Transportation Research Board annual meeting, January 1997.
16. The information in this section relies in part on Stoelhorst and Zandbergen (1990), Pol (1991), In't Veld (1991), Hau (1992), and personal communications with H.D.P. Pol, former director of Project Spitzbijdrage, Dutch Ministry of Transport and Public Works, most recently on 5 November 1996.
17. See Clark and Kuijpers-Linde (1994) for an explicit comparison.
18. At 1992 prices, using the 1992 exchange rate of 1 guilder = US$0.57.
19. Dutch Ministry of Transport, Public Works and Water Management (1996), p 6
20. Exchange rates per British pound were $2.45 in 1973, $1 78 in both 1988 and 1990, and $1.77 in 1991.
21. UK Department of Transport (1995a, 1995b) consists of a three-volume final report and a 61-page summary. The six articles begin with Richards *et al.* (1996) and continue in the next five issues of *Traffic Engineering and Control* (March through July/August 1996). See especially Bates *et al.* (1996) for many of the results described in the text.
22. UK Department of Transport (1995b), pp. 38–9, 42–3. This figure for operating cost applies to read–write tags, transponders with smart cards, and hybrid systems. We do not report the lower cost estimated for a transponder with electronic cash (also known as an 'electronic purse') because some of its costs are assumed in the study to be borne by financial institutions providing the cards and maintaining the accounts, hence are omitted from the calculations.
23. The foregoing figures are reported in UK Department of Transport (1995b), pp. 21, 37, 39, 42, 45.

24. The description in this section is based on Hug *et al.* (1997).
25. Hug *et al.* (1997) state that the block allocation in a given month depended in part on the expenditures by that driver in the previous month. If the test subjects knew or guessed this, their perception of the money cost of a trip might have been reduced.
26. See 'Testing the Limits' (1996). This was also reported in the newsletter of the UK Transport Research Laboratory

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