Vehicular Pollution control in Delhi, India - Are the efforts enough?

Abstract

Delhi, the capital of India figures prominently in the world environment map for the simple dubious reason that it is one of the most polluted cities in the world caused by spectacular vehicular growth in the past 2-3 decades. Incidentally, few years back it was acclaimed as one of the greenest capital also. To restore the air quality and refurbish its image, a number of command and control (CAC) policy instruments have been implemented in Delhi in the past few years. The paper is an attempt to investigate whether the enactment of policy instruments and the efforts have led to commensurate fall in air pollution in Delhi or not. Our results and analysis shows that the imposition has not resulted in concomitant improvement in ambient air quality. One of the reasons is reliance on new vehicles, with little emphasis on in-service vehicles. Even with new vehicles, the focus is on emission limits not on the limit on ambient air quality. With nearly 370 to 600 new vehicles being registered every day, any expectation of improvement in air quality is simply far-fetched. The paper concludes with the suggestion that the containment of vehicular pollution requires an integrated approach, with combined use of transport policies like improved public transport, road pricing, parking etc. going in tandem with the CAC instruments.

August 7, 2001

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Acknowledgements

A substantial part of this paper was drafted during my stay at The Beijer Institute, The International Institute for Ecological Economics, Stockholm from June 10th to August 7th. I acknowledge with thanks the financial support received from the Environmental Economics Unit of Gothenburg University during the stay. The usual disclaimers nevertheless apply.

1. Introduction

A compelling reason for controlling air pollutants such as suspended particulate matter (SPM) or respirable particulate matters (RPM) or sulphur dioxide (SO_2) is their damaging effect on human health. These effects include mortality i.e., premature death as well as morbidity i.e., increases in the incidence of chronic heart and lung disease. According to the World Health Organisation (WHO), 4 to 8% of deaths that occur annually in the world are related to air pollution. Of all air pollution constituents, the WHO has identified SPM as the most sinister in terms of its effect on health. Numerous epidemiological studies conducted, mainly in the US and other developed countries, since the early 1970s have estimated dose-response parameters for particulates measured by either total suspended particulates (TSP)[1] or of the particulate spectrum defined by particle diameter (e.g., PM_{10}) or the chemical composition (e.g., sulphates SO_4^{2-}). With few exceptions the studies have found that particulates have a statistically significant impact on mortality rates. That is, after controlling for other factors, mortality rates are lower in areas with lower ambient particulate concentrations (see Vincent and Tan, 1997 for a recent review of this literature).

Increased mortality is not the only health consequence of exposure to elevated TSP concentrations. Several epidemiological studies conducted in the US have found that particulates have a statistically significant impact on morbidity also.[2] Increased risk of morbidity results in direct economic costs related to efforts to reduce exposure (e.g., by purchasing pollution masks or household air filters or staying indoors during heavily polluted days), expenditure on medication and health care, lost earnings due to illness, and reductions in welfare due to pain and suffering (Freeman, 1985).[3] However, the studies by Krupnick and Portney (1991) and Hall *et al*. (1992) have found that the impact of reductions in particulate concentrations on mortality are usually economically more important than the morbidity impacts.

Although epidemiological evidence of an impact on mortality is weaker for most other air pollutants except SPM, all other pollutants – SO_2, NOx, Ozone, Hydrocarbons (HC), carbon monoxide (CO) and lead (Pb) – have well-established morbidity impacts (Tietenberg, 1988, Table 15.1; World Resources Institute, 1992 notes to Tables 24.5 and 24.6 as referred in Vincent and Tan, 1997). The impacts include respiratory diseases (SO_2, NO, Ozone, HC); cardiovascular diseases (SO_2, CO, Ozone); and

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[1] The Suspended particulate matter (SPM) is measured and characterised in various ways: (i) Total Suspended Particles (TSP) is the fraction sampled with high-volume samplers, approximately particle diameters <50-100 µm; (ii) PM_{10}: Inhalable particles, diameter <10 µm. Penetrates through the nose, by nose breathing; (iii) Thoracic particles: approx. equal PM_{10}; (iv) $PM_{2.5}$: "Fine fraction", diameter <2.5 µm. Penetrates to the lungs and (v) Black smoke: a measure of the blackness of a particle sample, sampled on a white filter paper, transformed to a mass value (µg/m3) for the particle sample by means of a standard curve. Gives a relative value for the soot content of the sample (Source: http://reports.eea.eu.int/2-9167-057-X/en/page021.html). Only fairly recently the studies have started paying attention to PM_{10} and $PM_{2.5}$ particles. In this paper, wherever SPM is mentioned, it essentially means TSP unless specified.

[2] See Vincent and Tan (1997) for a recent review of health impact of air pollution. The review also includes a small group of studies that failed to find any statistical significant relationship. Small and Kazimi (1995) have also reviewed the current literature.

[3] Ridkar (1967: 34) argues that costs may be classified according to four categories. These are associated with: (i) premature death, which include the loss of output and the burial costs; (ii) morbidity; (iii) treatment; and (iv) avoidance. According to him, the total costs should include all type of costs whether they are direct or indirect; material or psychic.

impaired mental and physical development of infants and children (CO, Pb). The evidence is huge and is mounting every day. However, the silver lining to this dark cloud is the fact that in many developing countries the promulgation of new regulations are primarily motivated by the concern of health impacts of air pollution. For example in Malaysia, both the ‘Black Smoke’ rules and the ‘Clean Air Regulations’ were primarily enacted with concerns about the health impacts of air pollution (Tan, 1993 as referred in Vincent and Tan, 1997).

The above description thus implies that controlling air pollution would lead to significant benefits. But benefits would not accrue free of costs, as any abatement measure would entail significant costs. The costs could be economic or inconvenience or any other. For example, environmental taxes on gasoline or scrapping old vehicles may lead to economic costs to people; phasing leaded petrol can involve people shelling out large sum to retrofit the carburettor engine to fuel-injection system; retrofitting CNG (Compressed Natural Gas) engines may force people to change their consumption behaviour, besides exclusive dependence on (so far limited) CNG filling stations, which may have high nuisance value. The costs could be numerous but studies have argued that a more favourable ratio of benefits to costs would be expected in places that are earlier on in their pollution abatement efforts, especially the developing countries and economies in transition. For example, a study by Cofala *et al*. (1991)[4] of particulate pollution in the Polish town of Tarnobrzeg found that the economic benefits related to reduced mortality, morbidity and material damage exceeded the costs of pollution abatement by up to 70%.

In practice, the quantification of health benefits with reduced air pollution and associated costs to reduce pollution often precedes any policy initiative to control and abate the pollution. The present paper does not attempt to quantify these costs or benefits as most of these have been well researched in the context of developed and developing countries. The paper contributes to the second stage of this pollution control, as it attempts to find out whether policy initiatives have led to improvement in air quality or not in one of the most polluted cities of the world i.e., Delhi, India.

The focus of the present study is on Delhi for two particular reasons: (i) for the past several years, Delhi is among the ten most polluted cities of the world. The severity of the problem is also reflected in the mortality and other epidemiological data as calculated by various studies. For example, Brandon and Hamman (1995) estimate that 7,490 deaths could be avoided in Delhi using the accepted metric (from US) with a 141.6 ?g/m^3 change in PM_{10}.[5] Cropper *et al*. (1997) using their own parameters find that it would result in 3,430 avoided deaths. (ii) In the past few years, a number of policy instruments have been employed in Delhi to control and abate the pollution. The instruments include banning old vehicles, banning leaded gasoline, desulphurisation of diesel, conversion of taxis from diesel to CNG etc. A third minor reason is that in India, among all the cities, Delhi has a much higher level of air pollution and a significant share of this pollution is contributed by vehicular growth.

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[4] Cited in the World Bank (1992: 71-72).

[5] The value 141.6 ?g/m^3 is in fact a change that would reduce levels to the lower end of the WHO guidelines. The study also finds that the percentage decrease in deaths corresponding to a 100 ?g/m^3 reduction in TSP is 2.3% (Cropper *et al*., 1997).

The remaining paper is organised into five sections. Next section gives in brief the main contributor and its source to Delhi's air pollution problem. The data shows that the vehicular pollution contributes nearly two-third to the air pollution in Delhi. The section then briefly looks into the economics of vehicular pollution control and discusses the instruments that can be applied to control the vehicular pollution. Section 3 gives an exhaustive list of policy instruments actually employed in Delhi to control the vehicular pollution. The section then investigates whether the efforts have led to commensurate fall in pollution level by analysing the average trend of air pollution and their violations from the stipulated standards. To attribute proper role to the policy instruments, an econometric model is formulated in section 4. The data and the variables definition are also given in the section. Section 5 gives the statistical results of the estimated model. Paper concludes in section 6 with some remarks and policy implications.

2. Air Pollution – Causes and Remedies

There are three broad sources of air pollution from human activities: stationary or point, mobile, and indoor. In developing countries especially in the rural area, indoor air pollution from using open fires for cooking and heating may be a serious problem. Industries, power plants etc. are the cause of stationary air pollution. But in urban areas – both developing and developed countries, it is predominately mobile or vehicular pollution that contributes to air quality problem. In Delhi, the data shows that of the total 3,000 metric tonnes of pollutants belched out everyday, close to two-third (66%) is from vehicles. Similarly, the contribution of vehicles to urban air pollution is 52% in Bombay and close to one-third in Calcutta.[6] In Delhi, the contribution of vehicular pollution has increased only in past 2-3 decades, as the share, which was a paltry 23% in 1971 rose to 43% in 1981 and became 63% in 1991 (Source: WWF, 1995). This is also reflected from figure 1 that gives the increase in pollution load with the growth in vehicular traffic for few major cities in India.

Vehicles contribute significantly to the air pollution elsewhere in other parts of the world also. In Bangkok, Thailand vehicular pollution accounted for 80% of total pollution in 1987 (Tienchai *et al*., 1990 as referred in Israngkura, 2000: 74). In Budapest, Hungary in 1991, NOx, CO and HC emissions from transport contributed 57%, 81% and 75% of total emissions of respective pollutant (Lehoczki, 2000: 123).

The worst thing about vehicular pollution is that it cannot be avoided as the vehicular emissions are emitted at the near-ground level where we breathe. Pollution from vehicles gets revealed through symptoms like cough, headache, nausea, irritation of eyes, various bronchial problems and visibility and are due to discharges like CO, unburned HC, Pb compounds, NOx, soot and aldehydes, among others, from the tail pipes of vehicles.

[6] Source: www.oneworld.org/cse/html/eyou/eyou222.htm. The study also reports that in Delhi one out of every 10 school children suffers from asthma that is worsening due to vehicular air pollution (*ibid*.).

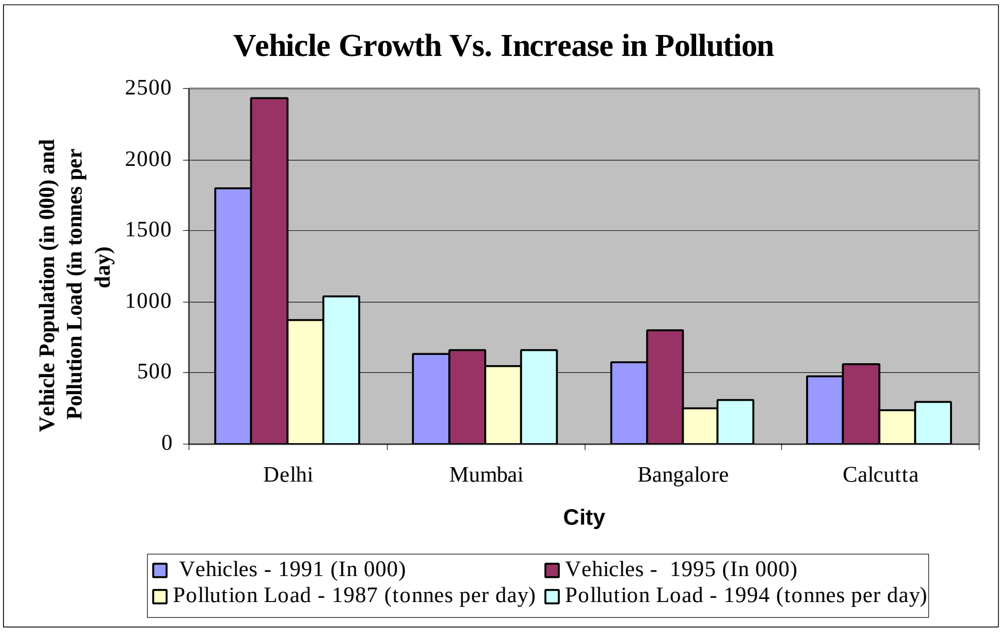

Figure 1: Vehicle Growth vs. Increase in Pollution in different cities in India

(i) Emissions from Vehicles:

Before going into what instruments can be used, it is instructive to see what causes the vehicular pollution. Vehicular pollution sources are not homogenous as there is a complete range of technological mix. The mix could be in terms of fuel used – gasoline or diesel; engine type – two-stroke or four-stroke and a combination of these.

Emissions from Gasoline Vehicles

Gasoline-powered engines are of two types – four-stroke and two-stroke. Table 1 gives the various sources of emissions in the two cases. From the table it is seen that exhaust emissions consisting of CO, HC, oxides of nitrogen (NOx), SO_2, and partial oxides of aldehydes, besides particulate matters including Pb salts account for the larger chunk of all pollution from gasoline-run vehicles.

Table 1: Emission from Gasoline vehicles

	Source	**Amount of Emissions (%)**		**Remarks**
		4-stroke	**2-stroke**	
1	Crankase blowby	20		Carburreted air-fuel mixture and combustion fuel under pressure escape the combustion chamber past the engine piston and ring and enter the crankbase to be discharged into atmosphere through vents
2	Evaporative Emissions	20	3	Fuel vapours lost to the atmosphere from tanks and carburettor
3	Exhaust Emissions	60	97	Exhaust gases emitted with pollutants through the tailpipe

Source: CPCB (1999a)

The incomplete combustion of gasoline due to an imbalance in the air-fuel ratio leads to emissions of CO and HC. In two-stroke engines, unburned HC are emitted due to the short-circuiting of the air-fuel mixture. On the other hand, the NOx are formed due to high combustion temperature and availability of oxygen and nitrogen in the combustion chamber, while aldehydes result from the partial oxidation of HC. In cities, majority of the pollution is emitted by vehicles consuming gasoline ? especially two and three-wheelers, having predominantly two-stroke engine.

The two-stroke two- and three-wheelers require 2 T oil for lubrication of engine. The lubrication is carried out through either premixing mode or oil injection system. In either case it is a total loss system, as the oil is burnt along with the fuel. Since the burning quality of mineral based lubricating oil is very poor vis-à-vis gasoline, major fraction of the lubricating oil entering the engine either remains unburned or burns only partially. This unburned and partially burned oil comes through the exhaust and is responsible for smoke and SPM emission. The studies indicate that two-stroke engine's exhaust contains almost 15-25% of the fuel unburned (Pundir, 2001). In actual practice, the two-stroke vehicles require 2% concentration of 2 T oil i.e., 20 ml in a litre of petrol. The studies show that even a modest 1% increase of oil, may lead to 15% increase in SPM besides visible smoke (CPCB, 1999a). In Delhi, gasoline or petrol driven vehicles comprise over 90% of the total vehicles registered at least since 1971. The data shows that as on 1996, close to 93% of total vehicle registered were petrol driven (UNEP, 1999: 24). This implies controlling pollution from them can have significant pay-offs.

Emissions from Diesel vehicles

As diesel engines breathe only air, blowby gases from the crankcase (consisting primarily of air and HC) are rather low. Moreover, due to its low volatility, evaporative emissions from the fuel tank can safely be ignored. Though the concentration of CO and un-burnt HC in the diesel exhaust are rather low, they are compensated by high concentration of NOx (higher than that in gasoline vehicles). There are smoke particles and oxygenated HC, including aldehydes and odour-producing compounds which have high nuisance value.

Smoke from diesel engines comes in three different hues – white smoke emitted during cold start idling and at low loads; blue smoke from the burning of lubricating oil and additives; and black smoke, a product of incomplete combustion. Black smoke, the most obvious type of vehicular air pollution, consists of irregular shaped agglomerated fine soot/particulates, the formation of which depends on injector nozzle parameter and type of combustion chamber (direct or indirect injection). Black smoke is a particular problem with diesel engines that are not well tuned.

Impact of Fuel Quality

Much of the pollution control depends on the quality of the fuel. So the characteristics that determine fuel quality also become important. A high Reid pressure[7] in the case of gasoline engine causes a high evaporative emission while an increase in the density is followed by a simultaneous increase in CO and HC in the exhausts. Likewise in the case of diesel vehicles, a higher density causes higher smoke, CO and NOx emissions, while a heightening of the cetane number[8] of ignition quality lowers the

[7] The Reid vapor pressure (RVP) means the absolute vapor pressure of a petroleum product in pounds per square inch (or kilopascals) at 100 degrees Fahrenheit (37.8 degrees Celsius).

[8] The cetane number measures the ignition quality of a diesel fuel. It is the % volume of cetane (n-hexadecane, cetane number = 100) in alpha methylnaphthalene (cetane number = 0) that provides the specified standard of 13 degrees (crankshaft angle) ignition delay at the identical compression ratio to that of the fuel sample. A high cetane number indicates greater fuel efficiency (Source: www.bartleby.com/61/88/C02118800.html).

smoke emission. The sulphur content of diesel has been observed to have a direct bearing on the SPM and SO_2 emissions (CPCB, 1999a).

(ii) Economics of Vehicular Pollution Control and Policy Instruments

The above discussion, thus suggests that there are three stages/avenues through which the vehicle emissions can be controlled: (i) stage I or pre-combustion stage where the quality of fuel can be upgraded; (ii) stage II or combustion stage where engine modifications are required; and (iii) stage III or post-combustion stage where exhaust treatment devices like catalytic converters are required. As a consequence the instruments that can be employed can be oriented at any of these three stages and can be directed towards either producer (fuel or vehicle producers) or dealers (petrol pump owners or vehicle dealers). Besides these, there are few 'non-technical' instruments that can be aimed at consumers, requiring behavioural adaptations either in the mode of transport or necessitating periodic maintenance check to minimise the pollution levels. It means any instrument intended for these behavioural changes would either be before stage I (i.e., stage 0) or after stage III (i.e., stage IV).

The standard externality diagram provides the intuition how the various policy options work. The potential users of polluting transport (say car or 2-wheelers) will use transport services up to the point where the benefits they derive, as represented by their demand schedule is equated with the marginal (or additional) costs they have to incur (i.e., to traffic volume, T_a) (see figure 2). However, they do not take into account the environmental costs they impose on others by increasing the air pollution or by crowding the roads or by driving the poorly maintained vehicles, but if they are forced to internalise this cost, by paying an amount equivalent to $P_o - P_a$, the effect will be equivalent to the limited traffic volume, T_o. There are a number of ways to achieve this optimal value that internalises this negative externality – by regulations, subsidies, taxes, incentives etc.

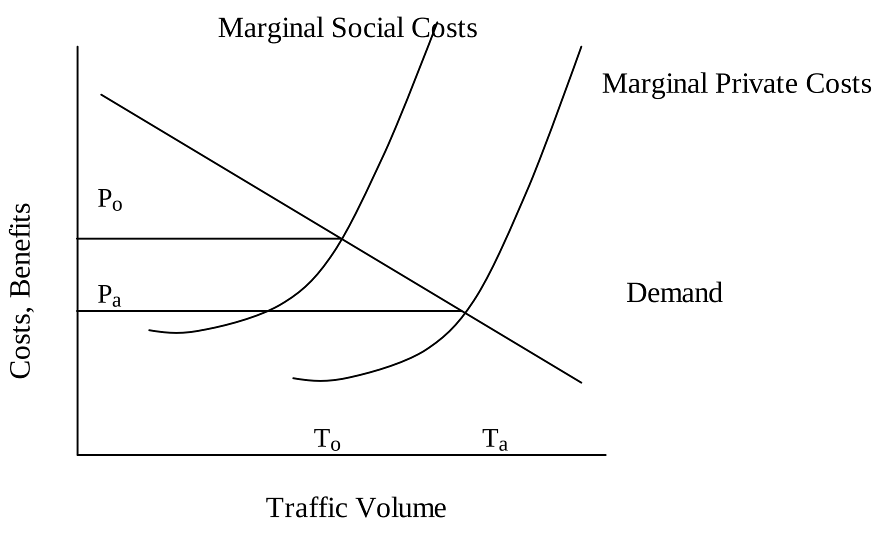

Figure 2: Economics of Vehicular Pollution - Externality Diagram

Traditionally, environmental regulation instruments are classified based on two criteria – a) how much pollution to abate and how to abate; b) need for regulator to monitor emissions. In the former category we have command and control (CAC) instruments and market-based (MB) instruments. The second category has direct and indirect instruments. The direct instruments are emission standards, emission fees and market permits; and indirect instruments are environmental taxes, technology standards etc. (Blackman and Harrington, 2000). Thus, both CAC and MB instruments can be applied at different stages and at different levels. Table 2 gives an illustrative list of some of these instruments along with the stage at which they can be aimed at:

Table 2: Policy Instruments to curb environmental impact from vehicles

	Market Based (MB) Instruments		**Command and Control (CAC) Instruments**	
Type	**Direct**	**Indirect**	**Direct**	**Indirect**
Engine/ Vehicle	Emission Fees (IV)	Tradable Permits (IV)	Emission Standards e.g., EURO I, II (II)	Compulsory Inspection and Maintenance of emission control system e.g., Pollution Certification (IV)
		Differential Vehicle Taxation (I)	Technology Standards, e.g., Catalytic Converters (III)	Mandatory Use of low Polluting Vehicles or Change in Engines e.g., from Gasoline to CNG or Electric (II)
		Tax allowance for new vehicles (I)		Compulsory Scrappage of Old Vehicles (0)
Fuel		Differential Fuel Taxation (I)	Fuel Composition e.g., Desulphurisation or Pre-mixed 2T (I)	Fuel Economic Standards (I)
		High Fuel Taxes (I)	Phasing out of high Polluting Fuels e.g., Unleaded petrol (I)	Speed Limits (IV)
Traffic	Auctioning Traffic Routes e.g., in Chile (IV)	Congestion Charges (IV)	Physical Restraint of Traffic (IV)	Restraint on Vehicle Use e.g., in Singapore, Mexico (0)
		Parking Charges (IV)	Designated Routes (IV)	Lanes for buses, 2-wheelers and cars etc. (IV)
		Subsidies for less Polluting Modes (0)		Better Public Transport (0)

Source: Button and Rietveld (1999: 586) and author's own compilations

Note: Figure in parentheses is the stage at which these instruments can be applied.

3. Policy Instruments employed in Delhi and their impact on Ambient Air Quality

In view of the fact that the transport sector alone accounts for about 66% of the air pollution in Delhi, most of which is in close proximity to the breathing zone, to combat this menace, in the past few years, a number of instruments have been employed in Delhi. Table 3 gives the type and dateline of these instruments and the stages at which they have application.

From the table, it is clear that the focus is predominantly on applying CAC type instruments. The instruments have been applied at all levels – customer, dealer and producer and at all stages from 0 to IV. Along with these few indirect MB instruments have also been made use of. Some of these instruments are indirect not only by definition, but also in the motive, as they were not intended to reduce pollution. These include – higher tax on gasoline and diesel i.e., a kind of environmental tax etc. It needs to be mentioned here that the effectiveness of tax on gasoline or diesel in controlling pollution is limited due to the price inelasticity of demand. Still the proceeds can be used to cleanup the environment as has been used in Hungary.

Table 3: Various Instruments adopted to reduce Vehicular pollution in Delhi[9]

	Measures	Time Target	Status	Instrument Type (Stage)
1	Complete removal of leaded petrol in NCT Delhi (<0.013 g/l)	01.09.1998	Done	CAC (I)
2	Complete removal of leaded petrol in National Capital Region (NCR)	01.01.1999	Done	CAC (I)
3	Phasing out of 17 years old commercial vehicles	30.11.1998	Done	CAC (0)
4	Phasing out of 15 years old commercial vehicles	31.12.1998	Done	CAC (0)
5	Installation of pre-mixed 2T oil dispensers in petrol filling stations	31.12.1998	Done	CAC (I)
6	Low smoke 2 T oil in petrol filling stations	01.04.1999	Done	CAC (I)
7	Setting up of 2 independent fuel testing labs for checking the quality of fuel	01.06.1999	Delayed	CAC (0)
8	All Passenger Cars to meet EURO I norms.	01.06.1999	Done	CAC (II)
9	All Passenger Cars to meet EURO II norms.	31.03.2000	Done	CAC (II)
10	Automated inspection and certification facilities to be set up for commercial vehicles	31.03.2000	Delayed	CAC (IV)
11	Replacement of all pre-1990 autos and taxis with new (subsidized) vehicles using clean fuel	31.03.2000	Done	CAC, MBI (II)
12	Expansion of CNG Supply Network (from 9 to 80 stations)	31.03.2000	Delayed (60 commissioned)	CAC (0)
13	New autos and taxis to be registered with only new CNG or battery operated	01.04.2000	Done	CAC, MBI (0, II)
14	No 8 years old bus is to ply except on CNG or other clean fuel (CNG kit subsidized)	01.04.2000	Delayed	CAC, MBI (0, II)
15	Desulphurisation of petrol (0.05%)	31.05.2000	Done	CAC (I)
16	18 years old two-wheelers to be banned	01.06.2000	N.A.	CAC (0)
17	4-stroke 2-wheelers fitted with catalytic converters to be registered in Delhi	01.10.2000	N.A:	CAC (II)
18	All commercial and transport vehicles to meet EURO II norms	01.10.2000	N.A.	CAC (III)
19	Petrol with maximum 1% benzene introduced	01.11.2000	Done	CAC (I)
20	15-18 years old 2-wheelers to be banned	31.03.2001	N.A.	CAC (0)
21	All buses to switch over to CNG or other clean fuel	31.03.2001	Delayed by 6 months	CAC (II)
22	The bus fleet to be augmented to 10,000 from existing 6,600	01.04.2001	Delayed by 6 months	CAC (0)

Source: CPCB (1999a) and author's compilation from different sources
Note: N.A. - Information not available

India is not the only country where extensive use of CAC instruments has been made to combat vehicular pollution. A number of countries like Chile, Hungary etc. have also used CAC instruments. Chile since early nineties has made use of regulations like mandatory retirement of old buses; the introduction of vehicle emission standards, which in practice makes use of the 3-way catalytic converters mandatory; limits on the operation of vehicles based on the licence plate number for non-catalytic engines (Motta and Behrem, 2000: 179).[10] Hungary has also used CAC instruments like two- and four-stroke engines programme to retrofit catalytic converters, alternative fuels like CNG,

[9] Some of these measures are not specific to Delhi. They were/are being implemented all-over the country. For example, by April 1999 the diesel in the entire country changed to low sulphur content (0.25%). Similarly, unleaded petrol (0.013 g/l) was/is to be made available to entire country by April, 2000 (at least it was planned) (CPCB, 1999).

[10] Not only CAC, Chile has used MBIs also like auctioning of routes for urban buses and tradable permits especially in Santiago (Motta and Behrem, 2000: 179).

acquisition of new vehicles. In Hungary, the first MBI used was introduced way back in 1992 when an environmental product charge on transport fuel was introduced (Lehoczki, 2000: 123).[11]

From the instruments employed, it is evident that India has relied only on air pollution related regulatory instruments. Recently, in many countries policy makers have initiated a shift from dedicated fuel efficiency and atmospheric pollution regulation to pure transport policies like road pricing, parking and collective transport. This shift has multi-facet benefit as it addresses the pure transport related externalities like congestion, traffic accidents etc., besides having a large beneficial impact on air pollution. Unfortunately, India has not yet resorted to such policies and still considers the two problems separable.

Impact of Instruments on Ambient Air Pollution

To see whether the use of above instruments has led to any perceptible fall in pollution, the study looks into how the various air-quality parameters have behaved in the past 3-4 years and their percentage violations from the stipulated standards.[12] Table 4 gives the average values of ambient air pollution data for five parameters – SO_2, NOx, SPM, PM_{10} and CO along with their percentage violations for 1999 to 2001.[13] Figures 3 and 4 give the weekly trend of SPM and PM_{10}; SO_2 and NOx parameters respectively. The local EPA i.e., the CPCB monitors ozone also but no standards have been yet prescribed for it, so no comparison can be done. The daily ambient air pollution data has been taken from the most busiest traffic intersection in Delhi i.e., the Bahadur Shah Zafar Marg (BSZM). The data is for the period June 14, 1999 to June 10, 2001. Until June 2000, the CPCB was monitoring ambient air quality only during working days, but afterwards, even during weekly offs, it has started taking readings.

Table 4: Average values (in μg/m^3) and violation from standards of various parameters (in %)

Year	SO_2	Nox	SPM	PM_{10}	CO (6am-2pm)	CO (2pm-10pm)	CO (10pm-2am)
CPCB Standard	**80**	**80**	**200**	**100**	**2000**	**2000**	**2000**
1999	25 (0)	68 (27)	423 (94)	212 (79)	3250 (82)	5583 (96)	4426 (76)
2000	18 (0)	59 (16)	481 (95)	188 (77)	4071 (96)	5663 (98)	4695 (95)
2001	16 (0)	60 (5)	515 (99)	173 (83)	2479 (67)	3461 (88)	3052 (81)

Source: Author's own compilations

Notes: The parameter CO is in milligram per cubic meter (mg/m^3). The figures in parentheses are percentage time violations from the stipulated standards.

[11] A charge on fuel is close substitute to direct emission tax. Though applying a direct emission charge is economically efficient and environmentally effective, and can result in the reduction of emissions via least costs measures, but is not feasible due to high enforcement costs. An alternate i.e., imposing a charge on fuel can closely substitute direct emission tax and would yield intended results (Lechcozki, 2000: 124).

[12] Table A1 in the appendix gives the annual and 24 hours average standards for various parameters stipulated by the local EPA i.e., the Central Pollution Control Board (CPCB).

[13] In case of CO, the figures are for 8 hours violations.

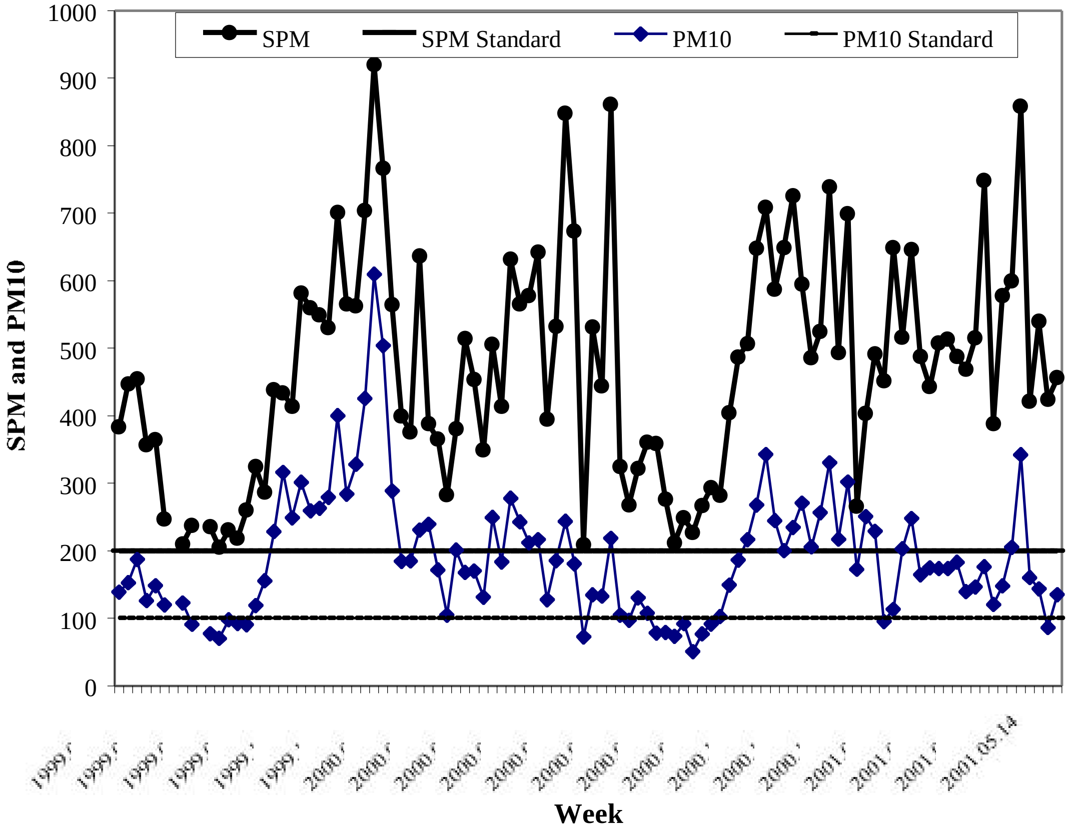

Figure 3: Weekly Trend of SPM and PM_{10} from June 14, 1999 to June 10, 2001

It is quite disturbing to note that despite enactment of several instruments, the SPM quality is deteriorating every year as indicated by its average value. For SPM, PM_{10} and CO, the violations, which should not have exceeded 2% throughout the year, has adherence rate just opposite. The adherence, which was 4% in 1999 in case of SPM, has fallen to just 1% in 2001. This is also clear from Figure 3, as in none of the weeks the average value touched the standard. About particles of smaller size i.e., PM_{10}, though the average value is continually falling, the extent of violation from the standard in 2001 is much higher than preceding two years. The CO violation for each 8-hours category increased alarmingly in 2000 but in 2001 it shows good improvement, yet nowhere close to the designated standard. The only parameter within stipulated limit and showing regular decline is SO_2. This also validates the fact that Delhi vehicles are mostly gasoline driven, and may hardly be emitting SO_2. With respect to NOx, the compliance is increasing, though the average value has increased marginally in 2001 after showing a decline in 2000. The violation, which was 27% in 1999, has fallen to 5% in 2001. If we compare with the CPCB definition of '*clean air*' i.e., *achieving ambient air pollution levels that are 50% of the standards set for each pollutant round the year*, the results seems quite catastrophic except for SO_2.

The above table and the figures indirectly suggest that the policy decisions taken or the instruments employed in past few years have had no impact in reducing the level of pollution at BSZM. In fact, the figures for many parameters for the period are higher than the figures between 1991 and 1994. The average SPM level in Delhi, which was 375 ?g/m^3 during the period 1991-1994 – approximately

5 times the annual average standard of the WHO,[14] has increased by more than 20% to 460 ?g/m^3 for the period 1999 to 2001 – over 6 times the annual average standard of the WHO. With respect to PM_{10} and 8-hours CO, the average over the 1999-2001 period are 190 and 3546, 5022, 4119 respectively. All these values violate the standards to a great extent. From the analysis it is perceptible the enactment of instruments has not induced any improvement in air quality. However, it is still possible that any policy decision taken may have had only a short-term impact rather than a persistent one. To shed some light on this an econometric model is postulated in the next section.

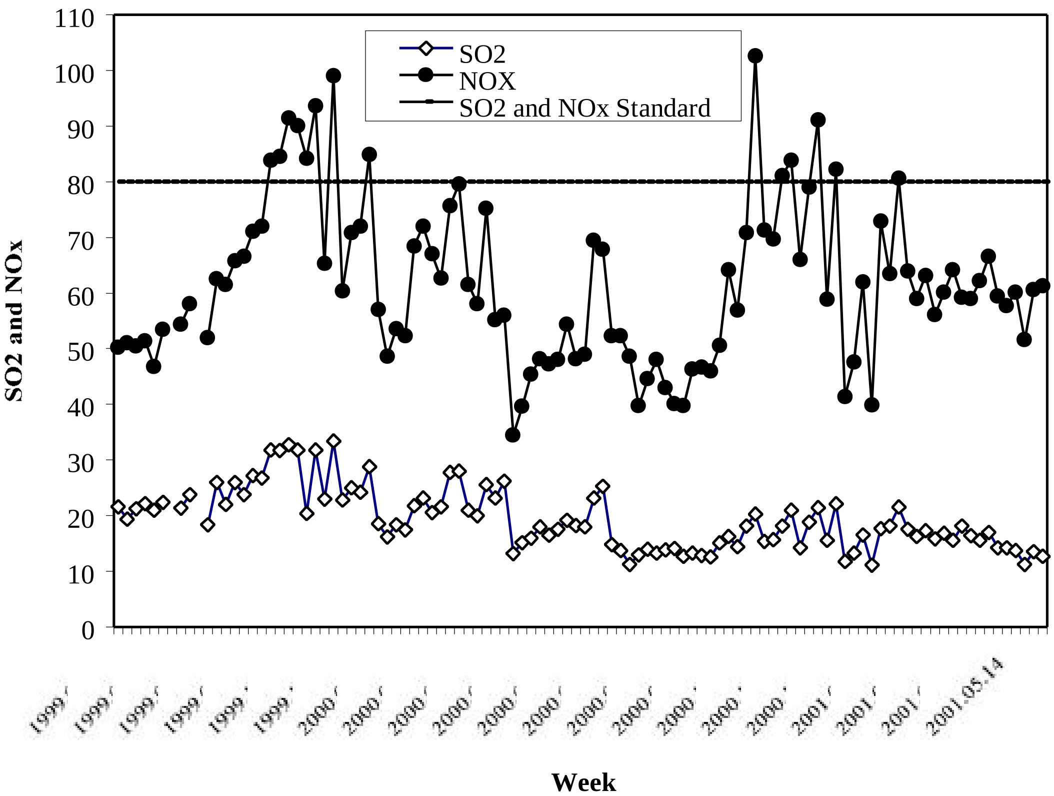

Figure 4: Weekly Trend of SO_2 and NOx from June 14, 1999 to June 10, 2001

4. Model formulation, Data and Variables

Ideally speaking any enactment of policy instrument (if implemented) should lead to fall in ambient pollution level. But the above analysis indicates that it has not taken place. A possible explanation is that the instruments were/are too blunt to have any impact. Since most of the instruments have already been implemented world over, their efficacy cannot be doubted easily. The only probable explanation is that the effect of any imposition or introduction of a policy instrument could have been short-lived and thereafter other factors started dominating. In fact, any introduction of instrument say desulphurisation or conversion of taxis from diesel to CNG might have resulted in immediate fall in

[14] Source: Cropper *et al*. (1997).

emission levels, but over time with increased population of vehicles or any other factor, the ambient quality may have spurted back to earlier level. Given the fact that in Delhi on an average nearly 370-600 vehicles are registered daily,[15] such a possibility cannot be ruled out. As a consequence, the paper employs an alternate modelling strategy. In the modelling exercise, the imposition / introduction of any policy instrument is seen as an event, the occurrence of which should have led to fall in ambient pollution level for an immediate short period (say till a week after the imposition).

Since vehicle emissions depend on a number of factors and as discussed in section 2, they are primarily determined by emission technology, fuel characteristics, vehicle-age. Besides, the speed of the traffic and the vehicle-size also influence the emissions. The section 3 shows that the various instruments employed were/are intended to affect fuel characteristics, vehicle age, size and emission technology, thus it can be safely assumed that they would directly affect the level of emissions. If P_I is the introduction of any policy instrument, then the level of emissions (E_i) would be:

$$E_i = f(P\_I) \quad (1)$$

Since change in vehicular emissions is likely to affect ambient air quality directly,[16] which, in turn is strongly influenced by meteorological and climatic conditions.[17] This implies

$$Amb\_Air = f(E_i, \text{weather, climate}) \quad (2)$$

From (1) and (2), we have

$$Amb\_Air = f(P\_I, \text{weather, climate}) \quad (3)$$

The equation 2 suggests that the local concentrations of air pollutants depend upon two factors: (i) the strength of their sources as reflected by E_i; and (ii) the efficiency of their dispersion, which depends on weather and climate. However, day-to-day variations in concentrations are more affected by meteorological conditions than by changes in source strengths unless there is an exogenous factor affecting the source like introduction of policy instruments in our case.

The variables accounting for weather include temperature, rainfall, wind speed etc. measured on the same day. With its semi-arid climate, Delhi experiences only three seasons: (i) the dry season from April through June; (ii) the monsoon season from July through September; and (iii) winter from October through March. The problem of many of the pollution parameters like SPM is more acute during the summer due to local dusty conditions. On the other hand, rainfall ‘scavenges’ particulates from the air. During the winter months, lower ambient temperatures, lower mixing depth temperature inversion, higher consumption of fuel aggravate the pollution problem.

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[15] A report says that in the year 1999, 370 vehicles were registered every day (Source: The Hindustran Times, 01.10.2000). Another report says that on average 600 vehicles are registered every day in Delhi (Source: http://www.htpcindia.com/lpgfuel.html).

[16] This assumes a linear relationship between total emissions (E_i) and ambient pollutant concentrations (Amb_Air). The studies for countries like Chile also have assumed linear relationship in their air dispersion model (see for example, Motta and Behrem, 2000).

[17] The topography of the region also affects the dispersion. For instance, the dispersion of air in an area circumscribed by mountains would be a severe problem as in Santiago, Chile or Dehradoon, India. Whereas a region near the sea will have relatively faster dispersion. The relevance of topography is high if analysis is carried out across regions, which is not the case in the present study.

Since any pollution parameter has a short-term persistent effect i.e., if the ambient air quality is extremely bad today, the effect may persist even next day unless the wind disperses it or rain scavenges it. To see the persistent effect, the parameter should enter the model with one-day lag.

Other variable that may affect the ambient air quality is the volume of traffic, which has two components: (i) the number of vehicles on the road (v_road); and (ii) the vehicles newly registered (v_reg). The number of vehicles on the road is primarily a reflection of the economic activity taking place in the area, which might vary depending upon the day of the week. If it is a weekly-off, the number of vehicles on the road would be less and *vice versa*. Thus the final model could be:

$$Amb\_Air_t = f(Amb\_Air_{t-1}, P\_I, weather, climate, v\_road, v\_reg) \quad (5)$$

Assuming a linear relationship between ambient air quality and various factors affecting pollution, the econometric model can be written as:

$$Amb\_Air_t = b_0 + b_1\, Amb\_Air_{t-1} + b_2\, P\_I + b_3\, weather + b_4\, climate + b_5\, v\_road + b_6\, v\_reg + u_t \quad (6)$$

Econometric Issues:

As the above model (y_t = ? y_{t-1} + ? x_t + u_t) has lagged dependent variable among the explanatory variables, this implies we have serially correlated errors i.e., u_t = ? u_{t-1} + e_t. Since u_t depends on u_{t-1} and y_{t-1} depends on u_{t-1}, the two variables y_{t-1} and u_t will be correlated. Thus the ordinary least squares (OLS) estimator ? will be inconsistent (Greene, 1999: 580).

If ? is positive, the estimator of ? will be biased upward and the estimate of ? will be biased downward. Hence the standard Durbin-Watson (DW) statistic (which is = 2(1–?)) to measure auto-correlation, will be biased towards 2. This implies the result won't show any significant serial correlation even if the errors are serially correlated. Under the situation an alternate test suggested by Durbin called the *h-test* need to be performed to check for serial correlation. The test uses

$$h = ?\ [n/(1–nV(?))]^{1/2} \quad (7)$$

as the standard normal variable. Here, ? is the estimated first order serial correlation from the OLS residuals, V(?) is the estimated variance of the OLS estimate of ? and n is the sample size. If *h* lies between –1.96 and 1.96, then the null hypothesis of no autocorrelation can be accepted at 5% and model can be estimated by simple OLS.

If there exists serial correlation, Hatanaka (1974) has derived an efficient estimator, which is asymptotically equivalent to maximum likelihood. The efficient estimator is obtained in following four steps: (i) In step 1, the instrumental variables (IVs) are used to estimate [?,?]. A suitable IV for the lagged value of y_t might be the lagged value of the prediction of y_t from a regression on x_t and x_{t-1}. (ii) The step 2 uses the consistent estimates as obtained in Step 1 and estimates ? consistently by the autocorrelation of the residuals, $u_t = y_t$ – $?_{iv}$ x_t – $?_{iv}$ y_{t-1} i.e., computing the residuals using actual values, not predictions. (iii) The step 3 uses the Cochrane-Orcutt transformation to do Generalised Least Squares (GLS) based on the original data, however it adds an additional regressor to the model, u_{t-1}. (The transformation is not applied to the lagged residual). (iv) The last step estimates the efficient estimate of ?, which is the original estimate plus the slope on the lagged residual in the regression at

Step 3. The asymptotic covariance for this estimate is that provided for the slope in Step 3 (see Greene, 1999: 550-52 for further details).

Data and Variables:

As mentioned earlier, the ambient air pollution data has been taken from the busiest intersection in Delhi as given by CPCB. Initially there were 596 daily observations on various pollution parameters for three years from 1999 to 2001 excluding public holidays and the days when no readings were taken. Since the model involves lagged values of air quality parameter, all those observations for which previous day no reading was taken had to be taken out. This reduced the sample size to 537. On five occasions, the data remarks that there was a dust storm or weather was extremely dusty. This might have severely affected the ambient air quality especially SPM and PM_{10} values. These observations have also been taken out from the sample. This leaves a final sample of 532 observations for SPM and NOx parameters. For PM_{10} on three occasions, there was some instrument failure, hence no reading was taken, leaving its final observations to 526.

The date of introduction of policy instrument has been taken from various reports (refer Table 3). The variable Policy Instrument (P_I) has been constructed as a dummy, which attains a value 1 if the time elapsed between enacting a policy is one week or less. The maximum (MaxT) and minimum (MinT) temperature and the rainfall (Rfall) capture the daily meteorological variations.[18] The meteorological data has been taken from the Hindu newspaper. Rainfall (Rfall) is the rain during the day in millimetre. MaxT and MinT are the maximum and minimum temperatures of the day as recorded by the meteorological department in degree Celsius.

To capture the climatic conditions, three seasonal dummies (season_dummy) for summer, winter and rainy season have been introduced in the model. To account for any persistent effect of SPM (or PM_{10} or NOx), the parameter enters the model with one-day lag also.

As mentioned earlier, the level of activity influences the vehicles in use and hence the ambient air quality, this is controlled for by using dummy for each day (Day_dummy). Unfortunately, we do not have any data on how many vehicles have been registered each day. In absence of information of number of registered vehicles daily, a daily time trend (Time) has been considered. The variable has been constructed in such a way so as to partially capture the vehicle registration also. Since during weekly off or any other public holiday no registration takes place, the variable retains the previous day (constructed) value. For example, if we assume only one vehicle is registered per day, then on Friday the total number of new registered vehicles for the week would be 5. Due to weekly off, the cumulative registered vehicles would be 5 on the following Monday also. Similarly the variable retains the same value for a holiday. The major drawback of this variable is that it assumes fixed registration of vehicles each day. A daily time trend (Time) and yearly dummy (year_dummy) have been introduced to account for population increase and other unobserved factors thought to influence the ambient air quality.

[18] Besides temperature and rainfall, the wind and turbulence are two other important meteorological variables that affect the dispersion. The studies indicate that for ground level sources pollutant concentrations are inversely related to wind speed. Similarly, a rough terrain, as produced by buildings, tends to increase turbulence and better dispersion of pollutants. Unfortunately, we do not have data on both these variables.

Thus the final model to be estimated is:

$$SPM\ (\text{or } PM_{10} \text{ or } NOx)_t = b_0 + b_1\ SPM\ (\text{or } PM_{10} \text{ or } NOx)_{t-1} + b_2\ P\_I + b_3\ Rfall + b_4\ MaxT + b_5\ MinT + b_{6\text{-}7}\ Season\_dummy + b_{8\text{-}9}\ Year\_dummy + b_{10}\ Time + b_{11\text{-}16}\ Day\_dummy + u_t \quad (8)$$

5. Empirical Estimation – Impact of Policy Instruments

The model (equation 8) is linear in form. As only three parameters – SPM, PM_{10} and NOx – exceed the standards, the analysis is carried out for these parameters only. First, simple OLS method is performed to calculate *h value*, which ascertains whether there exists serial correlation or not. The computations, after obtaining OLS results, yield the value of *h* for SPM, PM_{10} and NOx parameters as -1.04, -5.23 and -2.91 respectively. This implies the null hypothesis of no serial autocorrelation can be accepted at 5% only for SPM. However, for PM_{10} and NOx, even at 10%, the null cannot be accepted. Thus, there exists serial correlation in case of model with lagged values of PM_{10} and NOx. The models for these air quality parameters are then estimated using Hatanaka (1974) estimator, which corrects for autocorrelation, whereas for SPM the model is estimated using simple OLS.

Since emissions are from vehicles of varying technology and size (i.e., emissions from bus, cars, 2-wheelers, 3-wheelers etc.), the chances of heteroscedasticity exist. Under the situation, the estimated variance of the GLS and OLS results might be biased. This is also confirmed by the Breusch-Pagan test that gives the chi-square statistics as 333.93 for 16 degrees of freedom for the model estimating impact on SPM parameter. The value is much higher than the tabulated value indicating the presence of heteroscedasticity in the data. The models are thus estimated with White's (1980) correction for unknown form of heteroscedasticity. Table 5 gives the results for the heteroscedasticity corrected model for SPM, PM_{10} and NOx parameter respectively. The results are for the null that the impact of enacting a policy instrument lasts one-week minimum.

From the results one notes that the pollution parameters have a persistent effect, as the lagged value significantly impacts the current value. With respect to parameters pertaining to the weather, the rainfall has a varying impact on the ambient air quality. Though rain scavenges particulates matter (SPM and PM_{10}) as hypothesised, it aggravates the formation of NOx. On the other hand, if the weather is hot, as indicated by highly positive and significant coefficient, it leads to high SPM and NOx formation. Same is true if weather is too cold as is reflected from the negative and significant signs of MinT for the two. However, the impact of temperature on the PM_{10} is found to be statistically insignificant.

The variable, Time, a crude proxy for new registered vehicles though attains correct sign, but is significant only in case of NOx. The day dummies to look into weekday effect also attain significance mainly in case of NOx. For SPM, only on Wednesday and Thursday (i.e., the middle of the week) when the economic activity is at its peak, it results in high pollution. However, for PM_{10}, the coefficients are not significantly different from zero. The sign and significance of year dummies reflect that compared to 2001, the pollution during the years 2000 and 1999 was higher. For the year 2000, it was statistically significant also for SPM and NOx.

Table 5: Impact of Policy Instrument lasting one week on Ambient Air Quality

Variable	SPM	PM_{10}	NOx
SPM_{t-1} / $PM10_{t-1}$ / NOx_{t-1}	0.577*** (9.11)	0.874*** (3.44)	0.40*** (2.43)
MinT	-5.43** (2.07)	-1.05 (0.565)	-0.53*** (2.43)
MaxT	6.07*** (2.44)	-0.44 (.28)	0.57** (2.26)
Rfall	-2.17*** (3.37)	-0.848*** (2.75)	0.17*** (3.2)
Day1 (Monday)	25.91 (1.18)	-1.03 (0.083)	6.52*** (2.69)
Day2 (Tuesday)	11.69 (0.58)	1.96 (0.201)	5.13*** (2.74)
Day3 (Wednesday)	35.70* (1.73)	9.47 (0.89)	3.0 (1.58)
Day4 (Thrusday)	35.73* (1.73)	9.39 (0.81)	4.36** (2.28)
Day5 (Friday)	28.36 (1.14)	3.7 (0.29)	5.33*** (2.84)
Day6 (Saturday)	2.8 (0.14)	-2.48 (0.19)	5.51*** (3.2)
Season_dummy1 (Summer)	29.2 (1.32)	16.08 (1.33)	-5.33* (1.9)
Season_dummy2 (Rain)	-78.12*** (3.13)	-3.15 (0.12)	-11.38*** (2.99)
Yr_dummy1 (1999)	61.75 (1.28)	38.42 (0.82)	22.41*** (2.78)
Yr_dummy2 (2000)	52.17** (2.18)	20.81 (0.88)	8.82*** (2.54)
Time	0.139 (1.12)	0.056 (0.67)	0.034** (2.03)
P_I (7 days)	-27.26 (1.36)	-3.55 (0.31)	-0.82 (0.39)
Constant	33.05 (0.49)	19.35 (0.36)	9.97 (1.43)
Durbin-h test	-1.04	-5.23	-2.91
Rho	-.018	-0.119	-.0574
Adjusted r-square	0.557	0.572	0.527
Estimator	Heteroscedasticity Corrected OLS	Hatanaka (1974)	Hatanaka (1974)
N	532	525	531

Note: Figures in parenthesis are t-values. ***,**,* are significance levels at 1%, 5% and 10% respectively.

Row 14 of the tables gives the coefficients of policy instrument (P_I). It is surprising to find that enacting a policy instrument has not led to any fall in the air-pollution as none of the coefficient attains significance, though coefficients for all the three parameters have correct sign. This raises a question: is the 7-day period too long? If in the intervening period, a number of new vehicles are registered, the pollution load would have reverted back to the old level. To see whether even for a brief period, the effect persisted, the model has been run with Policy instrument constructed as a dummy that attains the value one for 5 days, 3 days, 2 days, 1 day, 10 days and 15 days respectively after the enactment. Table 6 reports the results for only policy instrument (P_I) variable. The coefficients as reported in the table attain negative sign for all the variables barring twice. The results suggest that in general, imposition of policy instrument has no effect as the number of days increase.

The impact of imposing or enacting a policy instrument is immediate leading to fall in ambient pollution level especially for SPM and PM_{10} after that other factors start dominating.

Table 6: Impact of Policy Instrument on Ambient Air Quality

Variable	Parameter SPM	Parameter PM_{10}	Parameter NOx
P_I (1 day)	-79.07*** (3.22)	-12.78 (0.88)	-1.88 (0.45)
P_I (2 days)	-56.52*** (2.98)	-19.71* (1.81)	1.13 (0.75)
P_I (3 days)	-13.89 (0.53)	5.18 (0.36)	-0.53 (0.18)
P_I (5 days)	-27.79 (1.33)	-0.34 (0.03)	-0.05 (0.022)
P_I (7 days)	-27.26 (1.36)	-3.55 (0.31)	-0.82 (0.39)
P_I (10 days)	-11.76 (0.52)	-3.63 (0.31)	-1.12 (0.53)
P_I (15 days)	-12.0 (0.57)	-7.72 (0.64)	-1.78 (0.94)

Note: Figures in parenthesis are t-values. ***,**,* are significance levels at 1%, 5% and 10% respectively. The days in the parenthesis in column 1 indicate that the variable P_I has been constructed in such a way that it is assigned a value 1 for those days after imposition of policy instrument and zero after that.

One possible reason for policy efforts not yielding desired results is that the emphasis as of now is solely on new vehicles – in terms of formulation and implementation of emission standards, for in-service vehicles there has been little progress. The contribution of in-service vehicles become evident from the data, which indicates that for Indian conditions 20% of bad in-service vehicles contribute as much as 60% of total vehicular emissions (Pundir, 2001).

Though emission regulations for in-service vehicles exist since mid-1980s at least in cities like Delhi, Mumbai and other large cities and to enforce these regulations, a number of gasoline retail stations and some garages have been authorized to carry out pollution check (known as Pollution Under Control, PUC check centres) and the vehicles have to do the PUC check every six months, the quality of pollution-checks remain doubtful. Our conjecture gets strength from a recent survey done by the CPCB along with the State Transport Department, Delhi during May-June 1999. The teams inspected 21 Vehicular Pollution Checking centres pertaining to their operation, maintenance and calibration of instruments. The survey finds that at some centres, operators were not fully conversant with the operation of the instruments. It was observed at many places that the analyser instruments were exposed to dirt and heat leaving the sampling probe dirty and choked, thus affecting the performance of the instruments (CPCB, 1999b). At many places, even calibration was not performed (*ibid.*).

Besides increase in vehicle population and lack of focus on in-service vehicles, another reason for variable not coming out significant in the long run could be related to the expectation of the people. Since many a times in India, the measure / policy instrument announced gets delayed or even revoked after a brief implementation due to opposition from the pressure-group, which can easily modify the expectation of the people that any new instrument promulgated will not be implemented fully. The case of plying of CNG run buses partially testifies this, as the implementation decision has been deferred for another six months despite significant time at the disposal of state government to implement it (refer Table 3).

6. Concluding Remarks and Policy Implications

Delhi figures prominently in the world environment map for the simple reason that it is one of the most polluted cities in the world caused by spectacular vehicular growth in the past 2-3 decades. Incidentally, few years back it was acclaimed as one of the greenest capital also. In order to restore the air quality and refurbish its image, a number of CAC policy instruments have been implemented in Delhi in the past few years. Our results and analysis however shows that the imposition has not led to concomitant improvement in ambient air quality. There exist a number of explanations for this lacklustre result.

First of all, even with stricter enforcement, a regulatory approach based on emissions standards is fated to result in greater pollution discharge if the number of sources increases, unless the standards are made more stringent. Perhaps this is happening in Delhi. Secondly, most instruments fail unless people are made aware of the benefits. That could be the other reason for instruments not showing intended impact. In Bangkok, Thailand though government disseminated information to the public and automobile users on the benefits of using unleaded gasoline and which vehicles can use unleaded gasoline, still some studies indicate that many users continued using unleaded gasoline because of lack of adequate information and doubted the effects of unleaded gasoline on engine performance (see for example, Maneerat, 1991; Pradit, 1992; Nitichai, 1994 as referred in Israngkura, 2000: 75).

Thirdly, if instruments require scrappage of old vehicles, then simply mandating sales of new clean vehicles does not fully address the ambient air quality problem. This is because it still remains unknown who will purchase the vehicles, where will they be living (highly polluted or cleaner regions), or how much will they drive the vehicles once purchased.

Lastly the emphasis is only on CAC instruments and that too directed towards air quality. As mentioned earlier, many countries like Singapore, Chile etc. have initiated a shift from the dedicated fuel efficiency and atmospheric pollution regulation to pure transport policies like road pricing, parking and collective transport. This shift has multi-faceted benefit as it addresses the pure transport related externalities like congestion, traffic accidents etc. besides, having a large beneficial impact on air pollution.

In fact, the containment of vehicular pollution requires an *integrated approach*, with many essential components: (i) improvement of public transport system; (ii) optimisation of traffic flow and improvement in traffic management (e.g., area traffic control system, no-traffic zone, green corridors, removal of encroachment on roads, regulation of construction activities and digging of roads);[19] (iii) comprehensive inspection and certification system for on-road vehicles; (iv) phasing out of grossly polluting units; (v) fuel quality improvement (e.g., benzene and aromatics in petrol, reformulated gasoline with oxygenates/additives, reduction of sulphur in diesel); (vi) tightening of emission norms (e.g., EURO-IV); (vii) improvement in vehicle technology (e.g., restriction on the 2-stroke engines,

[19] A recent study by Central Road Research Institute (CRRI) said that the 321 kilolitres (KL) of petrol and 101 KL of diesel is wasted everyday at 466 intersections in Delhi. The annual loss because of this comes to about Rs. 2,450 million per annum at 1996 prices (Source: Hindustan Times, 14.1.1999), which can be minimised by proper synchronization of traffic signals.

emission warranty, on-board diagnostic system); (viii) checking adulteration of fuel; (ix) checking evaporative emissions from storage tanks and fuel distribution system (CPCB, 1999a).

The present study and the results obtained has policy implications for all those developing countries like Nepal, Bangladesh etc. that have embarked upon widespread use of CAC to control air pollution. As long as these countries including India consider the problems of air quality and transport related externalities as separable, the control of air pollution will not be achieved.

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Appendix

Table A1: National Ambient Air Quality Standards

Pollutant	Time Weighted Average	Concentration in Ambient Air		
		Industrial Area	Residential, Rural and other	Sensitive Area
Sulphur Dioxide (SO_2)	Annual 24 hours	80 µg/m^3 120 µg/m^3	60 µg/m^3 80 µg/m^3	15 µg/m^3 30 µg/m^3
Oxides of Nitrogen (NO_2)	Annual 24 hours	80 µg/m^3 120 µg/m^3	60 µg/m^3 80 µg/m^3	15 µg/m^3 30 µg/m^3
Suspended Particulate Matter (SPM)	Annual 24 hours	360 µg/m^3 500 µg/m^3	140 µg/m^3 200 µg/m^3	70 µg/m^3 100 µg/m^3
Respirable* Particulate Matter (RPM)	Annual 24 hours	120 µg/m^3 150 µg/m^3	60 µg/m^3 100 µg/m^3	50 µg/m^3 75 µg/m^3
Lead (pb)	Annual 24 hours	1.0 µg/m^3 1.5 µg/m^3	0.75 µg/m^3 1.00 µg/m^3	0.50 µg/m^3 0.75 µg/m^3
Carbon Monoxide(CO)	8 hours 1 hour	5.0 µg/m^3 10.0 µg/m^3	2.0 µg/m^3 4.0 µg/m^3	1.0 µg/m^3 2.0 µg/m^3

Source: Ministry of Environment and Forests (MoEF), Government of India notification, 1994

Note: *Particle size less than 10 µm i.e., PM_{10}

Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval;

24 hourly/8 hourly values should be met 98% of the time in a year. However 2% of the time, it may exceed but not on two consecutive days.

The CPCB has started measuring RPM only few years back, whereas in countries like Malaysia, the Malaysian Meteorological Service (MMS) started collecting data on PM_{10} at some of its monitoring stations since late 1980s (Vincent and Tan, 1997: 291).