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Research challenges in modelling urban road pricing: an overview

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Research challenges in modelling urban road pricing: an overview

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Abstract

This article introduces the contributions of this special issue on modelling of urban road pricing and its implementation. The issue focuses on the design of urban road pricing schemes, and their spatial and temporal impacts, using quantitative transport (and land use) models. The policy implications of road pricing, including welfare and equity aspects, are studied for Paris, Brussels and Oslo using state of the art planning models. The issue is completed with a study of public acceptability and the upcoming road-pricing trial in Stockholm, and a review paper on the history of thought and future prospects of road pricing.

Key words: urban transport planning models, road pricing, transport policy implementation, earmarking, efficiency, equity, acceptability

JEL codes: D62, R41, R48, R52

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1. Introduction

The core of this special issue on "Modelling Urban Road Pricing Implementation" is the study of the design and impacts of urban road pricing schemes using quantitative transport models. In this issue, the effects of road pricing are studied for four European cities (Paris, Brussels and Oslo) using state-of-the-art models that differ in their spatial and temporal resolution and in the dimensions of travel behaviour that they treat endogenously. The issue is completed with a study of public acceptability and the upcoming road-pricing trial in Stockholm, and a review paper on the history of thought and long-term prospects of road pricing.

In a recent *Transport Policy* paper, Prud'homme and Bocarejo (2005) used a simple diagrammatic model to cast serious doubts on the economic benefits of the London congestion charge. Mackie (2005) responded by pointing to the simplicity of the back of the envelope model and the choice of basic parameter values including values of time. This interchange illustrates the need for a careful *ex ante* study of the economics of urban road pricing. An *ex ante* study has to consider at least two dimensions: what level of sophistication in pricing instruments is used and what is the optimal time sequence for the introduction of pricing schemes. These dimensions are incorporated into the concept of an implementation path that specifies what type of pricing scheme (e.g. cordon, time differentiation) is introduced and when, and which accompanying measures (e.g. public transport, toll revenue use) are needed.

Most of the papers of this special issue originate from the MC-ICAM research project of the European Commission. The main goal of MC-ICAM was to study alternative hypothetical implementation paths using advanced transportation models. MC-ICAM analysed both urban and interurban road pricing, but the literature suggests that current pricing inefficiencies are more pronounced in urban than in non urban areas (see, e.g. Proost et al., 2002). This special issue is devoted exclusively to pricing in urban areas.

The remainder of this introductory article is organised as follows. In Section 2, we explain some background concepts, and in Section 3 we briefly present five case studies treated in this issue. Four of the studies deal with implementation paths of road pricing (Paris, Brussels, Oslo and Helsinki[1]) and were part of the MC-ICAM project. A fifth study (Stockholm) assesses the impact of road tolling and public transport enhancements on political acceptability of road pricing. Section 4 summarises the main lessons drawn from the case studies. Finally, to help to put in perspective the case studies featured in this special issue, we provide in Section 5 a brief review of the current state of urban road-pricing practice.

A related special issue on urban road pricing appeared in 2002 in *Transport Policy*. That issue concerned theoretical studies, existing tolling schemes and mainly non European applications, whereas the current special issue focuses on Europe only, on potential rather than existing pricing schemes and on long-run implementation paths. Moreover, this issue illustrates the application of large-scale urban models in ex ante studies.

Other collections of studies on road pricing can be found in Santos (2004) and in de Palma and Quinet (2005). Both these contributions have a broader focus than does this special issue.

[1] The Helsinki case study is not included as a separate article in the special issue.

2. Implementation paths, economic optima, barriers and constraints

In economics it is well known that free access to public roads can generate a misallocation of resources. The fundamental reason behind this phenomenon is a so-called external effect: if there is congestion, each trip on the road forces other users to slow down and therefore to experience longer trip times. In the absence of a toll, a driver does not have to pay for the additional costs he imposes on others. The situation can be improved by corrective policy measures such as road pricing. Rouwendal and Verhoef (2005) in this special issue introduce the key economic concepts of road pricing, including marginal cost pricing, external costs, marginal cost of public funds, and first and second best.

There are many potential reasons why a first-best road tolling scheme is not implemented once and for all, and why instead a gradual approach is necessary. Barriers that prevent an immediate and complete optimisation can be classified as technical and practical, legal and institutional, and acceptability-related barriers These barriers can be translated into constraints for policy makers on the coverage of the policy, the composition and levels of charges, the degree of differentiation of charges, the use of the revenues and on the possibility to utilise supplementary policies. An implementation path is a temporal sequence of policy measures, satisfying the constraints at each stage that strives to reach or approach a first-best optimum in the most efficient way.

Rouwendal and Verhoef use a simple illustrative numerical simulation model to demonstrate the different dimensions of an implementation path. Their simulation study bridges the gap between theoretical analysis and issues that arise in actual transportation policy, and serves as an introduction to the full-scale simulation models that are featured in the four urban transport case studies.

3. Five urban transport models

In this issue four studies from the MC-ICAM project deal with hypothetical implementation paths for urban road pricing in four European cities, and one study deals with the political acceptability of a road pricing proposal for Stockholm that will be implemented in 2006.

To assess the implementation paths of road pricing in the first four studies, different state-of-the-art simulation tools are used. These models provide a finer level of detail, and operate under more comprehensive and realistic assumptions, than is possible at either the conceptual stage of analysis or with analytical models. The models also facilitate consideration of political, institutional, legal, and psychological barriers to the implementation of marginal cost pricing (MCP). Welfare effects of alternative pricing policies are also reported.

As summarised in Table 1, the four implementation-path case studies are similar in a number of respects. They are all concerned with large cities in Western Europe (Paris, Brussels, Oslo and Helsinki). They all examine a phased sequence of implementation in which constraints on the set of pricing instruments and accompanying policy measures (specific to each city) are progressively relaxed. Both the sets of instruments and the constraints are treated as exogenous at each phase. The studies also differ in a number of features: the models used, the dimensions of user behaviour that are endogenous, whether land-use decisions are considered, the level of detail in which road and public transit networks are represented, the set of policy instruments considered, and the accuracy with which optimal first-best or second-best policies can (and are) computed.

de Palma and Lindsey (XX) in this issue use the dynamic network equilibrium model METROPOLIS to study road pricing in the Ile-de-France region which contains Paris. In METROPOLIS, individual choices of mode, departure time and route are endogenous. This tool is similar to micro-simulation models in that it tracks the progress of every vehicle from origin to destination, although some microscopic details such as lane changes and congestion at intersections are not featured. Unlike micro-simulation models, METROPOLIS can handle large networks with modest data requirements, and can undertake dynamic simulations (with a time step in the order of one minute) over a full day at reasonable speed in terms of computation time.

The main focus of the simulations is to assess the efficiency gains of link-based and road cordon tolling, as well as a time-based tax. The simulations are used to construct an advantageous sequence of policy packages as MCP is progressively phased in. Emphasis is placed on evaluating and ranking alternative second-best pricing policies.

TABLE 1 ABOUT HERE

Proost and Sen (XX) use the TRENEN strategic model to study pricing of transport in Brussels. The case study focuses on two types of difficulties that arise in the design and execution of optimal implementation paths for MCP. This case study examines first which instruments can contribute most to a more efficient transport situation. The pricing policies considered are more efficient parking pricing, improved public transport pricing, and an optimal road cordon toll. The second type of difficulty that is examined arises with multiple levels of government that differ in their objectives and political powers. For example, local governments may assign lower weights to the welfare of non-residents than do national governments. Cost of funds may differ because of differences in the types and levels of taxes that governments rely on for revenue. And control of various pricing and non-pricing policy instruments may be divided up between levels of government. All these differences create the potential for conflict, as well as strategic behaviour in the form of “tax exporting”, “tax competition”, *etc*. (see De Borger and Proost, 2004).

To explore these dimensions of intergovernmental relationships it is assumed that the city government chooses the level of parking fees inside Brussels, while power to set the cordon toll resides with the regional government — which has authority over a wider population that includes Brussels. The city government is concerned about the total welfare of its inhabitants, while the regional government cares about the welfare of both the inhabitants and commuters to Brussels. A Stackelberg equilibrium (with the regional government as leader) and a Nash equilibrium are computed, and the results compared with the full optimum solution where the central government level would control all the instruments.

In the Oslo case study, Vold (XX) uses the RETRO model to study passenger transport and land use in the Greater Oslo area. RETRO is a disaggregated network equilibrium model for passenger transport. It includes sub models for residential location, workplace location and car ownership decisions. It is coupled with optimisation algorithms to determine the optimal levels of policy instruments.

Marginal cost transport pricing for Oslo is implemented in a phased manner by initially applying second-best pricing measures for the region, and then gradually refining the instruments towards first-best MCP. RETRO is capable of forecasting the short- and long-term effects of first- and second-best MCP, and in this respect it is suited to analysing a phased implementation path.

For Helsinki an interactive land-use and transport model based on the MEPLAN modelling framework is used. MEPLAN encompasses all eight major subsystems of urban regions: transport networks, land use, workplaces, housing, employment, population, goods transport, and passenger transport. It also incorporates five levels of behaviour: workplace location, residential location, auto ownership, travel mode, and route; and a relatively detailed representation of the road network and system of transit lines.

The analysis is focused on the inter-sectoral implications of transport policies - including land-use constraints and effects on the general economy of the region - rather than just on transportation. Cost-benefit accounts are drawn up relative to a business-as-usual or "do-minimum" reference scenario. Policies are assumed to be in operation in year 2000, and evaluated over a 30-year period. A stepping model with five-year increments enables analysis of temporal phasing of policies. Policy packages are chosen from a broad range of pricing measures: link-based tolls, zone and distance-based congestion pricing, city centre and outer ring cordon charges, parking charges, and fuel taxation

Finally[2], Armelius and Hultkrantz (XX) study the full-scale road pricing trial that will be performed in Stockholm from January to July 2006. As in London, the road tolls are presented as part of a package that includes major improvements of public transport, in particular by extension of bus services. This trial will be followed by a local referendum in September 2006 that will decide on whether to make the system permanent or not. The authors use an aggregate modal choice model to study the likely impact of road tolling and public transport enhancements. The model is calibrated on traffic count data collected in Stockholm and demonstrates that designated measures to improve public transport can have a substantial influence on the probability for acceptance of road tolls. They also study the effects on acceptability of the redistribution of part of the toll revenue.

4. Summary and assessment of the case study approaches: directions for future research

In the article following the case studies, de Palma, Lindsey and Niskanen (XX) review and compare the results of the four MC-ICAM project case studies as well as the illustrative numerical simulation model of Rouwendal and Verhoef (XX). They discuss the transferability of the results and assess the weak and strong points of the different modelling approaches used. They draw the following lessons regarding the implementation paths of urban road pricing[3]

- Efficiency gains from pricing increase with the proportion of a transport network that is priced (Paris). If only a small fraction of the network is tolled, tolls need to be set at relatively low levels in order to avoid extensive traffic diversion to untolled alternative routes, and the potential efficiency gains are inherently quite limited.

[2] This study was not part of the MC-ICAM research consortium and the model is not designed to study implementation paths with the same degree of detail as the other four case studies.

[3] This list is based on MC-ICAM, Deliverable 7, http://www.strafica.fi/mcicam/handouts/DELIVERABLES/d7-jan4-04.pdf

- Greater efficiency gains derive from measures that are more finely differentiated with respect to mode, location, time (Paris, Brussels), and vehicle characteristics (Brussels), and so on.

- The welfare gain from a package of policy measures can be equal to, greater than, or smaller than the sum of the gains from the individual package components. For example, the gains from tolling several routes are approximately additive if the routes are located far apart so that traffic spill-over effects between routes are minimal (as in Paris). By contrast, diseconomies in benefits can obtain for pricing parking and public transport (Brussels) or for congestion tolls (Oslo).

- An implementation path may not progress monotonically. Prices can first rise and later fall, or fall first and then rise (Brussels). And users can gain in the early phases of implementation, but lose later on (Oslo) or *vice versa*.

- Welfare losses can result from lack of coordination between levels of government that control different policy instruments. The extent of the inefficiency depends on how much their jurisdictions overlap, and can be alleviated by changing the sharing rules for revenue (Brussels).

- Investing in additional transport infrastructure capacity may help to gain acceptability for pricing measures, but it is not justifiable on efficiency grounds unless there is adequate demand to use the capacity. Because marginal-cost pricing generally boosts transit ridership at the expense of auto travel, investments in public transport tend to be more justifiable than road investments (Helsinki).

- The direction of land use effects can vary with the policy measure used. For example, residents and employers may choose to move away from a toll ring (both inwards and outwards) whereas link-based tolling induces them to concentrate towards the city centre (Oslo). The impacts of land use in the Helsinki and Oslo studies proved to be broadly similar in percentage terms. While the percentages may not seem particularly large, they might still tilt the balance of a cost-benefit analysis towards or against a pricing initiative.

Armelius and Hultkrantz find that investing in additional transport infrastructure capacity may help to gain acceptability for pricing measures (Stockholm), but it is not justifiable on efficiency grounds unless there is adequate demand to use the capacity. More precisely, they find that road tolling may be more acceptable when the share of public transit is already high and the proceeds of the road tolls are returned to them via public transport improvements.

The four studies of implementation paths can be considered as a test of the capabilities of models to assess ex ante road pricing implementation paths. There is clearly a considerable gap between an idealised approach, and what is feasible in applied modelling work using large-scale empirical network models. The four urban case studies sought an optimal compromise between the theoretically ideal approach and a pragmatic approach. The results are indicative of what one might expect to encounter along a realistic implementation path, but the implementation paths assumed are unlikely to represent the best possible path given the local circumstances. The contribution of the case studies – and of the underlying MC-

ICAM project – is only a first step towards a more rigorous approach to the economic analysis of transport policy implementation issues.

In the concluding article of this special issue, Pahaut and Sikow (XX) return to the Pigou – Knight debate that is at the heart of the road tolling issue. Are governments indeed capable of implementing new pricing systems and do they use the revenues properly? How do they deal with the redistributive issue that is unavoidable in any pricing reform?

Over the last 10 years, one of the major supporters for marginal cost pricing in transport has been the European Commission. Pahaut and Sikow report on the policy developments on this front as this will probably steer the developments in the next decade in Europe.

5. Existing road-pricing schemes

To help put in perspective the urban road-pricing case studies featured in this special issue, it is instructive to examine how urban road pricing has been implemented, and evolved, in practice worldwide. This section reviews the four most prominent schemes to date: Singapore's schemes, the Norwegian toll rings, the US High Occupancy Toll lane projects, and London's congestion charge. All of these schemes have some history that can be interpreted (heroically) as the first steps along an implementation path. And collectively they present a range of technological and other features. Their main features are presented in Table 2.[4] We first present briefly their history and then link the experience to our research questions and findings.

History

Singapore: The history of road pricing in Singapore spans three decades. The Area Licensing Scheme (ALS), introduced in 1975, was limited to a restricted zone (RZ) within the CBD. A daily paper license was required for entry to the RZ and enforcement was by visual inspection. In 1995 a paper-based Road Pricing Scheme (RPS) was introduced as a transitory measure to familiarise drivers with link charging on arterial roads and expressways with payment required for each passage rather than only once daily. Charges on the links and for entry to the RZ were automated when Electronic Road Pricing (ERP) began in 1998. Toll rates have remained relatively constant under ERP, but charging has been progressively extended over the road network.

Norway: Toll financing of road infrastructure projects in Norway dates back to 1929, and following tradition the toll rings were originally established to generate revenues rather to manage demand. The first two rings in Bergen (1986) and Oslo (1990) featured flat tolls, discounts for pass holders, and ceilings on the number of charged crossings per day or per month. Modest time-of-day variations were adopted in Trondheim (1991), and the single cordon there was replaced in 1996 by a system with six zones in order to boost revenues and enhance equity by extending charges to more drivers. Toll revenues were initially earmarked largely for roads, but amendments to the Road Acts in the mid-1990s now permit expenditure on public transport, environmental quality and safety. There is also increasing emphasis on demand management, as is evident in Oslo with the funding scheme *Oslo package 2* that was introduced in 2002, and the possibility under discussion of implementing a new road pricing

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[4] Table 1 is compiled from a number of sources. The main references are Chin (2002), Goh (2002) and Santos *et al*. (2004) for Singapore; Tretvik (2003) and Ramjerdi *et al*. (2004) for Norway; DeCorla-Souza (2004) and Value pricing home page (2005) for the US; and Transport for London (2005) and Mackie (2005) for London.

scheme designed for congestion relief.

High Occupancy Toll (HOT) lanes: US federal legislation passed in the 1990s established a Value Pricing Pilot Program to fund innovative road and parking pricing measures for congestion relief. The most prominent types of measure implemented so far are High Occupancy Toll (HOT) lanes. HOT lanes are a variant of High Occupancy Vehicle (HOV) lanes that allow vehicles that do not meet occupancy requirements to use the lanes for a toll. Five HOT facilities are in operation: SR-91 and I-15 in California, I-10 and US 290 in Houston, and I-394 in Minneapolis. General-purpose toll-free lanes run in parallel with the HOT lanes on all these facilities. On SR-91 tolls vary hourly according to a predetermined schedule, whereas on I-15 and I-394 tolls are adjusted dynamically every few minutes to maintain high flows. A number of studies of SR-91 and I-15 have documented how time-of-day pricing influences ride-sharing, lane choice, trip-timing and other dimensions of traveller behaviour. More HOT lane projects are under development or have been proposed, including networks of HOT lane roads.

London: Serious planning for road pricing in London began in 1998 with the Road Charging Options for London (ROCOL) study. Congestion pricing was introduced on February 17, 2003, as a flat daily charge of £5 for moving a vehicle or parking on public space within a 21 km^2 area around the city centre. The charge applies from 7:00-18:30 on weekdays. A number of vehicle categories are exempt, and residents of the charge area receive a 90% discount. Payment can be made in several ways. Vehicles are detected by Automatic Number Plate Recognition technology, but confirmation of payment is labour-intensive and system-operating costs are high. Violations are relatively frequent, and penalties for late payment generate considerable revenues. On July 4, 2005, the charge was raised to £8, and there are plans to expand the charge area to include affluent neighbourhoods to the west.

Assessment

From this brief and selective survey it is clear that urban road-pricing schemes differ along several dimensions including the type of tolling (facility or area-based), degree of time variation, types of exemptions and discounts, charging and enforcement technology, operating costs as a fraction of toll revenues, etc. But there are also important similarities across the four schemes considered (as well as other urban road-pricing projects). With the exception of the Norwegian toll rings congestion relief has been the official goal, but improved environmental quality is promoted as an additional benefit and revenue generation is likely to be a motivating factor behind increases in toll levels. All schemes feature some toll differentiation in the form of exemptions or discounts according to vehicle type, personal characteristics or vehicle occupancy.

All the schemes are part of policy packages of instruments designed to enhance public/political acceptability and to provide additional degrees of freedom to meet objectives. In most cases revenues are earmarked for transportation or environmental initiatives. In Norway each toll ring was linked to a well-defined package of road infrastructure improvements, and the benefits became apparent soon after the scheme was introduced. Singapore is an exception in not earmarking toll revenues. However, Singapore is notable in terms of the extensive array of measures that have been used, even before the ALS was introduced, to improve transport generally and public transport service in particular.[5]

As far as the histories of the schemes it would be rash to suggest that each has progressed along a predetermined – let alone optimal – implementation path. Moreover, the histories of the HOT lane projects and London's congestion charging schemes are very limited. Nevertheless, the developments that have occurred are generally consistent with the notion of a gradual sequence of steps towards increasingly extensive and sophisticated systems. In Singapore the shift from ALS to ERP represented a quantum leap in technology that permitted finer differentiation of charges with respect to time and space. Both the ALS and ERP have been repeatedly fine-tuned with respect to the timing and levels of charges, and changes that were judged to be counterproductive were later retracted. Norway has persevered with toll rings since the Bergen ring was introduced in 1986, but evolution is apparent in terms of a shift from manual to electronic collection, changes in the structure of tolls towards demand management, and more flexible rules for allocating revenues.

The US Value Pricing Pilot Program was designed to encourage experimentation, and more than 30 projects with a wide range of facility types have been funded to date. HOT lane projects have proceeded the most rapidly, arguably because of their relatively small set-up and operating costs, and the fact that parallel toll-free lanes enhance acceptability. The existing HOT facilities differ as far as their vehicle occupancy requirements, whether tolls are set according to a predetermined schedule or dynamically, allocation of revenues and the degree of private-sector involvement.[6] The only significant change to London's scheme so far is the fee increase from £5 to £8. Assessments vary as to whether the original £5 fee approximated a second-best congestion toll for the charge area.[7] An increase in the fee is consistent on simple second-best principles (Verhoef *et al*., 1996) with the planned expansion of the charge area, but acceptability and other considerations are likely to influence how the scheme evolves.

It may seem from the above discussion that, despite the recent political support, Europe is not the forerunner when it comes to urban road pricing. Indeed, Singapore is the world leader. The US may also appear to be ahead of Europe in two respects: the number of experiments that are underway or planned, and the fineness of time variation and use of dynamic/responsive pricing on two facilities. But the US was slow to start: the first scheme, SR 91, began only in 1995. And the schemes are all facility based, and small in scope compared to Norway and London.

This review of existing projects shows that long-run implementation paths were not announced *ab initio*. The sequence of steps that are now apparent in Singapore and Norway are probably the outcome of a series of incremental decisions by the officials who were in charge at the time. This means that well developed ex ante modeling exercises are a necessary step, but by no means sufficient for a successful implementation of road pricing.

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[5] To meet its demand management goals according to marginal-cost pricing principles, Singapore has been shifting from reliance on fixed vehicle charges towards variable charges – including not only tolls but also fuel taxes and parking charges. As Goh (2002, p.30) remarks "Singapore has always sought to make the case against congestion through economic terms … as long as motorists are prepared to pay the full social cost of their driving, they can drive as much as they want."

[6] SR-91 was privately financed, and privately operated until January, 2003. Ownership was then transferred to a public authority due to growing congestion on the untolled lanes and a "non-compete" clause in the private contract that precluded capacity improvements to the freeway until 2030.

[7] See Shaffer and Santos (2004), Prud'homme and Bocajero (2005) and Mackie (2005).

6. Conclusions

What did we learn about implementation paths of urban road pricing? The four modelling studies (Paris, Brussels, Oslo and Helsinki) of urban road pricing implementation showed that there is clearly a considerable gap between an idealised approach (which is difficult to formulate mathematically – let alone to solve analytically or numerically), and what is feasible in applied modelling work using large-scale empirical network models and taking into account city/country-specific barriers and constraints. The contribution of the case studies is only a first step towards a more rigorous approach to the economic analysis of transport policy and implementation issues.

This issue is mostly focussed on the optimal pricing of existing urban infrastructures. It appears, however, that implementation of road pricing is more acceptable when it is limited to new links, and when new investments are paid by new tolls put in place. That is, users are prepared to pay for new services but not for services that were previously free. This raises the important question of the optimal use of the revenues of road pricing, and whether these revenues need to be hypothecated either to the mode from which they are collected or to the wider transport sector. These new issues are discussed in a collection of articles in de Palma, Lindsey and Proost (2006) that deals specifically with the optimal use of transport charges for investments or other purposes.

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Table 1 The five case studies

	Model	**Main focus**	**Special feature**
Paris	METROPOLIS	Implementation path	Dynamic pricing
Brussels	TRENEN-URBAN	Implementation path	Urban and regional policy makers
Oslo	RETRO	Implementation path	Land use and optimisation
Helsinki	MEPLAN	Implementation path	Land use issues
Stockholm	Analytical mode choice model	Political acceptability	Revenue use

Table 2 Characteristics of four real-world urban road-pricing schemes

	Singapore: area license & electronic road pricing	**Norway: toll rings**	**US: High Occupancy Toll (HOT) lanes**	**London: area congestion pricing**
Inception	1975	1986	1995	2003
Objectives	**ALS** (1975-98): Congestion relief **RPS** (1995-98): Familiarise users with link pricing **ERP** (1998-): Control congestion by maintaining range of speeds	Initially revenue generation. Amendments to Road Acts now permit demand management to enhance environmental quality, safety	Congestion relief	Demand management: primarily congestion relief
Type(s) of tolling	**ALS**: inbound cordon. Paid daily **RPS**: Linear. Per passage **ERP**: CBD cordons and linear. Per passage.	Inbound cordons. Per passage.	Link. Per passage.	Area licensing scheme. Includes parking on public roads. Paid daily
Tolled area or infrastructure	**ALS**: 7 km^2 restricted zone **RPS**: Expressways **ERP**: CBD, expressways & arterial roads. Charged infrastructure progressively expanded.	Toll rings successively added in Bergen, Oslo, Trondheim, Kristiansand, Stavanger & Namsos. Trondheim ring converted to zonal system in 1996	Five projects: SR-91 & I-15 in California, I-10 & US 290 in Texas, I-394 in Minneapolis-St. Paul	21 km^2 charge area around city centre. Expansion to west under consideration.
Means of payment	**ALS & RPS**: paper licenses with manual enforcement **ERP**: In-Vehicle Units (IUs) and smart cards	Electronic and manual	Electronic	Manual payment by various means
Time variation	**ALS**: Morning peak, extended to evening in 1989 and to inter-peak in 1994 **RPS**: Morning peak **ERP**: CBDs 7:30-10, 12-19;	Variable tolls in Trondheim & Stavanger. Flat tolls elsewhere.	**I-10**, **US 290**: Flat **SR-91**: Variable **I-15**, **I-394**: Dynamic	Flat charge on weekdays except holidays, 7:00-18:30

	expressways: 7:30-9:30. Changes in 5 or 30-min. steps. Reviewed quarterly.			
Differentiation by vehicle & user characteristics	**ALS**: Exempt: police cars, ambulances, fire engines, buses. Formerly also HGVs, taxis, HOV3+ **RPS**: Same as ALS **ERP**: Differentiated by six vehicle types. Exempt: police cars, ambulances, fire engines	By vehicle type. Discounts for passes	**I-15**, **I-394**: HOV2+ free **SR-91**, **I-10**, **US 290**: HOV3+ free **I-10, US 290**: SOVs prohibited on toll lanes **All**: HGVs prohibited on toll lanes	Exempt: various vehicle & individual categories. Discounts: 90% for residents, 12.5% for fleets, various for monthly & annual payments
Changes in toll levels over time	**ALS**: S$3, S$4 (1975), S$5 (1980), S$3 (1989) **ERP**: Constant	Moderate increases	**SR-91**: Progressive increases (private & public operation). Other 4 facilities: constant.	Initially £5. Raised to £8 on July 4, 2005
Annual revenues[1]	**ERP**: ≈€35M (1998)	**Oslo**: €143M (2002) **Bergen**: €21M (2002) **Trondheim**: €23M (2002)	**SR-91**: $32M (2004)	Charges: €165M Enforcement: €102M
Annual operating costs[1]	**ERP**: ≈€3.75M	[Fraction of revenues] **Oslo**: 0.098, **Bergen**: 0.19, **Trondheim**: 0.15	**SR-91**: $21M (2004)	€130M
Earmarking/ hypothecation	None. Transport charge revenues greatly exceed expenditures on roads.	Formerly restricted to roads. Amendments to Road Acts now permit funding of local transport, environmental quality & safety.	**SR-91**: Operations, maintenance, improvements **I-15**: Express bus service & operations **I-10, US 290**: Operations **I-394**: operations, bus service	Revenues earmarked to transport for minimum of 10 years
Supplementary measures	Part of extensive package (multiple vehicle ownership taxes, fuel taxes, parking	Road and tunnel investment, public transport	**SR-91**: Capacity expansion	Increase in bus service, retiming of traffic signals

	fees; road expansion, mass rapid rail system, buses, taxis; P&R schemes, car cooperatives, signal timing)			
Private-sector involvement	**ERP**: Design and Build project to implement	Subcontractor; public sector bears risks	**SR-91**: Private from 1995 until 2003 when acquired by Orange county to bypass non-compete clause and rising congestion	Toll collection

Notes: **ALS** = Area Licensing Scheme; **RPS** = Paper-based Road Pricing Scheme; **ERP** = Electronic Road Pricing; **PT** = Public Transport; **HGV** = Heavy Goods Vehicle; **HOT** = High Occupancy Toll; **HOV** = High Occupancy Vehicle; **SOV** = Single Occupancy Vehicle; **SR-91** = State Route 91, California; **I-15** = Interstate 15, California; **I-10** = Interstate 10 (Katy Freeway), Houston; **US 290** = US 290 (Northwest Freeway), Houston; **I-394** = Interstate 394, Minneapolis-St. Paul. **S$**: Singapore dollars

[1] Annual revenues and operating costs converted at historical exchange rate. Sources: Goh (2002, p.33) and Santos et al. (2004, p.226) for Singapore; Ramjerdi et al. (2004) for Norway; 91 Express Lanes (2004) for SR-91; Transport for London (2005) for London.

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