A PRELIMINARY ASSESSMENT OF THE RATIONALE AND SCOPE OF IMPLEMENTING CONGESTION PRICING IN DELHI NCR

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Abstract

Delhihaswitnessedsubstantialgrowthinpopulation, income and vehicles over the past few years. The projected trends indicate furtherrapid growth of these variables,whichcouldresultinworseningofthetrafficcongestionprobleminthemetropolis.Trafficcongestionisanurbanmenacethatimposesseveralcostsonthesociety.Thisnegativeexternalityisaresultofthe socialcostsnotbeingtakenintoaccountbyindividualdecision-makers.Congestionpricingisa manner through which the social costs can beinternalizedint oprivate decisionmaking, therebyeliminatingtheexternality.GiventherecentinterestoftheDelhiTrafficDepartmentinthispolicy, itisessentialtoexamineitspotentialwelfareimpacts.Thisstudyattemptstoachievethefollowingobjectives:determinethecongestioncostsandassesstherationaleofintroducingcongestionpricinginDelhi;discussthefeaturescriticaltothesuccessofcongestionpricingandidentifytheexistingknowledgegapsscope forfurtherresearchintothisarea.Thequalitativeresultsofferastrongrationaleforimplementingacomprehensivepolicywithcongestionpricingasitscentralcomponent.Therecentexperienceofothercitieswiththismeasureprovidesusefulinsightsintodesigningandimplementingthepolicytoensuremaximumwelfaregain.Theanalysisemphasizestheroleofpoliticalwillandcommitmentandtheimportanceofefficient designandenforcement measures inframingan effective policy.

Keywords:traffic,congestionpricing,externalcongestioncosts,externality,policydesign, enforcement

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1. Introduction

Delhi, the capital city of India, has been growing rapidly over the past few years, both in terms of average income and population. This growth can be attributed to the recent spurt of economic activity, and in-migration from neighbouring states. Closely associated with the increased incomes and population, is the need for personal mobility for occupational, recreational and other purposes. High travel demand, coupled with the long trip distances owing to the mushrooming of important satellite towns such as Gurgaon and NOIDA, has contributed towards the escalation of total travel on the Delhi road network, and consequently, congestion.

1.1 The reasons behind congestion

According to official statistics, the Delhi road network, which incidentally is the one of the most extensive networks in the country, has been expanded by about four times in the past three decades. However, this expansion of the road infrastructure has been dwarfed by the gigantic vehicular growth of about 26 times, in the corresponding period. This huge dichotomy between the growth trends in roads and vehicles is the proximate cause of traffic congestion. The underlying factors explaining this trend are outlined below:

a. Increase in private vehicle ownership

A combination of factors such as advertising, emergence of a middle class that considers the ownership of vehicles a status symbol, and easy terms on car loans has contributed towards the increase in private vehicle ownership in Delhi. Easy availability of inexpensive parking has played a role in further fuelling this growth. Figures reveal that cars and two-wheelers constitute bulk of the motor vehicles in Delhi.

A large number of private vehicles with low occupancy rates—that is, carrying very few people in comparison to public transport—result in congestion, by choking off the road capacity.

b. Neglect of sustainable transport options

The effects of increased private vehicles on congestion have been further accentuated by the gross neglect of sustainable modes of transport such as public transit and non-motorized transport (primarily walking and cycling). Poor maintenance and unreliable service, lack of safety and frequent accidents have been the problems consistently associated with the public bus transport in Delhi, leading to its unsatisfactory patronage. In addition, lack of facilities such as clean and safe sidewalks for pedestrians and clearly demarcated lanes for cyclists has resulted in the use of cars or scooters even for short distances, further worsening the congestion situation.

Other traffic characteristics such as lane indiscipline, poor maintenance of the traffic network system (signalling, stop signs) and the dismal condition of roads (potholes, piling of construction debris, on-street parking) have further contributed to recurrent and non-recurrent congestion.

1.2 Consequences of congestion

Congestion is considered an urban nuisance due to the various damages it imposes upon the society. Among the most important costs it imposes are journey time unreliability, higher vehicle operation costs and pollution. Journey time unreliability occurs due to unexpected time delays arising out of the sudden formation of queues, stop-and-go traffic conditions and low average speeds. Wachs (2002) asserts that high variability in travel times resulting in "schedule delay costs" is of great concern to commuters because it makes planning for a trip difficult and unreliable. Time delays thus suffered by commuters comprise of important losses (of productive time) to the society. Further, the increased fuel consumption (because of "idling"), frequent acceleration (due to the stop-and-go traffic) and the tendency for engines operating at low speeds to emit more of certain pollutants result in higher emissions and pollution (Stopher 2004), apart from contributing towards greater wear-and-tear (and hence higher maintenance and operation costs) of the vehicle. Driver stress, road rage and noise are other undesirable effects of congestion (Wachs 2002, Bilbao-Ubillos 2008).

1.3 Taxes as a correction to the congestion externality

The conventional Pigouvian theory suggests that negative externalities can be corrected by imposing a Pigouvian tax equal to the marginal external cost (difference between marginal private cost and marginal social cost) at the optimum (Rouwendal & Verhoef 2006). This Pareto efficient solution is said to "internalize" the externality by making the private cost and social cost coincide (at the optimum) and resulting in the agent taking an optimal decision.

Thus, to arrive at the socially optimal level of tax required to contain congestion to the efficient level, information is required on the marginal external cost of congestion (in addition to the demand (marginal benefit) function).

The rationale of congestion taxes is that making the marginal trip-maker pay for the use of the road link/network will induce behavioural changes: namely, reduced overall travel, increased carpooling, shifting trips to off-peak periods and modal shift in favour of public transport (Parry 2008, Rouwendal & Verhoef 2006). Since the tax will drive up the private costs of driving, the marginal trip-maker with a trip valuation less than the tax rate will forego the trip (in a private vehicle) and hence the traffic volume will converge towards the socially efficient level.

Further, an argument often given in favour of congestion taxes is that it raises revenue, which can be redirected towards investment in public transport and road infrastructure (Rouwendal & Verhoef 2006, Parry 2008).

Although numerous attacks on such a policy have been made (with regard to equity, public acceptance, political feasibility and efficiency criteria), cities such as Singapore, London and (more recently) Stockholm have experimented with congestion pricing and found it to be a useful measure to contain congestion. A careful study of the experience of these cities can provide us with useful lessons regarding the potential implementation of such a policy in cities such as Delhi.

2. Objectives

Given the problems associated with congestion, and projections indicating substantial increases in vehicle ownership in the future, it is imperative to identify the magnitude of the potential effects of congestion and devise effective measures to contain this menace. Motivated by this need, the objectives of this paper have been identified as follows:

a. To numerically quantify congestion costs for Delhi, using economic modelling.
b. To discuss the need and rationale for congestion pricing, a tool proposed by economists to contact congestion.
c. To discuss the crucial features of an effective congestion pricing policy.

3. Data and Methodology

3.1 Materials and Data Sources

This study employs secondary data from reports published by different government and private agencies, such Planning Department, CRRI, RITES, TERI, Wilbur Smith Associates, EMBARQ[1] and others. Academic literature was also consulted to compile information on various estimates.

In addition, scholarly papers were referred to for the purpose of literature review and understanding the critical (economic and policy) elements of congestion pricing.

3.2 Methodology

3.2.1 Calculation of congestion costs for Delhi

The study makes an attempt to calculate the external time costs imposed on the society due to congestion in Delhi. For this purpose, we follow the models discussed in Sen et al. (2010). The model used by Sen et al. (2010) is set out in the following paragraphs.

The relation between time taken for a journey (inversely related to the speed) and traffic volume (calculated as PCU km/hr) is estimated using the following time-flow equation:

$$t_{ij} = \frac{60}{s_{ij}} = A_{1,j}\left[A_2 + A_3 e^{(A_4 \cdot q_i)}\right] \qquad (3.1)$$

Here,

t_{ij} is the time taken in minutes (inversely proportional to speed, s_{ij}) to travel one km by mode 'j' in period 'i' (peak or off-peak)

q_i is the PCU km per hour travelled in period 'i'

A_i (i=1 to 4) are the parameters to be estimated

Using the parameter values, the following equation gives the external congestion costs:

[1] CRRI: Central Road Research Institute; RITES: Rail India Technical and Economic Services; TERI: The Energy and Resources Institute

$$MECC_{q_i} = \sum_j \frac{\partial t_{i,j}}{\partial_{q_i}} x_{i,j} \mathrm{VOT}_{i,j} \qquad (3.2)$$

Where,

$MECC_{qi}$ is the external congestion cost of an additional PCU km

x_{ij} is the passenger km travelled by mode *j* in period *i*

VOT_{ij} is the value of time per passenger

This equation values the increase in journey time imposed by additional traffic on the road ($\frac{\partial t_{ij}}{\partial q_i}$) at the value of time of each passenger.

The model has been modified slightly to suit the data available. The detailed methodology is explained in **Appendix A.1**.

4. Observations and Discussion

4.1 The burden of congestion in Delhi

The severity of congestion is quite high in Delhi—as indicated by the Mobility (Congestion) Index reported by Wilbur Smith Associates (2008). The findings suggest that the figure for Delhi is 0.47—which is the highest among the 30 investigated cities. In a study by Sen et al. (2010), an economic model (Mayeres 1993) has been applied to estimate the marginal congestion costs (in terms of time delays) and other external costs (noise, pollution and accidents) imposed on the society due to traffic. The authors report that the marginal external cost due to congestion incurred per vehicle-km is in the range of Rs. 4.91 to Rs. 9.82 (USD 0.109 to 0.218) during peak-periods for different kinds of vehicles.

The congestion costs reported in this study have been calculated as Rs. 20 per vehicle-km during the peak period. Precise results are presented in **Table 4.1**.

Table 4.1: Estimates of congestion costs for Delhi

Methodology followed	**Estimates for marginal congestion costs in the peak-period (Rs./Vehicle-km)**	
Sen et al. (2010)/Mayeres (1993) (details given in Appendix A.1)	Car/Taxi	6.05
	Bus	11.86397796
	Two-wheeler	1.603353346
	Auto (three-wheeler)	0.891857938
	Total	20.409

Source: Author's calculations

Even though these estimates are possibly downward biased, because of the neglect of road conditions and other factors affecting vehicle operation costs, and the lack of adequate data, multiplying the cost per vehicle km by the aggregate daily vehicle-km gives an indication of the magnitude of monetized time delays imposed upon the society.

4.2 The need for congestion pricing

Given the problems associated with congestion, it is imperative that Delhi takes urgent measures to contain it. An ‘obvious’ supply-side solution to contain congestion often offered is to increase road network capacity: since congestion occurs when demand outstrips capacity, it sounds reasonable to invest in road-building to meet the growing demand (Stopher 2004, Parry 2008). However, there are limits to increasing capacity, especially in a city such as Delhi—practical constraints to road building, including concerns of land acquisition, environmental impact and the substantial capital costs involved make it unviable to further expand the already extensive network (Parry 2008, Bureau of Infrastructure, Transport and Regional Economics 2008). Moreover, as is evident by past experience, increasing capacity often results in a corresponding increase in demand and traffic volume, ultimately resulting in higher congestion in the medium- to long-run (Rouwendal & Verhoef 2006, Parry 2008).

Another supply-side measure suggested is reducing urban sprawl and encouraging compact cities with mixed-use land pattern. Many regions in Delhi already have a mix of commercial and housing development (Tiwari 2003); however, as noted elsewhere in this report, the growth of satellite towns in the NCR has amounted to a manifold increase in the travel requirements to and from the city core to the periphery. Despite the presence of direct Metro routes, road traffic to and from these areas is substantial—a RITES (RITES et al. 2010b) study reports an estimate of about 1.2 million vehicles entering Delhi from nearby areas (Gurgaon, NOIDA, Faridabad and Ghaziabad) daily. Presumably, a high proportion of this travel demand comprises of work-related trips; hence it is not clear how can this existing structure be retrofitted so as to reduce the need for mobility in and out of Delhi.

Without doubt, addressing the issue of skewed modal split can help ease congestion on Delhi roads. Some of the measures to encourage public transport usage are subsidization of fares and expanding the public transit system (Sen et al. 2007). However, unilaterally decreasing public transport fares may not help much, given the low own-price elasticity (responsiveness) of public transit—Deb (2010) reports an own-price elasticity of -0.46 for public transport buses for a sample of 22 Indian states, while Sen and colleagues (2007) estimate it to be -0.18 during peak-period (-0.66 for off-peak period) for Delhi[2]. Although these estimates may be downward biased, as the analysis does not include other modes of public transport (Metro, three-wheelers etc.), the substantially small estimates imply price *inelasticity*—in other words, subsidizing fares is not expected to increase ridership proportionately, and might prove to be a burden on the exchequer. Thus, measures other than subsidizing fares need to be explored to improve the modal split—this is where the rationale of implementing congestion pricing is highlighted. Since the scope to implement the measures discussed above is limited, and their effectiveness is questionable, the classic solution suggested by economists, that of *congestion charging* needs to be considered as a possible option (Bureau of Infrastructure, Transport and Regional Economics 2008). This policy works through the price mechanism, and if designed and enforced carefully, can induce a desirable modal shift, in addition to generating revenues for the Treasury. An examination of the features of an "ideal" congestion pricing scheme is carried out in the following section, drawing upon the experience of this policy in other cities.

4.3 Examining the features of an "ideal" congestion charging scheme

Before considering the implementation of a congestion charging scheme in Delhi, it is necessary to understand the features that contribute to the success (or failure) of such a policy—to accomplish this, we have the benefit of learning from the experience of other cities; their

[2] The figures are interpreted thus: for a doubling (100% increase) of bus fares, there will be a 46% corresponding decrease in ridership (and vice versa), according to (Deb & Filippini 2010), and 18% decrease, according to the estimate by (Sen et al. 2007). Since the absolute value of the estimates (0.46 and 0.18) is each less than 1, the demand is said to be *price inelastic.*

drawbacks and strengths act as guiding forces for us to design our policies so as to ensure maximum social welfare gain.

The three broad themes that one may be concerned with while sketching out the policy are *design*, *implementation* and *enforcement*. Although these components are interrelated, a careful examination of their individual features is warranted.

The choice and *technical design* of the optimal charge are the first steps in drafting the scheme.

First, a choice between area/cordon charging scheme and facility charging needs to be made. An *area license* or *cordon charging scheme* imposes a charge (either a flat rate as in London or time-differentiated as in Stockholm) for entry and travel within the "tolled area"—the charge can be on a per-entry basis (as in Stockholm) or a "day pass" (as in London). Given the examples of this scheme in Singapore, London and Stockholm, the central business district of Delhi—Connaught Place (CP)—is an eligible area to implement such a policy. However, the relatively small geographical area[3] of CP might make investment in the scheme unviable from an economic standpoint. Moreover, given the subsidized parking charges, there might be an incentive to park cars right outside the chargeable zone, apart from traffic spill over on the neighbouring roads. A more practicable option would possibly be to include the area bounded by the Inner Ring Road (a 40 km (25 mile) long arterial road) into the tolled area. Apart from increasing the expanse of the chargeable zone, the Ring Road will also serve as a "barricade" to the tolled area, similar to the natural geographical boundaries used to demarcate the cordons in London and Stockholm. Since there exist many entry/exit points from the Ring Road into the road network, such a scheme will require investment in transponders and possibly GPS-based technology as well, to ensure effective monitoring.

Another option to consider is *facility charging*, where a toll is charged for the use of a 'facility'—here, a road. The links that witness heavy traffic volume during peak hours in Delhi include Ring Road (near Sri Venkateshwara College), Mathura Road, Outer Ring Road (near Soami Nagar), Swarn Jayanti Marg (near Dhoula Kuan) and Gurgaon Road (near Mahipalpur), among others (RITES et al. 2010b). Introducing HOV (High Occupancy Vehicle/HOT (High

[3] CP is spread over an area of about 0.186 km^2, while the toll areas in London and Stockholm are spread over 25 to 40 km^2.

Occupancy Toll) lanes is an example of facility charging that could be implemented on these individual road links—in such a scheme, high occupancy vehicles with minimum two or three passengers (buses, car-pools) are rewarded by dedicating special lanes to them; at the same time, single occupant vehicles can utilize the HOV lane by paying a toll. However, there are very few examples of successful implementation of HOV/HOT lanes internationally, and the effectiveness of this policy is also ambiguous. Moreover, implementing such a policy in Delhi will be especially difficult, given the lane indiscipline among drivers. In addition, investment in cameras to capture the images of vehicles (to identify the number of occupants) will be required—which may drive up costs in the long run. Nevertheless, the Delhi government is contemplating a distance based congestion charge of about Rs. 15 (USD 0.33) per day on Delhi roads, which can be construed to be a variant of facility charging (Transport Department, Govt. of NCT, Delhi 2010).

Once the location and type of pricing is decided, the next step is to determine the *optimal toll rate*. Since welfare gains which accrue to the society will depend largely on the charge level, it is necessary that it be based on economic theory. The efficient tax rate will be given by the magnitude of the marginal external congestion cost, which can be determined using economic modelling and computer simulations. Robust assumptions on time valuations, travel demand elasticities and traffic characteristics will be required to accurately measure congestion costs, which will further aid in the determination of the optimal charge. Although (Santos & Fraser) (2006) emphasize that political considerations govern the choice of charge level, and hence the policy design may not always be based on economic theory (but might still improve welfare), the knowledge of congestion costs will also serve as a benchmark to compare the imposed toll rate with, and assess the difference between the ideal and actual welfare gain, if any.

A feature that is of extreme importance is the time-dependence of charges. Since congestion is time-variant, ideally the tolls should also be time-differentiated. However, a minute-by-minute variation of tolls may not be practically feasible, and even if so, would be too costly and also result in information overload for commuters. On the other hand, a flat rate will not fully internalize the congestion externality, especially if there is high variance between traffic volumes during peak and off-peak hours[4]. The Stockholm structure of charges finds a “middle path”; charges increase and decrease (although not continuously) in line with peak hours—the charges for different time intervals are presented in **Table 4.2**. This is a possible model that can be followed while determining the charges in Delhi.

Table 4.2: Stockholm’s congestion charges in different time intervals (levied on weekdays only)

Time interval	Charge
0630—0700	10 kronor
0700-0730	15 kronor
0730-0830	20 kronor
0830-0900	15 kronor
0900-1500	10 kronor
1530-1600	15 kronor
1600-1730	20 kronor
1730-1800	15 kronor
1800-1830	10 kronor

Source: Eliasson et al. (2009)

A crucial component of the congestion pricing scheme is the exemption or concession given to some vehicles. Vickrey (1992 cited in (Bureau of Infrastructure, Transport and Regional Economics 2008)) asserts that these ‘special provisions’ amount to compromising upon the efficiency of the policy—for instance, in London, usage of exempted taxicabs increased, while in Stockholm, the Lidingö exception pushed up monitoring costs. However, going by the experience of these cities, it appears to be often necessary to introduce these provisions because of the political considerations involved—without these exceptions, it might even be difficult for the policy to see the light of the day. This issue is discussed in further detail below.

The next broad area to be considered is the *implementation* of the policy. This is especially a crucial area for Delhi (and India, in general), since our otherwise sound plans and policies usually perform unsatisfactorily in the implementation stage. The measures that are important in the implementation of this policy are described in the following paragraphs.

First, it is essential to develop and accurately *test the technology* which is to be employed in the policy. Since electronic congestion pricing depends largely on the smooth functioning of technology used, technology-testing is an integral component of the implementation strategy.

[4] The London charge was chosen to be a uniform rate since there was not much difference in peak and off-peak speeds. Presumably, the level of congestion was uniformly high throughout the day.

Errors in the technology used can be a source of confusion and increased costs—for example, in London, initially, the automatic number plate recognition system had trouble distinguishing the digit zero (0) from the letter 'O', and the digit 1 (one) from the letter 'I' which led to complaints and appeals.

As discussed elsewhere, a desirable modal shift will occur if the elasticity of demand for public transportation travel is high enough. This will happen if there exist sufficient *alternatives* to private transport. It follows that for congestion pricing to be successful, steps need to be taken to encourage public transport and non-motorized vehicle transport (walking and cycling). These modes of travel will need to be made more convenient, comfortable and affordable, so that they become a viable alternative to public transport. Measures to achieve this include increasing bus fleet and coverage, introducing new routes, improving frequency of buses and metro service (to reduce waiting time) and improving the quality of service. The latter is especially important, as evident by the findings of (Deb & Filippini 2010)—they estimate a bus demand elasticity of 0.834 with respect to service quality. This high and significant figure suggests that improvement in service quality of buses (and public transport in general) can induce a modal shift in favour of public transport. Providing facilities for walking and cycling (clean and wide sidewalks, bicycle lanes, shared biking system etc) can also go a long way in achieving a desirable modal split.

Recently, a "Mega Car Pool" scheme has been launched in Delhi NCR to formalize and centralize the car-pooling system. This ambitious model uses sophisticated GPS and smart-card based technology to encourage and facilitate car-pooling to reduce congestion across the state (Mohan 2009). However, this appealing scheme will need to be strongly advertised as a safe and effective option, to induce people to make full use of it.

Further, high parking fees, fuel taxes and registration charges (McCarthy 2001) can be introduced to discourage private vehicle ownership and use, as has been done in Singapore. In addition, investment in improvement of road infrastructure and traffic signalling system can help contain incidental and network-and-control congestion, thereby improving the effectiveness of the congestion pricing scheme. In short, a *comprehensive policy* needs to be implemented, which includes public-transport inducing 'carrots' along with car-use restraining 'sticks'. Ideally, these measures should be taken simultaneously; however, some of these can also occur in response to the observed behavioural responses.

It is clear from the above discussion that substantial investment is needed to successfully implement the policy. The revenues from congestion pricing can be utilized for the investment mentioned above—such an earmarking of revenues for specific purposes is known as *hypothecation* (Leape 2006). However, earning revenue should not be the primary motive of the scheme, since congestion reduction and earning revenue are incompatible objectives—if congestion reduces a lot (cars are 'priced-off' the roads), revenues won't be too high, and vice versa.

Hypothecation is an important feature of the policy from the 'acceptance' point of view as well. Undoubtedly, this policy is controversial and presumably unpopular (perhaps this is the reason only a few cities have experimented with it)—hence, diligent measures are required to make the policy acceptable to the public. Not surprisingly, acceptance literature forms an integral supplement to the economics and policy literature on congestion pricing.

The primary reason that the policy is unpopular is because it levies charges on a public good that is viewed *free* by the public. Moreover, this policy creates unambiguous winners (revenue collecting agency, those involved in operation of the scheme, road users with high VOT, those who receive exemptions or concessions) and losers (those who pay and stay, the "tolled-off", users of alternate routes which now may witness higher traffic volume)(Bureau of Infrastructure, Transport and Regional Economics 2008), and unless individual interest groups are 'compensated' for their respective losses, public acceptance is difficult to come by. This is where hypothecation plays an important role. Small (1992, cited in (McCarthy 2001)) suggests three possible uses of revenue to benefit various interest groups, and hence secure public support: reimburse road users directly, replace existing taxes (travellers and general public gain through these measures) and invest in new transportation services and infrastructure (to benefit business centres).

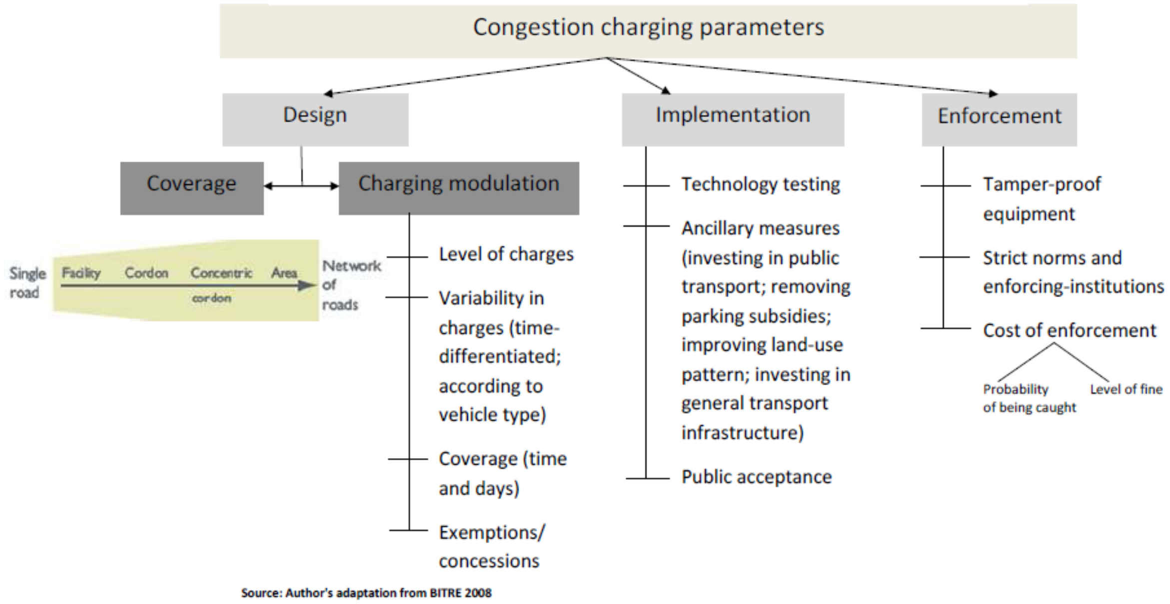
Other reasons why this policy is unpopular is because it is often viewed as a threat to privacy and also considered regressive. London and Stockholm worked around these issues by taking the public into confidence through extensive public awareness campaigns and feedback sessions. The community was made aware of the benefits of introducing congestion pricing and misconceptions were clarified; policy design was modified to accommodate the community's interests. These measures enthused the community and diluted the initial hostility against the policy. This is an important lesson for Delhi authorities—not long ago, there were protests against the construction of an elevated Delhi Metro track in South Delhi, because the public was not informed about the benefits and cost-effectiveness of an elevated track over the underground one. Further, transparency, accountability and simplicity of the policy aid in turning public opinion positive. Given these examples, it is unmistakable that *public acceptance* is indispensable for the success of this policy (and any policy, in general).

However, as highlighted by Vickrey (1992 cited in (Bureau of Infrastructure, Transport and Regional Economics 2008)), there exists a trade-off between achieving the technical objectives and making the policy publicly acceptable. Exemptions and discounts, given to secure public support, also dilute potential efficiency gains. Ensuring a balance between these two goals is the true test of authorities.

The third crucial element of the policy package concerns *enforcement*. Measures include strict number plate design norms (to correctly enforce charges, concessions and penalties) and parking regulations (to contain illegal parking). Further, it'll be important to ensure that the equipment used (transponders and ANPR cameras) is tamper-proof. In addition, strict institutions will be essential to identify evaders and take suitable action against them, and also to improve compliance. For instance, London has exorbitant penalties (upto £150) for non-compliance; frequent offenders are also liable to have their vehicles impounded (Walder 2007)—such regulations naturally deter evaders by increasing the cost of non-compliance. Delhi transport authorities can also consider giving benefits/rebates for timely payment, to improve compliance.

Figure 4.1summarizes the above discussion diagrammatically.

Figure 4.1: Parameters for congestion pricing policy



While the design aspect of the policy is dependent on the expertise of transport economists, engineers and architects, effective implementation and enforcement are largely the functions of political will and commitment. London's example clearly illustrates the role of political will in implementing the policy and also getting it accepted by the public. The complex nature of this policy requires considerable investment of time and resources; moreover, conceptualizing and implementing the policy often involves substantial delays below[5], and carrying the policy to its logical conclusion requires remarkable dedication and political resolve.

Although there is a lot to learn from the examples of other cities, Lee (2008) asserts that key aspects of the *planningprocess* and not just the scheme need to be replicated, for successful policy transfer. The upshot of the argument is that the policy features can't be blindly applied, especially in a developing country such as ours, without carefully understanding the relevant political, social, economic and cultural context.

4.2 Limitations of the analysis

[5] The London congestion pricing scheme took almost 40 years to see the light of the day (Bureau of Infrastructure, Transport and Regional Economics 2008)

The congestion costs estimated in this study vary significantly from the ones reported in the literature. Limited data and simplifying assumptions could have led to a bias in the results. Moreover, only time costs have been estimated and other effects such as noise, pollution and accidents have been ignored. Further, the effect of road type and vehicle mileage on congestion costs has not been incorporated into the analysis due to limited data.

In this report, the analysis of the desirable policy features is based on a small sample of developed countries. Further assessment of the policies implemented in other cities can provide a more comprehensive understanding of the components of an "ideal" policy.

5. Conclusions

Traffic congestion is one of the worst by-products of growth in urban areas. For a long time, economists have suggested congestion pricing as an efficient measure to internalize the congestion externality. The recent experience of cities with this policy has encouraged other cities to experiment with it—Delhi being one such region.

The congestion problem in Delhi has worsened over the years, owing to rapid urbanization, income growth and other traffic characteristics. The projections for future trends in vehicle and population growth indicate a potential accentuation of this problem, if immediate measures are not taken. Gauging the seriousness of the issue, the Traffic Department of NCT, Delhi is considering congestion pricing as a possible corrective measure.

Motivated by this decision of the Traffic Department, the present study makes an attempt to assess the rationale of introducing congestion pricing in Delhi. The important elements of an effective policy have also been discussed, drawing upon the experience of other cities. The following suggestions can be made about the Delhi policy proposal in the light of the lessons drawn from recent examples of cities that have experimented with this scheme.

- The congestion charge should approximate the actual marginal external cost, given the estimates reported in the literature. However, as the results reported in the present study suggest, further investigation of the external congestion costs using more recent and accurate data, and robust methodologies is warranted.

- The proposal must put into place a "traffic management package" incorporating measures to discourage vehicle usage, penalize peak-hour congestion and improve the public transport system. However, the focus of the policy should not be solely raising revenues. It is important to shift the focus away from using congestion pricing as a revenue-generating mechanism. The objective of the policy should be well-defined and unambiguous—multiplicity of goals needs to be avoided.
- The potential opposition to the policy should be considered. Securing public support through public service messages and feedback is a crucial step in ensuring the success of the policy.

This evaluation suggests that the key to success is to frame a comprehensive strategy suited to the local context, with congestion pricing as its central component. Further, issues of political acceptance and enforcement call for more attention than what has been discussed in the current proposal.

This is the first study which has attempted to make a preliminary assessment of the feasibility of congestion pricing in Delhi. Primary investigation suggests a strong rationale for the introduction of this policy. Nevertheless, as discussed earlier, further research into this area is justified—better data and assumptions can aid in accurately identifying the magnitude of the congestion externality, and thereby correcting it. The recent interest of the traffic authorities in this measure and its policy relevance highlight the need for such research. The experience of other cities provides important insights regarding the elements of congestion pricing, and further understanding of the policy structure can help us in avoiding design and/or implementation flaws and ensuring maximum social welfare gains from what could be a potentially effective and efficient solution to the congestion problem in Delhi.

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Appendix A.1

The work by Sen et al. (2010) estimates the parameters of the following regression:

$$t_{ij} = \frac{60}{s_{ij}} = A_{1,j}\left[A_2 + A_3 e^{(A_4 \cdot q_i)}\right]$$

The current study estimates the costs for four vehicle types, namely cars, two-wheelers, three-wheelers (auto rickshaws) and buses. Thus, there are seven parameters to estimate (A_{1j}, j=1 to 4, A_2, A_3 and A_4). However, our data consists of only eight observations (four vehicles in peak- and off-peak-hours each). To get plausible results, the model was modified in the following ways:

Model 1:

$$t_{ij} = A_{1j}[1 + A'_3 e^{q_i}]$$

The parameters thus reduce to five.

Model 2:

$$t_{ij} = A_{1j}[e^{q_i}]$$

The parameters further reduce to just four in this formulation.

The parameters of these non-linear models were estimated using the first principles method of minimizing the residual sum of squares[6]. The steps are described below:

- Vehicle kilometres were converted in to PCU km by multiplying with the respective PCU values. (Peak-hour traffic volume was assumed to be 72% of the total daily traffic (RITES 2010b)).
- The residuals (t_{ij}-predicted value) and squared residuals were calculated.
- The sum of squared residuals (RSS) was minimized with respect to the estimated parameters.
- Once the parameters were obtained, $\frac{\partial t_{ij}}{\partial q_i}$ was computed.
- Using the derivative values, the costs were calculated using the following relation:

$$MECC_{q_i} = \sum_j \frac{\partial t_{i,j}}{\partial_{q_i}} x_{i,j} \mathrm{VOT}_{i,j}$$

(x_{ij}, the passenger kilometres were computed by multiplying vehicle kilometres with the occupancy rates of vehicles).

The data and sources used for the analysis are presented in **Table A.1**.

[6] The software used was Solver in MSExcel. An iterative process was used to determine the parameters.

Table A.1: Data and sources

Vehicle type	Vehicle kilometre (million per day)	PCU	Vehicle Occupancy	Value of time (Rs. per hour)	Average peak-period speed (km/hr)	Mileage (km/l)*		
Car /Taxi	30.689	1	2.2	105	30	Petrol		13.60558
						Diesel		14.3284
						CNG		17.8279
Two-wheeler (Scooter, Motorcycle)	33.823	1.4	1.2	54	35	Scooter	2-stroke	35.817
							4-stroke	43.995
						Motor-cycle	2-stroke	45.68
							4-stroke	54.44
Three-wheeler (Auto)	9.357	11.7	2.1	39	22	29.938		
Bus	2.851	2.4	65	30	12	5.82709		
Source	Jalihal 2005	Tiwari 2000	RITES 2010a; Sen et al. 2010	RITES 2010a	Mohan 1997; Kumari 2007			

*km/kg for CNG vehicles

Note: Fuel prices assumed to be Rs. 50/l (petrol), Rs. 29/kg (CNG) and Rs. 37 (diesel)