CHAPTER 16
ROAD PRICING FOR CONGESTION MANAGEMENT: THE TRANSITION FROM THEORY TO POLICY*

*Small, Kenneth A., and Jose A.Gomez-Ibanez***

Abstract

This paper reviews a variety of examples of road pricing covering a wide range of sites, objectives, and implementation strategies. Objectives range from raising revenues to reducing traffic externalities. Locations include single facilities, city centers, and entire metropolitan regions. Five of the projects are in place, two are in the process of implementation, and four were seriously considered proposals. We focus on the political, institutional, and operational features that shed light on how urban governments are able to approach congestion pricing.

We find evidence that significant pricing incentives can produce major changes in behavior, and that even small incentives can produce targeted changes, such as small shifts in the time of day of travel. Furthermore, experience shows that road pricing can operate smoothly given thorough planning, attention to detail, and a willingness to learn from prior experience.

Projects that are politically acceptable show several characteristic traits. They tend to be fairly simple in design, to build incrementally on previously existing arrangements or experience, to address clearly understood and widely supported objectives, and to involve transparent financial flows that facilitate public trust in the use of the monies. Too simple a design may reduce the possible congestion savings and other benefits, but great complexity does not add much to the benefits and can

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** *The authors are at University of California at Irvine and Harvard University respectively.*

increase political opposition. The incremental accumulation of experience and public trust in Scandinavia has facilitated the progressively more sophisticated applications of toll rings around city centers in Norway and Sweden. This same experience may have facilitated the serious consideration given to more ambitious proposals in the London and Randstad regions. In France and southern California, time-varying tolls were seen as a way to solve particular problems of a toll road operator; in each case the rationale was transparent and acceptable to the public given the particular context.

I. 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, there is a consensus among urban economists, and a growing number of other analysts, 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 subject to peak demands. The intention is to alter people's travel behavior enough to reduce congestion.

Discussion of congestion pricing of roads benefits from a long history of practical policy development that supplements the theoretical and empirical base. 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), U.K. 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 National Research Council (1994) is almost entirely concerned with implementation. 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.

Recent years have witnessed sharply increased practical interest in congestion pricing and related policies involving pricing incentives, including innovative road tolls and parking fees. This broader group of policies is called road pricing. Interest has arisen especially from the urgent need to find new revenue sources for transportation investments, and from the failure of alternative policies to significantly stem the growth of traffic congestion.

It therefore seems an opportune time to assess the practical experience with road pricing 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 in the political sector. These cases cover a wide range of sites, objectives, and details of implementation. Many are reviewed by Hau (1992), Lewis (1993), and Gomez-Ibañez and Small (1994).

Table 1. Cases of Road Pricing Studied

Type of road pricing	Degree of implementation		
	In place (date)	Scheduled (date)	Under Study
City center: congestion pricing	Singapore (1975)		Hong Kong Cambridge, UK
City center: toll ring	Bergen (1986) Oslo (1990) Trondheim (1991)	Stockholm (1997)	
Single facility: congestion pricing	Autoroute A1, France (1992)	State Route 91, California (1995)	
Area-wide: congestion pricing			Randstad London

This paper summarizes eleven such cases, including Singapore, and from them draws lessons about implementation. In particular, we examine how well the theory of congestion pricing holds up in the transition to practical and politically achievable policies. The cases are divided into four broad categories: congestion pricing of a center city, center-city toll rings for raising revenue, congestion pricing of a single facility, and comprehensive area-wide congestion pricing. Table 1 lists our cases according to these categories, and shows whether each case is already implemented, scheduled for implementation at a definite date, or only under study.

II. Pioneers: Congestion Pricing of City Centers

Three cities have seriously considered congestion pricing of a congested central area. Each was the pioneer of an important new concept, the evaluation of which sheds light on what is required to make the theory of congestion pricing work. For Singapore, the concept was congestion pricing itself, and the implementation 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 performed visually by traffic officers. For Hong Kong, the new concept was an operational one: electronic road pricing (ERP), a flexible and comprehensive system involving multiple cordons and fully automated charging through the electronic identification of devices attached to vehicles. 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 taken bids on 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 and at one point the scheme had the support of the County Council; but many details remained to be filled in when a new and unsupportive Council came to power in 1993.

1. Singapore's Area License Scheme

The Singapore scheme, begun in June 1975, is part of an extremely stringent set of policies designed to restrict automobile use in this crowded island city-state with a population of 3 million. The scheme was chosen by the national government, dominated by a strong executive, following a review of options including conventional road tolls and higher parking charges. These alternatives were rejected because space for toll stations was lacking and parking charges were believed 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. It is imposed on vehicles entering the restricted area during certain hours, originally just the morning peak period. For cars, the fee has ranged from approximately $1.50 to $2.50 per day in U.S. currency equivalent.[1] Carpools and taxis carrying four or more people were originally exempted, as were motorcycles and commercial trucks. In 1989, charges were extended to include these vehicles and the restraint hours were extended to the afternoon peak (but still in the inbound direction, since that produced the desired effect on through traffic). In 1994, the hours were extended to include the time between the morning and afternoon peaks. Collection costs are modest, amounting in the early years to about 11 percent of the US$2.7 million annual revenue.

Effects on modal choice and on traffic within the zone 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 2, traffic entering the zone during restricted 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 a.m. 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 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). 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.

1. The exchange rate between the Singapore dollar and the U.S. dollar was S$1=US$0.48 in 1975, and S$1=US$0.55 in 1992. 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).*

Table 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 (1000's):				
7:00–7:30 a.m.	9.8	11.1	9.7	9.7
7:30–10:15 a.m.[a,b]	74.0	41.2	51.8	44.8
10:15–11:00 a.m.	NA	NA	22.1	21.8
4:00–4:30 p.m.	NA	NA	12.9	12.4
4:30–6:30 p.m.[b]	NA	NA	51.5	23.8
6:30–7:30 p.m.	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

a: Restraint hours in effect Aug. 1975-May 1989.
b: Restraint hours in effect Feb. 1990-Dec. 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.

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 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.

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).

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 succeeded in thoroughly verifying the ability of electronic charging mechanisms to operate with very high degrees of accuracy. The system, now somewhat obsolete, 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).

A variety of pricing structures and charging locations were considered. Results were predicted for three such schemes based on a simulation model designed by the MVA Consultancy in London (Harrison, 1986). These schemes varied in complexity (see Table 3), but all included at least five zones. (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 ed ge of the zones; 130 distinct charging points would have had to be equipped, each imposing an identical charge which varied by time 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 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 3). Total daily car trips would be reduced by 9–13 percent. Using Scheme B as a middle prediction that is not too different from the others, 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).

Table 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

a: The 1985 exchange rate was HK$1=US$0.13 (International Modetary Fund, 1992).
Source: Transpotech, Ltd. (1985), pp. 2.69, 2.70, 2.74, 2.79.

Projected net benefits, ignoring collection costs, are shown in the last row of the table. Taking the most complex (Scheme C) as a benchmark for the possible benefits, we see that the simplest (Scheme A) achieves 80 percent of these benefits, while Scheme B achieves 95 percent. This suggests that five zones and two charging levels are sufficient to reasonably well approximate marginal-cost pricing; charging more in the peak direction (Scheme B) does substantially better, but further refining the geography (Scheme C) makes little difference. Of course, all these schemes are far more complex than Singapore's.

Ultimately none of the schemes were adopted. A number of factors worked to defeat them. The policy deliberations 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. Poor economic conditions in the early 1980s had lowered automobile ownership and so 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 the annual license fee.

Analysts have debated the extent to which Hong Kong's failure to implement any of the proposed schemes represented tactical errers, bad luck, or inherent political weaknesses of congestion pricing.[2] 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.

3. Congestion-Specific Charging for Cambridge, England

Cambridge, a historic city of 100,000 people located 60 miles north of London, was the site for a unique proposal that would carry congestion pricing close to its theoretical

2. *See Ho (1986), Fong (1986), Borins (1988), and Hau (1989).*

extreme. Within a ring encompassing the congested city center, charges would vary in real time to match the amount of congestion actually experienced by the individual vehicle (Sharpe, 1993). The rationale for this was that the amount of congestion experienced by a vehicle may be closely related to the externality imposed by that vehicle 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, but subsequently has been shelved for further study.

Real-time congestion pricing was to be implemented by means of an in-vehicle meter, which contains a clock and is connected to the car's odometer. For example, under one suggested charging regime, the meter would assess a charge of £0.20 ($0.36 at the 1990 exchange rate) whenever a distance of 0.3 mile is traversed either (a) at a speed less than 16 miles per hour or (b) with more than four stops.[3] 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.

Oldridge retired in 1993 and his replacement, J.Michael Sharpe, widened the range of schemes under consideration to include more conventional forms of road pricing, such as cordon charges or zone fees, as alternatives to congestion metering. Sharpe apparently recognized the potential for public outrage when charges are unpredictable. From the user's point of view, real-time charging means that on those very days when travel conditions are unexpectedly poor, a financial penalty is added to the aggravation already experienced. It seems likely that many citizens would blame politicians or traffic planners for incidents of severe congestion rather than accepting the idea that they should pay more because they are imposing higher marginal costs on others.

The metering technology was tested in 1993 as part of the ADEPT project within the European Union's DRIVE-II program (Blythe and Hills, 1994). However, moves toward implementation ended in 1993 with a change in the shire government. Modeling studies of various road pricing possibilities 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 has served as a useful setting for demonstrating the technical feasibility of more sophisticated forms of road pricing. However, there is a need to develop grass roots support simultaneously with concrete proposals, especially ones as radical as the original Cambridge plan. It seems to us unlikely that any locality would accept a real-time pricing proposal with unpredictable charges, at least in the absence of lengthy prior experience with more prosaic pricing policies.

III. The Scandinavian Toll Rings

The previous discussion illustrates the evolution of increasingly sophisticated proposals for congestion pricing. Meanwhile, a more modest type of road pricing has emerged as a

3. *See "SERC Funds Research" (1990) or Oldridge (1994).*

serious tool for highway finance in Scandinavia. Toll rings now surround three Norwegian cities, and one is planned for Stockholm, Sweden.

The Scandinavian toll rings do not represent congestion pricing according to our definition because they are designed mainly to generate revenue. Congestion management is not among the objectives in Norway, and is only secondary in Sweden. Rather, in each case the primary motivation is to generate revenue to finance desired transportation infrastructure improvements. As a result, Norway's tolls are low, ranging from approximately $0.70 to $1.75 per entry,[4] 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 rough distributional balance among residents of city and suburban jurisdictions while altering people's trip-making as little as possible.

Revenue generation is also the dominant factor in the proposed Stockholm toll ring, although in this case traffic reduction for environmental reasons is another objective. Congestion management is a lower priority, and so tolls are not planned to vary by time of day, although this remains an option for later consideration.

Despite these modest beginnings, the Scandinavian toll rings may evolve into a system of congestion pricing. Except for the low levels and limited variation of the toll rates, they are virtually identical to a cordon scheme for congestion pricing. Furthermore, each Scandinavian toll ring has been more technologically sophisticated than its predecessor. Two of the three Norwegian toll rings offer electronic toll collection as an option. The Swedes plan to go further by collecting the tolls from free-flowing traffic on multilane roads without physical lane barriers. This gradual progression of technologically more sophisticated implementation 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.

1. Norway's Three Urban Toll Rings

Norway has long used toll financing for special projects such as tunnels and bridges. The toll rings extend the concept of toll finance to cities as a whole. Each is part of a financial package of major regional road improvements. For each, the ability to toll inbound movements is facilitated by the existence of natural barriers created by mountains and fjords. An operational and financial summary is contained in Table 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. Among the road projects funded by the Oslo ring is the Oslo Tunnel, an express bypass for congested downtown arterials that opened the previous month with bond financing, to be paid off by toll revenues; this and other tunnels are regarded in part as environmental improvements. An electronic charging option, available by subscription at reduced daily or monthly rates, adapts a microwave technology pioneered in 1987 at the Ålesund tunnel on the western coast; subscribers are billed monthly and enforcement is by video camera.

4. We use the average exchange rates for 1992: NOK 1=US$0.16 for Norway, and SEK 1=US$0.17 for Sweden.

Trondheim instituted a more complex system in 1991. It operates 11 hours per day on weekdays, with a discount for trips entering after 10:00 a.m. and ceilings on the number of charges that can be incurred in any hour and in any month. The discounts and ceilings apply only to electronic subscribers, who now account for 85 percent of all tolled crossings. No seasonal pass is available in Trondheim. These features could enable Trondheim's system to approximate congestion pricing. However, 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.

Table 4. Overview of Norway s Toll Rings

	Bergen	Oslo	Trondheim[a]
Urban area population, '000s	300	700	136
−% inside toll ring		28	40
Starting date of toll ring	Jan. 2, 1986	Feb. 1, 1990	Oct. 14, 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 a.m.)	NA	NA	2
Monthly pass[f]	100	250	NA
Times charges are in effect:			
Days	Mon-Fri	all days	Mon-Fri
Hours	6a.m.–10 p.m.	all hours	6 a.m.–5 p.m.
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

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 crossings per month.
e: Charges shown are for the following prepayment quantities. Bergen: booklets of 20. Oslo: 350 trips. Trondheim: NOK 2500 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-Røed (Bro-og Tunnelselskalpet A/S, Bergen), K.Waersted (Directorate of Public Roads), G.Fredriksen (Trøndelag Toll Road Company, Trondheim), T.Tretvik (SINTEF, Trondheim).

Evasion of the video license plate enforcement is possible but rare except in Bergen, which lacks electronic collection but still allows nonstop passage by seasonal pass holders. Privacy for electronic subscribers is protected by the Data Inspectorate, which has strict regulations on all government data registers containing personal information. Use of electronic billing information for criminal 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 5:00 p.m. (the normal work day ends at 4:00 p.m.); downtown shop owners have even extended their hours of operation to accommodate this response. The small price reduction at 10 a.m. in Trondheim has little or no effect on travel.

Public response has been surprisingly muted, despite survey evidence showing that support is lukewarm at best. A few incidents of vandalism accompanied the opening of the Oslo system, but other startup problems have been minor. As shown in Table 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, according to a survey taken in Trondheim which showed a slight plurality in favor after the system had been in operation for about two months.

Table 5. Public Attitudes toward Toll Rings

	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

Source: A/S Fjellingjen (Oslo); Surveys by NOREAKTA (Trondheim), as reported by Tretvik (1992), p. 7 and figure 4.

2. The Dennis Package for Stockholm

Swedish interest in road pricing has arisen in a quite different political context than Norway's. Sweden has little history of toll finance of roads, bridges, tunnels, or even ferries; but it does have a strong and politically potent environmental movement. As a result, the Swedish program has stressed reducing environmental problems associated with traffic, especially in inner cities.

Notwithstanding these differences, Sweden has decided to create a toll ring for the capital city, Stockholm, which in many respects resembles the Oslo toll ring. Discussions are also underway for two other cities, Gothenberg and Malmö. The fact that different goals have produced similar policies illustrates the appeal of pricing schemes that are relatively simple and that build incrementally on experience elsewhere.

Stockholm is more than twice the size of Oslo, with a regional population of 1.64 million. 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 the chief political parties in each of the three largest metropolitan areas, leading to three separate agreements in 1991. All three include toll financing, and Gothenberg's includes a "green zone" in the inner city with limited road investments and various traffic restraints.

The Stockholm agreement has evolved into a toll ring instead of just tolls on new facilities. Stockholm's appointed negotiator was Bengt Dennis, Governor of the Bank of Sweden, and the resulting three-party agreement is known as the Dennis package. This package and the process producing it provide evidence that allocation of toll revenues can play a critical role in designing politically acceptable pricing schemes.

The central components of the agreement are improvements to public transit, new bypass roads, and road pricing as the chief financing mechanism. The total 15-year investment package (including some subsequent cost reestimates) is $6.9 billion (1992 prices and exchange rate). Somewhat over half is for roads, the rest for 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 will lie just outside the ring road, charging inbound vehicles, and will require about 28 toll stations. The ring toll, scheduled to go into effect in 1997, is expected to be set initially at $2.55 (1992 prices) and will be adjusted automatically for inflation. Discounts of an undetermined structure may be offered (Cewers, 1994).

The final package required compromise by each of the three main political parties. The Moderate Party (a conservative party) objected to the toll ring and proposed instead to finance the inner ring road with conventional tolls. But by placing the cordon line just outside the ring road, a conceptual compromise was attained: the toll will help limit traffic coming into the inner city, while still being viewed partly as a toll on the ring road itself, since most people using that road will come from outside the cordon.

The Dennis agreement states that toll collection initially will allow for either cash or electronic payment. However, the agreement also directs the Swedish National Road Administration to undertake technical development of a fully automated electronic fee-collection system for eventual use. The system is 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 is 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 will complement the bypass routes' goal of reducing motor-vehicle travel in inner Stockholm, and will 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.

3. Lessons from the Scandinavian Toll Rings

Norway and Sweden have adopted a pragmatic approach to road pricing. Initiated primarily to finance transportation investments, the policy has increasingly been enriched to ameliorate congestion and environmental effects of traffic. 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 is designed to significantly reduce inner-city traffic.

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 anticipates more than 350,000 (Cewers, 1994). This large scale spreads the burden of financing road improvements widely. The use of seasonal passes or caps on the number of charges incurred further limits the burden on any one household.

The evolving features of the toll rings highlight the benefits of building on others' experience. Each project has been carefully planned and has used methods and equipment that are 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 in the reliability of increasingly sophisticated pricing systems has been built, while the schemes remain closely tied to well articulated and widely shared objectives.

IV. Congestion Pricing of a Single Facility

We now turn to two innovative experiments that resulted from specific problems with financing or operating a congested expressway. In each case a form of congestion pricing arose out of the needs of a private operator.

1. Autoroute A1 in Northern France: Weekend Peak Spreading

Autoroute A1 is an expressway connecting Paris to Lille, about 120 miles 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 (4:30–8:30 p.m.), 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;[5] but on Sunday it falls to $7.41 at 2:30 p.m., rises to $12.35 from 4:30 to 8:30 p.m., then falls again to $7.41 before returning to its normal value at 11:30 p.m.

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

5. Using the 1992 exchange rate of 1 france=$0.19.

(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 (2:30–4:30 p.m.) 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).

2. California's Private Toll Lanes: Riverside Freeway Median

California is about to become the first site of congestion pricing in the United States. This also will apply to just a single facility, but it will be more temporally refined than the French experiment and is being accomplished through a very different process.

In 1989, California's conservative Governor pushed through a program permitting the construction of four private transportation projects, subsequently selected in a bidding process in which private consortia submitted detailed proposals including locations and pricing structures. All four selected projects were for toll expressways, including two on which tolls would vary by time of day.[6]

One of those two is under construction at the time of this writing, and is scheduled to open in December 1995. It is in the median strip of the existing Riverside Freeway (State Route 91), an extremely congested commuter route connecting rapidly growing remote suburbs in Riverside County to employment centers in Orange and Los Angeles Counties. The existing four lanes in each direction carry about 250,000 vehicles per day with one-way delays of as much as 50 minutes (Perlman, 1993). The project will add two lanes in each direction along a ten-mile stretch in Orange County, and will link publicly built high-occupancy vehicle (HOV) lanes in Riverside County to planned HOV lanes further west in Orange County.

The project was controversial in Riverside County, whose residents will pay most of the tolls, even though it adds new capacity and the existing lanes will remain free of charge. The reason is that it substitutes for an originally planned single HOV lane in each direction, which was supposed to be funded by Orange County. (Riverside County has already funded and partly built the HOV lane on its side of the border.) This objection is partially ameliorated by an arrangement in which vehicles with three or more people will pass at reduced rates, or even for free if financial results from the road are sufficiently favorable.[7]

6. *Gomez-Ibañez and Meyer (1993), pp. 172–193.*

7. *See California Department of Transportation and California Private Transportation Corporation (1992), p. 2; or Fielding (1994), p. 392.*

The design and collection of tolls are the responsibility of a private French toll road company, Cofiroute, which is part of the consortium that is building the project. Profits are constrained by a flexible ceiling on rate of return, negotiated with the State in a franchise agreement, but otherwise the toll rates and structure are freely determined by the company. This freedom was crucial to the project's viability and, in particular, to the builders' ability to apply time-varying tolls.

Of course, the existence of free parallel lanes just a few feet away greatly constrains the tolls that can be profitably charged. As a result, the company is planning to set toll rates that vary in fine increments in response to real-time measurements of congestion levels. This will be accomplished by restricting entry to cars equipped for electronic charging. Unlike the Cambridge scheme, the price of a given trip will be announced on electronic message signs prior to the entrance to the priced lanes, so that motorists can decide whether to opt for the priced or unpriced lanes. The signs will also provide information about delays on the free lanes. The maximum toll is expected to be \$2 (Perlman, 1993).

3. Lessons and Future Prospects for Congestion Pricing on Single Facilities

France and California have produced the only two instances of true congestion pricing other than Singapore's. Neither came about from any comprehensive theory of social welfare. Rather, both are narrowly targeted responses to specific problems: a peaking problem in France and a funding problem in California. Each turned to pricing as a commonsense adaptation of ordinary toll financing 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. In California, financial viability in the face of parallel free lanes required fine-tuned time-varying tolls.

A number of other congestion pricing projects are under consideration in the United States. 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; eleven miles 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). The San Diego Association of Governments has proposed to allow low-occupancy vehicles to travel on HOV lanes on Interstate Route 15 for a fee (Duve, 1994). With funding for demonstration projects authorized by federal highway legislation, planning is underway for congestion pricing on the San Francisco Bay Bridge (Dittmar et al., 1994), although as of this writing no sponsor was found for state enabling legislation. A program of private highways in the State of Washington resulted in several congestion pricing proposals being approved for consideration by the state's Transportation Commission (Washington State Department of Transportation, 1994).

V. 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. Neither appears to have prospects for implementation in the near future.

1. The Netherlands' Randstad Region[8]

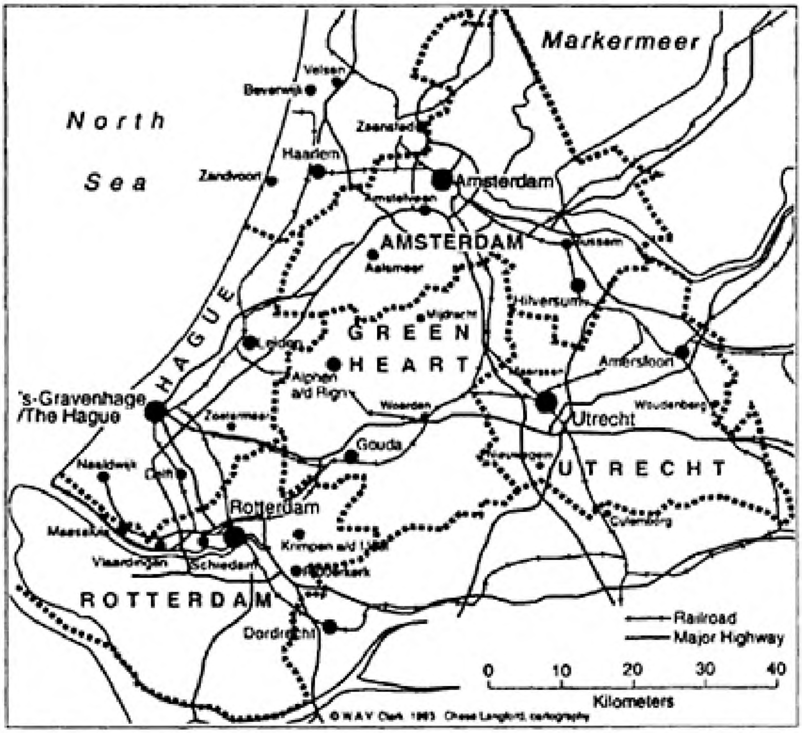
The Randstad region of The Netherlands, shown in Figure 1, is a sprawling urban region that covers more than 2,000 square miles and is home to some 6 million people. It includes the nation's four largest urban areas: Rotterdam and Amsterdam, with one million people each, and The Hague and Utrecht, each with over half a million. In both its urban form and its degree of road congestion, the Randstad resembles the larger Los Angeles region in the United States:[9] both areas are polycentric with multidirectional peak flows, both areas contain vital international ports and airports, and planners in both areas have turned to congestion management strategies to cope.

During the late 1980s, The Netherlands Government developed a proposal called "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 impacts. However, critics questioned its technical feasibility, its immunity to invasions of privacy, and its ability to prevent spillover traffic onto local streets. Unable to obtain support in Parliament, the Government in 1990 substituted a more modest plan for conventional road tolls.

8. The information in this section relies primarily on Stoelhorst and Zandbergen (1990), Pol (1991), Int't Veld (1991), Hau (1992), and personal communications with H.D.P. Pol, Director of Project Spitzbijdrage, Ministry of Transport and Public Works, The Netherlands.

9. See Clark and Kuijpers-Linde (1994) for an explicit comparison.

Figure 1. Randstad Holland



Source: Clark and Kuijpers-Linde (1994). Reprinted by permission.

Further study, however, convinced the Ministry of Transport and Public Works that conventional tolls would require too much land for toll plazas and would cause even more traffic diversion. In 1992, the Ministry developed a new proposal called "peak charging." It would again incorporate 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[10] and apply during the hours 6–10 a.m. The purchase of a daily, seasonal, or annual pass would be recorded by license plate and enforcement would be by random video pictures.

A new government, elected in 1994, has tabled further consideration of this proposal. Hence it appears that in the end these proposals were all too radical to attain the needed political support.

2. Greater London

Greater London, with seven million people and nearly four million jobs, has been the site of a remarkable series of comprehensive studies of congestion pricing, covering a variety

10. 1992 prices, using the 1992 exchange rate of 1 guilder=\$0.57.

of time periods, policies, and models. The resulting proposals have garnered considerable political support, but none has been adopted.

During the 1970s, the Greater London Council became interested in restraining traffic through supplementary licensing, a form of congestion pricing in which a daily license is required to drive within a defined area during peak hours. The favored options all involved a daily charge of around $2.00 (1973 prices)[11] to drive in Central London between 8 a.m. and 6 p.m. 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 because it has extensive transit service, these charges were expected to dramatically reduce traffic there, raising 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 under Prime Minister Margaret Thatcher. The strategy relied heavily on traffic restraint, including pricing measures. This time the congestion pricing proposal involved 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 isolating just the pricing measures showed dramatic predicted reductions in inbound traffic, by 15 percent into Inner London and 25 percent into Central London (May et al., 1990). More recent analysis shows that the distributional impacts of such a scheme would be concentrated among suburban car-owning households. Restricting the charges just to Central London would lower total benefits and shift the adverse impacts more toward poorer households (Fowkes et al., 1993); it would also make benefits more sensitive to the charging level, creating a greater likelihood of overdoing the policy as apparently happened in Singapore.

The most recent study of congestion pricing was a massive three-year research program begun in 1991 under the sponsorship of the U.K. Department of Transport. It investigated technology, public attitudes, changes in travel behavior, effects on reliability of travel times, effects on goods vehicles, and many other aspects (U.K. Department of Transport, 1993). These studies generally verified the behavioral responses expected from theory. However, 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.

3. Assessment

Despite the commitment of some important political figures, neither The Netherlands nor the United Kingdom has yet put in place any of the ambitious schemes for congestion

11. Exchange rates per British pound were $2.45 in 1973, and $1.78 in both 1988 and 1990.

pricing that have been proposed. The magnitude of the operation is so large, the technical and operational details so numerous, the effects so far-reaching, and the interest groups so many, that it appears to be exceedingly difficult to find a viable plan to introduce comprehensive pricing all at once. Meanwhile, much is being learned about how road pricing might be administered and what effects it would have.

VI. Conclusion

Both studies and actual experience have shown beyond a doubt that congestion pricing can substantially affect behavior and reduce traffic congestion. At the risk of over-generalizing, it appears that in the nations reviewed here, charges of $2 to $3 per day for entry to a restricted area during peak periods would 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 reasonable, around 10–12 percent of revenues.

For any road pricing project, no matter how limited, 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.

Regardless of how well planned, winning political approval for any congestion pricing project is difficult in a democracy. Many reasons have been suggested, but perhaps the most fundamental 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 likely to clearly understand the relationship between their payments and tangible benefits.

People are suspicious of plans to change arrangements they are comfortable with. The progression of innovations that we have reviewed here offers the possibility of overcoming this barrier through incremental change. The Norwegian toll rings began as means of financing transportation infrastructure, but the progressive increase in sophistication has made it possible to include traffic management as a subsidiary goal. The accumulated experience has enabled Stockholm to pursue 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 make the approach of demonstration projects, embodied for example in U.S. federal legislation, an attractive one.

However, 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.

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 the political problems, while difficult, may not be insoluble.

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