EFFICIENT PRICING STRUCTURE FOR FINANCING HIGHWAY IMPROVEMENTS AND EXPANSION

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1. INTRODUCTION

There has recently been much discussion in the public arena, in Finland and world wide, about charging drivers for their use of the road. This topic is by no means new, a French engineer, Jules Dupuit, derived the basic results of congestion pricing as early as in the 19th century. On the other hand, a variety of direct charging mechanisms are already in use in many countries: there are private toll roads in the U.S., driving on the French and Italian freeways is charged for, to circulate in a private car in Singapore necessitates an area licence, etc.

In most countries, including Finland, the majority of road constuction and maintenance is financed from the government's general budget. However, in many big cities traffic volumes have increased with such a speed that only very complicated and thus expensive investments (usually tunnels) can alleviate the congestion and its negative effects on the efficiency of the economy. Yet the traditional funding mechanism and planning process do not usually allow for the concentration of road investments in a few urban regions only. The general shift from income taxation towards taxing consumption makes it even more difficult for the governments to find funds for big road investments. Charging road users directly would bring a solution to these problems.

2. FINANCING SYSTEM IN FINLAND

Highway funding in Finland is arranged in a traditional way found in many countries. The government collects tax monies from motorists to the general tax fund and finances highway maintenance, reinvestment and new investments in an annual budget cycle. A special feature of the highway user tax is a very high new vehicle tax but there is no annual license or other annual vehicle tax. Highway user taxes, gas and new vehicle taxes, have become popular sources of government income owing to rather low cost elasticity of new car purchases and of travel demand.

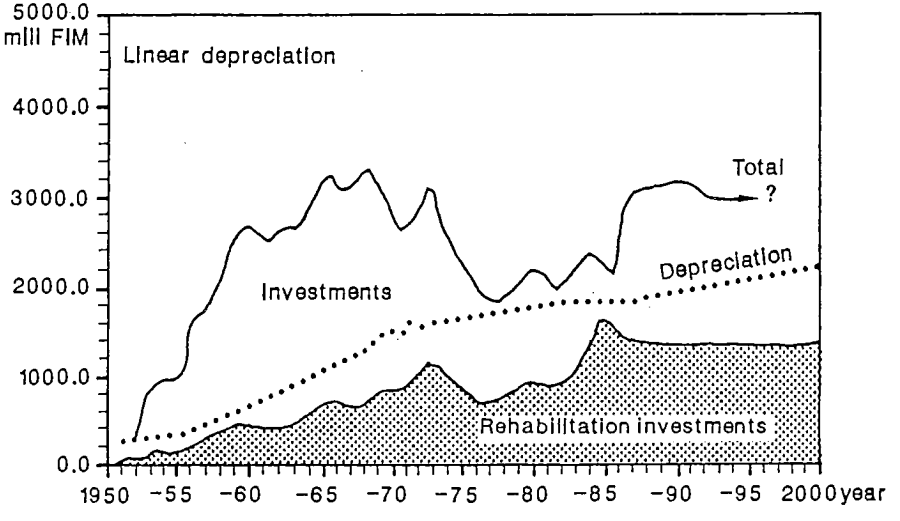
The government levies the following taxes on highway users: the gas, lubricant and tire tax, the vehicle tax, the car insurance tax, and the emissions tax. The emissions tax was instituted 1991 in the form of additional gas tax; vehicles using leaded gas pay higher tax.

Formally there is no correspondence between the highway taxes collected and money spent on highways. The parliament decides in the annual state budget also the budget of the Highway Administration, including identification and financing schedule of major projects. The ministry does, however, conduct studies to examine the cost allocation in general, between trucks and cars, and between different travel modes. In general, leaving environmental damage unpriced, it is found that the highway sector is overtaxed, especially cars; heavy trucks probably break even, and railroads are substantially subsidized. This overtaxation of the highway sector critically depends on the values placed on negative environmental impacts.

The figure below shows that the current highway expenditures are inadequate to meet the depreciation of highway infrastructure; the situation is aggravated by high growth of traffic rates especially in southern Finland and the existence of some low standard roads in the rural areas which both necessitate new investments The situation is especially acute in the Helsinki region and also near other large cities in southern Finland where most of the economic activity of the country is located. Transport investments in the urban areas are also needed to alleviate the environmental impacts of traffic growth. Occasionally substantial bridge or tunnel investments are needed to improve accessibility in the Finnish archipelago or to isolated islands.

ROAD INVESTMENTS AND DEPRECIATIONS IN FINLAND

COUNTRY TOTAL (costs in 1985 level)



Against this background, high road user taxes whose increases are rarely, one could say never, allocated to road improvements, deteriorating highway stock, steeply increasing travel demand, and selected access target areas, the Finnish National Road Administration has conducted studies to find more reliable sources of funds. In part alternative funding sources are also desired to enable more economical implementation schedule and timing of beneficial projects. The objective of these studies has been twofold, to find an economically efficient pricing structure and to gather monies to investments if these investments were necessary when biases in the highway pricing were corrected.

3. PROPOSED PRICING MECHANISM: MARGINAL COST PRICING

The proposed pricing system starts from one of the basic axioms of the economic theory: the only efficient pricing mechanism is the marginal cost pricing. If average cost is the charging basis instead of marginal cost, or in other words, if the negative externalities of congestion and environmental effects are not priced explicitely, the level of demand (traffic volumes) is too high. This leads to over-investment in road capacity or in inefficient use of scarce public monies. The objective of marginal cost pricing is thus to minimize the total cost of the road sector. The total cost of a transport system can be divided into the following three components: the cost of the provision and maintenance of the infrastructure, the cost to the users of the system, and the environmental cost caused by the system and the use of the system.

3.1 Theoretical framework

With the help of a mathematical model an efficient marginal cost pricing system can be derived. It covers the following three cost components: maintenance and new investments, user costs, and environmental damage. The following presentation owes much to Larsen (1991).

Assuming that the cost of the road construction and maintenance (infrastructure) is a function of the length of the system, its quality (or standard) and the traffic volumes, the functional relationship can be written as follows

$$C_{infra} = L^*f(S,X)$$

where C_{infra} = cost of road construction and maintenance
L = length of the system (km)
S = standard or quality of the road system
X = traffic volumes (vehicle km / unit of time)

The cost to the users of the road system is assumed to be dependent on the quality of the road and the utilization of capacity (level of congestion) multiplied by the traffic volumes or

$C_{user} = X*g(S,k)$

where C_{user} = total user cost
X = traffic volumes (vehicle km / unit of time)
S = standard of the road system
k = utilization of capacity or X/(S*L)

The degree of the environmental cost is assumed to be a function of traffic volumes, road quality, length of the road system and level of congestion or

$C_{env} = m(X,S,L,k)$

where C_{env} = total environment cost of a road system
X = traffic volumes (vehicle km / unit of time)
S = standard of the road system
L = length of the system (km)
k = utilization of capacity or X/(S*L)

In the optimum the highway authority chooses such a road network quality that the total cost to the society is minimized or mathematically

$$\min C = C_{infra} + C_{user} + C_{env}$$

A necessary condition for a minimum to exist is that the partial derivatives vanish. With some further manipulation of the derivative equation (see Larsen (1991)), the following marginal cost with respect to vehicle kilometers in a unit of time can be obtained (as the motorist covers his own time cost and the vehicle operating cost, they need not to be taken into account when determining the marginal cost based price)

$$\partial C/\partial X = p = \partial f/\partial X + \partial m/\partial X + k*(\partial g/\partial k) + k*(\partial m/\partial k)$$

This is also the price to be set on road use. The price should cover the cost of wear and tear of the existing network ($\partial f/\partial X$), harm done to the environment of road use in general ($\partial m/\partial X$) and of congested traffic ($k*\partial m/\partial k$)), and the utility losses due to congested traffic ($k*(\partial g/\partial k)$).

When this optimal price equation is inserted into the equation minimizing the total coslt of the road sector to the society, the following marginal cost based investment criteria is obtained

$$\partial f/\partial S = X*(p - \partial f/\partial X - \partial m/\partial X - \partial)/(S*L) + X*(\partial g/\partial S)/L - \partial m/\partial S$$

where $\partial f/\partial S$ = cost per km of capacity expansion and/or quality improvement

$X^*(\partial g/\partial S)/L$ = benefit to road users of the capacity expansion and/or quality improvement

$\partial m/\partial S$ = environmental harm due to the capacity expansion and/or quality improvement

$X^*(p - \partial f/\partial X - \partial m/\partial X)/(S^*L)$ = revenues from congestion pricing per a unit of capacity or quality

In short, the above equation states that investment in road capacity or quality is beneficial to the society as a whole when the revenues from congestion pricing, the benefits to the road users from the new road, the environmental damage taken into account, exceed the cost of producing the capacity. Or in other words, the drivers should pay for the maintenance of the existing road network, for highway improvements and capacity expansion, and for environmental harm caused. This leads to the following concrete proposal of a comprehensive, efficient and economically justifiable pricing structure.

3.2. Marginal cost based solution

3.2.1. Maintenance cost

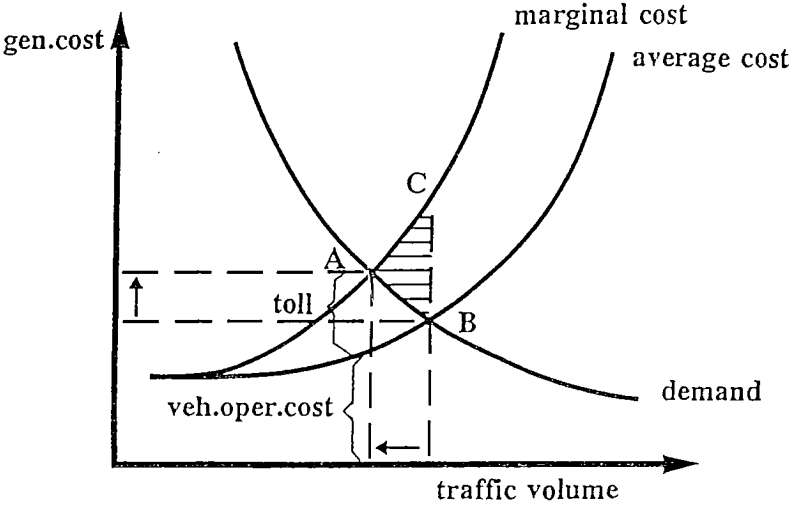
It has been shown in the transport literature that wear and tear of the road and thus the necessary amount of maintenance actions is a function of traffic volumes and especially of the axle loads of the vehicles (the 4th power rule). Thus there is good reason to assume that for private cars the consumption of fuel is a good approximation of the wear and tear caused to the road. From this it follows that a special tax should be added to the market price of fuel to cover the maintenance cost of light vehicles. As to the heavy vehicles, the axle loads need to be taken into account. A charge should be set according to the axle weights of the vehicle and distance traveled.

3.2.2. Capacity expansion

Road sector, as all economic sectors, can be analyzed in the conventional marginal cost and revenue framework (see chart below). The average cost curve represents the time and vehicle operating (fuel, capital) costs that the motorist perceive as a concrete and direct cost. The AC curve is upward-sloping because as the traffic volumes increase, the speed of the flow decreases and travel times raise. The marginal cost curve, on the other hand, represents the costs to the society. Whenever the AC curve rises, the basic price theory suggests that the MC curve lies above it. The vertical difference between the two cost curves represents the externalities, congestion and environmental damage (noise, pollution, accidents), which do not have a price in the markets and which thus are not perceived by the road users as costs.

The demand curve represents the motorist's willingness to pay for additional trips. In other words it shows the traffic volumes as a function of perceived (average) cost. As long as the externalities are not charged for, the AC curve will represent the motorist's decision curve.

CAPACITY EXPANSION COST



On congested roads, the cost that road users experience are the vehicle operating and time expences (average cost, point B) only. The additional costs (marginal cost, point C) he/she imposes on other road users do not affect his/her travel decisions or behavior, because the user does not have to pay for these external costs him/herself. From economic point of view, the situation is not optimal because the demand is too high due to a too low price in peak hours compared to the total costs the society faces. The welfare loss to the society due to inefficient pricing is represented by the triangular area ABC. The solution to this is to price the negative externality of congestion, thus the road user would be charged the difference between society's marginal cost and the perceived average cost through congestion tolls.

Congestion pricing is charging for the use of road space. During rush hours, the capacity of the road becomes limited, because the momentary demand (traffic volumes) is greater than the supply (road capacity). Thus the price should be raised to reflect the scarcity. When price is increased, the demand drops inevitably, the more the higher the price elasticity is. The optimum is reached when demand equals the marginal social cost (point A) allowing for a more optimal use of the existing road network and putting less pressure on further capacity investments. In practice the price should depend on the level of congestion, but also on the amount of space used by each vehicle, so the price for larger vehicles would be higher than for smaller ones.

The most efficient pricing mechanism, marginal cost pricing, can thus be achieved in the traffic sector by implementing a road price, or toll, on congested road sections. The more congested a road section is, the greater the revenues through road pricing, because the demand exceeds the supply. Similarly to the private enterprise where (expected) profit is the sole incentive for new investments, congestion tolls are the only criteria for capacity expansion in the road sector. The intuition is clear: if a road is not congested, there is no demand for further capacity. According to the theory, the funds raised by congestion pricing would cover the road expansion investments, and environmental damage (which might be included in the investment cost of a project).

A uniform road price throughout the day is not economically efficient. If drivers who circulate outside the rush hours are charged the same amount as those driving in the peak hours, they participate in financing a capacity expansion they do not need. As they pay more than the marginal cost, they subsidize the drivers who actually need the capacity expansion and who are thus charged less than the marginal cost. Such a charging policy do not affect the congestion pattern as there is no incentive to change the timing of the trip or the mode of travel. The risk of over-investment is evident: as the distortions in the price structure imply too high traffic volumes, further investment in capacity seems justified.

3.2.3. Environmental externalities

Environmental costs should be charged by many different methods, as they are caused by many different reasons. First of all, the technical properties of a car affect the amount of damage it does to the environment: cars with catalyzers pollute less than those without, cars that use less fuel also pollute less, usually older cars are much more detrimental to the environment, etc. These costs can be controlled through different kinds of rules and regulations, but it is also possible to charge each car individually, depending on its technical properties, with a car tax, or as an additional expense. In addition to regulations, pricing can also be used to affect the consumers decision on what kind of car he/she plans on buying. In the ideal situation, the technical condition and the amount of pollution put out by each car would be checked i.e. yearly, and taxes would be defined for each car separately. This way old cars that have been used a lot would be charged a higher tax rate than cars of the same age, but with less use, and thus in better condition.

The amount of vehicle use is also an important factor when determining environmental damage: the more a car is used, the greater the damage. Because the amount of use is closely related to the amount of fuel consumed, the simplest way to pay for this kind of environmental damage would be with an additional fuel tax.

Because acceleration and idling cause more exhaust pollution than driving at a steady speed, environmental damage is greater on those sections of the road network where there is more congestion. Thus, the third form of environmental damage is based on the level of congestion on a road. The only way to pay for the damage caused in this manner, is by implementing a road pricing system in congested areas.

4. SOLUTION FOR QUALITY IMPROVEMENTS

Sometimes it is beneficial for society to improve the quality of the road network, even if there is no need to expand the capacity. These benefits stem from eliminating accident black spots, removing barrier effect, enhancing economic development, alleviating environmental damage, reducing queues due to bad quality of the road, etc. In these cases, revenues raised by congestion pricing will not act as a signal for necessary investments, rather a socio-economic cost-benefit analysis must be made to compare the road investment's cost, including environmental damage, with the benefits it would provide. In other words, a comprehensive cost/benefit analysis is the only way to determine the significance of the project in the absence of congestion pricing.

Although congestion is, according to the economic theory, the only criteria for capacity investments, road pricing can be applied to non-congested roads also. This makes it possible to improve the road quality even when increase in capacity is not necessary. If capacity expansion and quality improvement do not depend on each other (or mathematically if they can be assumed to be separable), quality improvements can be fully financed by user charges.

However, when capacity expansion and quality improvement are joint products (mathematically non-separable) the first best solution will not be reached. In such cases, too low traffic volumes and the existence of an alternative, free route (usually) do not allow for a first best marginal cost pricing, and besides, charging the non-necessary but joint capacity expansion from the few users only could make the charges irreasonably high. This calls for a second best solution where subsidies from Government budget are necessary in order to achieve an efficient solution. The amount of the subsidy is the smaller the higher the traffic volumes are.

One of the problems related to pricing in the absence of congestion is due to the fact that capacity expansion and improvement are usually joint products. In theory only the quality improvement should be charged from the users who benefit from it whereas in the absence of congestion the "additional" capacity expansion should be financed through other means, e.g. through general taxation.

The case for second best pricing occurs mainly outside the urban areas where congestion is not a problem but where there is need for improving the quality of existing roads and/or for building new connexions. In the second best solution, the price is set at the marginal cost (e.g. per kilometer of capacity) as in the first best solution. However, in the absence of the congestion externality, the price actually charged is lower and thus the funds collected are not sufficient to cover the total construction costs. Government or other modes of financing are thus necessary.

5. THE VALUE OF LAND

Similarly to pollution being a negative externality of road use, increase in the value of land due to a road investment is a positive externality. Both have in common the lack of a market or an explicit price. If the land owner is not charged for the increase in the value of land, he benefits from the road investment without participating in the financing

of it – or in other words there is a transfer of income from the society to the land owner. In order to internalize the positive externality of road investments, the increase of the value of land should be charged for also. In some cases, e.g. in the center of Helsinki where a major artery is planned to cross the town in a tunnel and which would reliese considerable amounts of new building land, the increases in the value of land would fully cover the road investment cost. (However, in the case of Helsinki, the City itself is the major land owner and is thus not attracted to the idea of an impact fee on land.)

6. RECOMMENDATION FOR FINLAND

6.1. Congestion pricing for Helsinki

The system based on congestion pricing and proposed for Helsinki is described below. The model is still rather rough, as it is difficult to determine exact prices, etc., without further investigation. This system would contain four charging levels: three toll rings around the city center plus a charge on the use of the Ring Road I, which circles the Helsinki area (see the map in Appendix 1). The streets of downtown Helsinki are not individually priced in this model, even though many of them are severely congested. This model indirectly takes the length of the trip into account, because the further away the vehicle comes to the center, the more toll stations it passes.

1) The innermost ring encompasses the downtown area. The first toll zone would be composed of 10 tolls stations, which would collect tolls from vehicles entering the downtown area during the morning rush hour (7:30 – 9:00), and from those leaving the downtown area during the evening rush hour (16:00 – 17:30). The congestion is at its worst in the downtown area, so the toll should be higher here than in any of the other toll zones. Once practical experience has been obtained, it would be easy to change the price of the toll according to the degree of congestion.

2) The second toll zone would cover the area immediately south of Ring Road I. There would be 9 toll stations which would work during the same time period as the ones in the first toll zone. Because the congestion in this toll zone is less than in the first toll zone, the price should also reflect this.

3) The toll stations of the outermost toll zone would be placed on the southern side of Ring Road III (for historical reasons Ring Road II does not exist). There would be 10 toll stations, which would also work at the same time as in the other toll zones. If the toll system is to be implemented gradually, this toll zone could be added on at a later date. This would also allow for examining the effects of the toll zones on traffic volumes and peek hour traffic. As this toll zone is the furthest from the downtown area, its price would also be the smallest.

4) Because the congestion on Ring Road I is very severe, there is a need for pricing its use. There should be 5 toll stations on this road, which, if necessary, could collect a toll from traffic travelling in both directions at the same time.

6.2. Organization of the system

In the following proposal concerning the organization of the road sector pricing and fund raising system, the existing system has been used as a starting point and its benefits has been taken fully into account.

1) Maintenance (fuel tax) – taxes would be collected directly in the price of the fuel like they are now, and would be put into district "accounts" according to traffic volumes in the different highway districts. In order to keep maintenance costs low, competitive tendering of the different maintenance tasks is recommended;

2) Capacity investments (congestion pricing) – tolls collected would be put into a road fund, which would have a clear list of necessary projects based on cost/benefit analyses. As with maintenance, competition in the construction markets should be ensured.

3) Quality investments including new connexions e.g. replacing a ferry by a bridge, but where there is not congestion (road pricing) – the collection of the revenues could be organized as described in the previous case. It is also possible and probably more efficient to form a company for every project, which could be composed of the state and/or district, private road builder(s) or toll company and land owners.

4) Environmental costs (car and fuel tax, congestion pricing) – probably the most practical solution is to continue collecting taxes in the fuel price, and gradually introduce a yearly "pollution fee" depending on the technical properties of the vehicle in addition to a congestion toll.

7. "EAR MARKING" OF THE FUNDS

7.1. General ideas of "ear marking"

It is commonly held to be self-evident that tax money which is raised from the road sector can be "ear marked" for this sector. In other words, all the money raised from the road sector chould be spent in the road sector. This is not necessarily the case, and currently there is much debate going on about this in economic literature.

The usual argument against "ear marking" is that it can lead to non-optimal allocation of society's resources. It is possible that some sectors, whose services are not readily priceable, get less money than they should, thus lessening the wellfare of the society as a whole. "Ear marking" tax funds also reduces the governments power to

allocate money from the "general funds", as it is often difficult to determine what is the optimum level. If a certain sector raises more money than it needs, resources are wasted. On the other hand, if a sector does not raise the money it needs, "ear marking" has not accomplished what it should have. For the entire society, the optimum situation is reached when one additional unit invested in one sector (marginal cost) produces as many units of benefits as the unit invested in all of the other sectors. Ear marking taxes could ruin this economic balance.

The closer a public product is to a product on the competetive market, the more justifiable it is to use the price recieved from that product for investments in that sector. In this case, the principle "user pays" justifies "ear marking". Road use charges also make it possible to privitize roads, or to collect the necessary funding from the private sector, for example through loans which are paid back with the road use fees. In this way it is possible to raise large amounts of capital which would otherwise be difficult to collect.

7.2. Road users and road charges

Road pricing is an attractive approach for road funding, even from the road users view point, because it adheres to the "user pays" ideal. It is, however, possible that in the practice the effects of road pricing on the supply and demand in the road sector will be very different from what is expected, especially in countries where the perceived cost of road use has traditionally been "free of charge". If the road users see the road pricing only as a new way of collecting money from their already heavily taxed pockets, without getting anything in return, it is probable that they react in a hostile way towards direct road user charging.

According to a series of studies by Jones (1990, 1991) which examined how road users reacted to different kinds of traffic policies which were meant to ease congestion in London. Most people were for improving mass transportation efficiency (69%). Partially restricting traffic in the downtown area also had quite a bit of support (53%). Congestion pricing was not one of the more popular ideas among road users, most of them were against it (34% for and 46% against). Studies done elsewhere in Britain and Norway also achieved similiar results, in other words congestion pricing was far less popular than traffic restrictions.

This situation changes clearly when road pricing is connected to some sort of traffic policy package. In other words, road pricing is much more likely to be approved of when it is seen as an important part of investments which improve public traffic, make optimum decisions regarding the environment and pollution, and lastly increase the capacity of existing roads.

7.3. Conclusion

To return to the recomendation for installing a road pricing system in the Helsinki area described in the previous chapter, it is easy to see that much time and effort must be put towards marketing and making the system an integrated part of the traffic sector around the Helsinki area. International experience shows us that the best way to introduce

a road pricing system is in a three part package. This package should evenly involve the following issues related to the traffic sector: 1) alleviation of environmental damage caused by traffic, 2) improving the current level of service of mass transport systems, and 3) necessary capacity investments for car traffic.

It is also important to ensure that the development package is concrete: the operations for improving the environment must be clear and simple; the money directed towards public transportation cannot be "wasted" in increased production costs, rather the money needs to be used for making mass transportation a better option by improving its service level and flexibility; and road investments need to be "ear marked" for specific projects so that the buyers (road users) know what they are getting for the money they are charged for. And finally these promises must be kept according to a declared schedule.

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