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Estimating marginal external costs of transport in Delhi

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ABSTRACT

This paper develops the model and methodology to estimate the marginal external cost of urban road transport, which is necessary for analysing optimal urban transport prices. Four major marginal external costs analysed in this paper include the marginal external costs for congestion, air pollution, road accidents and noise. The paper estimates the marginal external costs for cars and buses in peak and off-peak periods for Delhi urban agglomeration for the year 2005.

1. Introduction

With the rapid growth of urbanization in the recent decades, urban transport has become one of the major problem areas in the city. There has been increase in the personalised mode of travel in most cities, leading to increase in traffic density resulting in longer travel time, reduced average speed, and increased fuel consumption, higher levels of pollution and discomfort to road users. All these are resulting in considerable environmental damage and health hazards. The problem of traffic congestion is worsening day by day. There has been a growing pressure on the policy makers to devise ways of tackling this problem.

The economic literature suggests that one way of approaching the problem is to introduce optimal transport pricing to reduce negative transport externalities by making road users pay for driving in the peak periods. The theory of welfare economics shows that one of the conditions for achieving maximum economic efficiency is that all prices throughout an economy be set equal to marginal social costs. The word ‘social’ indicates that all costs need to be taken into account, including any externalities. This means that optimal prices should include all resource costs and external costs (congestion, air pollution, accidents, noise, etc.). It is this external cost component of road pricing that has generated substantial research on optimal externality taxes and optimal tax reform in the urban transport sector. It is no wonder, therefore, that estimation of marginal external costs of urban transport currently attract a lot of attention in scientific, academic and policy-making circles for urban transport pricing reforms.

Estimating the marginal external costs of urban road transport is essential for calculating the marginal social cost. The marginal social cost is the sum of marginal private resource costs paid by the road user and the marginal external costs with respect to congestion, air pollution, noise and road accidents. Economic literature suggests that the marginal external costs of transport use correspond to the costs caused by an additional transport user that are not borne by the user himself but by others. They may consist not only of costs in the monetary sense, but also of, for example, time losses, pollution, noise, accidents and so on. It is proved in the transport literature that pricing based on marginal social cost is better than that based on average social cost (Walters, 1961; Vickrey, 1963, 1969; Keeler and Small, 1977; Glaister and Lewis, 1978; Small, 1983; Kraus, 1989; Arnott et al., 1993; De Borger et al., 1996, 1997; Mayeres and Proost, 1997, 2001; Parry and Bento, 2001; Proost and Van Dender, 2001.

Many researchers have tried to estimate the marginal external costs of urban road transport use. Important contributions in this field include the studies by Newbery (1988), Jones-Lee (1990), Mayeres (1993), Jansson (1994), Peirson et al. (1994), Small and Kazimi (1995), Maddison et al. (1996), Mayeres et al. (1996), Bickel et al. (1997), Delucchi (2000), De Borger and Proost (2001), and Mayeres and Van Dender (2001). Results from all these studies reveal that some marginal social costs can be internalised in the decision-making process of the additional transport user and some costs are external in nature. The main marginal external costs are the marginal external congestion costs, air pollution costs, noise costs, accident costs and road damage costs. In this paper, the cost functions are determined for two different road transport modes: cars and buses. The methodologies, for different marginal external costs used here, are based on the works of Mayeres et al. (1996), Bickel et al. (1997), Delucchi (2000), Jones-Lee (1990), Sengupta and Mandal (2002), and TCS (1999).

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The paper is structured as follows: in Section 2 we give a brief survey of literature on determining marginal external costs of urban road transport. Section 3 gives an overview of the urban road transport scenario in Delhi urban agglomeration. In Section 4 we discuss the model for calculating the marginal external congestion costs of urban transport and apply this model numerically to Delhi for estimating the marginal external congestion costs. In Section 5 we calculate the marginal external air pollution costs of urban road transport by using various methods developed in the literature. Sections 6 and 7 estimate the marginal external accidents costs and noise costs, respectively. Section 8 combines the marginal external costs of congestion, pollution, accidents and noise and gives the total marginal external costs of urban road transport in Delhi Urban Agglomeration. Section 9 presents concluding remarks.

2. A survey of literature on estimating the external costs of transport

A number of studies have tried to determine the marginal external costs of road transport use (congestion, pollution, noise, accidents, climate change, etc.). Important contributions include the studies by Newbery (1988), Jones-Lee (1990), Mayeres (1993), Jansson (1994), Peirson et al. (1994), Small and Kazimi (1995), Persson and Odegaard (1995), Maddison et al. (1996), Rothengatter (1996), Mayeres et al. (1996), Bickel et al. (1997), Delucchi and McCubbin (1999), Delucchi (2000), Mayeres and Van Dender (2001) and Sengupta and Mandal (2002).

For estimating marginal congestion cost of urban transport, many researchers in the literature (e.g., Mayeres et al., 1996; Bickel et al., 1997; O'Mahony and Kirwan, 2001) used the following exponential congestion function, which expresses the minutes needed to drive 1 km in a certain period as a function of the million PCU per hour at that moment in the city.

$$\frac{1}{s} = A_1 + A_2 \times (\exp(A_3 \times q)) \tag{1}$$

where 's' is average speed in kilometer per hour, 'q' is million passenger car units (PCU) per hour and A_1, A_2 and A_3 are speed-flow relationship parameters. For example, Mayeres et al. (1996) estimated the following exponential congestion function for Brussels, which expresses

$$\frac{1}{s} = 1.194428 + 0.005571 \times (\exp(7.890545 \times q)) \tag{2}$$

the minutes needed to drive 1 km in a certain period as a function of the million PCU per hour at that moment in the city.

In this function, average speed (s) is related to traffic flow (q), which is measured in million passenger car units (PCUs) per hour. Once the time loss suffered by other road users is worked out on the basis of this function, willingness-to-pay approach is used to estimate the value of time (VOT) for road users. The VOT in 2005 for car users moving in peak hours is 7.7 ECU[1]/h, for users of public transport 5.4 ECU/h, and for truck users 34.2 ECU/h. A linear relationship is estimated between VOT and income; the elasticity of VOT with respect to income is found to be 0.368. The marginal external costs of congestion in peak hours for Brussels in 2005 are as follows: car, 1.387 ECU/h and bus, tram and truck, 2.774 ECU/h. Mayeres et al. (1996) also calculated the costs to the society of a marginal increase in the emission of air pollutants by road transport. They estimated a health cost of 83.19 mECU/g for PM_{10}, 1.51 mECU/g for VOC, 7.55 mECU/g for NO_x, and 93.70 mECU/g for SO_2 for Brussels.

[1] ECU is European Currency Unit, now called as "Euro".

Rothengatter (1996) evaluated the costs of air pollution on the basis of SO_2, NO_x and VOC emissions and covered impacts on health, natural environment and material values. These costs, based on prevention assumptions and on damage estimations, were found to be as follows: SO_2 (yearly emissions), 12,994 ECU/tonne; NO_x (summer emissions), 13,475 ECU/tonne; and VOC (summer emissions), 12,175 ECU/tonne. The total external costs of air pollution from transport in Europe are found to be 5865 billion ECU per annum, or 1.17% of GDP on the average.

Brandon and Hommann (1995) carried out a study that valued the economy-wide impact of environmental degradation in India resulting from urban air pollution, surface and around water pollution, individual pollution and hazardous wastes, soil and range land degradation, deforestation, and tourism. The results showed the reductions in morbidity and mortality in 36 Indian cities if pollution levels were reduced to the prevailing WHO annual average standard. The number of premature deaths that would be avoided was over 40,000, with the main metropolitan cities contributing the major share. The economic valuation of these premature deaths suggested a monetary estimate of loss of between $400 and $1600 million.

Delucchi and McCubbin (1999) studied the health costs of motor-vehicle-related air pollution in the US. They examined the cost of all the health effects of all pollutants from all emission sources related to motor-vehicle use. They found that damages from particulates dominate the total costs of the health effects of motor-vehicle air pollution. Ambient carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), and toxics caused much smaller damages than did ambient PM. The damages from ambient O_3 (range between $0.01 and $0.11), which was the most heavily regulated criteria pollutant, were less than the damages from CO (range between $.01 and $0.09), and NO_2 (range between $1.1 and $16.21) for the US, and two orders of magnitude less than the danger from ambient PM. The damage costs from PM were so high (range between $8.78 and $116.01), because PM pollution kills or chronically sickens far more people than do other pollutants.

Using 'transfer of benefit method' from the US to the Indian situation, Sengupta and Mandal (2002) estimated the health damage cost of urban air pollution for 35 major urban agglomerations of India arising from automotive emissions and the savings that can be achieved by the regulation of fuel quality so as to conform to the *Euro* norms. They found that the health damage cost of particulate matters (PM) was the highest (Rs. 63.73/kg under low-cost estimates and Rs. 869.57/kg under high-cost scenario), followed by NO_x (Rs. 7.37/kg and Rs. 108.26/kg, respectively), HC (Rs. 0.60/kg and Rs. 6.73/kg, respectively) and CO (Rs. 0.05/kg and Rs. 0.46/kg, respectively). They also found that the annual health damage cost for Delhi worked out to be Rs. 269 crore in 2000–2001 under low estimates for pre-Euro norms. The corresponding estimate under high-cost scenario was Rs. 3689 crore.

The studies carried out by Rothengatter (1996) and Mayeres et al. (1996) also developed methodologies for estimating marginal external noise costs of transport use. Using a willingness-to-pay approach, Rothengatter (1996) estimated the annual noise costs of transport as 0.65 per cent of GDP on the average in Europe. The average noise costs for passenger transport found to be 4.5 ECU/1000 PKMS for cars and 4.2 ECU/1000 PKMS for buses. Mayeres et al. (1996) estimated the marginal external noise costs of transport in Brussels by using the following noise function on the assumption that the average street in Brussels has a U-shape.

$$L_{eq}(A) = 53.9 + 10\log(Q_{vl} + EQ_{pl}) - 10\log l + \mathrm{k} \tag{3}$$

where L_{eq} (A) is the equivalent noise level in decibels at 2 m from the facade, Q_{vl} stands for the flow of light vehicles (< 3.5 tonnes) in vehicles/hour, Q_{pl} is the flow of heavy vehicles (> 3.5 tonnes) in vehicles/hour. E is an equivalence factor between different types of vehicles. For slopes smaller than 2%, one heavy vehicle is assumed to be equivalent to 10 light vehicles. The width between the facades (in meters) is given by l. The term k is a correction factor for speed, which means that 1 decibel is added for each speed range of 10 km/h above a speed of 60 km/h. The marginal external noise cost for cars and buses for Brussels in 2005 in peak hours were calculated as 1.141 and 14.1 ECU/vehicle km, respectively.

Mayeres et al. (1996) also worked out the marginal external accident costs for the city of Brussels. In peak hours, the total marginal external accident costs (in mECU per vehicle-kilometer) for the various types of vehicles were as follows: car, 98.29; bus, 854.02; tram, 616.58; metro, 7.76; and truck, 268.27. The total marginal external costs including congestion, pollution, accidents and noise (in ECU per vehicle-km) of transport moving in peak hours for Brussels in 1991 found out to be as follows: small gasoline car, 0.385; small diesel car, 0.405; bus, 1.661; tram, 1.771; and truck, 1.560.

Persson and Odegaard (1995) presented a model of road traffic accident pricing in which the marginal external cost of an accident was basically computed as the product of the marginal cost per accident multiplied by the marginal accident risk. The study compared the external costs of road traffic accidents in Sweden, Finland, Denmark, the UK, Germany and Switzerland and found substantial differences in the external costs per vehicle-kilometer of road use in these countries. The study recommended an extra charge to internalise the external accident costs, especially in the case of lorries and buses.

Rothengatter (1996) found that 99 per cent of the total accident costs are caused by the road sector, and less than 1 per cent by rail. The "human value" component covers 91 per cent of the accident costs for a fatality and 96 per cent for injury. The annual external costs of accidents were worked out at 148 billion ECU, which was 2.5% of GDP. The average European accident costs for passenger transport were 32 ECU/1000 passenger kilometers (PKMS) for cars, 9 ECU/1000 PKMS for buses and 1.9 ECU/1000 PKMS for trains. There were strong variations in country-specific costs resulting from very different accident rates.

In the Indian context, it is not very easy to access data that are needed to assess all costs based on above principles. There have been a few attempts in India to estimate the costs of road accidents over the past decades using variants of 'gross output approach'. Two important earlier studies are economic cost of road accidents for Delhi for the year 1968 (Srinivasan et al., 1975) and costs of road accidents (Natarajan, 1980) using insurance company data for Chennai for the year 1978. The first major road user cost study (RUCS) was published in India in 1982 (CRRI, 1982). The costs included were: medical expenses, legal fees, property damage, insurance costs, and loss of output due to death. The most recent study on road accidents was carried out in 1998–1999 by Tata Consultancy Services (TCS) sponsored by Ministry of Surface Transport. A summary of the values calculated in these studies is given in Table 1.

All the above studies in India are based on the 'Gross Output method' where there is scope for under estimation. No efforts have been made in India for calculating the real costs of accidents based on the Willingness-To-Pay model. A review on calculating social costs of road accidents in India can be referred in Mohan (2002).

3. Urban transport scenario in Delhi

In India, as in other developing countries, urbanization is most evident in the country's metropolitan areas. It is expected that the population of Delhi will grow from 12.90 million in 2001 to 19.0 million by 2011 and 23 million in 2021 (RITES, 2005). The total area of Delhi is 1486 km^2. with an urban area of about 500 km^2 (RITES, 2005). Delhi's population has increased by 18 times in a span of last six decades. Delhi has been experiencing a consistently high rate of growth of motor vehicles during the last few decades. The ring road of Delhi, which was designed for 75,000 vehicles per day, has been experiencing a daily traffic of 160,000 vehicles. Given the rapid pace of urbanization, construction of car-friendly infrastructure and subsidies to cars in the form of free parking, it is expected that motor vehicles would grow at an even faster rate.

Unlike most Indian cities, the traffic in Delhi is predominantly motorized vehicles. The share of motorized trips is over 63% of the total daily trips. The road space is shared by at least seven different types of vehicles, each with different static and dynamic characteristics. Among the motorized vehicles, private cars and public transport buses are dominant vehicle classes. The proportion of fast moving vehicles – especially light, fast vehicles – has increased dramatically over the years.

The rapid urbanization in Delhi, together with industry and transport, has resulted in an equally rapid increase in urban air pollution. Major motorized modes of transport like buses, cars, auto rickshaws, trucks and scooters/motorcycles (SC/MC) are major contributors for air pollution. The use of poor-quality fuel (e.g. coal with high sulphur content and leaded gasoline till recently), inefficient methods of energy production and use, poor condition of automobiles and roads, traffic congestion are major causes of increasing airborne emissions of sulphur dioxide (SO_2), oxides of nitrogen (NO_x), carbon dioxide (CO_2), suspended particulate matter (SPM), lead (Pb), carbon monoxide (CO) and ozone. In a city like Delhi, even after many years of efforts to reduce pollution from motor vehicles, road transport is responsible for 60% of the total urban air pollution (CPCB, 2000). Road transport alone responsible for 90% of carbon monoxide (CO) and 72% of total NO_x emission. CO2 contributes the maximum, i.e. 62% of the total pollution, which is due to vehicular emissions.

Table 1
Estimates of road accident costs in India.
Source: Mohan (2002).

Type of accidents	1968 study for Delhi	1978 study for Chennai	1982 RUCS for India	1999 TCS study
Estimated average costs in Rupees for year of study				
Fatal	27,805	129,987	49,804	535,489
Serious injury	7470	35,447	29,510	106,959–242736[a]
Minor injury	870	10,503	321	18,855
Property damage	1155	10,033	–	–
Damage to buses	–	–	5467	47,100
Damage to cars	–	–	1200	16,200

[a] In this study, two categories, serious and major injuries were used.

Although cars are getting cleaner in Delhi with each new model, they are also getting more numerous and traveling more kilometers, which offset much of the improvement in cleaner car technology. The transport sector also contributes significantly to emissions of green house gases (GHGs) and discharge of chlorofluorocarbons (CFCs), and is hence implicated in global warming.

Congestion in Delhi is severe and worsening day by day. In congested roads, motor vehicles appear to be in chaotic disarray: lanes are nonexistent, and vehicles of all sizes slide into available spaces. Average speeds during peak periods range from 10 to 15 km/h in central areas and 21–39 km/h on arterial roads, giving the average speed of 24 km/h for the entire Delhi urban agglomeration. Congestion is generally not severe during off-peak hours.

The noise levels in Delhi vary from 54 to 84.6 dB(A). The highest level is near the main highway. In the heart of the city area, it varies from 60 to 78 dB(A). In addition to causing ill-health effects, noise from roads leads to reductions in property values. Road accidents are also on the rise in Delhi despite growth in traffic management.

The deaths on Delhi road have increased from about 500 in early 1970s to over 1000 in 1980s and to over 2000 in 1990s. The main victims are the pedestrians whose share among the deaths on Delhi roads is 50 per cent.

4. The marginal external congestion costs

Estimates of the economic costs of congestion vary, and none has been comprehensive. Most have focused on such easily quantified values as lost time, wasted fuel and increased insurance premiums due to accidents, and most exclude such costs as vehicle wear due to constant braking, driving stress, and other comparatively elusive damages (Mackenzie et al., 1992). A study by the Petroleum Conservation Research Association, India in 1998 reveals that Delhi wastes $300,000 in fuel daily just through vehicles idling at traffic lights (Bose and Sperling, 2001).

The marginal external congestion costs occur when an additional vehicle on the road transport network reduces the speed of the other transport users in the network. The equilibrium model used in this paper determines endogenously the marginal external congestion costs of urban road transport. The marginal external congestion costs are important because the resulting lower speed affects the time and vehicle operating costs of other road users, increases accident risks, and other environmental costs. In our model, the marginal external congestion costs are interpreted as time losses of the other road users due to decrease in speed caused by the additional vehicle on road. Environmental costs, noise costs and accidents risks are taken up separately.

4.1. *The time-flow (or speed-flow) relationship and choice of functional form of congestion function*

Though congestion effect varies between different road networks, for simplicity our model computes the marginal external congestion costs in a more aggregate way by assuming homogenous traffic conditions throughout Delhi and road networks are represented as one-link system.[2] Adding one vehicle to the traffic flow slows down all other vehicles using the same road network at that moment. The time–flow relationship captures the influences of traffic flow on the time needed to drive 1 km, which is otherwise called the speed–flow relationship. We measure the traffic flow in million passenger car units (PCU) kilometer per hour, which reflects better congestion effects of the vehicle types rather than number of vehicles.

[2] Though this is a simplistic assumption for congestion function, the overall direction of result will not change by this assumption.

It is necessary to determine what type of functional form of the congestion function most suited the traffic speed–flow relationship in Delhi. For this purpose, we tested 4 types of non-linear functional forms as given in Table 2 with the goodness-to-fit parameter, R^{2}, to choose the suitability of each function for Delhi traffic flow data. It is evident from Table 2 that the power and exponential functions requiring 3 parameters to describe the relationship give the best-fit curves with R^2, coefficients of 99 and 92, respectively. On the basis of this, it was decided to use the exponential form of type 2 to describe the congestion function relationship for our case study.

In the model, we convert a bus as 2.2 PCU as per the present estimates available for Delhi (IRC, 1990). We use the following exponential form of time–flow relationship, as also used in the literature for other cities (e.g., Mayeres et al., 1996; Bickel et al., 1997; O'Mahony and Kirwan, 2001):

$$t_{ij} = \frac{60}{s_{ij}} = A_{1,j}\left[A_2 + A_3 e^{(A_4 . q_i)}\right] \tag{4}$$

Eq. (4) indicates that '$t_{i,j}$', the time needed to drive 1 km (in minutes) by mode 'j' in period 'i' (i=peak, off-peak), is a function of the number of PCU km per hour in that period (q_i). 'S_{ij}' is the speed of the vehicle type 'j' in period 'i' in km per hour. A_2, A_3, A_4 are parameters of the time–flow relationship. The speed of bus is assumed to be proportional to that of cars, which is expressed by the parameter $A_{1,j}$. In the case of Delhi it is assumed to be 1 for car and 1.2 for bus, which reflects the fact that in the reference situation the speed of public transport is approximately 83% of that of car mode for Delhi. We assume that non-motorized transport does not affect the speed of other modes and is independent of the volume of other traffic.

The time–flow (or speed–flow) relationship allows us to compute the time loss suffered by other road users if an additional PCU joins the traffic flow. This combined with value of time gives us the marginal external congestion costs (MECC) of an additional PCU km. Thus,

$$MECC_{q_i} = \sum_j \frac{\partial t_{i,j}}{\partial_{q_i}} x_{i,j} \mathrm{VOT}_{i,j} \tag{5}$$

where $x_{i,j}$ is the number of pkm traveled in period i by mode j. $\mathrm{VOT}_{i,j}$ is the value of time or value of marginal time saving per passenger.

4.2. *Value of time (VOT)*

Assigning a value to the time losses suffered by other road users is complex. Table 3 gives the value of time assigned to travel by different modes, estimated by Tota (1999) and RITES (1998) for Delhi. The average value of time saving differs between work-related trips and non-work-related trips and also between different studies. Since our analysis takes into account overall trips and does not look into trip purposes, we derived the

Table 2
Choice of functional form of congestion function for Delhi.

Function type	Equation	Goodness-of-fit (R^2)
Power function type-1	$T=A_1+q^{A3}$	67.60
Power function type-2	$T=A_1+A_2q^{A3}$	86.69
Exponential function type-1	$T=A_1+e^{A3q}$	92.00
Exponential function type-2	$T=A_1+A_2e^{A3q}$	99.00

Table 3
Average value of time for passenger transport (Rs. per hour).
Source: RITES (1998) and Tota (1999) for TERI.

Mode	RITES (1998)	Tota (1999)		
	Average VOT	Work trips	Non-work trips	Average VOT
Car	24.65	70	17.5	50.84
Bus	10.59	23.57	8.86	17.11
SC/MC	17.97	35.45	5.89	25.74

Table 4
Marginal external congestion costs for Delhi in 2005.
Source: Own estimate using GAMS; conversion rate US Dollar (USD) 1=Indian Rupees (Rs.) 45.

Mode	Peak		Off-peak	
	(Rs/vkm)	(USD/vkm)	(Rs/vkm)	(USD/vkm)
Car	4.91	0.11	0.32	0.007
Bus	9.83	0.22	0.63	0.014

weighted average value of time, as reported in the last column of Table 3, using the value of time figures for work (63.5%)- and non-work (36.5%)-related trips estimated by Tota (1999) for Delhi. For simplicity we assume that the value of time saving in both peak and off-peak periods of the day is the same.

4.3. *Results of marginal external congestion costs*

The model is calibrated to a Delhi dataset using a locally suited congestion function derived through a speed–flow relationship function. The congestion function is non-linear exponential, with a free flow speed of 45 km/h, peak traffic speed of 24 km/h and off-peak speed of 40 km/h. The value of time, as implied by the calibration is Rs. 55/h (USD 1.22/h) and Rs. 45/h (USD 1.00/h) in off-peak for cars and Rs. 20/h (USD 0.44/h) in peak and Rs. 15/h (USD 0.33/h) in off-peak for buses.

Table 4 presents the estimation of marginal external congestion costs per vehicle kilometer (VKM) for the reference situation in Delhi in 2005. As can be seen from Table 4, marginal external congestion costs are very high in the reference situation, especially in the peak period due to saturated traffic load in the road network. The results clearly indicate that there is a need to reduce congestion via an optimum road pricing policy, which would build the marginal external congestion cost into the total cost per kilometer for driving on the road.

5. The marginal external air pollution costs

Apart from marginal external congestion costs, another externality generated by transport use is the air pollution. Air quality is emerging as a principal motivation for improving Delhi's transport system. Pollutant levels are often several times higher than the ambient standards set by the Central Pollution Control Board and they are increasing. Mostly carbon monoxide and smog have reached unhealthy levels in Delhi with motor vehicles being the principal source. Motor vehicles are also important contributors to acid rain through their emissions of sulphur oxides and nitrogen oxides. In this section we estimate the social cost of a marginal increase in the emission of air pollutants by road. The first step is the calculation of the emissions caused by an additional vehicle km. The next step consists of calculating ambient concentration of major air pollutants due to vehicular emissions. The third step involves the effects of air pollutants on health, vegetation, materials, eco-system, visibility, climate change and so on. The final step assigns a monetary value to the different effects of air pollution. In Delhi, there are four major air pollutants affecting the environment, i.e. carbon monoxide (CO), hydrogen compounds (HC), nitrogen oxides (NO_x) and particulate matters (PM). Table 5 gives the changing emission factors for cars and buses for different fuel types in grams/vkm for these four major pollutants in Delhi. The figures are taken from data published by Central Pollution Control Board for 2005 (CPCB, 2000).

Table 5
Emission factors (gm/vkm).
Source: CPCB (2000), Transport fuel quality for Year 2005, Govt. of India.

	CO	HC	NO_x	PM
Petrol car				
1986–1990	9.8	1.7	1.8	0.06
1991–1995	9.8	1.7	1.8	0.06
1996–2000	3.9	0.8	1.1	0.05
2001–2005	1.98	0.25	0.2	0.03
Diesel car				
1986–1990	7.3	0.37	2.77	0.84
1991–1995	7.3	0.37	2.77	0.84
1996–2000	1.2	0.37	0.69	0.42
2001–2005	0.9	0.13	0.5	0.07
Bus				
1986–1990	5.5	1.78	19.0	3.0
1991–1995	5.5	1.78	19.0	3.0
1996–2000	4.5	1.21	16.8	1.6
2001–2005	3.6	0.87	12.0	0.56

Table 6
Vehicle fleet age structure (proportions).
Source: Bhalla et al. (2005)

Year	Car+taxi	2-Wheelers	TST	Bus
1986–1990	0.047	0.063	0.059	0.048
1991–1995	0.217	0.299	0.220	0.362
1996–2000	0.281	0.302	0.126	0.575
2001–2005	0.455	0.336	0.595	0.016
Total	1	1	1	1

As can be seen from Table 5, the standard emission factors for different vehicle types are becoming stricter over the years. For buses, prior to the year 2001, the fuel type was diesel. Since 2001, the emission factors, as given in above table, are for CNG buses. Since our main aim is to estimate the emission factors caused by an additional vkm for different types of vehicles using different fuel types during different time period of the day, we require vehicle fleet age structure. This is provided in Table 6 for different types of vehicles.

There are vehicles of different ages in operation on Delhi roads (Bhalla et al., 2005). There are more than 50% cars and taxis whose age ranges between 10 and 20 years as is evident from Table 6. Similar is the case for other vehicle categories. Using the information on vehicle fleet age structure (Table 6) and emission factors for different years and different types of vehicles (Table 5), the average emissions factor in grams per vkm, can be estimated as has been given in Table 7.

Not much work has been done to estimate disaggregated emission factors in India. The disaggregate emission factors are required for our model to calculate the emissions by vehicle type and fuel type used. We disaggregate the average emission factors into large and small cars, to occupancy rate and to peak

Table 7
Average emission factors (g/km).
Source: Calculation based on information provided in Tables 5 and 6.

Vehicle type	CO	HC	NO_x	PM
2 Wh—2T	4.298	3.123	0.053	0.130
2 Wh—4T	2.610	0.736	0.304	0.060
Petrol car	4.581	0.787	0.875	0.044
Diesel car	2.671	0.261	1.152	0.371
Bus	4.896	1.438	17.626	2.157

Table 8
Disaggregated emission factors for private and public transport (g/km).
Source: Calculations based on information provided in Table 7 and ExternE ratio (Bickel et al., 1997).

Vehicle type	CO	HC	NO_x	PM
Peak.solo.petrol.small car	4.706	0.787	0.731	0.044
Peak.solo.petrol.big car	6.365	0.787	1.036	0.044
Off-Peak.solo.petrol.small car	3.061	0.787	0.662	0.044
Off-peak.solo.petrol.big car	3.756	0.787	0.926	0.044
Peak.pool.petrol.small car	4.944	0.787	0.808	0.044
Peak. pool.petrol.big car	6.631	0.787	1.130	0.044
Off-peak. pool.petrol.small car	3.216	0.787	0.719	0.044
Off-Peak. pool.petrol.big car	3.970	0.787	0.988	0.044
Peak.solo.diesel.small car	1.943	0.261	0.982	0.342
Peak.solo. diesel.big car	6.631	0.261	1.571	0.560
Off-peak.solo. diesel.small car	1.437	0.261	0.662	0.209
Off-peak.solo. diesel.big car	3.244	0.261	1.179	0.336
Peak.pool. diesel.small car	2.002	0.261	1.006	0.352
Peak. pool. diesel.big car	4.004	0.261	1.615	0.576
Off-peak. pool. diesel.small car	1.548	0.261	0.835	0.240
Off-peak. pool. diesel.big car	3.186	0.261	1.215	0.353
Peak.bus	6.10	1.44	19.70	2.66
Off-peak.bus	3.70	1.44	15.55	1.65

Table 9
Estimates of pollution costs for India for 2005 at 2004–2005 prices.
Source: Own estimation.

Pollutants	Sengupta and Mandal estimates				ExternE estimates	
	High		Low		(Rs./kg)	(Rs/g)
	(Rs/kg)	(Rs/g)	(Rs/kg)	(Rs/g)		
CO	0.5295	0.0005	0.058	0.00006	0.04	0.00004
HC	7.75	0.008	0.69	0.0007	10.38	0.01
NO_x	124.63	0.12	8.48	0.008	93.19	0.09
PM	1001.03	1.001	73.37	0.07	4619.74	4.62

Table 10
Marginal external air pollution costs in Delhi in the reference equilibrium (Rs/vkm).
Source: Own estimation using GAMS.

Vehicle type	CO	HC	NO_x	PM	Total
Petrol car					
Peak small	0.0002	0.008	0.07	0.20	0.28
Peak big	0.0003	0.008	0.10	0.20	0.31
Off-peak small	0.0001	0.008	0.06	0.20	0.27
Off-peak big	0.0001	0.008	0.09	0.20	0.30
Diesel car					
Peak small	0.00007	0.003	0.091	1.58	1.67
Peak big	0.0003	0.003	0.146	2.59	2.74
Off-peak small	0.00006	0.003	0.062	0.97	1.03
Off-peak big	0.0001	0.003	0.110	1.55	1.67
Bus					
Peak	0.0002	0.01	1.84	12.29	14.14
Off-peak	0.0001	0.02	1.45	7.64	9.11

and off-peak traffic, based on the ratios used in ExternE project (Bickel et al., 1997), applicable to European cities. Table 8 gives the emissions factors for both private and public transport in gm/vkm, taking into account time period, vehicle size and occupancy rate. Cars have been divided into small and big according to their size. Car sizes which are less than or equal to 4000 mm are treated as small cars and cars above 4000 mm are considered as big size cars. Regarding occupancy rate, it is estimated that the average occupancy rate for buses in peak and off-peak periods is 66 and 30, respectively (Tota, 1999) and average occupancy for car is 1.30 in both peak and off-peak periods.

Now after calculating the disaggregated emission factors for different vehicle types, sizes, etc, we need to estimate the damage cost per gram of pollutant emitted. This combined with the emission factors of the different vehicle types gives the air pollution costs for the reference equilibrium. Instances of estimation of pollution cost in Indian context are rare. Using the 'Transfer of Benefit' method, which is an accepted method of valuing ecosystem services by transferring available information from studies already completed in another location/context, Sengupta and Mandal (2002) calculated the damage cost of air pollution in select Indian cities from the figures of Deluchhi (2000), who estimated the health cost of pollutants in US dollar for kilogram of emission at 1991 prices for the US economy. For example, Sengupta and Mandal (2002) estimated environmental benefits for air pollution abatement for selected Indian cities by transferring the parametric estimates of health damage cost done by Delucchi (2000) for US cities, after making appropriate adjustments for differences in demographic, income, currency purchasing power and other temporal and cross-country differences between US and India. This way the values of air pollution cost became endogenous for Indian conditions.

A relevant study by Bickel et al., 1997 (for ExternE project) estimated the overall global damage cost including health costs, costs due to changes in eco system, climate change, material costs, etc. in Euro per kg at 1997 prices for some of the European cities. A comparison of values assigned to different pollutants indicates that both Delucchi (2000) and ExternE valuation are similar except for particulate matters (PM) where it is very high for ExternE. In the Indian Context, PM assumes much significance due to the fact that it mostly cause severe health damages including respiratory tract illness, chronic bronchitis, hypertension, coronary heart diseases, etc. which are common in most cities in India. Therefore, PM needs to be assigned more weight among the 4 pollutants taken in this paper. In view of this, values of pollutants taken for this estimation of air pollution cost are given in Table 9. Since ExternE values reflect all costs including health cost, we have taken these values for our damage costs per gram of pollutant rather than Delucchi's values, although ExternE values fall within the high and low estimates of health damage cost estimates of Delucchi (2000).

In order to calculate the marginal external air pollution costs, the damage costs per gram of pollutant as estimated in Table 9 are combined with constant emission factors for different vehicle types in the different transport markets (time of day, occupancy rate) as given in Table 8 for private and public transport. Table 10 presents the marginal external air pollution costs of standard passenger cars and buses in Delhi in 2005.

As can be seen from Table 10, among the cars the variation in air pollution costs between different car types and uses is quite significant. For example, marginal external air pollution costs of a large diesel car in the peak period are significantly different from those of a small petrol car in the same period. For both petrol and diesel cars, particulate matters (PM) is the dominant cause of air pollution followed by NO_x. The high marginal air pollution cost for buses is due to high value attached to the particulate matters and the buses generate more PM per vehicle kilometer (vkm) than cars.

6. The marginal external accident costs

Besides congestion and air pollution costs of transport, another important external cost of transport is the cost of road accidents involving deaths, injuries, vehicle damages and damage to infrastructure. When a driver takes a vehicle on to the road, he imposes two distinct risk externalities on the rest of society (Jones-Lee, 1990). In the first place, there is the risk that he himself may be killed or severely disabled, in which case his family and friends will experience the psychological costs of grief and suffering. Besides, society at large will bear the costs of vehicle damage and police and medical costs, and will also lose his contribution to current and future output. The second kind of externality is the risk that the driver may kill or injure someone else, such as a pedestrian, cyclist, or motorcyclist, or cause damage to someone else's vehicle or property (Deb Choudhury, 2003).

Economic literature suggests that accident cost relevant for pricing is the marginal external accidents cost. It is the difference between marginal social and the average private accident cost. Following Jansson (1994) and Mayeres and Van Dender (2001), the total accident cost (TAC) of a given equilibrium can be written as

$$TAC = \sum_{j=1}^{5}\sum_{n=1}^{4}(C_A^n + C_B^n + C_C^n)\sum_{v=1}^{6} ar_{j,v}^n V_j \tag{6}$$

The indices '*j*' and '*v*' represent the transport modes. In the case of road transport these modes are: car, bus, Truck, 2-wheeler and non-motorized transport. In addition, index '*v*' includes external objects (such as a wall or a tree) as a category (indexed by v=1–6). Index n indicates the severity of the accident, namely, fatality, serious injury, minor injury or material damage. C_A^n stands for the victim's own willingness to pay (WTP) to avoid an accident of type '*n*'. C_B^n is the willingness to pay of the relatives and friends of the victim to avoid an accident of type '*n*'. C_C^n consists of pure economic costs (net or gross output loss, ambient costs, police and medical costs), which are borne by the rest of the society. 'V_j' is the number of vehicle kms traveled by transport mode '*j*'. Finally, $ar_{j,v}^n$ is the probability that an accident of severity '*n*' occurs between transport modes '*j*' and '*v*' and in which '*j*' is the victim. It is defined as

$$ar_{j,v}^n = \frac{ACC_{j,v}^n(V_j, V_v)}{V_j}\forall j, v \tag{7}$$

$ACC_{j,v}^n$ gives the number of accidents between modes j and v in which j is the victim. The marginal social accident cost (MSAC) of a car is the derivative of the TAC with respect to the number of car km, i.e.

$$\begin{aligned} MSAC_{car} = & \sum_{n=1}^{4}(C_A^n + C_B^n + C_C^n)\sum_{v=1}^{6} ar_{car,v}^n V \\ & + \sum_{n=1}^{4}(C_A^n + C_B^n + C_C^n)\sum_{v=1}^{6}\frac{\partial ar_{car,v}^n}{\partial V_{car}} V_{car} \\ & + \sum_{j \neq car}\sum_{n=1}^{4}(C_A^n + C_B^n + C_C^n)\sum_{v=1}^{6}\frac{\partial ar_{j,car}^n}{\partial V_{car}} V_j \\ & + MSAC_{car}^1 + MSAC_{car}^2 + MSAC_{car}^3 \end{aligned} \tag{8}$$

The first term gives the social costs of the risk that the car occupants themselves are involved in an accident. The second term gives the social costs of the increased accident risk for other cars. The third term gives the social cost of the increased accident risk for road users due to the additional car kilometer. Similar expression can be obtained for public transport.

Part of the marginal social cost is internalised in the transport users' decision process through insurance premium, their own utility loss due to the accident risk (C_A) and also the utility loss of their relatives and friends (C_B) (Jones-Lee, 1990). Thus in the above expression, only C_C cost category is the external cost. The total external accident costs (TEAC) and the marginal external accident costs of a vkm driven by mode j ($MEAC_j$) can be defined as

$$TEAC = \sum_{n=1}^{4} C_C^n \sum_{j=1}^{5}\sum_{v=1}^{6} ar_{j,v}^n . V_j \tag{9}$$

$$MEAC_j = \sum_{n=1}^{4} C_C^n \sum_{j=1}^{5}\sum_{v=1}^{6} ar_{j,v}^n \tag{10}$$

This is simply the accident risk multiplied with that part of the social cost, which is external, namely, the direct economic costs (C_C). The direct economic costs (C_C) are equal to the current and future output loss due to accidents plus police and medical costs. This approach of valuing accident cost is called the "gross output" approach. It can be argued that the utility loss of friends, relatives and others are also external to the decision-making process. Therefore, part of it has been built into the direct economic cost (C_c) under insurance and gross output loss. In some cases, a further allowance for the pain, grief and suffering of the victim and his/her dependents, relatives and friends is also incorporated. The gross output approach can thus be seen as an attempt to measure the impact of death or injury on current and future levels of national output, broadly construed to include various non-marketed services (Deb Choudhury, 2003).

There have been a few attempts in India to estimate the costs of road accidents over the past decades using variants of gross output approach (e.g. Srinivasan et al., 1975; Natarajan, 1980; CRRI, 1982; TCS, 1999). The costs included were: medical expenses, legal fees, property damage, insurance costs, and loss of output due to injuries and death to self, friends, relatives and others.

The methodology used in this paper is similar to the one used by TCS (1999). Table 11 gives the details of number and proportion of road accident statistics for Delhi in 2004, derived from Delhi Traffic Police (2005). As Table 11 indicates, approximately 10.45% of road accidents involve non-injuries. With respect to the cost of vehicle damage, we assume that each accident for a particular category of vehicle results in damage to at least one such vehicle. Since the extent of vehicle damage in a road accident is not broken up between serious, major and minor categories, we apply the average cost of vehicle damage to the number of vehicles damaged for each type of vehicle.[3] The costs of vehicle damages

Table 11
Number and proportion of vehicles involved in road mishaps in Delhi in 2004.
Source: Delhi Traffic Police (2005).

Vehicle types	Car	Bus	Truck	MTW	Unknown	Total
Fatal crashes (%)	12	19	16	7	46	100
Numbers	214	339	285	125	820	1782
Accidents (%)	26	15	9	16	34	100
Numbers	2362	1362	817	1453	3088	9083
Injuries[a] (%)	26	15	9	16	34	100
Numbers	2115	1220	732	1301	2766	8134

[a] Delhi Traffic Police Data do not give separate proportions distribution for injuries and here we assume this to be the same as that of accidents.

[3] The average cost of vehicle for different vehicles has been calculated based on the value used by TCS, updated to 2004–2005 prices.

Table 12
Values of fatality and injury and average cost per vehicle damage in Delhi.

Values of fatality and injury			Average cost per vehicle damage		
Type of accident	Value (Rs. at 2004–2005 prices)	Value (USD)	Type of vehicle	Value (Rs. at 2004–2005 prices)	Value (USD)
Fatality	895,171.42	19,892.70	Car	1478	32.84
Serious injury	364,046.87	8089.93	Bus	62,591	1390.91
Major injury	158,892.42	3530.94	Truck	50,968	1132.62
Minor injury	20,983.49	466.30	MTW	5536	123.02
Avg. cost of injuries	181,307.59	4029.06	TSR	11,837	263.04

Conversion rate: 1 USD=Rs. 45.00.

Table 13
Marginal external accidents costs for Delhi.

Category	(Rupees per pkm)		(Rupees per vkm)	
	Car	Bus	Car	Bus
Fatality	0.02	0.02	0.021	0.881
Injuries	0.04	0.015	0.042	0.643
Vehicle damage	0.003	0.005	0.004	0.248
Total MEAC	**0.06**	**0.04**	**0.067**	**1.771**

as given in the TCS study can be applied to the number of vehicles damaged in road accidents.

Since reliable information on classification of vehicles involved in injuries separately are not available because injury accidents are underreported, the assumption is made that the same proportion of vehicles is involved in both total accidents and injuries. Though this is a weak assumption, which is unlikely to hold, the direction of results would not change. This is one of the weaknesses of the current accident data available with the traffic police where perfect information on accidents is not available.

Table 12 presents the values used for the direct economic costs (C_C) of the different accident types in Delhi at 2004–2005 prices and also the average cost per vehicle damage. In the case of fatal accidents these costs consist of the sum of gross loss of future output, national value of pain, grief and suffering (as a percentage of gross output loss), medical expenses, police, loss of earnings during hospitalization, lawyers' fees, surveyors' fees, court expenses and relative costs.[4] Costs of damages to vehicles consist of the sum of repair charges of the damaged vehicle, wages of the crew, surveyors' fees and expenses of insurance companies.

The final step is the calculation of marginal external accidents costs for the reference situation. This is calculated by dividing the total cost of accidents of each of vehicle types by the relevant vehicle km and passenger km. Since we are concerned for car and bus transport only, we calculate the marginal external accidents costs for these two vehicle types in Table 13. The marginal external accidents costs in Delhi for a passenger kilometer is Rs. 0.06 where as the per vehicle kilometer cost is Rs. 0.067 for cars. Similarly, for bus transport for a passenger kilometer it is Rs. 0.04 where as the per vehicle kilometer cost is Rs. 1.77. The difference is due to the occupancy rates, which are 66 persons in peak period and 30 persons in off-peak period in case of buses and 1.3 in case of cars in both periods.

[4] Costs of serious injury, major injury and minor injury are based on TCS (1999) study.

7. The marginal external noise costs

Another important external cost we consider in this paper is the noise cost. In addition to causing ill health effects, noise from roads leads to reductions in property values. For example, by one estimate, even after mitigation, traffic noise was reducing home property values by $6–182/dB in USA (Mackenzie et al., 1992). In order to calculate the marginal external noise costs, one needs to determine the effect of an additional vehicle km on the noise level. The general index used for noise is the energy mean sound level, L_{eq}(dB(A)), representing the average sound level over a given period. Following Mayeres and Van Dender (2001) we use the following noise function:

$$L_{eq}(A) = 53.9 + 10\log\{V_{light} + E.V_{heavy}\} - 10\log l + K \tag{11}$$

$L_{eq}(A)$ being the equivalent noise level at 2 m away from the source. V_{light} stands for the flow of light vehicles (<3.5 tonnes, e.g. cars) in vehicles per hour. V_{heavy} is the flow of heavy vehicles (>3.5 tonnes, e.g. bus) in vehicle per hour. E is an equivalence factor. We assume one heavy vehicle is equivalent to 10 light vehicles. The width between the facades is given by 'l'. 'K' is a correction factor for speed which means that one decibel is added for each 10 km/h above a speed of 60 km/h. We assume that the noise function given in Eq. (11) represents the average noise function for the citywide noise level.

The total road network of Delhi is approximately 28,508 lane km long, taking into account all kinds of roads (arterial roads, collector roads, residential roads, etc.). However, not the entire road network is experiencing heavy traffic. We assume only one-third of total road lengths are having heavy traffic. This amounts to 9503 lane km. We further assume that 80% of all traffic is concentrated on this 9503 km road network and these are the only areas where noise externality occurs. This means that the noise function (11) becomes:

$$L_{eq}(A) = 53.9 + 10\log\left\{\frac{0.8[V_{car} + 10(V_{bus})]}{9503}\right\} - 10\log l + K \tag{12}$$

Having defined the noise function as above, our next step is the monetary valuation of the noise function. As in practice, for monetary valuation, we use the hedonic housing market method, which is the most widely used method for the valuation of the social costs of noise. The basic idea underlying the hedonic technique is that the value of a house depends not only of its intrinsic characteristics but is also a function of a number of environmental attributes including noise pollution. Ceteris paribus, houses located in noisy areas are of less value than those located in quiet areas. Therefore, the housing market constitutes a surrogate market for noise (Pearce and Markandya, 1989).

In order to know the value of a marginal increase in the noise level, we need the expected life of a house, a standardized value of a house in Delhi, a house value depreciation rate per dB(A) and a discount factor. Most of the studies in literature assume the expected house life time of 50 years and find a house value depreciation in the range of 0.2–0.6 percent for dB(A), giving an average of 0.4 per cent. Alexandre and Barde (1987) found that as a rule of thumb a 0.5% house value depreciation per dB(A) constituted a reasonable guide and was based on substantial number of studies. This depreciation rate is valid only above a certain noise threshold. We assume this threshold to be 50 dB(A)L_{eq}, which is the prescribed noise level standards in practice. Table 14 provides the noise level standards as in practice in India.

From the literature, we use the average house depreciation rule of 0.5%. We assume a standard value of Rs.10,00,000 per census house in Delhi whose average life is 50 years. Thus for an increase of 1 dB which would continue during 50 years, the value of one exposed house decreases with Rs. 5000 per year. Assuming a discount factor of 5%, we calculated Rs. 0.05/dB(A) during 1/h for one exposed house. Total number of occupied census houses in Delhi, as per Census of India 2001 data, is 30,02,166. Dividing this figure with the total road length in Delhi gives a figure of 105 exposed houses per km of road network. This gives Rs. 4.85/dB per road of 1 km as the marginal external noise cost.

The total external noise cost for Delhi is the monetary value per dB, multiplied by the noise level above the threshold of 50 dB(A), multiplied by the number of road km where a noise externality is generated (9503 km). The marginal external noise cost is computed by taking the derivative of total external noise cost with respect to the number of vehicle km. Using the noise formula given in Eq. (12) we find that the marginal external noise cost (MENC) of a car km is given by

$$MENC_{car} = dB\,cost + \left[\frac{10}{\log 10}\,\frac{1}{V_{car}+10(V_{bus})}\right]9503 \qquad (13)$$

The resulting marginal external noise cost for Delhi for 2005 reference situation is given in Table 15, which indicates that buses are noisier than cars in both peak and off-peak periods.

Table 14
Noise level standards dB(A).
Source: RITES Ltd. (2005).

Standard for	Day	Night
Industrial area	75	70
Commercial area	65	55
Residential area	55	45
Silence zone	50	40

Table 15
Marginal external noise costs (Rs./VKM).

Period	Car	Bus
Peak	0.05	0.49
Off-peak	0.13	1.28

8. Total marginal external costs of transport

Table 16 presents the total marginal external costs of urban transport in Delhi for different transport modes. Table 16 indicates that the marginal external costs vary widely in respect of vehicle type, the volume of traffic and the time of the day. Considering the fact that the occupancy rate of a bus in peak period is 66 persons and off-peak period 30 persons, the marginal external cost for passenger kilometer (pkm) is much lower in case of buses (i.e. Rs. 0.40/pkm in peak and Rs. 0.43/pkm in off-peak period) than private vehicles like cars (e.g. Rs.5.30/vkm or Rs.4.08/pkm for a small petrol can driven in peak period), as 83% of cars were driven with single occupancy in Delhi in 2005 and the average occupancy across the periods is 1.3 persons. The level of marginal external congestion cost in the reference period 2005 is shown in the first column. The model used represents the city as a hypothetical one-link system with homogenous congestion conditions for the whole city. The congestion function used is exponential. As the table shows, congestion is the most important external cost resulting from excessive use of motor vehicles in peak period of the day in case of private vehicles. For example, it accounts for more than 90% of the marginal external cost per vehicle kilometer in Delhi in peak hours in case of petrol cars. In case of public transport buses, congestion is less severe but still a dominant factor in total marginal external cost. Marginal external air pollution cost is the most important cost in case of public transport vehicles as can be seen from the second column of Table 16. The table shows that the total air pollution costs can be reduced via choosing a cleaner vehicle with improved technology, a smaller car or by reducing the volume of transport. The marginal external accident costs, given in the third column of Table 16, can only be reduced by affecting the total volume of transport. It may

Table 16
Total marginal external costs of urban transport (Rs./VKM).

Vehicle type	Congestion	Air pollution	Accidents	Noise	Total	Total (USD/VKM)
Petrol car						
Peak small	4.91	0.28	0.067	0.05	5.307	0.118
Peak big	4.91	0.31	0.067	0.05	5.337	0.119
Off-peak small	0.32	0.27	0.067	0.13	0.787	0.017
Off-peak big	0.32	0.30	0.067	0.13	0.817	0.018
Diesel car						
Peak small	4.913	1.674	0.067	0.05	6.704	0.149
Peak big	4.913	2.736	0.067	0.05	7.766	0.173
Off-peak small	0.316	1.030	0.067	0.13	1.543	0.034
Off-peak big	0.316	1.665	0.067	0.13	2.178	0.048
Bus						
Peak	9.826	14.140	1.771	0.49	26.227	0.583
Off-peak	0.632	9.106	1.771	1.28	12.788	0.284

Notes:

1. Conversion rate: 1 US Dollar=Rs. 45.00 (Indian Rupees).
2. Occupancy rate in buses: Peak: 66 and Off-peak: 30. This implies total per kilometer (pkm) MEC for buses would be: Rs. 0.40 (or US $ 0.001) in peak and Rs. 0.43 (or US $ 0.001) in Off-peak period.
3. For cars, the difference between pkm and vkm would be marginal, as in 2005 the average occupancy rate in cars was 1.3.

be pointed out that unlike some other studies (e.g. Mayeres et al., 1996) where air pollution cost is less than marginal external accident costs, in case of Delhi air pollution cost is higher than accident costs due to emission resulting from severity of congestion, lower standard of car technology used by many older cars, etc. Finally, the external cost of noise, which contains the subjective discomfort of all inhabitants of a city caused by the vehicle noise, is given in the fourth column of Table 16. The only way to reduce noise level is by changing the volume or composition of the traffic.

9. Conclusion and policy implications

In this paper, we have developed the methodology for estimating the marginal external costs of congestion, air pollution, road accidents and noise. We have applied the methodology to the urban road transport market in Delhi to calculate the marginal external costs of urban transport. As the results suggest, motor vehicles in Delhi almost certainly impose very large social costs most of which users do not shoulder. There is, therefore, a strong case for optimal pricing of road pricing based on the principles of marginal social costs. It is only fair that those who enjoy the benefits of motor vehicle use should pay the costs of that use directly. Ideally, the price should be based on "polluter pay" principle. Since the automobile sector in India contributes a substantial amount to the national GDP, curbing ownership of vehicles cannot be an ideal solution. Hence, City authorities must consider adoption of measures that modal shift in favour of public transport and restrain the use of motor vehicles through market mechanisms such as higher fuel taxes, higher parking fees, reduce availability of parking space and reforming road pricing policies including imposing time-variant road tolls, electronic road pricing and better public transport technology as well as pricing. Besides, zoning and land-use reforms to mitigate congestion and devising an appropriate institutional framework are some of the policy options that can be considered to mitigate the negative externalities of urban transport.

There is, however, growing realization of policy makers and planners in India that the negative externalities of urban transport mainly congestion, air pollution, accidents and noise need to be addressed on a priority basis. Towards relieving congestion, various measures have been taken including widening of roads, construction of flyovers and bridges, pedestrian pathways and cycle lanes in some parts of Delhi. It has also been realized by the city authorities that the city's traffic may already have grown to a point where new flyovers no longer help in clearing the congestion. Apart from this, Delhi Metro rail and high capacity bus system (HCBS) have been in operation in some part of the city in order to decongest the city by modal shift. It is hoped that the full effect of these projects would be realized when citywide network of metro rail and HCBS is completed. Some ad-hoc measures like marginal increase in fuel prices have resulted in reduction in peak period traffic. More people are using car-pooling as a preferred option, which has also helped in reduction in peak period traffic. Towards reducing air pollution, cars with improved technology (e.g. Euro-III norm) are being allowed to run on Delhi roads. Vehicles older than 15 years are not allowed in Delhi. All public buses and many private cars are now running on compressed natural gas (CNG), thereby reducing air pollution considerably. Fatal road accident rates have also reduced due to a combination of factors including better road sense of the road users, better vehicle technology, separate pedestrian paths and cycle lanes, modal shift to metro rail, etc.

Towards the appropriate pricing of urban transport as a means of relieving congestion and other negative externalities, little progress has been made despite the realization that optimal road pricing based on Marginal Social Cost principles is the better way to proceed. Reasons for this could be due to the gap between the economic theory of Marginal Social Cost pricing and the quantification required for practical implementation being too large and the concerns of the distributional effects of such Marginal Social Cost pricing. However, awareness on pricing urban transport is growing in Delhi, which is being expressed in various policy frameworks like National Urban Transport Policy in India. More studies like the present one would certainly go a long way towards the goal of implementation of optimal road pricing in Delhi.

It may be pointed out that the marginal external costs estimated in this paper may be underestimated due to wide variations in the vehicle types and the assumptions underlying the calculation of accident costs and noise costs. For example, for calculation of accident costs we have used Delhi Traffic Police data, which we feel, grossly underestimated the total number of accidents and injuries on Delhi roads in 2004. Several modifications are required for getting actual accidents statistics in Delhi. It is also important to note that for meaningful comparisons between private and public transport modes, the occupancy rates must be taken into account. It is equally important to note that the marginal external costs calculations are only valid for the particular transport situations considered by us. In this case study, only the marginal external congestion costs are assumed to depend on the traffic flow. The other marginal external cost categories are assumed to be constant. It may be pointed out that given the paucity of data availability and very few studies available in India on estimation of marginal external costs of urban transport, we have tried to estimate the best possible marginal external costs of urban road transport in Delhi. More informative and disaggregated database for each of the inputs in the model would refine the estimation of these costs. There is therefore wide scope for further research in this important aspect of urban road transport.

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