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CONGESTION CHARGING MECHANISMS FOR ROADS, PART I – CONCEPTUAL FRAMEWORK[1]

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Parts I and II together investigates the implementation aspects of road pricing by setting down criteria for a 'good' road pricing system. Besides analyzing the gamut of indirect and direct methods of charging for road usage, the paper surveys alternative congestion pricing technologies including: 1) cordon pricing using manual tollbooths, 2) supplementary licensing, 3) off-vehicle recording systems such as automatic vehicle identification, commonly known as AVI, and 4) on-vehicle charging systems such as smart card technology. Each of these instruments is dealt with by a relatively in-depth case study analysis based on the benefits, costs and revenues of implementing and utilizing each charging mechanism. Since benefit figures are not always readily available, the cost per transaction of operating a system over the long run is used as an index of the relative cost-effectiveness of each technology. Based on alternative quantitative and qualitative criteria, the implications of using each of these technologies for tackling congestion are summarized in a key table and conditional policy recommendations are made.

KEYWORDS: Congestion externality, congestion charging, electronic road pricing, congestion tolling, charging technology

1. INTRODUCTION AND SYNOPSIS

Tollbooths suffer from being land intensive, labor intensive and time intensive and are clearly unsuitable for congestion charging in and of themselves. However, *cordon pricing* (as in the Bergen Toll Ring) can serve as an effective instrument of charging for congestion if half the toll lanes are reserved for the use of seasonal pass holders traveling through the pricing points at regular highway speeds. Enforcement of those driving on reserved lanes can be carried out by periodic videographs of vehicle license plates, just as radar technology is a socially acceptable tool to apprehend speedsters. An *area licensing scheme (ALS)* requires that vehicles entering the central business district during peak hours display a monthly or daily license prominently, with enforcement being undertaken at gantry points by traffic wardens who perform visual checks on the nonstop traffic. Enforcement of ALS would be prohibitively costly when carried out at motorway speeds but would likely involve relatively low cost in a standard congested urban environment with limited gateways. ALS, also known as supplementary licensing, is found to possess the lowest cost per transaction. *Electronic road pricing (ERP) with AVI* is electronic toll collection by time-of-day writ large and made obligatory on vehicle owners within a jurisdiction. Even though the cost of the electronic equipment for AVI is not considered trivial, the benefits are considerably higher than the cost. As the sensitivity analysis performed on the Hong Kong ERP Scheme in 1983-85 clearly demonstrates, even after excluding time savings on philosophical or other grounds, the savings in operating cost still yield benefit figures that outweigh the system cost. The much touted invasion-of-privacy issue that plagued the Hong Kong ERP scheme in the

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past can now be dealt with by providing road users access to confidential "numbered account arrangements" with prepaid cash deposit. The capital cost of *electronic road pricing with smart card technology* is higher than AVI alone technology, but the cost is still less than the benefits. Put together, the benefit-cost ratio and the cost per transaction can be regarded as acceptable, but this technology is still not yet widely used on a commercial basis. Nevertheless, rapid progress in microelectronics, cryptology and microwave technologies will continue to yield large-scale economies in the manufacturing of AVI equipment, read-write transponders, smart cards and the hardware and software accompaniments.

Electronic approaches of direct road use charging are shown to be superior to manual approaches whether from the perspective of a road user, road authority or society as a whole. Within these broad categories, ERP using AVI is ranked higher than ERP using smart card based on an unweighted index of all the criteria. In general, ALS is superior to cordon pricing. Hence, if budgetary conditions allow it, the feasibility of implementing ERP ought to be investigated. However, if budget is tight, then ALS (with its low cost and correspondingly high benefit-cost ratio) ought to be regarded favorably. It is argued that the most important measure (out of the twenty criteria listed) is the passage of the benefit-cost test. Nevertheless, by pursuing the multicriteria analysis introduced in the paper, the road authority could choose from amongst other criteria for deciding on the appropriate congestion charging instrument.

Finally, the disposition of the revenues collected from road pricing is crucial to its success. Based on experience as well as conceptual grounds, it appears that earmarking of the proceeds from road pricing would serve as an important prerequisite to the actual implementation of marginal cost pricing in the road sector.

2. CONCEPTUAL FRAMEWORK

Over 80 percent of the world's megacities are already projected in developing countries by the year 2000. It is unlikely, however, that road capacity can keep pace with the rapid growth in travel demand resulting from increases in population and vehicle ownership worldwide. Thus it is inevitable that urbanization yields traffic congestion as a by-product.[3] Some form of regulatory restraint or pricing mechanism is necessary to curtail congestion, where congestion is formally defined to be the additional cost that a motorist imposes on others.

In a couple of papers, the theory of road pricing-cum-investment is reviewed and synthesized into an integrated analytical framework (Hau, 1992a, 1998, 2005a,b). Even though I deal only with charging for the congestion externality in this paper, congestion pricing would also have as a by-product the reduction of air and noise pollution from mobile sources. This market-based approach could serve as an effective deterrent to the overuse of roads by internalizing negative externalities and would thus enhance society's welfare within an urban area. Even though congestion pricing *per se* is practiced only in Singapore, road use charging in the form of electronic toll collection is rapidly flourishing in countries such as Norway, France, Italy and the United States. Charging by daylight hours in Trondheim, Norway (and further discounts for electronic tag holders during the morning peak) can be viewed as crude forms of road pricing. As part

[3] For estimates of congestion costs and indices in the United States, see Hanks and Lomax (1990, 1992).

of the Intermodal Surface Transportation Efficiency Act (ISTEA) signed into law in December 1991, the U.S. Federal Highway Administration invites state and local governments to participate in five federally-funded congestion pricing pilot programs (which include the funding of parking pricing (see U.S. Department of Transportation, 1992; Office of the Federal Register, 1992)). Further, bills to implement variants of road pricing are in the parliament of cities suffering from both pollution and congestion such as Santiago and Stockholm.

The first section of the paper presents a conceptual framework for congestion pricing and sets down the criteria for a 'good' road pricing system. The second and third sections review and analyze the indirect and direct methods of charging for road usage. Both sections cover a taxonomy of alternative technologies to implement congestion pricing. The several basic technologies include: 1) cordon pricing using manual tollbooths, 2) supplementary vehicle licensing, 3) off-vehicle recording systems such as automatic vehicle identification, commonly known as AVI, and 4) on-vehicle charging systems such as smart card technology. The paper introduces manual and electronic toll collection methods as precursors to the off-vehicle and on-vehicle charging instruments. The various approaches to road pricing are analyzed progressively by their level of technological advance up to the increasingly popular electronic toll collection mechanisms which exploit developments in automatic vehicle identification and smart card technology. The benefits, costs and revenues of implementing each charging mechanism are analyzed. Since benefit figures are not always readily available, the cost per transaction of operating a system over the long run is used as an index of the relative cost-effectiveness of each technology. Based on both quantitative and qualitative criteria, the implications of using each of these technologies for tackling congestion are summarized and conditional policy recommendations are made. With the conceptual framework developed here, Part II explores several case studies of congestion charging mechanisms used in practice (Hau, 2006b).

Urban transport is chiefly characterized by a regular pattern of peaked demands on a diurnal basis, with the highest demand occurring during the morning and afternoon peak periods. Because of the peaking characteristic of urban travel demand, in addition to pent-up demand, Parkinson's Law or Downs' Law of peak-hour expressway congestion holds (Downs, 1962; Mohring, 1965). Downs' law says that whenever new expressways are built in metropolitan areas, crowded conditions develop quickly when previously suppressed trips are regenerated and daily travelers switch to their private automobiles and desired times of travel. Worse still, when traffic density is high relative to the capacity of a facility, travelers more often than not wind up in a common gluepot in which traffic comes to a virtual standstill during the peak -- as seen in the lengthy all-day peak period of cities such as Bangkok, Hong Kong, Lagos, Santiago, Sao Paulo and Seoul. This admittedly untenable state of affairs persists because property rights are not clearly defined. That is, even though roads are nominally owned by the government, excessive use is made of *free*ways because travelers are not appropriately excluded from using them. A road becomes 'worthless' precisely because it is free (see Vickrey's (1967) two road example)).

Yet there is considerable excess capacity in urban transport if one were to spread travel demand uniformly over a twenty-four hour basis -- as argued forcefully in *The Urban Transportation Problem*, by Meyer et al. (1965, pp. 83-88). Hence, it is the distinctive nature of the cyclic peak/off-peak period demands which leads to significant resource misallocation.

Indeed, economists have long held that road pricing could be a powerful tool in tackling congestion, improving social welfare significantly. For instance, as early as 1959 Professor William Vickrey championed road pricing via electronic means as a way of implementing the marginal cost pricing principle (when he testified before the Joint Committee on Washington Metropolitan problems of the U.S. Congress). It was his testimony which helped influence the distinguished members of a panel on road pricing set up by the Ministry of Transport in the United Kingdom, which culminated in the famous Smeed Report of 1964. To draw our attention, he starts out his celebrated paper (1963, pp. 452) on road pricing using automatic means as follows:

> "I will begin with the proposition that in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation. Two aspects are particularly deficient: the absence of adequate peak-off differentials and the gross underpricing of some modes relative to others. In nearly all other operations characterized by peak load problems, at least some attempt is made to differentiate between the rates charged for peak and for off-peak service. Where competition exists, this pattern is enforced by competition: resort hotels have off-season rates; theaters charge more on weekends and less for matinees. Telephone calls are cheaper at night . . . But in transportation, such differentiation as exists is usually perverse."
>
> The late 1996 Nobel Laureate of
> Economic Science William S. Vickrey

Almost thirty years have elapsed since Professor Vickrey made this observation. Although some progress has been made, it is agreed by some that saturated roadways -- with almost the same level of speeds -- are still a phenomenon in cities despite massive infrastructure investments (Holden, 1989). This observation seems to square with Downs' Law.

Indeed, the standard way of solving congestion in the long run by increasing highway capacity via investment in the road infrastructure seems to induce ever-increasing demand for travel. Clearly, when road capacity is relatively fixed in the medium run and fiscal constraints are fully binding, the economically efficient solution is to price the *use* of roads differentially by setting congestion tolls which reflect the scarcity value of highway services. This is not as radical a proposal as it may seem. While some people are used to the concept of providing parking spaces themselves in garages at home, others are similarly disinclined to demand free roadside parking -- which is simply scarce road space or premium real estate -- at work places in the central business district (CBD). If parking is no longer free in busy destinations of commuters, as it once was several decades ago,[4] then why should people not be made aware of the high value of road space during peak hours by paying for its use? Road space is indeed one of the few examples of a good or service which market forces have left relatively unscathed.

The Institution of Civil Engineers (1989) and the Royal Chartered Institute of Transport (1990) came out in staunch support of road pricing as the best available instrument for utilizing a nation's existing infrastructure. They concluded that the adoption of electronic road pricing technology via AVI is a viable means of directly charging for the use of roads in London. The United Kingdom's Department of Transport has since begun reinvestigating the feasibility of road pricing.

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[4] In the United States, the earliest date for which (private) parking was charged for was 1917 in Detroit (Hackman and Martin, 1969).

2.1 Criteria for a 'good' road pricing system

In order to implement the economic principles of road pricing, a 'good' road pricing system should include a number of operational requirements listed below (Ministry of Transport, 1964, pp. 7-8; The Chartered Institute of Transport, 1990, pp. 18-20; Thompson, 1990, pp. 526; and Stoelhorst and Zandbergen, 1990).[5]

2.1.1 From users' point of view (1-4)

(1) User-friendliness (Simplicity). The system should be simple to understand and convenient for motorists to use. Extremely complex and continuous pricing gradations should best be avoided because of 'bounded rationality' on the part of drivers' cognitive limitations. For safety reasons, drivers' attention ought not be diverted for more than a very short time period in the process of using the system.[6]

(2) Transparency (via ex ante pricing). The system should inform the motorist of the prices to be charged ahead of time and place, so that the trip decision can be rationally made and rerouted if necessary. At the time when the trip decision is undertaken, a user ought to be made aware of *when, where* and *how much* the charges will be. This is to be contrasted with *ex post* pricing, where users are charged only *after* the fact (as in the proposed Cambridge road pricing scheme).

(3) Anonymity (Protection from invasion of privacy). The system should have safeguards -- both legal and otherwise -- that are capable of assuring its citizenry of their privacy. For instance, monitoring of vehicle movements for other than strictly traffic-related purposes should be prohibited. This is regarded by some to be the *sine qua non* of a politically acceptable road pricing scheme. Be that as it may, currently available prepayment mechanisms using "numbered account arrangements" discussed below should prevent fears of such a 'big brother' government.

(4) Prepayment/postpayment option for charging. Periodic payment should be available to the user on both a prepayment and postpayment basis. For postpayment, users can pay by standard billing procedures -- by cash in person, by check via mail, by credit card, by electronic funds transfer, etc. For prepayment, a user can set up an account by cash, for instance, and have a pre-specified sum of money transferred every time a threshold amount is reached (as is done in the Oslo Toll Ring). Ideally, such a Swiss-type "numbered account arrangement" which eliminates any paper trail should be available for those who wish to retain their privacy. If pre- and postpayment options are both offered to the user in a road pricing system, it would allow the user to choose the type of technology that suits him or her, thereby obviating the need for a potentially costly system that uniformly demands anonymity as a basis.

2.1.2 From road authority's point of view (5-11)

(5) Enhanced efficiency via direct charging. In order to enhance economic efficiency, the road pricing system should be able to charge directly -- as closely as possible -- the external costs arising out of *road use*. Usage of the road could be defined in terms of distance or time (as in 'closed' ticket-type toll systems). Zeroing in on usage directly

[5] As some of the requirements conflict, not all of them can be achieved simultaneously.

[6] Similarly, the system should be relatively straightforward for operators to implement.

would help capture and internalize congestion externalities better, in contrast to merely focusing on a proxy to usage via indirect charges. Further, normal traffic flow and speed should not be impeded artificially.

(6) Flexibility (Responsiveness to demand). The prices charged should therefore be flexible and vary in concert, for instance, with the corresponding rise in costs caused by the increase in demand during peak periods. Sophisticated, differential pricing should vary *temporally* according to use by time-of-day, time-of-week, time-of-year, and also *spatially* according to geographical location, route and possibly mode. *Per contra*, the lack of responsiveness to demand and the crudeness of the design of a given road pricing domain could lead to boundary problems both temporally and spatially. For example, traffic would be queued up just before and after certain pricing zones go into effect (as in the Singapore Area Licensing Scheme) if pricing gradations are not made continuous and fine enough.

(7) Reliability. The road pricing system should be able to operate reliably under harsh environmental conditions and should charge users correctly. However, charging a user -- or even a nonuser -- incorrectly is a much more serious error than omitting to charge. After all, a single erroneous charge could result in public relations damages that might not be salvageable (as in the case of the Gross Ile Toll Bridge, Michigan (Smoke, 1990)). On the other hand, even though a road authority may occasionally fail to charge, a vehicle which crosses a number of pricing points would still have to incur most of the charges imposed.

(8) Security and enforcement. An ideal charging mechanism should be secure at two levels. It should be: a) free from theft of proceeds by private individuals and (toll) operators and b) free from fraud and abuse to the payment system by both individuals and operators. Whether it is deliberate or unintentional, internal or external, fraud and malfunction should be minimized to ascertain public support for the road pricing system. The system ought to be made secure: difficult for users to evade and easy for operators to spot evasion, which may necessitate the videographing of license plates in certain situations. To create deterrent effects, violators should be suitably penalized by the law for evasion and theft. To the extent possible, the burden on the regular police force ought to be minimized to maintain an acceptable level of enforcement costs.

(9) Provision for occasional visitors. The system should be capable of handling the infrequent visitor driving across state lines or national borders and even the regular out-of-towner. Devices for registering transactions should be made easily available for purchase or rental from common retail outlets such as post offices, gas stations, kiosks or perhaps even automatic teller machines.

(10) 'Market' price as an investment signal. The cost-based level of price simply reflects the intensity of demand and the revealed preference of travelers for certain times and locales. A high price would draw attention and mobilize resources to popular routes for investment. As such, this surrogate market mechanism serves as an indispensable guide in the planning of investment and the improvement of the services of highway links.

(11) Passage of revenue-cost test. Even though revenues are transfer payments to society as a whole, the passage of the revenue-cost test could serve as an additional stipulation to the benefit-cost ratio test in the light of increasingly tight fiscal constraints and consideration of the benefit principle. However, a revenue-maximizing pricing strategy may not be consistent with a benefit-maximizing pricing one. Nevertheless, from a governmental or road authority's financial point of view, the revenue-cost ratio is

perhaps more relevant if the goal of cost recovery is pursued. A positive revenue-cost ratio is a necessary condition for commercial viability.

2.1.3 From society's point of view (12-20)

(12) Passage of benefit-cost test. Applying the standard cost-benefit test, the benefits of a road pricing scheme (in terms of the savings in travel time and operating costs, etc.) should exceed the implementation cost of such a system. That is, from a social welfare viewpoint, any road pricing instrument worthy of consideration should at least exceed a unitary benefit-cost ratio. With a limited public budget, only the most favorable projects with highest benefit-cost ratios should be implemented. The opportunity costs of raising public funds or toll revenues should be taken fully into account. Further, if benefit figures are not available, the technical efficiency of the charging mechanism could be evaluated by the cost per transaction (or charged vehicle) -- an index based on a variant of cost-effectiveness analysis applied in the long run. It should be emphasized that cost per transaction decreases sharply with usage. In order to compare different technologies across countries, a one horse shay assumption for the capital recovery factor is used in annualizing capital cost. (The capital recovery factor of 0.125 corresponds roughly to a discount rate of 7% and a project life of 12 years as well as a discount rate of 4% and a project life of 10 years; see any discounting table.)

(13) Minimum of road work and environmental intrusion. To ensure as little disruption as possible to an already congested road network, road work for the purpose of installing certain types of road pricing technologies should be kept to an absolute minimum, especially during the day (possibly using turnkey systems). Similarly, environmental intrusion should be minimized in an already cluttered urban environment with numerous traffic signs and stoplights, etc. Trade-offs between road work and environmental intrusion exist. For instance, microwave readers of AVI transponders could either be mounted on gantries or buried underneath the road surface.

(14) Provision for mixed traffic. Prices for road use should vary in accordance with the congestive effects of different classes of vehicles, be they automobiles, buses or trucks. (In order to implement marginal cost pricing of heavy vehicles properly, charging for the road damage cost and environmental pollution are called for). By using road damage charging instruments based on the monitoring of vehicle and axle loading, the ideal road pricing system is therefore able to differentiate the impact occasioned by different vehicle classes. These instruments can be implemented with modern technologies such as weigh-in-motion systems and automatic vehicle classification equipment (see, for example, Davies, 1987; Ayland et al., 1990). Reimbursement for road pricing payments made by drivers of special categories of vehicles, disabled persons and/or residents who are granted exemptions should be made technically feasible. However, while rebates or discounts may satisfy certain public interest groups, they violate the criterion of economic efficiency.

(15) Handling of transitional phase. Since the installation of road pricing technologies and the minor restructuring of the transport infrastructure could not be made overnight, the system design must include a phase-in stage. For public acceptability and softening of the system's full impact, a gradual introduction in the form of a road pricing experiment may be necessary at first (as is being done in Singapore, the Netherlands, Norway and the United States (see Office of the Federal Register, 1992)). The final road pricing system should be technologically capable of handling the vehicle population of an entire city (or even a country).

(16) Compatibility with other systems. For the convenience of both out-of-state motorists, domestic and foreign governmental road authorities, it is desirable that a particular road pricing system be compatible (or at least be nonintrusive or integrable without major modifications) with other road pricing systems from other jurisdictions. (To this end, efforts to standardize both automatic vehicle identification technology as part of the *H*eavy *E*lectronic *L*icense *P*late (HELP) program in the United States and road pricing systems as part of the *D*edicated *R*oad *I*n-*VE*hicle Safety (DRIVE) project in Europe are consistent with this criterion of compatibility). In addition, if any electronic charging system is adopted, it should conform to the radio frequency bands and safety standards set by the International Standards Organization (ISO).

(17) Modularity to add-on options. If a modular system is used to electronically charge for road use, public on-street parking could in principle be charged for in this way eventually. To the extent possible, and if deemed cost effective, the ultimate road pricing system should be compatible with: a) other payment schemes such as public and private off-street parking and gasoline purchases, b) automatic route guidance, c) origin-destination management information systems, and d) the control systems of commercial vehicles of private firms.

(18) Tolerance to culture of non-compliance. Any pricing or tolling mechanism requires a reasonably law-abiding citizenry and a culture of compliance to rules and regulations. For instance, with supplementary licensing, a good rule of thumb to test its applicability to a particular city is to observe whether parking laws are in fact abided by generally, with double (or triple) parking regarded as a relatively uncommon occurrence. Thus a good charging mechanism should be able to have a high tolerance level of noncompliance. Yet no system is absolutely foolproof -- be it manually operated or electronically controlled.

(19) Tolerance to varied geography. Certain types of systems, such as cordon pricing, work well in cities with special geographical layouts. That is, a city with limited gateways (such as the island city of Bombay) may even favor a manually operated toll collection system (as in Bergen Toll Ring). Enforcement of the supplementary licensing scheme, for instance, is not amenable to traffic moving at freeway speed.

(20) Fairness and the availability of alternatives. It is necessary that the toll-tax incidence of the road pricing system be publicly perceived as ‘fair’ for it to be politically acceptable. One notion of fairness is for the government to maintain a truly revenue neutral system, where all the revenues from road pricing net of the system cost are directly or indirectly returned to the population of users (see Hau, 2005a,b, for the conditions). Otherwise, it would be difficult for road pricing to be implemented in a democratic society. Why? This is because those who are tolled are ‘forced’ into paying something which used to be free and those who are priced off are ‘forced’ into less desirable modes, routes or times of day. Even those who had not been tolled before (those public transport captives, for instance) may be worse off as a result of riding on more crowded buses, *ceteris paribus*. Thus, almost everyone is worse off except the government. Hence, *unless* toll revenues are plowed back into the transport system in the form of: a) a reduction in first registration taxes, annual license fees, or fuel taxes, etc., b) more and better roads, and/or c) improved public transportation, it is inconceivable that congestion pricing would take off. As an illustration, good public transport and bypass routes have been provided for by the Singaporean Government to serve as viable alternatives as part of their Singapore Area Licensing Scheme, ensuring that road pricing would work reasonably well. Simultaneous with the starting date of the Oslo Toll Ring was the opening date of a newly constructed tunnel in Oslo, which underscored to the

public the government's commitment to earmark toll revenues. Thus actual and proposed road use charging schemes in Europe and elsewhere attest to the theoretical finding reported in Hau (2005a,b).[7] Adjustments to the current road financing instruments of first registration taxes, annual license fees and gasoline taxes should be allowed for. This is because the perceived fairness of the road charging scheme -- aside from efficiency arguments -- may require some of the toll revenues to be plowed back to motorists, public transport users and the transport system. If redistribution is found to be necessary for the political acceptance of the scheme, it is desirable that the road pricing system be technologically capable of reversing certain current vehicle charges.

3. TRAFFIC RESTRAINT MEASURES

Traffic restraint can be achieved via either the regulatory approach on quantity with so-called command and control measures or the market-based approach (i.e., pricing approach). Examples of the regulatory approach to roadway usage are to control the physical number of vehicles, for instance, by an "odds and evens" system and by restricting the amount and hours of parking spaces (May, 1991). The odd/even number plate system prohibits the use of private vehicles one day a week, as has been done in Mexico City since November 1989 mainly because of its air pollution problem (Carbajo, 1992). Such Draconian measures have been found to be ineffective when applied permanently (Eskeland, 1992). Aside from public transport, government and residents' vehicles, private vehicles are forbidden to enter a cordon surrounding central Milan, Italy, during the day between 7:30 a.m. and 4:30 p.m. Sometimes thought of as a cordon toll (Orski, 1992), Milan's cordon is actually a nonprice one. Other historical cities such as Florence, Rome and Bologna, Italy; Strasbourg, France; Göteborg, Sweden; and Tunis, Tunisia have various restrictions to entry imposed on private cars -- a trend that has gained momentum (Jones and Hervik, 1992).

A World Bank Urban Transport Policy Study paper notes that even though demand management measures such as road pricing and parking controls have been valued for some time, parking controls are the ones that have mainly been carried out in developing countries (World Bank, 1986, pp. 42). While a combination of both regulatory and pricing approaches may ultimately be best suited for a particular transportation system, here we opt for the pricing approach for two reasons. First, pricing is more selective and flexible than a regulatory approach in that it provides a better market mechanism, signaling the more efficient trips to be undertaken (Pozdena et al., 1990). Second, pricing yields revenues to the community in addition to the users' savings in travel time. These revenue transfers are beneficial to society, in contrast, for instance, to society's loss of travel time due to the regulatory approach of "gating" or planned delays (May, 1986, pp. 116). In particular, traffic restraint measures of banning certain vehicles in some cities mentioned above via the use of auto-free zones at certain places and times may create considerable inconvenience to individual drivers and are tantamount to setting prohibitively high prices on vehicle usage. Under road pricing, on the other hand, motorists still retain the freedom to choose the combination of mode, route and time-of-day they best prefer -- provided, of course, they pay for the privilege of doing so. It

[7] In Hau (2005a,b), it is shown (diagrammatically) that road pricing hurts most people and that road users ought to be compensated, directly or indirectly, by the channeling of the toll revenues.

appears that administrative simplicity and political acceptability are the principal reasons why transport planners have traditionally embraced regulatory approaches.

Nevertheless, a cursory mention of other traffic management measures that include behavioral incentives such as staggered working hours, park-and-ride and vehicle sharing (carpooling and taxi sharing) is in order.[8] Flextime "contains the seeds of its own destruction." This measure, once deemed successful, would reduce congestion during the peak hour, thereby creating incentives for people to switch back to their preferred times (recall Downs' Law). It seems therefore that moral suasion would not be a sustaining force in the long run. Besides being quite costly in terms of space and construction, park-and-ride facilities built near the edge of Singapore's Restricted Zone, for instance, were one aspect of the Singapore Area Licensing Scheme that was deemed to be *un*successful (Watson and Holland, 1976). Apparently, motorists found that switching modes was onerous *despite* the provision of shuttle bus services. Vehicle sharing has but a small effect on reducing congestion relative to incentives that increase the provision and use of public transport -- a form of 'bus-pooling' -- in the medium run. Cars with four or more people were considered exempt from charging in Singapore's Area Licensing Scheme prior to June 1, 1989, but are thereafter charged when they enter the Restricted Zone during peak hours (ostensibly because authorities noted frequent pick-ups just before the zone boundary). (The same kind of abuse also occurs in some San Francisco Bay Area cities in response to the fiscal incentive that is inadvertently created when carpoolers are made exempt from tolls on bridges and tunnels or given preferential access to road capacity.) Carpooling can at best be considered a short-run strategy for combating congestion given the inefficient use of road space. Taxi sharing, while popular for cities like Washington, D.C., is not as often used in some densely populated Asian cities such as Hong Kong since taxi fares are relatively cheap and maxi-cabs (or mini-buses) traverse along the main corridors, obviating the practice of shared ride. The regulatory control of taxi medallions is employed in many places. By restricting the supply, the quota instrument is not flexible in utilizing vehicles efficiently: those regulated vehicles on the road may not have the highest willingness to pay. In general, regulatory approaches do not prove to be very effective in managing demand in an efficient manner because of their inflexibility and bluntness.[9] Thus, so-called traffic restraint measures that planners often aim for could be met more effectively -- albeit indirectly -- by restraints on vehicle ownership via price rather than quantity: market-based approaches are more potent than performance-based command and control measures.

4. CHARGING FOR ROADS -- INDIRECT METHODS

4.1 Indirect charging via vehicle ownership purchase tax and annual license fees

Methods of charging for roadway usage can be indirect or direct (see Figure 1). The most direct way of charging for road use is via electronic road use charging. The indirect methods involve charging for a surrogate of usage such as vehicle ownership. The

[8] A thorough review of traffic restraint measures can be found in May (1986).

[9] For instance, a policy to restrict the parking supply in Boston, Massachusetts resulted in motorists looking around for less expensive off-street parking spaces as well as bestowing large windfall gains for the owners of private parking spots (see section on parking charges below).

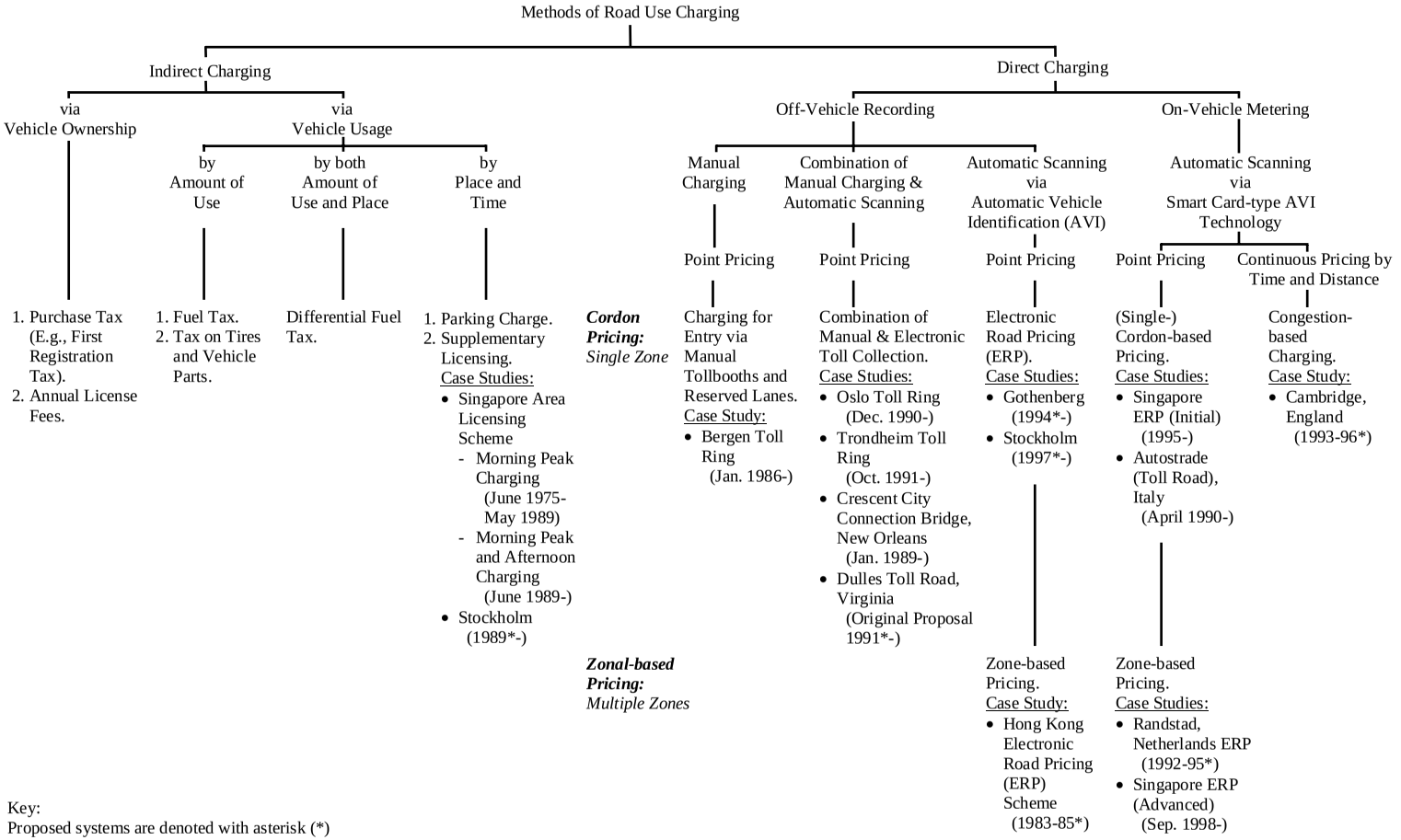

FIGURE 1: Methods of road user charging

primary instruments are acquisition/purchase taxes for vehicles, such as import duties and first registration taxes. High purchase taxes and annual license fees are often used as means of reducing the size of the vehicle fleet. They have been used quite effectively in places like Korea and Hong Kong by raising the ownership costs and dampening the rate of acquisition of private cars (Armstrong-Wright, 1986, pp. 126). Hefty first registration taxes (close to 100% of the landed price) for private automobiles have been instrumental in keeping a lid on the total vehicle fleet, in contrast to low purchase taxes (around 15% of the cost-insurance-freight value) for commercial vehicles (Hau, 1989). Indeed, the resultant decrease in the aggregate number of cars means that there would be an underutilization of the road network in uncongested and rural areas, whereas the existing vehicle fleet (notably the taxi fleet) would tend to be used much more intensively in urban areas. Nevertheless, the heavy taxation via first registration taxes and annual license fees has been regarded as administratively simple and effective albeit nonselective. While high taxes on a final consumption good (such as the private car) and low taxes on an intermediate input (such as commuting) are generally considered socially desirable, high annual license fees and purchase taxes are still sledgehammer approaches to the problem of congestion because they do not address the issue of efficient road utilization.

4.2 Indirect charging via vehicle usage

4.2.1 By amount of use: fuel tax and tax on tires and vehicle parts

A better method of charging for congestion indirectly is to aim for vehicle usage by the amount and the place of usage. The first instrument to consider is the ubiquitous fuel tax. Since fuel consumption is proportional to distance, given a certain engine class, a fuel tax is perhaps the best proxy for the *amount* of usage. However, even though both stop-and-go traffic and waiting time burn up fuel under congested conditions, this method is only regarded as marginally effective (and environmentally polluting). By uniformly taxing usage independent of time and place, the fuel tax is unable to differentiate between peak and off-peak periods and usage in congested and uncongested areas. The fuel tax may on average be adequate enough as a road user charge to cover the variable road maintenance cost of a road and perhaps the environmental externalities also. Indeed, many existing systems of road user charges in the U.K. and Europe possess a combination of both high annual entry fees and a (use-related) fuel tax, which serves more or less as a very crude two-or-multi-part tariff. Other user taxes on tires and spare parts boost the operating costs of an automobile and thereby serve to reduce demand indirectly. (However, caution must be exercised -- taxes on tires or spare parts should not be so high that vehicle safety is jeopardized.)

4.2.2 By both amount of use and place: differential fuel tax

Compared with a fuel tax, a spatially differential fuel tax with non-uniform rates would respond better to congestion. But this too, has its problems. Even though a differential fuel tax is administratively simple, it may result in wasteful “fuel-fetching” journeys, and would work only, for example, if distances between the urban and rural areas were sufficiently large. Instead of charging for vehicle use by both amount of use and place -- as a differential fuel tax does -- we can consider charging instruments related to vehicle usage by place only.

4.2.3 By place and time: parking charge

One of the most popular instruments which has been used to combat congestion is the parking charge on 'free' public space. The principal disadvantage of parking controls is that they lack the ability to tackle through traffic and they could actually encourage it, especially in the presence of high parking charges (footnote 9). If public on-street parking charges are set too high (and not aligned with private off-street parking rates), then congestion may result from motorists' long searches for parking; also, additional trips may be induced in the form of the 'drive and drop' or 'kiss and ride' mode. The current widespread practice of offering motorists who patronize private car parks' 'early bird discounts' before 9:30 a.m. (and charging casual motorists higher rates during the day) for instance, may not be early enough to mitigate those commuters' congestive effects. For parking charges to tackle congestion effectively, they should be time-of-day and/or location-dependent charges rather than present market-determined parking rates with locational monopoly element. Ideally, farther parking spaces are priced lower and closer ones are priced higher, with the result that early and late arrivals would select themselves in an efficient manner which minimizes the time that it takes people to arrive to work behind schedule (see Arnott et al., 1991, for proof).[10] Some cities such as Washington D.C. and San Francisco even institute parking taxes. Only if municipalities control a large fraction of both on-street and off-street car parks would the parking tax be an effective instrument at combating congestion (Department of the Environment, 1976). In general, increases in the parking tax would not be as powerful an instrument in combating congestion and pollution as direct charges would (Kulash, 1974).

Nevertheless, parking charges within the Restricted Zone of the Singapore Area Licensing Scheme (see below and Appendix) were raised substantially above market rates, in addition to a surcharge, as a matching tool to road pricing. In the absence of road pricing, a parking tax is sometimes regarded as a surrogate to charging for the use of congested urban streets (see Burns, 1972; Churchill, 1972, pp. 15). While a parking tax may or may not be desirable, parking pricing as well as controls ought to be pursued since driving and parking are jointly demanded (Churchill, 1972, pp. 15). After all, not charging the full cost would constitute subsidies (see World Bank's Transportation Sector Working Paper, 1972, pp.23; World Bank's Sector Policy Paper in Urban Transport, 1975, pp. 9, 15 and 42; and World Bank's Policy Paper on Urban Transport, 1986, pp. 91-92). Empirical case studies of employer-subsidized parking show that parking subsidies induce solo driving, decrease carpooling and public transport use (Willson and Shoup, 1990; Shoup and Willson, 1992). As a consequence, people suffer from worsening traffic congestion, increasing fuel consumption as well as air and noise pollution.

4.2.4 By place and time: supplementary licensing

The most important instrument of charging for road use by place of usage is with supplementary vehicle licensing, also known as area licensing. In principle, supplementary licensing requires that traffic moving within the designated area be

[10] A social optimum is reached only by combining time-of-day road pricing with a location-dependent parking fee (conditional on parking inward) (Arnott et al., 1991). Further, to signal commercial traffic and shoppers appropriately, time-of-day and length-of-stay parking charges should be used (see World Bank, 1986, pp. 11).

subject to enforcement but in practice this concept has never been carried out.[11] Hence this system is essentially an admissions charge to certain congested areas (such as the central business district) during certain (peak) hours, and is really a form of cordon pricing. Instead of stopping at a toll gate to pay for the entry manually -- and creating queues in the process -- as in the conventional notion of cordon pricing, motorists are required to prepurchase a sticker. Either a daily license or a monthly license is obtained at sales outlets such as post offices and so on, and the sticker is then placed in a visible area behind the windshield. If only one (or two) restricted zone is mandated, enforcement is relatively straightforwardly carried out by having traffic wardens standing by the side of the city street and marking down the license plates of those offending vehicles and mailing them a ticket afterwards. (In general, two or three traffic wardens are required to handle one station or gantry, as has been the practice for about 17 years in Singapore.) For ease of enforcement, stickers vary by shape and color to differentiate the days on which they are to be used. It is possible to vary charges by more than one time period or zone by a combination of two different stickers but, in principle, more complex time-of-day pricing schemes would involve problems of enforcement which may be difficult to manage even at city traffic speeds. Thus a distinguishing characteristic of supplementary licensing vis-a-vis cordon pricing using manual tollbooths is that it is relatively easier to implement more complex pricing schemes within two or three concentric zones by using multiple stickers and increasing modestly the enforcement personnel under area licensing than with manual tollgates.

The superiority of supplementary licensing as an instrument over the parking charge or tax is that it is able to price for the passage of through traffic nonstop. However, supplementary licensing suffers in reality from abrupt changes inside or outside of a designated zone boundary and also from changes just within or outside a time period, whereas the parking charge could be set to taper off towards both the city edge and the end of the rush hour. Another disadvantage is that a vehicle, having paid the entrance charge, would have the incentive of contributing to circular traffic within the zone since the leg of the trip therein is not charged, possibly exacerbating congestion. (As a variant, this problem could potentially be overcome if enforcement of area licenses was carried out for vehicles' presence within the zone, that is, on both moving and stationary vehicles (see previous footnote).) These are what I regard as the *spatial* and *temporal* boundary problems of supplementary licensing. One way of circumventing the boundary problems is to be flexible in its administration, for example, by expanding or narrowing the physical boundaries after a certain period and extending the time period(s) in which charging is in effect (as has been carried out in Singapore). A supplementary licensing scheme is very cheap to implement, requiring little capital outlay except for setting up gantries. To be cost-effective, supplementary licensing -- like cordon pricing -- requires that the number of entry and exit points be kept to a manageable figure. Area licensing schemes are especially suitable in labor-intensive developing economies and places that have a good track record of compliance with well-enforced traffic laws. Because

[11] In fact, the charging of the presence of vehicles within a cordon was proposed for London (Greater London Council, 1974). It was argued that the enforcement or personnel costs would be less if enforcement were carried out inside rather than at the numerous entry points. This variant is not as focused since vehicles which arrived before dawn, contributing nothing to congestion, would nonetheless be charged. Strictly speaking, supplementary licensing, without the enforcement of vehicles which have been left or garaged within the designated area overnight, say, amounts to direct charging for entry to a cordon via manual tollgates, to be discussed later.

operating costs involve only printing costs, the hiring of traffic wardens, and electricity, it is especially amenable to a short-term demonstration or field trial to test its feasibility in a small but congested city given its reversible and flexible nature. Other potentially minor problems such as theft and counterfeiting of daily and monthly licenses can presumably be dealt with by passing new legislation and imposing penalties that have deterrent effects. Supplementary licensing is exemplified by the only road pricing scheme in existence, albeit crudely, Singapore's Area Licensing Scheme (ALS), in operation since June 1975 (see Appendix). Just prior to June 1, 1989, drivers of automobiles entering the Restricted Zone were required to display prepurchased stickers of about *S*$5 [*US*$2.84 using 1990 exchange rate] in the morning peak. Thereafter, the daily license fee became *S*$3 [*US*$1.65 in 1990 dollars] during both the morning and afternoon peaks.

5. CHARGING FOR ROADS -- DIRECT METHODS

Having considered the major indirect instruments of charging for congestion, we turn now to direct methods of charging for the use of roads. Direct charging could be broadly categorized as off-vehicle recording versus on-vehicle metering. With off-vehicle recording, as with telephone, gas and electricity charges, the actual charging is monitored off the vehicle even though a transponder may be placed on the vehicle itself in the case of automatic scanning. On the other hand, with on-vehicle metering, actual charges are registered on the vehicle itself using automatic meters -- similar to the concept of taxi meters and (stored value) phone cards. All of the off-vehicle recording methods are based on point pricing whereas on-vehicle metering methods involve either point pricing or continuous pricing. Point pricing refers to the pricing of a vehicle when it passes a charging point such as a toll site. Continuous pricing, on the other hand, involves clocking a vehicle for the time spent or distance covered between two charging points.

5.1 Off-vehicle recording

Within the off-vehicle recording category are three instruments: 1) manual charging by admissions fee via tollgates and reserved lanes; 2) automatic scanning via automatic vehicle identification (AVI) technology, otherwise known as electronic toll collection (ETC) or euphemistically called electronic toll and traffic management (ETTM); and 3) a combination of manual and automatic scanning of vehicles. Manual and/or electronic toll collection involve point pricing and hence are less costly to operate than continuous pricing methods (see Part II (Hau, 2006b) for details of several case studies).

5.2 On-vehicle metering

Direct charging can either take place off a vehicle or with an on-vehicle metering system. The modern equivalent of a mechanical on-vehicle meter is an on-board unit consisting of a smart transponder and a smart card reader, the technology of which was described in the previous section. There are two types of pricing schemes, point pricing and continuous pricing by time and distance. Whenever a vehicle passes a pricing point, the vehicle is charged for crossing it, regardless of whether the motorist encounters another charging point. This type of charging is in contrast to the continuous type, which

relies on at least one other pricing point to clock in or out with -- so charging is based on distance or travel time (see Part II (Hau, 2006b) for details of several case studies).

6. DISCUSSION AND CONCLUSION

The gamut of indirect and direct congestion charging mechanisms is reviewed here and in Hau (2006b). Indirect charges via vehicle ownership such as a purchase tax and annual license fees suppress worthwhile trips in uncongested areas and are considered sledgehammer approaches to dealing with congestion. Charges imposed indirectly on the amount of vehicle use via the fuel tax fail to differentiate road use between congested and uncongested times and places. A parking charge, by nature, can deal only with stationary vehicles and fails to tackle through traffic. Also, it is likely that too large a discrepancy between public on-street parking charges vis-a-vis private off-street parking rates would exacerbate the congestion situation further, especially when vehicles cruise around in search of cheaper parking places. However, in many downtown areas where employer-subsidized parking prevails, parking *pricing* could serve as a vital complementary measure to road pricing. What remains are essentially four congestion pricing instruments: supplementary vehicle licensing, cordon pricing via manual tollbooths, direct charging via automatic vehicle identification (AVI) and smart card technology. Each of these instruments is dealt with by an in-depth case study analysis.

Although supplementary licensing is classified as indirect charging in Figure 1, it can be thought of as cordon pricing applied directly to vehicles which are in motion, with the possible option of undertaking multiple entries (see footnote 11). Even though manual and electronic toll collection mechanisms are not charging instruments per se, they do form the rudiments of cordon pricing via manual tollgates and electronic road pricing via AVI and smart card technologies, and hence are summarized alongside the four charging instruments in Table 1 (Hau, 1995). (The grouping of the criteria for choosing a technology vis-a-vis the others is based on the perspective of: the road user, the road authority and society. A charging instrument is evaluated on each of the twenty criteria on the basis of a ‘high’ (coded by a letter ‘H’), ‘medium’ (coded by a letter ‘M) or ‘low’ (coded by a letter ‘L’) ranking as it pertains to the specific illustrative case study. Because of the potentially divergent objectives of the different parties, an unequivocal result of one instrument dominating another is unlikely to emerge.)

Tollbooths suffer from being land intensive, labor intensive (due to the hiring of toll operators) and time intensive (due to the queuing delay to motorists), and are not ideal for congestion charging in and of themselves. The process of stopping and paying disrupts traffic flow and lengthens queues, defeating the ultimate goal of alleviating congestion. However, cordon pricing as in the Bergen Toll Ring could serve as an effective instrument of charging for congestion since half the toll lanes are reserved for the use of seasonal pass holders who travel through the pricing points at regular highway speeds. Enforcement of those driving on reserved lanes is carried out by periodic videographs of vehicle license plates, just as radar technology is a socially acceptable tool to catch speedsters. The *area licensing scheme (ALS)* requires that vehicles entering the central business district during peak hours display a monthly or daily license prominently, with enforcement being undertaken at gantry points by traffic wardens who perform visual checks on the nonstop traffic. Enforcement of ALS would be prohibitively costly when carried out at motorway speeds but would likely involve relatively low cost in a standard congested urban environment with limited entry and exit points. As a measure of the technical efficiency of a system, consider the long-run cost

of operating a congestion charging mechanism, which includes amortized capital and operating costs. Based on a variant of cost-effectiveness analysis, the cost per transaction is then used as an index of comparison among technologies: it indicates that supplementary licensing is the lowest, even lower than that of cordon pricing as in Bergen. The Oslo Toll Ring is designed for the purpose of *electronic* and *manual toll collection*, and the construction of large toll plazas accommodating both involves relatively high capital cost. (Note also that a flat rate, 24-hour toll used by a (standard) manual and electronic toll collection system such as Oslo's is not welfare enhancing. The use of such a system would improve social welfare if a differential pricing strategy were adopted by simply implementing a crude peak period toll). However, merely retrofitting an existing toll plaza setting with electronic toll equipment would not involve high capital cost, as the Crescent City Connection case clearly demonstrates. By the same token, *electronic road pricing (ERP)* is thus electronic toll collection *writ large* and made obligatory on vehicle owners within a jurisdiction. Even though the cost of the electronic equipment for standard AVI based on a one-way communication link is not considered trivial, the benefits are a multiple of the cost. As the sensitivity analysis performed on the Hong Kong ERP Scheme clearly demonstrates, even after excluding time savings on philosophical or other grounds, the savings in operating cost still yield benefit figures that are considerably greater than the system cost. Using yet another yardstick, the cost per transaction is also found to be low.[12] The much touted invasion-of-privacy issue that plagued the Hong Kong ERP scheme in the past can now be dealt with by providing road users access to confidential "numbered account arrangements" with prepaid cash deposit. The capital cost of *electronic road pricing with smart card technology* for the Comprehensive Road Pricing Scheme of the Netherlands is higher than AVI alone technology, but the benefits outweigh the cost also. Put together, the benefit-cost ratio remains respectable. Still, the cost per transaction of smart card technology -- based on a two-way communication link -- is about twice that of AVI alone technology, and, even though the cost per transaction can still be regarded as acceptable, this technology is still not widely used on a commercial basis. Nevertheless, rapid progress in microelectronics, cryptology and microwave technologies will continue to yield large-scale economies in the manufacturing of AVI equipment, read-write transponders, smart cards and the hardware and software that go with them. It may very well be the case that the cost per transaction of smart card-type AVI technology will soon approach that of AVI alone technology.

What emerges from a quick perusal of Table 1 is that electronic approaches of direct road use charging are superior to manual approaches, on average, whether from the perspective of a road user, road authority or society. Among these broad categories, ERP using AVI alone technology is ranked higher than ERP using smart card -- given the state of current technologies in 1992 -- based on an unweighted index of all the criteria (see Table 1). In general, ALS is superior to cordon pricing using manual tollbooths. Hence, if budgetary conditions allow it, the feasibility of implementing ERP ought to be investigated. However, if budget is tight, then ALS (with its low cost and correspondingly high benefit-cost ratio) ought to be seriously considered. If one is given only a single criterion to pick (out of the 20 criteria), I argue that the most important measure (although not an all-inclusive one) is the passage of the benefit-cost test.

[12] Note that this is so despite the fact that the standard capital recovery factor used to compare widely differing technologies is biased *against* capital-intensive AVI technology possessing long life.

TABLE 1: A comparison of road use charging mechanisms

	Manual			Electronic		
Congestion charging mechanisms		1	2		3	4
Manual and electronic toll collection plus Congestion charging mechanisms	Manual toll collection (24 hour)	Cordon pricing (combination of manual and reserved lanes) [1]	Supplementary licensing (single zone)	Electronic toll collection (24 hour) with AVI technology [2]	Electronic road pricing (ERP) with automatic vehicle identification	Electronic road pricing (ERP) with smart card technology
Illustrative case study	Common toll plaza	Bergen Toll Ring	Singapore Area Licensing Scheme (ALS)	Oslo Toll Ring	Hong Kong ERP Scheme	Netherlands ERP Proposal
From users' point of view (1-4)						
1. User-friendliness (simplicity)	□	□	□	□	□	□
2. Transparency (via *Ex Ante* pricing)	□	◨ [3]	◨	◨	□	□
3. Anonymity (protection from invasion of privacy)	□	◨	□	□	◨ [4]	□
4. Prepayment/ postpayment option for charging	Pay-as-you-go	Pay-as-you-go + Prepayment	Prepayment only	Prepayment/ Postpayment	Prepayment/ Postpayment	Prepayment [5]
From road authority's point of view (5-11)						
5. Enhanced efficiency via direct charging	■	◨	◨	■	□	□
6. Flexibility (responsiveness to demand)	■	◨	◨	■	◨ [6]	□
7. Reliability	□	■	◨ [7]	□	□	◨ [8]
8. Security and enforcement: a. Protection from theft	■ [9]	◨	■	□	□	■ [10]
b. Protection from fraud	■	◨ [11]	◨	□	□	◨
9. Provision for occasional visitors	□	□	◨ [12]	◨	◨	◨
10. 'Market' price as an investment signal	◨	◨ [13]	□	◨	□	□
11. Passage of revenue-cost test	Case-specific	□ [14] 6.3:1	□ 6.9:1 to 11.8:1	□ 5.9:1 to 2.2:1	□ 7.9:1 to 10.4:1	◨ 2.6:1

From society's point of view (12-20)

12. Passage of benefit-cost test	Case-specific	i.d.[15]	□ [16]	■ [17] 0.2:1 to 2.2:1	□ 14.7:1 to 17.8:1	◨ [18] 4.5:1
Long-run cost per transaction (US cents in 1990 figures)	Case-specific	11.0¢	5.6-9.9¢	21.2¢	6.6¢	12.5¢ [19]
13. Minimum of road work and environmental intrusion	■	■	□	◨	◨ [20]	□
14. Provision for mixed traffic	□	□	◨	◨ [21]	◨	◨
15. Handling of transitional phase	■ [22]	■	□	□	◨	◨
16. Compatibility with other systems	□	◨ [23]	◨	i.d.[24]	i.d.	i.d.
17. Modularity to add-on options (e.g. automatic route guidance)	■	■	■	i.d.	i.d.	i.d.
18. Tolerance to culture of non-compliance	□	◨ [25]	■	□ [26]	□	□
19. Tolerance to varied geography	■	■ [27]	■	□	□	□
20. Fairness and the availability of alternatives [28]	Case-specific	□ [29]	□ [30]	□	■ [31]	■ [32]
Other major characteristics and problems:	Land-intensive; Labor-intensive; Time-intensive (Queuing Delay)	Land-intensive; Labor-intensive; Time-intensive (Some Queuing Delay)	Labor-intensive technology; enforcement cost may be high; printing cost consideration.	Capital cost is high if the construction of large toll plazas for both electronic *and* manual toll collection is included. Use of AVI transponders is popular on toll roads.	Capital cost is high but the benefits are even higher; cost per transaction is low. Privacy issue is largely overcome with the use of numbered accounts.	Capital cost is high but the benefits are also high; cost per transaction is not high. Smart card technology is not yet widely commercially available.
Unweighted index (out of 3.0)	2.0	2.0	2.2	2.4	2.6	2.4
Ranking of congestion charging mechanisms [33]		4	3		1	2

Key: □ = High, ◨ = Medium, ■ = Low

Abbreviations: ALS = Area licensing scheme, AVI = Automatic vehicle identification, ERP = Electronic road pricing, i.d. = Insufficient data

Notes:

All the figures reported in this table specifically refer to the illustrated case studies in the text.

[1]The variant of cordon pricing considered here is the one based on the Bergen Toll Ring, which has half of all lanes equipped with manually-operated tollgates and the other half of the lanes reserved for seasonal pass holders.

[2]Manual toll collection option is available together with electronic toll collection at the Oslo Toll Ring, hence the privacy issue does not arise.

[3]For seasonal pass holders of the Bergen Toll Ring, the incentive to overuse passes is high once they are paid for. The same qualification applies to those holders of monthly ALS fee cards.

[4]Although the Hong Kong ERP Scheme suffers from having each vehicle identified explicitly, current uses of AVI technology have largely overcome the privacy issue.

[5]Although a smart card is pre-purchased, it is debited only at the moment of charging and functions like an electronic purse dispensing cash instantaneously.

[6]Although ERP allows prices to be varied continuously in response to demand, 'bounded rationality' considerations on the part of decision makers call for the judicious setting of pricing gradations.

[7]At the Bergen Toll Ring, some cheating occurs at the unmanned tollbooths reserved for seasonal pass holders.

[8]Although smart card technology was not considered sufficiently mature for ERP in the Dutch proposal of 1988 for four major cities, Telepass has a system for electronic toll collection based on smart cards -- operating on a limited basis on the Italian autostrada since 1989.

[9]One of the principal problems with manual toll collection is the problem of the transfer of cash cages. Theft of cash and coupon books by toll operators have been reported; theft of area licenses and seasonal passes also occur.

[10]Theft of a smart card is a problem, although the card could be made invalid when operated in conjunction with another in-vehicle unit.

[11]Counterfeiting of monthly licenses (or seasonal passes) is a potential problem.

[12]Visitors from out of town will have to incur additional time in searching for outlets where area licenses or electronic tags could be leased.

[13]Even though Bergen Toll Ring has a 16-hour charging period, a non-zero toll still serves as an investment signal reflecting the scarcity value of land use.

[14]Each revenue-cost ratio reported is based on the respective charging policy of the case studies examined. Since the revenue-cost ratios are high, i.e., low cost per dollar of revenue raised, the Norwegian schemes -- Bergen, Oslo (and Trondheim) Toll Rings -- are all road-financing schemes.

[15]Despite insufficient data, it is likely that the net benefits of cordon pricing would not be high since manual toll collection by tollbooths impedes traffic flow and causes congestion itself.

[16]Holland and Watson (1978) report a rough estimation of the economic rate of return for the first year of the Singapore ALS at 60% to 150%. Data from the Hong Kong ERP Project indicates that the benefit-cost ratios for ALS in Hong Kong, if implemented, would be in the range of 22.5:1 to 33.8:1, even higher than those of the Hong Kong ERP itself. All benefit-cost ratios are based on the specific case studies reported in the text.

[17]The lower bound estimate of the benefit-cost ratio is based on the actual Oslo Toll Ring, whereas the corresponding upper bound estimate is for a 'perfect' (link-based) road pricing scheme.

[18]The *social* benefit-cost ratio for the Dutch ERP Proposal using smart card technology is 3.2.

[19]Despite the fact that the capital cost for smart card technology is high, the multiple transactions yield a level of cost per transaction that is in the mid range. The annualized capital cost of a project is arrived at by using a capital recovery factor of 0.125, corresponding roughly to a discount rate of 7% and a project life of 12 years as well as a discount rate of 4% and a project life of 10 years; see any discount table.

[20]The Hong Kong ERP Scheme required some amount of road work, whereas current AVI technologies use gantry-mounted antennas or in-pavement antennas requiring minimal road work.

[21]Current AVI technology allows a simple version of vehicle classification by linking an AVI transponder with a vehicle's class. Classification equipment for heavy vehicles is available and further advances in automatic vehicle classification (AVC) are currently being made.

[22]Implementation of road pricing with manually-operated toll plazas is not expedient. Implementation of electronic road pricing with existing electronic toll collection facilities is feasible, especially with a modular design.

[23]Seasonal passes and area licenses may not be compatible with other cities nearby.

[24]There is a move to come up with an internationally agreed upon standard for AVI technology, plus its integration with automatic vehicle classification and weigh-in motion equipment.

[25]It is expected that noncompliance will take place at the unattended nonstop reserved lanes because video enforcement is carried out only on a periodic basis to minimize cost.

[26]Enforcement of moving vehicles under the Singapore ALS is carried out at normal traffic speeds. On the other hand, enforcement of vehicles at freeway speeds is likely to be infeasible. A good rule of thumb to use to ascertain whether a country is ready to implement ALS is the degree of its citizens' compliance with parking regulations.
[27]Natural cordon boundaries and limited access to the city are both prerequisites to cordon pricing and ALS.
[28]The criterion of 'fairness and the availability of alternatives' is clearly case-specific and does not apply to the charging instruments in and of itself.
[29]The Bergen and Oslo Toll Rings both succeeded principally because the toll revenues were earmarked for road construction (80%) and busways (20%).
[30]Without the provision of public transport and bypass routes, the Singapore ALS might not have succeeded.
[31]Although Hong Kong has exceptionally good public transport alternatives, ERP floundered because the public *perceived* that ERP was 'just another tax', despite Government's promise that it is revenue-neutral, and their privacy might be compromised in the light of 1997.
[32]The Netherlands' Comprehensive Road Pricing Scheme failed because the car lobby felt that it was another revenue-raising instrument and that it would place an unfair burden on those suburban residents who located where they had as a result of past government policy.
[33]The ranking is based on an unweighted sum of the 20 criteria applied to the illustrative case studies at hand. Criteria 11, 12 and 20, in particular, pertain more to the case studies than the charging instrument method per se.

Nevertheless, by pursuing the multicriteria analysis introduced here, the road authority or decision maker could -- on the basis of other criteria listed -- choose from amongst a variety of congestion charging instruments.

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APPENDIX. THE SINGAPORE AREA LICENSING SCHEME, 1975-1992

A.1 Background information

The Singapore Area Licensing Scheme (ALS) which began in June 1975, is the world's foremost example of road pricing. During the morning peak period of 7:30 to 9:30 a.m. (except Sundays and holidays), automobile drivers desiring to enter the Restricted Zone -- an area of over 5 kilometers square -- within the Central Business District of Singapore were required to purchase a daily or monthly license from the kiosks or post offices just outside the Restricted Zone.[13] Initially, taxis, buses, carpools (of more than four passengers) and commercial vehicles were exempt from the entry fee. The specially-shaped and color-coded licenses were priced by trial and error at around *S*$3 [*US*$1.25] each, with the day or month printed in large characters and displayed near the top left hand corner of the windshield. The visibility of the dated color stickers allowed traffic wardens to check them as vehicles drove by any of the gantry posts signaling the entrance to the zone at the city speed limit of 50 kph. It is the nonstop feature of the ALS -- as distinct from manually operated toll booths which also attempt to implement cordon pricing -- that is unique and reaps significant savings in travel time. The ALS is part of a comprehensive package of traffic restraint measures by the Singapore Government. Several months prior to the opening of the ALS on June 2, 1975, authorities instituted the following complementary traffic management measures in order to achieve the goal of 25% to 30% reduction in traffic volume: a) monthly parking charges in both public and private parking lots were about doubled (via mandated price increases and surcharges) and uniform hourly rates were replaced by rates which varied by geographical location and duration of stay; b) 15 park-and-ride facilities (providing about 10,000 new parking spaces) were constructed just outside the Restricted Zone to ease the switch from private to public transport; c) premium franchised shuttle bus services were provided to facilitate the transfer from the fringe parking lots to the downtown area; and d) flextime was encouraged by the government as part of a wider public information campaign. After 1975, there were a couple of changes in fees, boundaries and operating hours (see Ang, 1989, Table 2). Principally, the exemption of taxis from ALS fees were rescinded (August 1, 1975) and company cars were required to pay twice the rate of private cars (January 1, 1976).

[13]The Restricted Zone has now been increased (by land reclamation) to 725 hectares (or 7.25 square kilometers). The monthly license fee is set at twenty times the daily license fee.

Beginning June 1, 1989, there was a major revision of the ALS: a) the restricted times of operation were extended to cover both the morning and afternoon peak periods, with the latter occurring at 4:30-7:00 p.m. (but later changed to 4:30-6:30 p.m.); b) *all* vehicles were charged, with the exception of emergency vehicles (such as ambulances, police cars and fire engines) and public buses, so that carpools were no longer exempt; c) the daily license fee for automobiles was lowered from *S*$5 per day to *S*$3 per peak period entry -- a (more than) 40% decrease in real charges!; and d) motorcycles were to pay one Singapore dollar per day (after July 1, 1989).

A.2 Analysis of results (1975-89)

Even though the ALS was touted to be a resounding success, it was not free from qualifications. First, as expected from intuition, during the morning peak period, the number of motor cars dropped by three fourths within the first month whereas all vehicles dropped by between a third and a half during that period, easily surpassing the government's objectives (Toh, 1977, Table 1; Watson and Holland, 1978, Chapter 4). Second, however, as intuition would also expect, motorists rescheduled their trips to arrive during those periods just before and immediately after the restricted period, prompting authorities to extend the time period the ALS was in operation by three quarters of an hour to 10:15 a.m. on June 23, 1975. Third, simultaneously there was a significant increase in the number of taxis of about a quarter within the first three weeks, prompting authorities to remove taxis from the exempt list on August 1, 1975.[14] More importantly, a full year after ALS came into effect, there remained a decrease in private cars of three-fourths and a decrease in all vehicles of one-half, despite the fact that there was an increase in the ALS fee of one Singapore dollar on January 1, 1976 (Seah, 1980, Table 1). Fourth, one month before ALS began, new non-uniform parking charges (rising by length-of-stay and by proximity to the CBD) -- designed as a complementary measure to area licensing -- served to raise the out-of-pocket costs of motorists (Watson and Holland, 1978, pp. 24-27, 68-73). Monthly parking fees of government car parks were also raised (by at least 20-40%) and operators of private parking lots were required to match the price increases. In addition, the government levied a surcharge equivalent to the price increase. By discouraging circular traffic within the zone in this way, public transport was made more attractive and substitutable. Fifth, the fringe parking lots to promote the park-and-ride mode -- another complementary measure to road pricing -- were deemed unsuccessful almost from inception, with only 4% of the parking spaces taken up in the first year and a half (Watson and Holland, 1978, Table 3.3). Hence the authorities promptly responded by converting the empty parking lots into hawkers' markets and cooked food stores. Sixth, the quality shuttle bus service was also a failure, with ridership well below the capacity of the buses, and so the privately operated shuttle buses were quickly merged with the regular bus system (Watson and Holland, 1978, pp. 36; Wilson, 1988). Seventh, the enforcement of offenders was carried out by assigning entry point attendants (between 1 and 5) to issue traffic tickets via mail. Perhaps because of the stiff penalty of *S*$50 for an offender, which is just short of the cost of a monthly license fee of *S*$60, the rate of violation was only 1%-2% in 1975 (Watson and Holland, 1978, Table 3.1). Eighth, motorcycle travel -- presumably a crude substitute for private car use -- increased so much that charges for motorcycles were introduced. Ninth, as a

[14] As a compromise, authorities lowered the fee for taxis from *S*$4 to *S*$2 on April 1, 1977.

result of a doubling of the number of carpools within the first year and annual growth occurring thereafter during the operating hours of the ALS (Seah, 1980, Table 1), and because nine-tenths of carpoolers did not make return trips in the same fashion, carpools were no longer exempt as of June 1, 1989. Tenth, the "mirror image" effect hoped for in the afternoon peak period did not materialize because of cross-town traffic in the afternoon. One third of the total trans-Restricted Zone commuting traffic chose to travel on the ring road, which serves as a bypass route; two-thirds still chose to go through the Restricted Zone after ALS was introduced. (Only one-seventh of the (two-thirds) through traffic chose to drive into the Restricted Zone during the restricted hours; the rest of the through traffic switched to a different time or made a detour by traveling on the circuitous route in the morning peak or changed modes (Watson and Holland, 1978, pp. 7)). In due course, the detours resulted in heavy traffic along the ring road around the Restricted Zone, necessitating traffic management measures such as the re-timing of traffic lights. On the other hand, on the return trips, traffic traverses directly through the relatively uncongested downtown area in the afternoon peak. Further, only about one tenth of the carpoolers were estimated to make their return trips in the same fashion (others used public transport, taxis, or were collected in private vehicles). As a result, "bumper to bumper congestion" was observed during the afternoon peak in 1983, with average traffic speed being 18 kph, in contrast to 30 kph during the morning peak (Behbehani et al., 1984, pp. 36). Thus the morning ALS scheme was able to solve only part of the congestion problem.

A.3 Analysis of results (1989-92)

The "mirror image" phenomenon therefore contributed directly to the extension of the restricted hours of the ALS on June 1, 1989 (from the morning peak into the afternoon peak period, initially beginning from 4:30 - 7 p.m. but later curtailled to 6:30 p.m. to accommodate business interests and activities).[15]

The most comprehensive survey to date regarding the impact of the ALS was carried out in February, 1990 by the Public Works Department and the Nanyang Technological Institute (Menon and Seddon, 1991) and the results are briefly analyzed here. One, the traffic survey indicates that there was a marked increase in total in-bound traffic immediately before and after the afternoon peak period came into operation, similar to the historical pattern during the morning peak. Further, comparisons of traffic levels traveling in and out of the Restricted Zone were made between May 1989 (which represents the pre-June 1989 scheme) and May 1990 (which represents the post-June 1989 scheme). Two, as expected, the comparisons indicate that the total vehicle flow had decreased -- suggesting that cross-town through traffic had been curtailed -- concomitant with an increase in traffic on the ring roads. Three, both the drastic cut in daily license fee for cars and taxis plus the introduction of charging of carpools resulted in a net increase in inbound automobile traffic during the morning peak of three-tenths, relative to May 1989 (in which a high daily license fee of *S*$5 previously applied). Four, a significant reduction in inbound automobile traffic of seven-tenths naturally occurs

[15]The Singapore ALS did not try out a 'tidal flow' experiment charge, in which charges are imposed on homeward bound trips out of the central business district to the suburbs in line with the main traffic flow, as opposed to the post-June 1989 practice of charging for entry *per se* both in the morning and the afternoon. The 'tidal flow' idea is the basis of Hong Kong's Electronic Road Pricing System Scheme B.

during the afternoon peak -- relative to May, 1989 (when no charges were applied at all in the afternoon peak). Five, by contrast, since goods vehicles (and motorcycles) are subsequently charged when entering the Restricted Zone, there has been a significant reduction in these vehicles of six tenths, during both the morning and afternoon peak periods, as intuition would lead us to expect. Six, as a result of introducing the evening ALS, average traffic speed within the Restricted Zone increased to 30 kph in 1990, as indicated in the Report of the Select Committee on Land Transportation Policy (see Seventh Parliament of Singapore, 1990; Olszewski and Tan, 1991). Seven, despite a growing economy, the lowering of the daily license fee in June 1989 -- possibly the outcome of a trial-and-error pricing process -- suggests that the Singapore Government used ALS as a traffic management tool to curtail congestion rather than as a revenue-generating device.

A.4 Financial and economic evaluation

Even though the purpose of the ALS is not to raise revenue, it fulfills the government's multipronged objective of seeking a traffic restraint measure that does not involve subsidization (Toh, 1977). From a purely financial point of view, this policy measure is appealing to local authorities, especially in an age of declining municipal funds.

The capital cost of the ALS is *S*$6.6 million [*US*$2.8 million] in 1975 and the recurrent cost for the period 1975-89 is *S*$1.0 million [*US*$0.4 million], including about 40 entry point attendants operating 22 gantries for enforcement purposes, in 1975.[16] The monthly revenue from the sale of ALS licenses averages *S*$472,000 in 1975 for the last four months. After netting out the operating costs of ticket sales, car parks and enforcement, the monthly net revenue was about *S*$420,000, resulting in a net financial return to the authorities of about 76% (Watson and Holland, 1978, pp. 38-39). As a result of a one dollar increase in daily license fees on January 1, 1976, the gross revenue increased to a monthly figure of *S*$568,000, which, together with comparable operating costs of *S*$52,000, yield a net financial rate of return of 94%. Note that the capital cost of $6.6 million is less than that of building an urban expressway two kilometers long (Watson and Holland, 1978, pp. 37)!

Since the construction of car parks, bus shelters, provision of utilities and landscaping account for over nine tenths of the capital cost of the ALS, and since the park-and-ride facilities were considered a failure and converted to more productive uses, the capital cost of the ALS itself -- which is nothing more than overhead gantry structures, electric signs, and 15 or so booths for the sales of licenses -- is only *S*$316,000 (Watson and Holland, 1978, Table 3.6). This means that the net financial rate of return is 1,590%, or an equivalent revenue-cost ratio of 16.9 (see also Wilson, 1988). These figures can be compared with the net financial rate of return figure calculated on the basis of data the author compiled for 1975-89. There the net financial rate of return, based on annualized capital and operating cost and annual revenue-cost ratios, comes to 590% *with* the revenues and costs of operating the car parks and 1,080% *without* the associated revenues and costs of the car parks. The difference between the 'short-term' figures

[16] Note that the US dollar equivalent here is expressed in 1975 dollars, using the exchange rate of *S*$2.40 = *US*$1. The analysis that immediately follows is based on figures from Watson and Holland's (1978) study for the first year only, and the rest is computed from the data the author collected from Singapore's Public Works Department and Registry of Vehicles for the period 1975-89.

collected within the first year and a half and the 'long-term' figures collected over a 14-year period can perhaps be partially explained by: a) the amortization of capital costs over a longer time period, b) the reduction in operating cost of the ALS through learning by doing, and c) the 'long-term' figures include enforcement costs hitherto not taken into account. Based on an average daily car traffic volume of 45,000 in 1989 during the morning peak period and the number of operating days of the ALS of 301 (including Saturdays) in a year, the cost per transaction comes to *S*12.1 cents for the period 1975-89 [*US*9.9 cents in 1990 figures] *with* car parks and *S*6.8 cents for the period 1975-89 [*US*5.6 cents in 1990 figure] *without* car parks. Based on an average daily car traffic volume of 45,000 during the morning peak period and 24,000 during the afternoon peak and the number of operating days of 283 in a year, the cost per transaction comes to *S*16.5 cents for the fiscal year 1989 [*US*9.4 cents in 1990 figures] *without* car parks.[17] By employing the index of cost per transaction alone, the Singapore Area Licensing Scheme is among the least costly of alternative methods of charging for road use.

In a review of the impact of the ALS after nine years of operation, a team of World Bank researchers observed that had the ALS package of traffic management measures not been implemented, there would have been bumper-to-bumper traffic conditions universally in the Restricted Zone by 1982 (Behbehani et al., 1984, pp. 50). Further, the deferred or canceled investments for roads amount to savings to society of the order of *S*$1.5 billion.

The paucity of benefit-cost studies on the Singapore ALS means that it is difficult to come up with strong conclusions as to its economic viability. Holland and Watson briefly reported an economic evaluation in their 1978 article. A lower bound estimate of an economic rate of return of 15% is obtained for the first year. This figure seems to be on the low side for such a major undertaking. Nevertheless, it includes only time savings and not savings in operating costs and fuel which are normally calculated in transport projects. (Further, it does not employ the standard assumption of value of time being a function of the wage rate, but assumes that everyone has the same value of time.) Since at least three fourths (or nine tenths) of the capital cost of the scheme, which went into the construction of fringe car parks, could have been saved, the economic rate of return would have become 60% (or 150%) in the first year. The estimate here does not take into account: a) the costs to commuters of rescheduling or the loss in welfare for those tolled off the desired mode, and b) the gain in welfare to the ones who valued time highly and were tolled at the (lower) average rate upon entering the Restricted Zone.

In a rigorous welfare analysis, Wilson (1988) uses a joint mode choice and work start time choice model to analyze the same set of individuals surveyed in a pre- and post-ALS set of data by the World Bank. His results indicate that: a) some travelers are worse off as a result of being tolled off when entering the Restricted Zone during its operating hours and are diverted onto a different time period or even onto public transport, and having to incur the resultant rescheduling costs which exceed the payment of the ALS fee itself; b) some motorists (who used to travel, say, just outside the restricted hours) had to suffer increased congestion as a result of those motorists who were tolled off the restricted times, and those public transport commuters who had to face a more congested public transport environment following ALS would also be worse off; and c) those commuters who chose to remain *as is* and be tolled would be worse off unless their

[17] The difference in the number of days a year arises because the post-June 1989 scheme operated on a five and a half day a week basis. That is, (5 + 45000/69000) x 52 - 11 holidays = 283 days.

values of time savings are sufficiently high.[18] He concludes that a constant, flat-rate toll may in fact result in a decrease in social welfare as in Nash-Bentham-Sen, contrary to the "exuberant" feeling surrounding the positive results of the ALS scheme in 1975-78. Wilson simulates the effects of making various revenue-neutral assumptions by explicitly returning the toll revenues to the individuals in the sampled population and comparing the pre- and post-ALS results. However, he acknowledges that he has not taken into account incentive effects. The setting of the ALS fee in 1975-76 may have been widely observed to be on the high side and it resulted in the underutilization of the road network in the Restricted Zone. Subsequently, the ALS fee was lowered, on June 1, 1989. However, it is unclear how the simulation results would have panned out given a real decrease in daily licenses exceeding 40%.

A.5 Lessons for implementing area licensing

A few lessons emerge from analyzing the Singapore ALS for the purpose of charging for congestion: a) ALS, being fairly low cost and requiring one gantry per entry point, would be suitable for cities with limited access;[19] b) ALS defers hefty investment in roads and requires very little land for its implementation, except the dozen or so kiosks for sales of licenses; c) enforcement may be difficult for high speed expressways but the level of skills required is not high, so it is suitable for a low-tech, labor-intensive society; d) ALS works best as part of a package of complementary traffic management measures such as parking pricing and the provision of viable alternatives for travelers (in the form of improved public transport, alternative modes and routes); e) since ALS is not capital intensive, it is particularly amenable to a short-term experiment, leaving few long-term repercussions; and f) ALS has worked well and should adapt itself, with any necessary modifications, to a culture that has a tradition of compliance and law enforcement.

[18] Both intuition and theory suggest that these results are to be expected (see Hau, 2005a,b).

[19] For a typical United States inner-city size of two square miles and assuming 12 major streets to a mile, the total number of pricing points or gantries needed would be 96 (or 48 if half are one-way streets). If deemed economically efficient, a few minor roads located at the cordon boundary could be closed off (as was done in Singapore) to save on capital and operating costs of gantries. Further, note that ALS accommodates occasional visitors and does not require the enforcement of licenses once vehicles have entered the Restricted Zone.