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Review of Evidence on the Effects of Road Pricing

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ABSTRACT

Many national and local governments nowadays are, seriously considering road pricing as a policy measure to raise revenues or reduce congestion and emissions from road transport. A number of countries, states and cities have actually implemented such measures. This paper considers the effectiveness of road pricing by reviewing road pricing studies worldwide. The focus will be on the observed effects of schemes actually implemented. Road pricing can be effective but much depends on the objectives and the design of the scheme. The review carried out leads to the conclusion that road pricing schemes, where there are alternative routes and where the charges are likely to vary considerably by time of day, will probably cause substantial changes in route choice and departure time choice. A substantial increase in public transport use will only occur if public transport will be an attractive alternative for many of the origin-destination combinations, as in the case of the London and Stockholm Congestion Charging systems

KEYWORDS: road pricing, experiences, effects

1. Introduction

Unfortunately, the trend of increased road travel demand and automobile ownership has had negative consequences in terms of increasing congestion, environmental degradation and accidents. The rate of growth of car ownership was so fast that the supply of new infrastructure fell behind. The capacity of the existing road infrastructure became insufficient, particularly at specific sites during specific times of the day. Traffic congestion is nowadays a recurring ingredient of everyday life, making millions of car drivers suffer from significant time losses. Road transport is also one of the largest sources of environmental pollution in Europe. Environmental impacts associated with car use concern depletion of energy, mineral resources and land resources, air quality (emissions), global warming, noise and health (injuries and deaths from accidents). Estimates of these environmental costs of road use (excluding vehicle operating costs) amount on average to some 1.6% of GDP in Western Europe, including the external costs of accidents (0.5%), air pollution (0.6%), noise (0.3%) and global warming (0.2%) (UNITE, 2003). The total costs of road congestion amount to a further 1% according to this study.

Whilst the nature of this transport problem differs across regions, the calls for policy action are intensifying everywhere. Policy makers can choose from a range of policy instruments that deal with different transport externalities. Governments may influence the achievement of a more sustainable transport system by introducing regulations, imposing taxes, or providing subsidies (e.g. to stimulate the use and development of cleaner vehicles). In the present paper, the focus is on one specific instrument that is available to policy makers: road transport pricing.

Most countries use a number of coarse pricing mechanisms related to car ownership and use, such as fuel duties, registration fees and parking charges. These measures in car transport are in many cases used to raise revenues, or assist in traffic control, and not so much to reduce congestion or internalise external costs. This is not very efficient. Economists have advocated the use of more targeted pricing tools for a long time, and have demonstrated the welfare gains. However, more recently, the situation is changing rapidly, and different forms of road pricing are seriously considered and implemented by policy makers. The promising results, together with the growing need among policy makers to deal more effectively with the transport problems, seem to countervail low levels of acceptance and technical problems.

This paper addresses effectiveness of road pricing schemes worldwide. We define road pricing schemes as policy regimes where drivers have to pay for their actual use of the roads. We focus on congestion pricing and do not consider the well known toll roads (as existing in France and Italy). Most of the evidence presented comes from schemes that were actually implemented and where the effects were monitored (e.g. through before and after surveys). This is supplemented by some selected results from model simulations that are part of the ex ante assessment of specific road pricing plans.

This paper is organised as follows. Section 2 discusses the potential behavioural responses that may be achieved with the road pricing instrument. Section 3 reports the effects of fourteen cases where road pricing has been implemented. Section 4 gives an overview of impacts and compares. Section 5 concludes.

2. Behavioural responses to road pricing

Governments often play a major role in the transport market. Hence, transport prices are often set or influenced by the public sector. Governments may have several reasons or objectives for changing prices. Pricing measures are often used to raise revenues; they may assist in traffic control and contribute towards the internalisation of external costs. Most often it is a combination of these objectives that is behind the implementation of a pricing scheme. Transport pricing can be very diverse and very much targeted to a certain type of behaviour. Broadly speaking, transport pricing measures can be divided into five different types, according to the way charges and payments are applied (CAPRI, 1998):

- Vehicle pricing, related to car ownership and usage (independent of the roads used);
- Road pricing, related to use of specific roads and areas (possibly at specific times[1]);
- Parking pricing, related to use of parking spaces;
- Public transport pricing or subsidising, related to use of public transport;
- Special taxes, related to city centre employment, real estate, or particular locations (e.g. near public transport facilities) which may have an indirect effect on transport demand by influencing location decisions.

We focus here on road pricing. Road infrastructure users currently do not perceive the full marginal social costs of their travel decisions. This leads to traffic volumes in excess of what is socially desirable, and it implies a suboptimal distribution of transport flows over time and space. For dealing with the various types of externalities (congestion, noise and so on) economic theory argues that prices should be set according to marginal social costs. Due to various (practical) reasons, this first-best type of pricing is generally not used or even feasible in road transport (see also Ubbels, 2002, and Small and Verhoef (2007)). However, there are several policy instruments available to governments which can be used to deal with the various externalities. Road pricing is one of these, with the potential to deal more efficiently with existing problems than other pricing regimes. This depends on the design of the charging scheme.

Road users will respond differently to road pricing policies. The possible outcomes (in terms of behavioural responses) of pricing can be the following:

- different route choice;
- departure time choice (and scheduling of daily activities);
- change in driving style (e.g. speed choice);
- changes in modal split;
- changes in vehicle occupancy;
- changes in destination choice.
- trip suppression (travel frequency choice);
- vehicle ownership;
- spatial choices related to re-location;
- technology choice (type of vehicle);

Depending on the desired aim, policy makers may now decide to make use of a particular price instrument that is likely to steer travel behaviour in a more desired direction. In practice, revenue raising seems more important than economic efficiency. However, it should not be forgotten that the real effect of a price change depends on various factors which makes the predictability of a certain measure rather difficult. Factors affecting price sensitivity include (VTPI, 2002):

- Type of price change: the different types of pricing measures can have different impacts on travel behaviour. Road tolls may affect travel routes and destinations. A time-varying

[1] This also includes the recent experiments where road user subsidies are given to car users to avoid peak period driving (e.g the Dutch case of 'Spitsmijden').

fee may shift trips to other times. Fuel price increases tend to affect the type of vehicles purchased more than vehicle mileage, and so forth.

- Type of trip and traveller: commute trips tend to be less price elastic than shopping or recreational trips. Travellers with higher incomes tend to be less price sensitive than lower-income travellers. Business travellers tend to be less price sensitive than people travelling for personal activities.
- Quality and price of alternative routes, modes and destinations: price sensitivity tends to increase if alternative routes, modes and destinations are of good quality and affordable. For example, road users tend to be more price sensitive if there is a parallel untolled roadway.
- Scale and scope of pricing: in general, narrowly defined transport segments are more elastic than broadly defined transport segments, because consumers have more alternatives. For example, demand for peak-period automobile travel on a certain road is usually more elastic than for total personal travel along a corridor, since a higher price for driving at a particular time at a particular road may shift travel to alternative routes, destinations, modes and travel times.
- Time horizon: transportation elasticities tend to increase over time as consumers have more opportunities to take prices into effect when making long-term decisions (Oum et al., 1992). For example, if consumers anticipate low automobile use prices they are more likely to choose an automobile dependent suburban home, but if they anticipate significant increases in driving costs they might place a greater premium on having alternatives, such as access to transit and shops within convenient walking distance. These long-term decisions affect the options that are available. It may take many years for the full effect of a price change to be felt. Studies cited by Button (1993) estimate that short-term elasticities are typically one-third of long-term elasticities. Short run is typically less than two years, medium run is two to 15 years, and long run is 15 years or more, although definitions vary. Large price changes tend to be less elastic than small price changes, since consumers make the easiest accommodations first. Dargay and Gately (1997) conclude that about 30% of the response to a price change takes place within 1 year, and that virtually all takes place within 13 years.
- Large and cumulative price changes: Extra care should be used when calculating the impacts of large price changes, or when summing the effects of multiple changes, because each subsequent change impacts a different base.

Many studies have analysed the effects of road pricing, empirically as well as theoretically. Also multiple disciplines have analysed road pricing (for an overview of road pricing from a multidisciplinary perspective, see Verhoef, et al. 2008). This paper focuses on the behavioural effects of road pricing schemes that were implemented in practice. There are also many cases where road pricing proposals have been evaluated ex ante using traffic models (including at least five proposals for road pricing the Netherlands since 1990). These are not included in this paper, which is about observed effects (e.g. from before and after surveys). The aim is to give an up to date review of road pricing schemes where we compare effects and effect sizes and try to distil some lessons from this. It is impossible to conclude about overall successes of schemes, because many more aspects should then be included in the analyses (an overall assessment of cost and benefits would then be appropriate).

3. Effects of road pricing experiences

Facilitated by technological improvements and the need for efficient solutions, road pricing is no longer an experiment only. For many years, the only example of congestion pricing was in Singapore. Today, there is more experience, coming from Norwegian toll cordons and express lanes in the U.S. Singapore and Orange County (California), for instance, are interesting and valuable examples of situations where road pricing was actually implemented. But there is more. Below, we discuss 14 cases worldwide, where charging according to road use takes place. Congestion charging is obviously very interesting, but also kilometre charges for freight transport have been included. 'Conventional' toll schemes (as in France and Italy and south America), where payment indirectly is according to road use, without differentiation by time-of-day, have not been included. Also we are aware of a number of schemes (e.g. the M6 Toll in the UK, the Highway 407 toll in Canada), which have some variation by time-of-day, but for which we have not been able to find data on observed effects on traffic (and the underlying choice mechanisms). Below, we briefly discuss the selected schemes and their behavioural implications. The effects of these schemes will be compared in chapter 4.

Singapore

Objectives

In 1975 *Singapore* implemented the Area Licence Scheme (ALS) to restrict car ownership and car use. Downtown Singapore faced serious levels of congestion and the government expressed the necessity of managing traffic demand. It was the first urban traffic congestion pricing scheme to be successfully implemented in the world.

Description of the scheme

Singapore introduced a fee to enter the central area, comprising the central business district (the CBD). The size and the structure of the fee have changed over years. At first, the fee was only imposed during the morning peak, but in 1989 this was extended to include the afternoon peak. Public transport was exempted from the charge. Tolls were collected manually from the very beginning, but in 1998 the tolls were automated and made more variable (Electronic Road Pricing, ERP).

Effects of the scheme

The effects on traffic have been very significant. For the commuters travelling to jobs in the restricted zone, the share commuting in cars with less than four passengers (carpools carrying four or more people were exempted until 1989) dropped from 48% to 27% during the first few months of operation, while the combined modal shares of carpools and buses rose from 41% to 62% (Small and Gomez-Ibanez, 1998). Moreover, the number of vehicles of all types entering the zone during peak hours declined, while traffic rose during the half-hour period preceding the toll period. This shows that the congestion prices clearly affected the departure time choice of car users.
As of 1998, a method of shoulder pricing is used, which involves increasing the rate in steps every half an hour before the peak and decreasing it after the peak (with charges depending on vehicle type). It appears that traffic is quite sensitive to the road pricing system even though the charges are relatively low – the maximum rate for cars on expressways and for entry of the restricted zone is comparable to a 1-hour parking fee in the city (about €1.50) (Olszewiski and Xie, 2005). The elasticity values shown in Table 1 indicate that time of driving will change with time-dependent charges. Evening peak traffic flows show the highest demand

sensitivity, with an elasticity of -0.32 for cars. The low figures for the morning peak can be explained by arrival time restrictions for commuters, whereas trips home in the evening can be postponed to avoid the high peak charge. This suggests that time of day charging may lead to considerable departure time and mode choice effects, but much depends on the local situation (e.g. public transport availability).

Table 1: Elasticities of traffic entering the restricted zone by time interval

Time period	*Cars*	*Other vehicles (motorcycles, taxis, LGVs, HGVs, buses)*	*All vehicles*
7:30-9:30	–0.106	–0.019	–0.069
9:30-15:00	–0.082	–0.080	–0.083
15:30-17:30	–0.123	–0.151	–0.143
17:30-19:00	–0.324	–0.189	–0.265
7:30-19:00	–0.123	–0.106	–0.118

Source: Olszewski and Xie (2005).

Introduction of a Toll-ring in Bergen (Norway)

Objectives

Bergen in the second-largest city of Norway (200,000 inhabitants). The local authorities regarded new infrastructure as important for solving the problems of congestion, traffic accidents, noise and emissions, but its own means and the contribution of central government were not sufficient to finance this. The toll-ring was introduced to raise the revenues to build these new roads. So the objective was very different from Singapore (reduce congestion and traffic into the CBD).

Description of the scheme

The toll-ring was opened on 2 January 1986. There are six charging locations (of which four at bridges/tunnels), which are the entries to the CBD. The charge is on entering the CBD in the period 6.00 – 22.00 hours, Monday – Friday. The initial rate for a single ticket (for entering once) was about 0.75 Euro for light vehicles (including motorcycles) and 1.50 for heavy vehicles. There were yearly, half-yearly and monthly passes as well, which are cheaper if one enters the area more than once per day. Cars with seasonal passes can use separate lanes at the entry points so that they do not have to stop. The pass should be behind the windscreen, which is checked at random by video-cameras. Single tickets (and books of ten) can be bought beforehand at the local banks and at the charging sites.

The effects of the scheme

Contrary to the expectations of some, the introduction of the toll scheme did not lead to chaos. No new bottlenecks emerged and delays at the charging sites were small (except in the first months on the first day of the month). According to the video-camera registration, about 2% of the cars on the non-stopping lanes had no pass. The net revenues from the toll in the first year were 30% higher than expected, because of larger traffic volumes and a smaller share of seasonal passes than was anticipated.

The share of seasonal pass users however has been rising since, from 25% initially to 55% for the entire charging period and even 70% for the AM peak.

The impacts on travel behaviour and traffic flows were studied using before and after household surveys (using a panel design) and traffic counts in week 46 of 1985 and week 17 of 1986. The number of car users with usable information for both waves was 333. The main results are as follows (Larsen, 1988).

Because of the charges, the number of vehicles entering the CBD in the period of operation decreased by 6-7%. For cars with a seasonal pass, the number of trips into the CBD in the charging period increased by 5%, for other cars it declined by 30%. Some households with more than one car , used both cars to go into the CBD before the opening of the toll-ring and only one car (with a pass) after.

The use of public transport did not change. Therefore the decline in vehicle trips must be the result of changes in car occupancy, travel frequency and destination choice. There can also be a small shift in departure time, but given that the charging starts at 6.00 AM, this shift will be small. The impact on detours to avoid the tollgates is thought to be of negligible importance.

So, in the Bergen situation, where there were hardly any time of day and route choice alternatives to avoid the toll, there has probably been a small but not negligible impact of travel frequency and destination choice. This conclusion was not based on firm evidence but rather on elimination of other possibilities.

Introduction of the Toll-ring in Oslo (Norway)

Objectives

As in Bergen, the objective of the Oslo toll ring was to raise revenues for investment in infrastructure. In the Oslo case the investment programme included new main roads (e.g. a tunnel below the city centre) and public transport improvements.

Description of the scheme

The toll-ring is situated just outside the city centre. There are 18 toll stations. All motorised traffic (except public transport) going into the city has to pay. The charge for a single passage was initially about 1.5 Euro for cars, 3 Euro for trucks and 0.75 Euro for motorcycles. Monthly, half-yearly and annual passes were also available. The charging system operates day and night, seven days per week, and started on 1 February 1990. The toll stations have three lanes. One of these is for the seasonal pass holders, who can pass at 50km/hour. The other two have machines into which coins can be thrown and manual ticket sales. Here the drivers need to stop. Video-cameras are used to check out free-riders. Electronic toll collection (automatic debiting from pre-paid accounts) was introduced in December 1990, but the options of using seasonal passes, coin machines and manual payment were retained.

Effects of the scheme

The number of vehicles passing the ring from the outside to the inside is about 200,000 per day. The introduction of the toll initially resulted in a small decline in the number of vehicles entering the centre (in the order of not more than 5%). After a few months, the share of seasonal pass holders was 60% already. More than 100,000 passes have been sold (in an urban area of 600,000 – 700,000 inhabitants), often paid by the employers.

A large research programme was set up to evaluate the effects of the opening of the toll-ring, including automated traffic counts, public transport traveller counts, registration of retail sales, before and after surveys on attitudes, vehicle occupancy and a panel survey of travel patterns with 20,000 travellers in the fall of 1989 and the fall of 1990 (Solheim, 1990).

The introduction of the toll road and the new road networks in the longer run has reduced the number of vehicles going into the centre by 50,000 per day (-25%). Most of this effect is due to re-routing of through traffic. The revenue is about 90 mln Euro per year. The annualised capital cost amounts to €4 mln per year and the operating cost €11 mln (Ramjerdi and Larsen, 1992).

The traffic impact of the three Norwegian toll rings in Bergen, Oslo and Trondheim has been modest, reducing vehicle crossings by no more than 5 to 10 %. This was expected as the fees are relatively low and they only vary in time by a limited amount. The Trondheim system does seem to have induced some afternoon peak spreading as people delay inbound trips until the end of the toll period at 17:00. Interestingly, downtown shop owners have extended their hours of opening to accommodate this response. Attitudes towards the Oslo and Trondheim toll rings were negative, but considerably less so after the schemes opened than before.

Introduction of a Time-varying Toll on the A1 Paris-Lille

Objectives/description of the scheme

The Autoroute A1 is a tolled motorway connecting Paris and Lille, about 200 km to the North. The A1 is subject to heavy inbound peaking near Paris on Sunday afternoons and evenings. Therefore in April 1992, following a period of public consultation and publicity, time-varying tolls were implemented for Sunday only. A surcharge operates during the peak period (16:30-20:30) with toll rates 25 to 56 % higher than normal, whereas before and after the peak period the tolls is 25 to 56 % *lower* than normal. The tariff was designed so that total revenues are nearly identical to those collected previously with a flat toll. This property was believed to be essential for public acceptance.

Effects of the scheme

The impact of the A1 scheme has been primarily in the timing of trips. Southbound traffic near Paris declined approximately 4 %, whereas shoulder traffic rose by 7 %. The most pronounced shift was from the last hour of the peak to the later shoulder period. A survey in November 1992 confirmed that about 1/5 of those travelling in the shoulder has sought to lower their toll by shifting the timing of their trips (Small, 2002).

Experiment with Cordon Charging in Stuttgart in 1994/1995

Objectives/description of the scheme

An interesting experiment was undertaken in Stuttgart between May 1994 and February 1995. A cordon was established across the southern entrance to the city centre, and 400 *volunteer* motorists were used to test the toll equipment, subject themselves to actual tolls and to participate in a number of surveys and interviews. In return, they received a block allocation of funds that more than covered expected toll payments.

Effects of the scheme

When one of the three routes entering the city was charged a € 2.50 toll, 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 price differentials over time. The next most common responses was a shift to car pools and public transport. Shifts to public transport varied from 3.4 % to 5.9 % of total weekday trips (Small, 2002).

Orange County: SR 91

Objectives

As there are very few direct routes between Orange and Riverside Counties because of the Santa Ana Mountains that separate the two counties, the Riverside Freeway is subject to a very heavy traffic volume, comprised primarily of commuters traveling between where they work in Orange County and where they live in Riverside County Typical peak period delays were 30-40 minutes in each direction in the ten miles (16 km) of the tollway before construction. The chosen solution was to create a toll road in the median of the freeway. The toll road route operates between the Orange/Riverside county line and the Costa Mesa Freeway (SR 55) interchange in eastern Anaheim - a distance of about 10 miles (16 km). Opening in 1995, the 91 Express Lanes is the first privately funded tollway built in the United States since the 1940s, and the first fully automated tollway in the world. Tolls were installed to maintain travel time savings and attract private toll operators.

Description of the scheme
State Route 91 in Orange County (California) has 10 miles of express toll lanes, privately constructed and built, and funded by variable electronic tolls. These tolls vary throughout the day in relation to demand and to congestion on the parallel freeway, ranging from $0.75 to $3.50 per trip. Users need to be registered customers and carry transponders. There are discounted tolls for high-occupancy (3+) vehicles (high-occupancy/toll or HOT lanes). Field data collection included traffic measurements, vehicle occupancy counts, transit ridership data, and comprehensive travel surveys with current and former commuters. Data analysis included, inter alia, the time-of-day choices of commuters as well as vehicle occupancy.

Effects of the Scheme
It appeared that the traveller's decision to use the toll lanes is very closely related to hour-by-hour variations in traffic conditions (Sullivan, 2000). The analysis shows that peak period commuters on SR 91 value time at approximately $13-16 per hour, and that demand is moderately price-sensitive. New toll schedules implemented in 1997 introduce hour-by-hour toll differences in peak periods. As yet, the fairly small differences in these tolls have not been accompanied by much flattening of the peak period traffic distributions. Within three months after the opening, peak traffic observations showed a greater than 40% jump in high occupancy vehicles carrying three or more people. At that time, the lanes were free of charge. When carpool users were charged a 50% toll in January 1998, about a third (about 2000 vehicles a day) of the HOV3+ traffic left the lanes.
Models have been used to measure the responses to change in tolls. The price elasticity for use of the toll lanes during the 6-hour period of heaviest use (morning westbound or afternoon eastbound) is consistently about –0.7 to –0.8 based on response to uniform percentage toll changes. This indicates that a 10% across-the-board toll increase would result in about a 7% or 8% decrease in toll facility use. Analysis shows that doubling all the tolls causes just 0.7% of all SOV vehicles to switch to other modes in the morning. This increases the number of higher-occupied vehicles. Responsiveness in the afternoon is slightly greater. These calculations understate the true effects of a toll increase on vehicle demand because they do not include trip generation. Time-of-day shifts have been small. Increasing the peak of the peak tolls (that is at 7-8 a.m. and 5-6 p.m.) by 10%, results in overall shifts out of those time periods of just 0.5% in the morning and 0.74% in the afternoon.

Boarnet and Chalempong (2002) assessed whether the construction of new toll roads in Orange County, California, has impacted on urban growth patterns. They investigate the effect that 51 miles of additional tolled infrastructure has had on house prices, population and employment growth. It is noted that the toll charges do not vary with time of day or levels of congestion. A large dataset of 275,185 house sales in the Orange County between 1998 and

2000 was assembled. All of the tolled network was constructed during this period, and so ‘before and after’ data is available. A regression for the price of a house was estimated. The distance variables showed the expected pattern. The coefficients on distance before the toll road opened (effectively a validation variable) were insignificant, whereas the coefficients on distance after the toll road opened were significantly negative in the three regressions made. In the situation where the toll road is open and increases house prices nearby, house prices decrease *ceteris paribus* by approximately $ 7,000 per mile from the toll road in one corridor, and by approximately $ 24,000 per mile from the toll road in another corridor.

To validate the results, a control corridor was used that saw no significant capacity improvements in the period. An arbitrary threshold year was chosen to represent the ‘opening’ of new toll routes. All distance terms were insignificant as expected.

Population-employment growth regressions included highway access dummy variables, land use variables, demographic, socio-economic and housing variables to model changes in population and employment over the period. In the population change regression, the coefficient on the toll road area dummy variable is significant both before and after the toll roads were constructed, reflecting high population growth in these areas throughout the period. However for the employment regression, the terms demonstrated that the areas around the toll road changed from low employment growth prior to opening to growth levels comparable with the county average after opening.

Boarnet and Chalempong conclude that the construction of new toll roads in Orange county has had a significant positive impact on house prices in the area, and a positive impact on rates of employment growth. The authors did not discuss what the size of the areas where house prices are affected by the toll roads is.

Introduction of Value Pricing on the I-15 near San Diego, California

Objectives

On the I-15, North of San Diego in Southern California, a stretch of two reversible lanes of 8 miles long, separated from the rest by concrete barriers, had been functioning as high occupancy vehicle (HOV) lanes since 1988, for vehicles with two or more occupants. But the capacity of these lanes remained underutilised. In 1996 these lanes, also called Express Lanes were opened to paying solo-drivers. The goal was to reduce congestion by taking advantage of the underutilised capacity. The combined system now is called high occupancy – toll (HOT) lanes. Other HOT lane projects haven taken place in Houston, Minneapolis, Salt Lake City, Denver, Seattle, Miami, Dallas, and Alameda County. The I-15 freeway as a whole has 4-5 lanes in each direction and carriers more than 200,000 vehicles per day.

Description of the scheme

The project is called the I-15 congestion pricing project. Congestion pricing however implies that all users are charged. This project therefore can better be labelled value pricing, which means that people can choose to pay for an extra service (shorter travel time) that other users do not have (van Amelsfort et al., 2000). The project consisted of two phases:

- ExpressPass from December 1996 until March 1998;
- Fastrak that started in March 1998.

In the first phase, the solo drivers using the HOV lanes had to buy passes, which were billed on a monthly basis. The second phase uses transponders in the vehicles, which are identified automatically. Fastrak subscribers pay a fee per trip. The fee depends on the congestion on the Express Lanes and is posted on changeable message signs along the highways approaching the HOT lanes. The fee per trip can be varied every six minutes in order to maintain free-flow conditions[2] on the HOT lanes (Golob, 2001). If on a particular day the observed toll would be unusually high for that time of day, that fact informs the driver that congestion in the unpriced lane ahead is unusually severe (Brownstone and Small, 2002), So the toll rate not only acts as a price for the HOT lane use, but also has a signalling function with respect to congestion on the other lanes. The fee is debited automatically from a prepaid account or a credit card when the vehicle passes the toll station halfway the Express Lanes. The per-trip fee is between $0.50 and $4.00. Users of the Express lanes benefit from free-flow conditions for eight miles (there are no entries and exists along this stretch). The users of the 'normal' I-15 lanes have to face congestion (a recurrent problem on the I-15). In the morning period the express lanes are used Southbound and in the evening period Northbound.

Effects of the scheme

Brownstone and Small (2002) remark that unlike most revealed preference studies of value of time, in this project (and the SR-91 project described later) the choice to pay to use the toll facilities is relatively independent from other travel choices, such as whether to use public transport. Very little public transport services exist in this corridor.

The evaluation project by the San Diego State University includes the assembly and use of traffic and panel data. The panel was gathered by interviews twice a year and has five waves in total. The panel size is 1,500 travellers (500 I-15 FasTrak participants, 500 other I-15 travellers and 500 I-8 travellers). There is also a control corridor (the I-8), but both freeways turned out to be so different that the I-8 does not provide control information. More than a third of the Fastrak users decided to use it prior to departure (whatever the exact posted fee would be).

The traffic volumes on the I-15 main lanes have been increasing, after the introduction of the value pricing on the HOV lanes. Traffic on the HOT lanes increased even more, but the traffic conditions were still within the specified thresholds. During the busiest hours, many solo drivers are prepared to pay for free flow: the HOT lanes then carry 40% of the traffic, at 65 miles per hour (Reason Public Policy Institute, 2003).

The travel time savings when using the Express Lanes both in the morning peak and in the evening peak vary between 6 and 18 minutes per day (Van Amelsfort et al., 2000). The Fastrak (for paying solo drivers) is used proportionally more by:

- Persons in households with high incomes
- Persons with a high education level
- Persons who own their home
- Persons between 35 and 44 years old
- Women.

Because of the use by the well-to-do, the Express Lanes have been called 'Lexus lanes'.

Besides the dynamic FasTrak system, a simpler ExpressPass system operates whereby users simply purchase a monthly pass at fixed cost. Supernak (2003) demonstrated that this fixed fee structure was encouraging undesirable high express lane usage during the middle of the peaks, whereas the dynamic FasTrak system was able to create desirable shifting of traffic from the middle to the shoulder of the peaks. Therefore the study suggests that dynamic pricing can induce micro-level time switching within the peak periods.

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[2] More specifically, the toll rates are set maintain a service of at least a level called 'C' in the express lanes, which means a density of less than 27 vehicles per lane per mile.

To evaluate the impact of the I-15 pricing project on the housing decisions, respondents from 112 households along the I-15 study corridor and 92 households along the I-8 control corridor were surveyed using a mail-back questionnaire (Supernak et al., 2001). This survey made clear that the presence of the express lanes is only a secondary factor in housing choice along the I-15 corridor. However, for a small minority of respondents the express lanes were an important factor. Five percent rated them as of 'very high' importance, and five percent rated them as of 'high' importance.

A special I-15 business impact study was carried out (Steffey et al., 2001). Businesses were selected by random sampling from a telephone directory, and asked to complete a mail-back questionnaire. Businesses were surveyed in three specific areas: along the I-15 study corridor, along the I-8 control corridor, in downtown San Diego. A total of 616 businesses were surveyed across three waves. The perceived impact of the I-15 pricing program remained low across the three survey years. Furthermore perceived program impact did not vary significantly with either business type of business location. The I-15 program is considered secondary in importance to factors such as supply of goods and labour, price of commodities, and tax levels and policies. Businesses seem to prefer unlimited use permits to pay-per-use systems. Unlimited use permits tend to be cheaper per-trip for heavy users.

Introduction of Variable Pricing on the Cape Coral and Midpoint Bridges in Lee County, Florida

Objectives

Burris and Pendyala (2002) list 19 schemes in 7 countries with variable tolls (meaning that the charge varies with time-of-day or observed congestion). The US schemes include the high occupancy/toll (HOT) lanes in San Diego (I-15) and Houston (I-10, US-290).

The Lee County variable pricing project is one of four value pricing projects implemented under the US Federal Highway Administration's value Pricing Pilot Program. It has several objectives, including gathering information on driver response to variable tolls and introducing the travelling public to the concept of variable tolls and off-peak travel (Cain et al., 2000; Burris and Pendyala, 2002). The two bridges that are tolled (Cape Coral Bridge and Midpoint Bridge) both cross the Caloosahatchee River. The current traffic is 32,000 and 36,000 vehicles per day respectively. Both bridges have four lanes and are still uncongested, even in peak hours. But traffic volumes on these bridges are growing very fast (5-8% per year) and significant congestion could be expected in the near future. The variable pricing should help to avoid this situation. The toll itself was set to pay for the construction of the Midpoint Bridge (opened in 1997) and the operating cost on both bridges.

Description of the scheme

The variable pricing (off-peak discount) started on 3 August 1998. Participants in the variable pricing receive a 50% off-peak discount. For the majority of participants the regular toll would be \$0.50, so the discount is \$0.25. The requirements for receiving the discount are twofold:

The drivers have to pay the toll electronically (in 1999 26% of the toll transactions was paid electronically, drivers can also pay cash or buy a one-year pass, but in both these cases they do not get the off-peak discount)

The drivers have to pass the bridge in the discount periods (6.30-7.00 AM, 9.00-11.00 AM, 2.00-4.00 PM and 6.30-7.00 PM).

Effects of the scheme

A stated preference study before the start of the variable pricing scheme predicted that 33.5% of the toll bridge drivers would be participating in the variable pricing scheme (paying electronically and travelling off-peak). A revealed preference survey carried out in 1999 found that this participation rate in reality was 15.6%. Among the drivers eligible for the toll discount (the 26% mentioned above) there was a significant shift in time of travel from the peak to the off-peak periods after the introduction of the variable pricing scheme. Peak travel across the bridges in this group decreased by 2-8%, with the larger decreases in the morning peak. Even though the monetary incentive is only $0.25 for the participants, the elasticities of travel across the bridges in the peak range from -0.03 (late afternoon peak) to –0.36 (early morning peak). The travel timing of respondents that did not pay electronically (can be regarded as a control group) did not change significantly.

In 1999 a mailback survey was carried out among respondents that used the bridges, including eligible and non-eligible car drivers. This net response consisted of almost 2,000 drivers who used the bridges (Burris and Pendyala, 2002). Less than two percent had changed route (there are hardly any feasible route choice alternatives for the two bridges) and less than two percent had changed mode. But many had changed their time of day choice (also see above). The groups that were found to be more likely to change their time of day regularly to off-peak due to the toll discount are:

- Non-commuters
- Persons with flexible travel schedules
- Retired persons
- Persons with flexible working hours
- Persons who do not belong to the highest income group.

Burris and Pendyala also modelled the frequency of using bridges in the off-peak period. Here generally the same variables as mentioned above play a role, with variables increasing participation also increasing more frequent use.

Cain et al. (2000) defined a measure of peak spreading called the Peak Hour to Peak Period Ratio (PHPPR). The peak period consists of three hours: 6-30-9.30 AM and 3.30-6.30 PM. At the Midpoint Bridge in the morning peak, the introduction of the variable pricing, reduced the PHPPR from 44.7% to 41.6%. This was the largest reduction of the four bridge-peak period combinations studied. The authors note that the largest peak period demand reduction occurs in the case that had the highest initial PHPPR.

The Melbourne City Link Project

Objectives

The Melbourne City Link project is a major set of tolled tunnels in Melbourne, Australia. The tunnel system connects three highways which previously stopped short of Melbourne's CBD, and thus allows both more rapid access to the CBD, and removes through traffic from the congested streets of the CBD. The tunnel system, built between 1996 and 2000, cost about AUD 1.5 billion (€ 850 million). A project of this magnitude could not be financed in the public sector, and therefore the private sector financed and operates the City Link project. The City Link project was intended to achieve a range of social, economic, and environmental benefits, including facilitating traffic movement around the CBD, and remove heavy traffic from some of the parts of inner Melbourne. An essential requirement was to retain a viable toll free alternative route for travellers (Lay and Daley, 2002).

Description of the scheme

Given that the toll link passed through the centre Melbourne, tunnels were the only viable means of construction. Consequently toll plazas for manual tolling were impractical, and therefore an electronic tolling system was adopted. A key consideration in the design of the system was that research suggested that the public accepted the principle of paying for road use, but would not accept either being wrongly prosecuted, or the possibility of other drivers being able to evade payment. To ensure accuracy, a dual system was adopted, combining electronic tag recognition from overhead gantries with video images.
Tolls were set to maximise revenues at the start of the project. Tolls differentiate according to vehicle type (passenger cars, light commercial vehicles and heavy commercial vehicles) and distance (entry and exit sections). As of the first of July 2009 cars pay AUD 1,71 (= 0.97 €) for the shortest section. There is no time of day variation for passenger cars, tolls for commercial vehicles vary between day (6 a.m.-8 p.m.) and night (off peak).
When predicting the behavioural effects before the project, key issue was to determine whether the toll price would offset by a saving in vehicle operating costs (shorter distances) and reduced driver travel times. Given that there were no other toll roads in Melbourne at the time of construction, an SP survey was undertaken to determine how much travellers were willing to pay to use the tunnel, split by peak and off-peak, three vehicle classes and type of tolling system. An interesting aspect of the study was that many drivers would pay about AUD 0.30 (€0.17) just for the comfort and security of driving on a smoothly flowing facility. Studies also showed that trucks would be strongly attracted to the link (Lay and Daley, 2002).

Effects of the scheme
The constructing of the tolled link has attracted sufficient demand. The Melbourne city link is considered as a success, in particular in terms of its transport objectives. Demand from private car users and freight traffic has been in line with forecasts. One immediately noticeable effect was the higher than expected truck percentage in the link traffic and the drop in freight traffic on the associated non-link roads (Lay and Daley, 2002).

New York and New Jersey value pricing

Objectives
In March of 2001, the Port Authority of New York and New Jersey (PANYNJ) introduced the value pricing program on the following bridges and tunnels to reduce traffic congestion: the George Washington Bridge, Lincoln Tunnel, Holland Tunnel, Goethals Bridge, Outerbridge Crossing, and Bayonne Bridge. As part of this initiative, a new pricing scheme was implemented to foster a shift toward off-peak hours (and thus to reduce congestion) and to increase usage of electronic toll collection (EZ-Pass). Both passenger and freight traffic are tolled.

Description of the scheme
The tolls on the bridges and tunnels vary by time of day (peak rates from 6-9 AM and 4-7 PM on weekdays and on weekends and holidays from noon till 8 PM), but also by payment technology (EZpass payment is cheaper than cash payment). These tolls are collected only for eastbound (New York bound) traffic (more than 350,000 vehicle per day on average). .

Effects of the scheme
In the evaluation study (Holguín-Veras et al., 2005) a statistically significant shift in weekday peak period traffic was found to the hours just before or after the peak toll rates are in effect,

both for cars and trucks. For the weekend peak charge no significant time shifts were found. The value pricing scheme had minimal or no impact on public transport. In subsequent analyses (Holguín-Veras et al., 2007, 2008) based on interviews with carriers and receivers, it was found that carrier-centred policies (such as road pricing), working in isolation, have a limited effectiveness to shift truck traffic to the off-peak hours. This finding can be explained by the observation that not all the carriers can pass the extra costs to the receivers, but mainly by the fact that the toll costs (even when passed on to the receivers) are very small compared to the costs of off-peak hour operation. It is essential to make the receivers (as the dominant party in the timing of deliveries) accept off-peak delivery, for instance by providing them with financial incentives for this.

Distance based truck charging in Austria, Switzerland and Germany

Objectives

These three schemes are similar and have been grouped together. Objectives of these distance based charging schemes for heavy vehicles are:

- To address the fact that heavy goods vehicles (HGV's) are responsible for a disproportionately high share of the costs of construction, maintenance and operation of highways
- To move the funding method away from one based solely on tax revenues towards 'user pays'
- To introduce fairer conditions of modal competition and encourage a shift from road transport to rail and inland waterways transport.

Description of the Scheme

Switzerland introduced a Heavy Goods Vehicle Fee (HVF) in January 2001, as a result of a successful public referendum passed in 1998. The HVF charges heavy trucks (over 3.5 tonnes) based on their gross weight, kilometres driven and emissions. The system was carefully planned and has been widely accepted by the freight industry. Billing for most trucks is based on data collected by an electronic on-board data collection unit that records vehicle mileage and route.

In August 2001 the German cabinet approved plans to introduce tolls on trucks using roadways beginning in 2005. Vehicles over 12 tons have to pay the kilometer dependent Lkw-Maut on German motorways, with variation depending on exhaust emissions and axles. The toll rate was established by computing the costs of the extra wear and tear on roads and maintenance costs incurred by trucks. Toll levels have been changed over the years, with the latest change in January 2009 when toll rates were raised by over 40% (Significance and CE Delft, 2009). Euro 0 and 1 vehicles with 4-axles (or more) are in the most expensive category with a charge of €0,28 per kilometer. Revenue from the tolls is used for further transport investment, including an anti-congestion program.

In Austria, road charging for trucks and buses was introduced in January 2004. These vehicles are charged per kilometre driven on Austrian motorways and express highways. The toll levels depend on the number of axles and have been raised two times since the introduction. At the moment of introduction toll rates were ranging from €0.13 per kilometre (2 axles) to €0.27 (4 or more axles). Most recent levels (from May 2008) range from €0,15 to €0,33. In January 2010 the tariffs will be differentiated according to emission classes (Significance and CE Delft, 2009).

Effects of the schemes
We did not find many studies on the behavioural effects of these schemes. As the charge is not differentiated according to time, mainly route choice effects and mode choice effects can be expected. We did find some results for the Swiss case, where total truck volumes actually increased on many cross-Alpine routes when the HVF was implemented because maximum vehicle weights were increased from 28 tonnes to 34-tonnes at the same time, and will be raised to 40-tonnes in 2005, to match European standards. As a result, the total volume of goods transported by road through the Alps increased by 3% but truck trips declined 14% between 2000 and 2005, indicating that pricing encourages more efficient use of truck capacity. Rail transport has maintained its market share in Switzerland, while in France and Austria rail is losing market share (VTPI, 2009).
With the introduction of the Lkw Maut in Germany transport costs have increased. But so far no clear effects of the introduction of the Maut on modal shift, transport volumes or truck kilometers have been reported. Significance and CE Delft (2009) report that there might have been an effect in the average distance travelled per tonne freight. After 2005, statistics show a decrease in transport distance which might well be attributed to the introduction of the Maut.
As in the case of the German Maut, Significance and CE Delft (2009) report a decrease in the average distance travelled per tonne after the introduction of the Austrian Lkw-Maut. This effect can be due to improved route planning and/or change in trade patterns. They also find a small modal shift to rail transport.

Durham
Objectives

The Durham City congestion charge was the first congestion charge to be introduced in the UK in October 2002. Durham County Council introduced the toll for drivers for drivers using 1,000-year-old Saddler Street in the city centre, which stands on the peninsula above the River Wear. This is the only public access road leading to the historic city centre. It was mainly introduced to reduce traffic flow using the road. Before the scheme was introduced, around 2,000 vehicles used the street every day, causing difficulties for the thousands of pedestrians - many of them visitors to the world heritage site. The scheme was not intended to make a profit, merely to be self-financing

Description of the scheme

Vehicles are allowed to enter the loop road which leads up to the historic cathedral, but face the £2 (€3.20 in 2002) charge upon leaving (between 10.00 AM and 4.00 PM, Monday to Saturday). Exiting vehicles are controlled by a rising bollard, which is monitored by CCTV and linked to an intercom system. There are exemptions for certain drivers, including residents, but anyone who flouts the charge is fined £30.

Effects of the scheme.

Since the toll of £2 began, traffic levels have fallen from 2,000 vehicles a day to 200, with around half of those being permit-holders who do not have to pay the fee, far exceeding the hopes of traffic managers.

London congestion charging

Objectives

London faced serious levels of congestion: average speeds declined from around 18km/hour in the late 1970s to around 14 km/hour in 2000. The aim of the London Congestion Charging scheme was to reduce congestion in and around the charging zone. It was part of a wider transport strategy which aimed to reduce traffic congestion and improve car journey time reliability. The scheme would also raise revenue for investment in public transport including an upgrade of the underground and improvement of bus services.

Description of the scheme

London introduced a congestion charging scheme in its central area in 2003. The scheme, designed and managed by Transport for London, is an area licensing one. All vehicles entering, leaving, driving or parking on a public road inside the zone between 7.00 a.m. and 6.00 p.m. Monday to Friday, excluding public holidays, must pay a congestion charge. It requires each vehicle to be charged a fixed amount (£5 (€7.50 in 2003), later raised to £8) for crossing the cordon into the city centre.

Effects of the scheme

So far the key findings suggest that the scheme can be considered successful in terms of congestion reduction (Santos, 2008). After a year, traffic circulating within the zone had decreased by 15%, and traffic entering the zone by 18%, during charging hours (TfL, 2004). Of the car driver trips no longer crossing into the charging zone per day, 50 to 60% have switched to public transport, and furthermore changed routes (about 25%) or made other changes like destination changes or trip timing adjustments.

Public transport – particularly the bus network – acted as a key facilitator of the central London scheme, by providing a viable alternative for displaced car occupants. In turn, the traffic and mode shift changes brought about by congestion charging had implications for the operation of the public transport networks. This took place against the backdrop of substantial improvements to the bus network. To give an idea: passengers entering the central charging zone by bus increased by 37% during charging hours in the first year of operation of the scheme. Up to one half of the growth was estimated to have reflected displaced car travellers transferring to the bus network, and the remainder a background trend reflecting wider improvements to bus services. More generally, bus passenger numbers increased by 18% and 12% respectively during the first and second years after charging. The use of underground services and national rail has been more or less stable.

The impacts of the scheme on the economy in Central London have been neutral (Santos, 2008). A number of studies and databases were used to compare business performance in terms of variables such as number of businesses or sites , number of employees, sales and profits, inside and outside the congestion charging zone and before and after the introduction of the scheme. Overall, businesses have not been significantly affected by the congestion charge. Commercial and residential property markets do not show any impacts from the scheme.

When looking at efficiency, it appears that both the 5£ charge and the 8£ charge result in overall welfare gains (with higher gains for the higher charging scheme, Transport for London, 2007). There are however distributional impacts because of the heterogeneity of travellers who have different values of times, use different modes and have different journey purposes. With a 5£ charge, there is a small loss to road users as a whole since their savings (time, reliability, vehicle operating costs) fall just short of their charge payments and compliance costs. Business users, with their higher values of time, enjoy a net benefit. Bus passengers enjoy benefits from time and reliability savings, giving an overall benefit to transport users. Estimates have also shown societal benefits accruing from lower accidents levels and less emissions.

Stockholm congestion charging

Objectives
Congestion reduction was one of the means of the city council of Stockholm to improve accessibility and liveability in the most densely populated areas. Road pricing was part of a strategy, in which also public transport was included. First there was a road pricing trial, then there was a public consultation, which gave the green light for the implementation of the permanent system. Prior to the road pricing trial, public transport services were already improved. Bus and rail services were expanded and park-and-ride facilities created. The aim was to support the use of public transport, and to be ready for the increased level of demand when car users decide to switch to bus or tram.

Description of the scheme
In Stockholm, a congestion charging trial took place between January 2006 and July 2006, followed by a referendum in September regarding the future of the charges. All owners of vehicles registered in Sweden are to pay a congestion charge if they drive into or out of the city centre of Stockholm on weekdays between 06.30 -18.29 hours. It consisted of a cordon around the centre of the city. The charge varies in steps over time. Charges are highest during morning and afternoon peaks (20 SEK = €2.11), moderate during mid-day (10 SEK), and zero during nights and weekends. Various exemptions (e.g. taxis, buses and alternative fuel cars) meant that about 30% of the passages were free of charge (Eliasson, 2009). The result of the referendum was in favour of the charges (51.3 % voted yes). The congestion tax was reinstalled as a permanent system on the 1st of August 2007.

Effects of the scheme
The trial results were as follows. Compared to the same period in the previous year, traffic decreased with about 22% during charging hours (Stockholmforsoket, 2006). Private car traffic was responsible for the greatest reduction in the number of passages into and out of the inner-city. The reduction in truck traffic was smaller with about 10%. Traffic reductions in the afternoon were larger than in the morning peak. Car commuting trips have less often been changed (-3%) than trips that are made for social reasons (-10%).
It is interesting to analyse the behavioural responses of the car users who decided not to use the car anymore. Public transport use has increased compared with the same period one year earlier (+6%). About 4,5% is due to road pricing, the rest may be explained by other factors such as a fuel price increase and a reduction of the 1-hour public transport ticket. A few drivers changed route, while others chose not to travel at all. Car sharing and working at home have not increased. Interestingly, departure time changes were not significant. This may be explained by the small differences in peak and off-peak pricing.
The effects of the trial indicate that there was a marked increase in the demand for public transport. The effects of the investments in public transport are assumed to be small since demand did not increase before the trial (when improvements were already realised). Trips made by public transport for commuting reasons increased by 8% (realising a modal share for

this type of trips of 74%). About 66% of the social trips are made by public transport during the period of the trial, an increase of 9% (car use decreased for this purpose by 10%).
After August 1 2007 similar results were achieved. The Stockholm Congestion Charging System has reduced traffic in the Swedish capital by 18 percent, and the proportion of green, tax-exempt vehicles has risen to 9 percent. Access to the city has improved significantly with a reduction in travel times on inner city streets and approach roads.

4. Comparisons

In Table 2 is a summary of the findings from the review of literature on toll schemes that have actually been implemented. We find that the effect of a toll scheme on travel behaviour to a large degree depends on the specific toll design used and local circumstances. Car users are like water: they search for the lowest spot. The option with the lowest disutility or generalised cost (with different mixings of time and cost depending on population segments with different values of time and reliability, comfort, etc.) is searched for and found. Many toll schemes lead to considerable changes in route choice to other untolled routes, including routes circumventing the city centre (Singapore, Oslo, Stuttgart, SR-91, I-15). However in some schemes, there are no viable route alternatives (Bergen, Lee County bridges) and here the route switching remains minimal. The schemes that have variation between peak and off-peak tolls usually lead to peak spreading because of sizeable shifts in departure time (Singapore, French A1, Stuttgart, I-15, Lee County bridges, New York). An exception is the SR-91 toll, where there is differentiation in toll levels during the day, but only small departure time changes were found. Schemes with flat 24 hours rates (Oslo, the kilometre charges for heavy vehicles) or charging periods that start early and end late (Bergen: 6.00-22.00 hours) do not lead to substantial departure time shifts. Changes in mode choice (from car to public transport, from car driver to car passenger) in most schemes remain (very) small, but in central London, where public transport is widely available, a considerable increase in public transport use was observed after the introduction of the congestion charging. In Singapore and Stockholm there were increases in public transport patronage as well. In Singapore car occupancy increased. Some schemes also find (limited) changes in travel frequency and destination choice (Singapore, Bergen). Effects on the location of population and employment and property prices are usually not included in the evaluation studies, partly because these are long term effects and most studies end within one year after the opening of the facility. In the I-15 study, were consequences for housing and business location were investigated as a specific part of the evaluation project, these effects were found to be small. On the other hand in Orange Country, were spatial effects were studied as well. there was a significant positive impact on housing prices and employment growth.

Table 2. Lessons from toll schemes that were actually implemented

Toll scheme	country	Year of introduction	Charging period	Lessons on effects of toll scheme
Area licensing scheme in Singapore	Singapore	1975	7.30-10.15; later PM too	Large changes in departure time choice (to just before/after the charging period and route choice (to routes outside the cordon); also increase in car occupancy, and increase in public transport. Sharp reduction in number of multiple trips into CBD on one day (e.g. lunch trip) and considerable departure time changes after introduction of electronic road pricing in 1998
Toll-ring in Bergen	Norway	1986	6.00-22.00	Small changes in travel frequency and destination choice; No/very small changes in departure time, route choice and mode choice; some shift towards car in household with seasonal pass
Toll-ring in Oslo	Norway	1990	24 hours	Considerable changes in route choice; limited mode choice effect
Time-varying toll on A1	France	1992	Higher in Sunday PM peak	Major departure time shift to shoulders of the peak
Cordon-charging experiment Stuttgart	Germany	1994/5	Higher in peaks	Considerable shifts to untolled routes and cheaper periods; some increase in car occupancy and public transport use
Value-pricing on SR-91	US	1995	Higher in peaks	Large route change effects, small departure time and car occupancy change effects; very small effects on mode choice Significant positive impact of toll roads on housing prices and employment; no impact on population growth
Value-pricing on I-15	US	1996	Higher when congestion	Considerable route switching, considerable departure shifts to shoulders, very small mode choice effects; limited impact on housing choice and business
Variable pricing on Lee County bridges	US	1998	Off-peak discount	Hardly any route change (no alternatives) or mode change, considerable shifts to off-peak
Melbourne city link toll	Australia	2000	Time of day variation for trucks only	Considerable route choice effects: especially heavy freight vehicles use new toll road instead of inner city links
New York and new Yersey	US	2001	6.00-9.00 and 16.00-19.00	Significance changes in departure time choice; minimal or no mode shift.
Austria, Switzerland and Germany	Austria, Switzerland and Germany	2001	All day	Effect on vehicle type choice in freight transport (larger vehicles); decrease in average distance travelled per tonne, some impact on mode choice (rail)
Durham	UK	2002	all	Changes in route choice
London congestion charging	UK	2003	7.00-18.30	Considerable increase in public transport use; changes in route choice, some changes in destination choice and trip timing
Stockholm	Sweden	2006 (trial); 2007 (full)	6.30-18.29	Increase in public transport, small changes in route choice and trip frequency, no significant increases in car sharing and working at home or departure time shifts.

5. Conclusions/recommendations

Economists have advocated the use of more appropriate pricing tools for a long time by demonstrating the welfare gains. Nevertheless, road pricing measures have up till now only seldom been implemented in practice. The low level of implementation is nowadays not so much caused by technical or administrative problems. It is generally acknowledged that pricing measures meet public resistance and that acceptability is currently one of the major barriers to successful implementation of new and more efficient pricing measures.

Congestion pricing has shown its ability to substantially affect behaviour and reduce congestion. The specific design of the toll scheme (toll levels, time gradient of the charges, manual/electronic toll collection) and the potential for evasion or diversion (other routes, points in time, modes) are of vital importance for the actual behavioural responses to a scheme.

Road pricing can achieve a number of different objectives (Paulley, 2002). Firstly, it can act as a means of traffic restraint, and has great flexibility in this respect, as charges can by varied by location and time of day. Secondly, it can act as a revenue raising mechanism, providing funds to pay for new infrastructure of public transport services. A third possible objective is that of efficiency, as road pricing enables the costs incurred by road users to be directly related to the marginal external costs they impose.

Behavioural Effects

The review carried out leads to the conclusion that road pricing projects, where there are alternative routes and where the charges are likely to vary considerably by time of day, will probably cause substantial changes in:

- route choice
- departure time choice.

This is consistent with the findings on the effects of opening a new motorway (without toll) in a situation with multiple route options (Bovy et al., 1992, Kroes et al., 1996, De Jong et al., 1998).

Other effects might occur as well, but are likely to be of minor importance in the short run, and even in the long run (several years after the opening):

- mode choice and car occupancy (unless public transport will be an attractive alternative for many of the origin-destination combinations as in the case of the London and Stockholm Congestion Charging)
- home/business location choice
- trip frequency
- car ownership.

Finally some effects are likely to be of minor importance in the short run (up to one year), but may be more important in the long run:

- destination choice
- changes in business practices (inventory and distribution management).

Policy implications

Policy makers have multiple choices as road pricing can take different forms. We have focused on the express lanes (US), area charges, kilometre charges and point charges (bridges). Charges can be differentiated in various ways (time of day and location were key in this paper) and revenues can be used in different ways. So there are many decisions to take for a policy maker who considers implementation of road pricing. We have seen that effectiveness of road pricing might be considerable depending on the type of charge and local circumstances. It will be clear that the specific objective of road pricing will often be a decisive factor in making such choices. With efficiency as primary objective, the differentiation of charges will be important, as is the careful determination of charging levels. This in turn will have implications for the tax base and the charging technology. Furthermore, the use of revenues will affect not only the acceptability of the scheme but also the broader efficiency. Acceptance has not been included in this overview, but clearly the effects found in the empirical cases, as discussed in this paper, can help policy makers worldwide to convince the general public that road pricing can be effective, which is one of the major determinants of acceptance.

Recommendations on research on road pricing

Several implementations of road pricing in practice could not be included in this review, because no proper study into the effects of the scheme had been carried out. However, monitoring the changes in traffic and travel behaviour is very important for ex post policy assessment, for potential adaptations of a scheme (changes in the charging area, in the charges or even abolishing the scheme) and for public support. This requires measurement of the situation before the introduction of a scheme (before measurement) and one or more measurements after road pricing has been implemented (after measurement). Measurement should preferably include both traffic and public transport counts as well as interviews with travellers on their trip patterns before and after the change (the most efficient way to do this is using the same respondents before and after the change, that is panel data). In the interviews after the introduction of the scheme, the travellers can also be asked to state how they changed their travel decisions as a result of the road pricing scheme (route, departure time, mode, destination, travel frequency, …). For many of the road pricing cases that were included in this review, there was only one after measurement, which took place a few months after the introduction, or at most one year after the before measurement. The period of one year is then used to avoid seasonal effects. Practically all the results described above relate to a period up to one year. However, further measurements several years (e.g. five years) after the introduction can also be of great value to evaluate the long term effects of road pricing (including the full mode choice effect and changes of work location, residential choice, car ownership). A complicating factor in this respect is that in the longer run all kinds of other factors that drive transport (e.g. household income, fuel prices) will change as well. For an analysis of the long term effects of road pricing, one needs to correct for this, for instance by using transport models for the effects of autonomous factors or by comparisons against a control area where no such scheme was implemented, but where similar autonomous developments took place (de Jong et al., 1998).

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