ESM262
v. 1

Sustainable Transport Options for Sri Lanka

February 2003

Joint UNDP/World Bank Energy Sector Management Assistance Programme (ESMAP)

Contents

Acknowledgement

This study was carried out in 1999-2000, with assistance from the Danish Trust Fund (Global Overlays Program) and the ESMAP Energy-Environmental Review Program, by a team consisting of Mohan Munasinghe (ENVDR, Team Leader), Peter Meier (Consultant), and Sri Lankan counterparts including: D. Chandrasekere (CPC), S. Chandrasiri (Univ. of Colombo), A. Kumarage (Univ. of Moratuwa), and D.S. Jayaweera (Transport Policy Centre). Valuable comments provided by the staff of the South Asia region, and editorial assistance from Kate Sullivan and Nishanthi De Silva are gratefully acknowledged. The document was prepared at the Munasinghe Institute for Development (MIND), Colombo -- a founding partner of the World Bank Global Village Energy Partnership (GVEP).

Abbreviations and Acronyms

2S	2-stoke motorcycle
4S	4-stroke motorcycle
BoI	Board of Investment
CCPI	Colombo consumer price index .
CEB	Ceylon Electricity Board
CGPI	Greater Colombo price index
CKE	Colombo-Katunayake Expressway
CPC	Ceylon Petroleum Corporation
DMU	diesel multiple unit
DSD	District Secretariat Divisions
EER	economic rate of return
EMU	electric multiple unit
GDP	gross domestic product
GDPD	implicit gross domestic price deflator
GHG	greenhouse gas
GP	general practitioner
GVW	gross vehicle weight
HC	hydrocarbons
I/M	inspection and maintenance
IMF	International Monetary Fund
kPa	kilopascals (a measure of pressure)
LPG	liquid petroleum gas
MC	motorcycle
MEC	maximum effective capacity (of a rail line)
MEIP	Metropolitan Environmental Improvement Programme
MON	motor octane number
NPV	net present value
OLS	ordinary least squares
PCU	passenger car unit
PIA	project impact area

PPP	purchase power parity
psi	pounds per square inch
RON	research octane number
RVP	Reid vapor pressure
SLR	Sri Lanka Railways
SLTB	Sri Lanka transport Board
SURE	seemingly unrelated regression estimate
TEL	tetra ethyl lead
TSPC	Transportation Studies Policy Centre
URT	upper respiratory tract
WP	Western Province
WPI	wholesale price index

Executive Summary

E.1 Background and Results

The economic costs and environmental impacts of Sri Lanka's transportation sector have drawn the increasing attention of policy-makers and environmentalists. While traffic conditions and urban air quality in Colombo have yet to deteriorate to those encountered in many other Asian cities, particularly over the past five years there has been a significant increase in road traffic congestion in Colombo. Sustained economic growth and lagging investment in public transportation have led to increased vehicle ownership and corresponding growth in transport fuel consumption.

Table 1 shows survey results taken on the seven main radial roads from the centre of Colombo for the morning peak in 1997, 1999 and 2001. Over the past four years, speeds on all roads have fallen by at least half; moreover, while in 1997 peak conditions were observed only for roughly two hours during the morning peak, by 2001 these conditions extended until mid-afternoon (in the inward direction); and similarly in the outward direction, the congested period now starts already in mid-afternoon. Such dramatic reductions in network speeds result in significant increases in local air emissions, because fuel efficiency decreases non-linearly with speed – especially under stop-go driving conditions of highly congested roads.

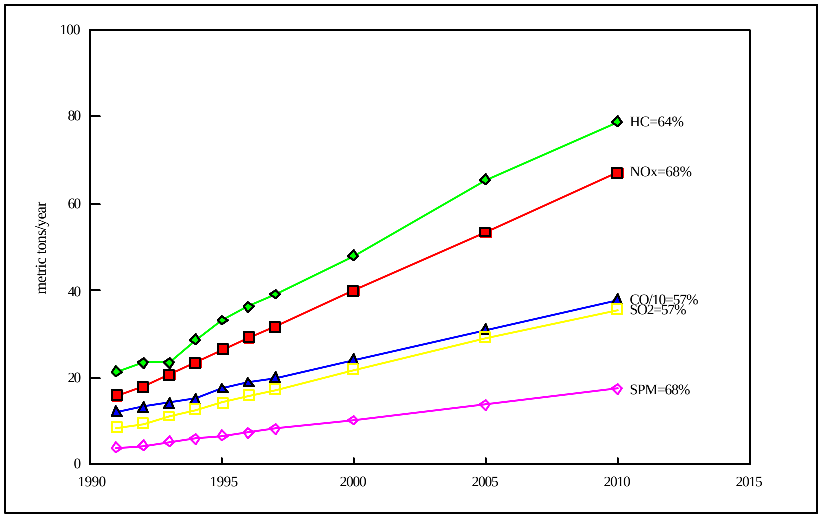
Table 1: Car journey time survey results (as average speeds, km/hour): Inward direction, morning peak

		1997	*1999*	*2001*
Colombo-Galle	MalibanJunction to Dickman Road	28	18	8
Colombo - Ratnapura	Maharagama to Kirulap	32	16	6
Colombo – Kandy	Kadawatha to Orugodawatte	23	22	11
Colombo - Puttalam	Mahabage to Kelani Bridge	18	16	7
Jayawardanapura - Kollupitiya	Battaramulla to Senanayake Juncti	23	17	9
Colombo-Horana	Papiliyana to Vilasitha Nivasa Junc	27	17	8
Wellampitiya – Kaduwela	Abatale to Wellampitiya	28	18	9

Source: Transport Studies Planning Centre, Ministry of Transport

Present expectations suggest significant increases in transport-related air emissions over the next decade: Figure 1 shows the projections made by the Clean Air 2000 programme.

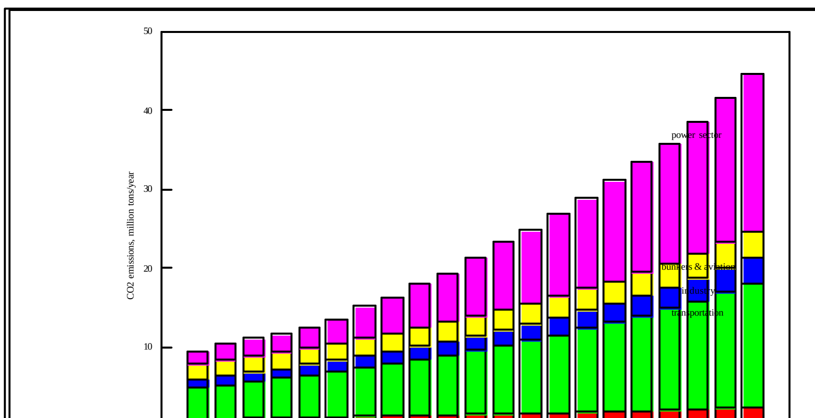
Figure 1: projections of local air-emissions in the Clean Air 2000 programme



Source: NBRO

GHG emissions from the transport sector are expected to show similar increases, quadrupling over the next 20 years. Although – as suggested in Figure 2 -- the share will decrease somewhat as emissions from the power sector increase, by 2018 transport still accounts for 35% of energy-related GHG emissions (down from 39% in 2000).

Figure 2: GHG emission projections



	1998		2000		2002		2004		2006		2008		2010		2012		2014		2016		2018
domestic [LPG+Kerosene]	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.3	2.4
transportation	3.9	4.3	4.7	5.0	5.4	5.8	6.2	6.7	7.2	7.7	8.2	8.7	9.3	9.9	10.6	11.3	12.0	12.9	13.7	14.7	15.7
industry	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.9	3.1	3.2
bunkers & aviation	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.7	2.7	2.8	2.9	3.0	3.0	3.1	3.2	3.3
power sector	1.7	2.1	2.3	2.3	2.5	3.0	4.0	4.5	5.6	6.2	7.4	8.6	9.3	10.5	11.4	12.7	14.1	15.2	16.7	18.4	20.1

Source: Global Overlay Study of Greenhouse Gas Mitigation Options in the Sri Lanka Power Sector

It seems prudent to take action before the situation becomes significantly worse – and for several reasons. First, as is true for many environmental issues that involve externalities not captured by markets and prices, prevention of further deterioration through proper planning is often cheaper than ex-post clean-up. Moreover, vested interests in some unfortunate present practices will become more entrenched the longer they are permitted to continue – for which a good example is the practice of on-street parking on many of Colombo's arterial roads, a major cause of congestion externalities. Second, many potential policy measures have long lead times. For example, since an outright ban on 2-stroke motorcycles is not practicable, efforts to lower the proportion of these vehicles in the fleet mix by banning further imports (or by tax disincentives) will take many years before all of the existing fleet of 2-stroke motorcycles is retired.

To date, the environmental aspects of Sri Lanka's transportation sector have been examined only an *ad hoc* basis. The work in the early 1990s that led to the adoption of the Colombo Clean Air 2000 programme focused mainly on emissions, but lacked systematic cost-benefit analysis (CBA). Subsequent analyses of measures to reformulate fuel (lower lead in gasoline, lower sulfur in diesel) were limited to financial analysis of the impact on the refinery. After intense criticism of the first Environmental Impact Assessment of the proposed Colombo-Katunayake expressway, a new Assessment in 1997 was the first attempt by the Road Development Authority (RDA) to monetise local environmental impacts and incorporate them into CBA – though as discussed in Section 11.1, not without problems. Transportation sector emissions were examined in the 1996 Greenhouse Gas Emission Inventory, and selected transportation measures were examined in a 1995 World Bank study, but to date there has been no systematic examination of the GHG emissions consequences of a broader range of policy options in the transport sector. An important study of congestion costs was completed in 1999, but this did not extend to valuation of the relevant environmental externalities. Finally, a comparison of the environmental consequences of selected policy options in the road transport sector was published in 2000, but the focus was limited to the trade-off between costs of policy implementation and emissions, and did not extent to benefit valuation. The first (and thus far only) rigorous study of health effects of vehicle pollution in Sri Lanka also appeared in late 2000, but it too was limited in scope, and quantified health damages only for a small group of highly exposed occupations. Another study of hospital attendance for asthma suggested a strong correlation with air pollution levels in Colombo.

Approach

In this study we build on past work, and examine a broad selection of sustainable transport sector policy options from the standpoint of a common set of consistently defined attributes. Ideally, sustainable transport development should focus on the economic, environmental and social dimensions of sustainable development. However, in this volume, the first two aspects receive greater attention. The social dimension is examined mainly from the equity viewpoint, due to lack of time and data with regard to other key social indicators. The attributes considered in this study include:

?? *economic efficiency*: quantified as the NPV of lifetime economic costs and benefits (discounted at the opportunity cost of capital taken here at 12%).

?? *local environment*: quantified as emissions of the main air pollutants (and monetised using the benefit transfer method).

?? *global environment*: for which we use emissions of GHGs over the next 20 years as a proxy (and monetised at $20/ton values per ton of carbon).

?? *government revenue:* the transport sector accounts for a significant share of all tax revenue (about 7%), and therefore potential interventions need to be mindful of the impact on government revenue streams. Wherever possible, we suggest reforms that are revenue neutral.

?? *equity:* because the main types of vehicles are associated with largely distinct levels of income, we may assess the probable equity implications by enumerating the private costs and tax burdens for each vehicle category. We show that the present system of transportation fuel taxation has some perhaps unexpected distributional results.

Table 2 summarises the options examined in the study.

Table 2: Options

Option	*Sectio*	*Description and rationale*
Congestion charge	8.1	Increasing congestion in the Centre of Colombo has led to proposals by the Municipal Council for a congestion charge, along the lines of the successful policy in Singapore. We examine economic and environmental consequences of congestion charge options.
School Bus	8.2	Vans that have replaced the previous school bus service are a significant contributor to Colombo congestion both during the morning rush hour and mid-afternoon. We examine a proposal for the re-introduction of school bus service.
Tax Equalisation	9.1	The present fuel taxation regime suffers from numerous shortcomings, most notably that its intended purpose of taxing high-income individuals thought gasoline taxes has been largely avoided by the strong growth of “dual-purpose” diesel vehicles: a significant fraction of the tax is in fact paid by motorcycle owners (who effectively subsidise diesel lorries). We examine the impact of a revenue-neutral fuel tax (which would lower gasoline taxes and increase diesel tax).
Unleaded gasoline	9.2	The present level of lead in gasoline is 0.10 gms TEL/litre (first six months of 2001), down from 0.3 in the mid 1990s. CPC is committed to the new standard for leaded gasoline of 0.15gms/litre. Efforts to introduce unleaded gasoline to date have been relatively unsuccessful due to poor pricing policy. We examine the costs and benefits of eliminating lead altogether.
Carbon tax	9.3	An “incremental” carbon tax is additional to the present rates of tax: if this incremental levy is based on a carbon externality value of $20/ton

Option	*Sectio*	*Description and rationale*
(incremental)		this incremental levy is based on a carbon externality value of $20/ton carbon, fuel consumption (and carbon emissions) will decrease as a function of the assumed value of price-elasticity (but will also bring joint benefits of local air emission reductions.
Carbon tax (equalisation)	9.3	Instead of revenue-neutral equalisation based on a fixed level of tax per litre, fuel taxes can be determined on the basis of their relative carbon emissions (which implies a ratio of tax for diesel to gasoline of 1.32:1.14).
ban2S MC	10.1	2-stroke motorcycles have significantly higher emissions than 4-stroke MCs. Since an outright ban is not practicable (due to the large existing stock of 2-stroke MCs), we examine the effect of a ban on new imports, so 2S-MCs would gradually be phased out over a 10-12 year period.
LPG conversion	10.2	We estimate that 10% of the gasoline-engine vehicle fleet has been converted to LPG – a development driven entirely by the tax differential between gasoline and LPG. However, in economic terms, LPG is significantly more expensive. We examine here the costs of continued conversion to LPG.
Colombo-Katunayake expressway(CKE)	11.1	The Colombo-Katunayake expressway is designed to alleviate congestion on Sri Lanka's most heavily traveled section of road, the A3 from Colombo to the international airport at Katunayake. Although a decision to build the CKE has already been taken, we re-examine the benefit-cost analysis by including current estimates of environmental externalities and new traffic data and time cost savings.
Inland Container Port	11.2	Colombo Port is significantly congested, and container lorries on the A3 road are a major source of congestion. We examine the Government's proposal to establish an Inland Container Port north of Colombo, to be served by a direct rail connection (thereby relieving congestion on the A3 and its access roads.
Railway electricifcation	11.3	Railway electrification has been discussed for over 30 years. We examine a proposal for the electrification of suburban rail service on the Northern main line.
Reduction of sulfur in diesel fuel	12.1	The present sulfur standard is 1.1%S, though actual sulfur content in autodiesel has been around 0.8% for the past few years (as the proportion of imported diesel has risen). We examine the economic and environmental consequences of 0.5% and 0.3% standards.

Option	*Sectio*	*Description and rationale*
2T oil for 3-wheelers	12.2	Elsewhere in South Asia it has been found that use of inappropriate lubricating oils in 2-stroke engines causes high particulate emissions. We examine the benefits of using 2T oil in Sri Lanka.

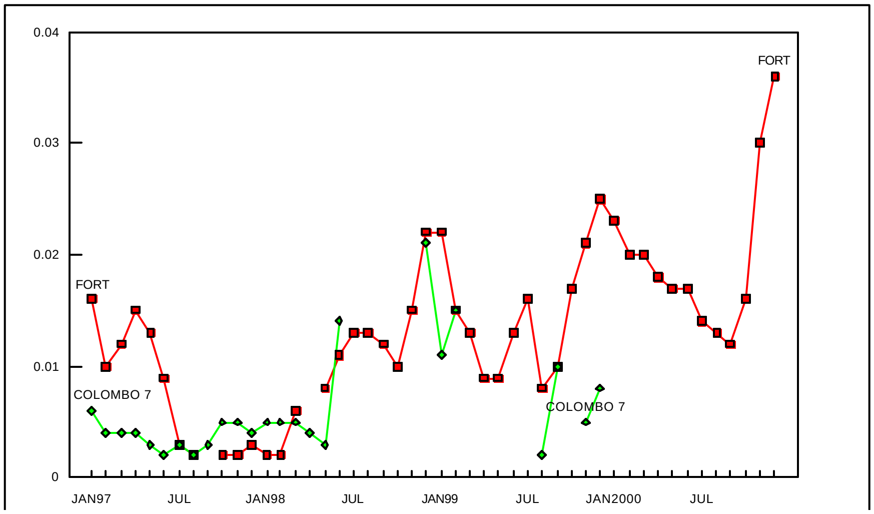
Air quality trends

Compared to the air quality data available in other Asian cities, that for Colombo is quite limited. Systematic monitoring started in 1989 under the auspices of the Environmental Division of the National Building Research Organisation (NBRO). A first study examined 49 locations in the city of Colombo for sulfation rate and dustfall, followed by a second programme at seven representative locations in 1992/1993. In late 1996, NBRO started a long-term monitoring programme at two Colombo locations – at Fort, in the centre of the city, and a site in Colombo 7 (Bauddaloka Mawatha, a mainly residential area) as a background station in Colombo. These sites have provided PM-10 once in four days, and continuous monitoring of NOx, CO, SO_2, ozone (plus corresponding meteorological data). This is the most important source of Colombo air quality data.

A first question is whether air quality in Colombo has in fact deteriorated, and to what extent any deterioration can be linked to vehicular emissions. Unfortunately, because of differences in sampling methods, and locations, the new data from 1996-2000 is difficult to compare with the earlier data from 1989, and 1992-1993. However, the new data set since late 1996 does permit some preliminary conclusions. Figure 3 shows monthly averages from 1996 to 2000 for SO_2. We note the seasonality of the data: the highest concentrations are in November-January, which is clearly reflects the impact of fumigation conditions during the NE monsoon -- when the prevailing wind direction is exactly opposite to the sea breezes that have W to SW direction, which are typical for the late afternoon-evening hours.

Although the Fort station data is unbroken over the four-year period, there are extensive gaps in the available data for the Colombo 7 location, so it is difficult to make judgments about the extent to which the Fort location – clearly a "hot spot" -- can be used to gauge average population exposures.

Figure 3: Monthly averages for SO_2



Another way of noting the trend is to examine the occurrence exceedances of the standard. For example, Table 3 shows the number of SO_2 exceedances of the CEA standard for 1-hour average of 0.08ppm – and again we see the dramatic change in the last few months of 2000. The same general trends are also observed for NOx.

Table 3: SO_2: daily exceedances/month

	1996	*1997*	*1998*	*1999*	*2000*
January				3	4
February					5
March			2		5
April		3			1
May		2			
June					
July					
August					
September					
October					2
November			3	1	25
December	5		2	1	40
total	5	5	7	5	82

Source: NBRO AQM Database

Vehicle fleet

Estimating the active vehicle fleet proves to be a major challenge, and many past studies have neglected to show the necessary consistency between estimates of the active vehicle fleet, the average annual distances traveled, rates of fuel consumption, and the total quantity of fuel consumed. Only the last quantity is known with any precision, and there exist an infinite number of combinations of these variables that could, in principle, yield the known total quantity of fuel consumed.

Based on earlier work at the University of Moratuwa, a detailed vehicle fleet model was developed for this study (and calibrated against the historical data against reconciliation of known gasoline and diesel consumption). It is only recently that rigorous research has been conducted on the composition and evolution of the vehicle fleet to the point at which one may have reasonable confidence in models to project the future growth of vehicles and the concomitant growth of emissions.

This work involved careful reconciliation of the available data sources; the formulation of appropriate models of vehicle growth based on hypotheses about survival rates: the calibration of model results with the empirical data (as obtained, for example, from traffic counts), and reconciliation of estimated vehicle fleets, fuel efficiency, and typical annual distances traveled by each class of vehicle with the total consumption of fuel. Table 4 shows our estimate of the 2000 vehicle fleet by type, average yearly km per vehicle, and average fuel consumption.

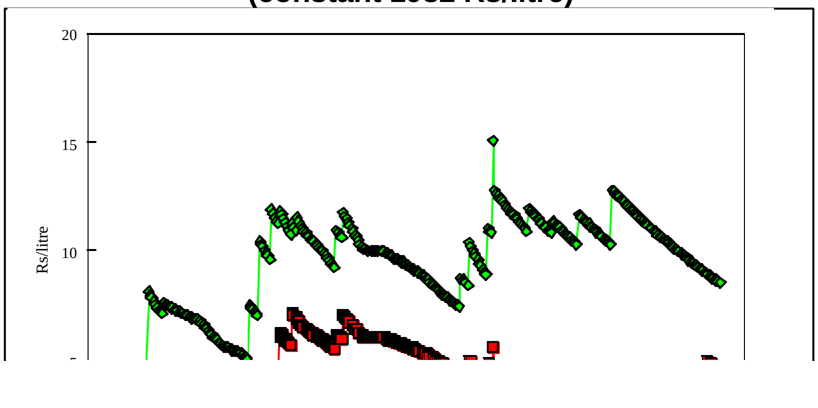
Table 4: Average fuel consumption by vehicle types, 2000

	fuel	*vehicle fleet*	*km/year*	*km/litre*	*fuel cons. 1000 tons*
MC -2S	petrol	179024	5533	41	18
MC -4S	petrol	377799	5171	41	35
Car	petrol	132929	8274	10	94
Dual purpose	petrol	24955	5468	8	15
Land Vehicle	petrol	1844	4881	5	1
Three wheeler	petrol	73991	19676	24	49
Total		790542			213
Car	diesel	20005	16759	9	29
Dual purpose	diesel	186488	14684	8	298
Bus	diesel	23948	40117	3	219
Lorry	diesel	65373	22394	3	351
Land Vehicle	diesel	73091	3652	6	36
Three wheeler	diesel	3716	22112	28	2
Total		372621			936

Fuel prices

Retail transportation fuel prices in Sri Lanka are distorted by a taxation regime that is obsolete, and ineffective in achieving its stated goals. As shown in Figure 4, which shows diesel and gasoline prices (in constant 1982Rs), diesel prices have been falling in real terms since the early 1980s, though recent prices have narrowed the gap to gasoline.

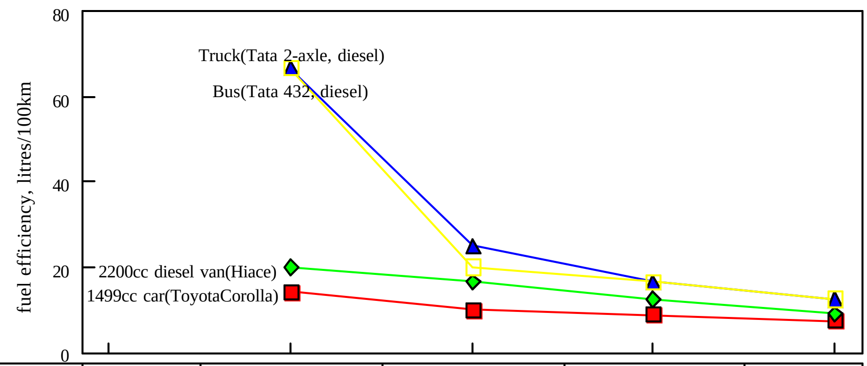
Figure 4: Retail diesel and gasoline prices (constant 1982 Rs/litre)



Emission factors

Most past studies have used standard values for emission factors expressed as gms/km for different vehicle types. However, with dramatically falling traffic speeds in Colombo, fuel efficiency has fallen (figure 5), and emissions per km have increased. We therefore derive speed-dependent emission factors for use in the study.

Figure 5: Results of the fuel efficiency survey for typical vehicles



speed, km/hour	10	20	30	40
1499cc car(ToyotaCorolla)	14.3	10.0	8.7	7.7
2200cc diesel van(Hiace)	20.0	16.7	12.5	9.1
Truck(Tata 2-axle, diesel)	66.7	25.0	16.7	12.5
Bus(Tata 432, diesel)	66.7	20.0	16.7	12.5

Source: Fuel efficiency survey, March 2001, Ministry of Transport

Health damages

Several studies that estimate the health damages from air pollution in Sri Lanka are reviewed (Table 5). All are based on the benefit transfer method, as no studies are available for Sri Lanka. In general we find that most of the previous estimates are based on power sector emissions (from relatively tall stacks in relatively remote locations): more recent studies (notably the World Bank Six Cities study) suggest that auto emissions (at street level in densely populated areas) have damage costs at least an order of magnitude greater than from power plants. The health damage values used in this report (for 2000) are $18,000/ton for PM-10; $700/ton for NOx, and $2,900 for SO_2 – which are all at the low end of the ranges found in the Six Cities study (of Bangkok, Shanghai, Mumbai, Krakow, Santiago, and Manila). Typically the switching values are an order of magnitude lower than these estimates.

Table 5: Comparison of damage valuation estimates (in $/ton), as estimated for Colombo (2000)

Basis	*$/ton*
particulates (1)	
six cities study, low value of range	17,790
	14,232
ADB benefit transfer method	258-478
RDA, CKE environmental assessment	8,500
LIFE	483
University of Moratuwa	262
SO2	
six cities study, low value of range	2924
ADB benefit transfer method	53-106
LIFE	825
University of Moratuwa	447
NOx	
six cities study, low value of range	700
ADB benefit transfer method	506-697
LIFE	334
University of Moratuwa	180

(1) Only the Six Cities study gives PM-10 health damage costs; the others are for total particulate matter.

Lead

There are no systematic health damage studies of lead in Sri Lanka. However, there is a vast international literature on the subject. In the US, the benefit-cost ratio of eliminating lead in gasoline was estimated as being in excess of 10; one estimate of the health benefits shows that reducing the US population's blood level by 1 ug/dl was $18.9billion (1989$) per year. A recent World Bank review of this literature notes that "*the magnitude of these benefits suggests that phasing out lead from gasoline is likely to produce substantial benefits in other countries as well*" – a conclusion that is evidently shared by most Governments in Asia who are in the process of phasing out lead in gasoline.

Studies of lead levels in blood were undertaken in Sri Lanka in the early 1990s. These showed high levels of lead in the most exposed groups (trishaw drivers, traffic policemen and traffic wardens) compared to the control population although the general levels do appear to be less than half those in other large Asian Cities.

Mindful of the hazards of extrapolation across countries, we may nevertheless make an order of magnitude estimate for the corresponding health damage in Sri Lanka. If we scale the US estimate by ratio of population and ratio of PPP adjusted GNP/capita, then a reduction of average concentrations of lead in blood of 1 ?g/dl converts to Rs 19 billion (for the year 2000), about 1.5% of GDP. Given year 2000 gasoline consumption of 277 million litres/year, this translates to 68.7 Rs/litre of gasoline. Even if this estimate were in error by an order of magnitude, the benefits of unleaded gasoline would still correspond to around 7 Rs/litre (under the even more conservative assumption that elimination of all gasoline lead emissions would reduce blood lead by only 1 ?g/dl). Notwithstanding the uncertainties of this calculation, it does seem to confirm the conclusion reached in many other countries that phasing out lead is likely to produce substantial benefits.

Results

Table 6 summarises the results. The local environmental benefit multiplier shows by how much the damage valuations could decrease and still justify the project on environmental grounds. For example, in the case of unleaded gasoline, the damage valuation could decrease by a factor of 5.9 before net benefits were zero. Thus, the higher its value, the more robust the conclusion that the environmental benefits justify the policy. On the other hand, where this multiplier is shown as a positive number, then it shows by how much environmental damages would need to increase for the project to have a positive NPV – in the case of railway electrification, environmental damage values would need to increase by a factor of 20.3 – which is sufficiently high for us to reject this option.

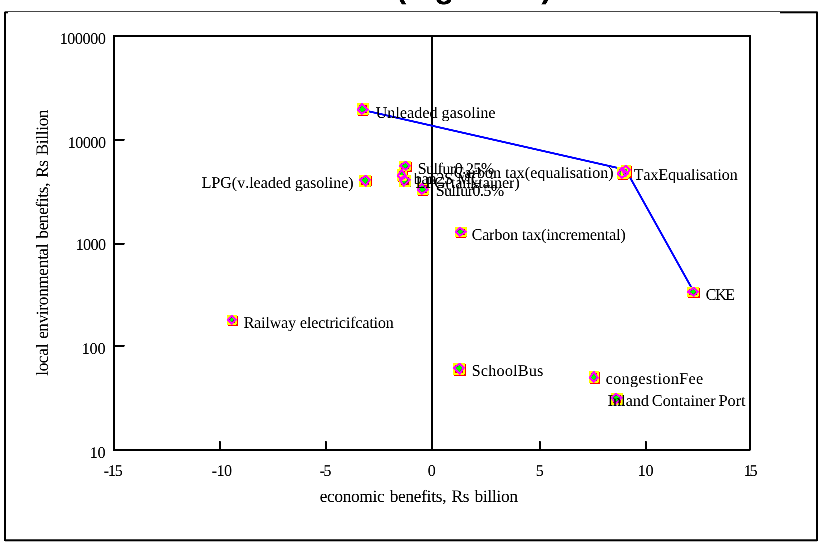
Table 6: Economic vs. environmental benefits, NPV (discount rate 10%), RsMillion

	NPV	*local*	*multiplier*	*global*	*NPV*
Congestion Fee	7616	50	win-win	21	7687
School Bus	1247	61	win-win	33	1341
Tax Equalisation	8920	4820	win-win	2073	15813
Unleaded gasoline	-3297	19549	-5.9	34	16285
Carbon tax(incremental)	1340	1279	win-win	601	3220
Carbon tax (equalisation)	9100	4989	win-win	2143	16232
ban2S MC	-1436	4463	-3.1	269	3296
CKE	12281	333	win-win	574	13188
Inland Container Port	8642	31	win-win	12	8685
Railway electrification	-9478	182	20.3	27	-9218
Sulfur0.5%	-467	3360	-7.2		2892
Sulfur0.25%	-1290	5600	-4.3		4309
LPG (v.leaded gasoline)	-3213	4077	-1.3		864
LPG (tanktainer)	-1315	4077	-3.1		2762
LPG (v.unleaded gasoline)	-3213	0			-3213

The most attractive options – that have the highest NPVs -- are tax equalization (whether by volume or by carbon content), the introduction of unleaded gasoline, and the Expressway (CKE). However, in terms of environmental benefit achieved, by far the most attractive is the introduction of unleaded gasoline. With a multiplier of 5.9 (based on a health benefit of Rs7/litre of gasoline), this would still be attractive even if the health benefits were reduced further to 1.2Rs/litre – which is two orders of magnitude lower than the value suggested by the benefit transfer method (i.e. using US data). One may therefore be reasonably confident that the option should be undertaken. Moreover, this does not include the additional benefits derived from catalytic converters (that are presently disconnected from the reconditioned Japanese vehicles).

Figure 6 displays these results in the form of a trade-off plot: the line shows the options in the non-inferior set (i.e. those that define the best set of options taking both objectives into account).

Figure 6: trade-offs, economic v. local environmental benefits (log scale)



Finally, Figure 7 shows the trade-offs between economic benefits and PM-10. Banning the importation of 2-S MCs is seen to be the most effective option for reducing particulates, though at some net economic cost.

Figure 7: trade-offs, PM-10 emissions v. economic benefits

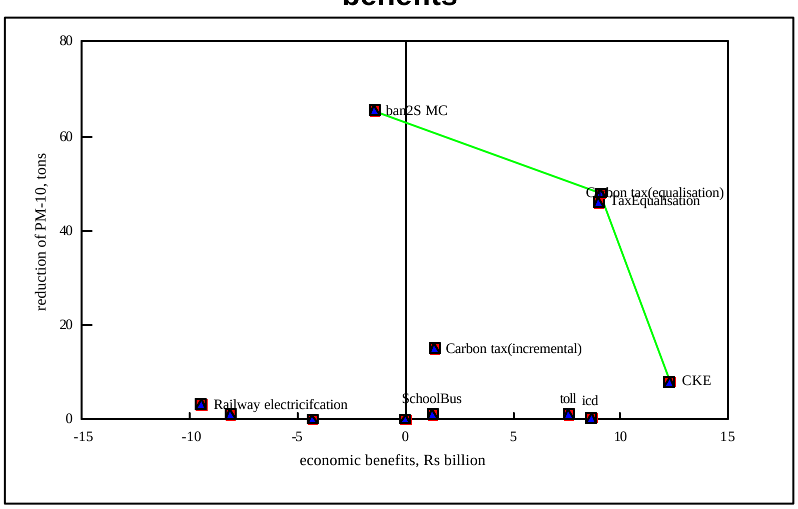
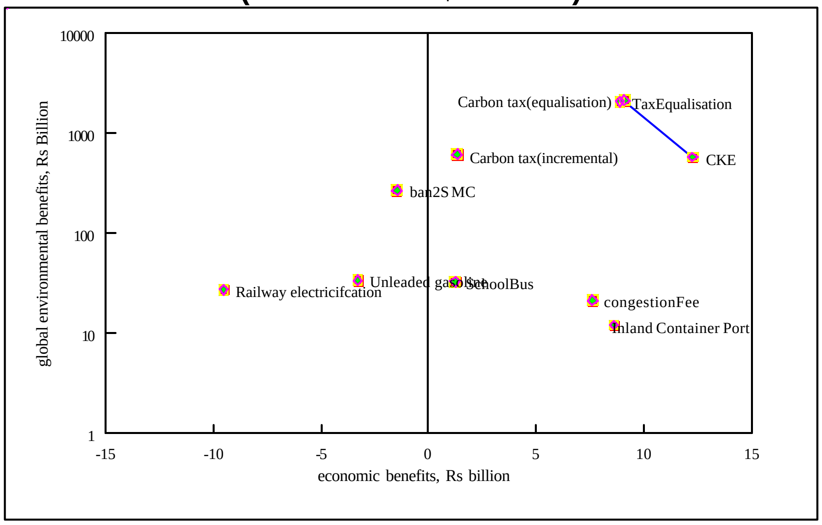


Figure 8 shows the corresponding figure for global benefits, based on a carbon price of $20/ton. Unleaded gasoline falls from the trade-off set, as expected: again the CKE and tax equalization are the best options.

Figure 8: trade-offs, economic v. global benefits (monetised at $20/ton C)



E.2 Implications for Policy

Fuel taxation policy

The highest priority is rationalization of fuel and vehicle taxation. If fuel taxes are to be equalized on the basis of revenue neutrality, then from an environmental perspective there is a slight preference for an equalization based on carbon emissions (which would give diesel a slightly higher rate of tax than gasoline on a Rs/litre basis). However, this is a relatively minor issue compared to the more important one of reducing the gap between diesel and gasoline taxes. Indeed, based on road damage externalities, there is an economic case for the tax on diesel to be *greater* than that on gasoline.

There is little evidence that the present tax structure is progressive, and that the high tax on gasoline serves the social objective of income redistribution. In fact, a significant proportion of gasoline taxes fall on the 700,000 motorcycle and 3-wheeler owners. Our analysis shows that it is unlikely that *private* owners of gasoline-powered cars account for more than 30% of vehicle-km (in gasoline cars), since the overwhelming majority of vehicles driven at high utilization are taxis, tourist vehicles, or owned by businesses.

Rationalisation of vehicle fuel taxation serves many objectives beyond correcting for road damage and environmental externalities. The present system of *ad hoc* adjustments to the retail price should be replaced by a system where the retail price is given by the cif import price + port charges and margins + a fixed rate of tax, adjusted, say, once a month (for variations in the cif price). This would increase transparency, promote competition, and ensure a relatively constant revenue take to the government.

Local environmental impacts

Given a number of recent detailed health damage studies in cities of other developing countries, it is clear that health damage valuations used in earlier studies in Sri Lanka are an order of magnitude too low with regard to emissions from vehicles (or from self-generated electricity). While the benefit transfer method used in this report provides reasonable indicative estimates of health damage costs, there is no substitute for local studies. The quality and consistency of monitoring data at the two NBRO sites since 1997 is good, but needs to be expanded to at least a third far-rural site to provide a better indication of background levels. A rigorous damage cost study using Colombo medical and hospital data remains a high priority.

There is evidence that air quality in Colombo has deteriorated over the last few years, and particularly in the winter of 2000/2001 the number of exceedances (of both daily average or daily maxima) has increased sharply.

Table 7: Comparison of daily auto-diesel v power plant emissions in Colombo

		Barge mounted fuel oil	*Puttalam coal*	*Auto-diesel*
capacity	[MW]	60	150	
heat rate	[KCal/kWh]	1954	2293	
fuel calorific value	[KCal/kg]	10300	6300	
kwh/day	[kwh/day]	1440000	3600000	
fuel/day	[10^6 KCal/day]	2814	8255	
	[Kg/day]	273181	1310286	
tons/day	[tons/day]	273	1310	
sulfur by weight	[ ]	0.025	0.006	
SO2/day(1)	[tons/day]	13.6	7.86	21.5
damage cost	[$/ton]	487	6	487
health damages	[US $/day]	6623	48	10470

However, the most likely explanation of this deterioration is the start-up of the 60MW barge-mounted power plant located in Colombo harbor, arguably the worst possible location for a power plant burning heavy oil. While there is evidence that traffic congestion during peak hours has also increased sharply over the past four years, the resulting increase in fuel consumption (consequent to lower fuel efficiency at lower speeds) does not explain this worsening of air quality.

Sulfur dioxide emissions are directly proportional to the quantity of diesel fuel used: and the fuel oil used in the barge-mounted plant is roughly 2.5% sulfur by weight, or over three times the present sulfur content of auto-diesel. Indeed, the quantity of sulfur released by the barge-mounted plant is 16.5 tons/day, as opposed to 21.5 tons/day from auto-diesel used in transportation in the Colombo area. Even if the barge-mounted plant were dispatched only 8 hours/day, its operation would still represent an increase in sulfur emissions of 25% -- upwind (for a majority of hours of the year due to strong sea breezes) of the most densely populated area of Sri Lanka.

A comparable calculation for the proposed coal-based plant at Puttalam is equally instructive. If the coal-plant had been constructed (as recommended by every CEB generation plan since the late 1980s), it would be reasonable to suppose that the first 150MW unit would now be in operation. Its daily emissions of SO_2, if using low-sulfur (0.6% by weight) imported coal, without flue gas desulfurisation, compute to 7.86 tons per day, i.e. 50% of the emissions of the 60 MW barge mounted plant! Moreover, recent studies by the World Bank show that the typical ratio of health damages per ton of emission from an urban, low stack source, compared to those of a remote, high-stack source are between 5 and 10 times greater. Thus per kWh generated, the probable health damages from the barge-mounted plant 20-40 times greater.

There is also no case for flue gas desulfurisation (FGD) at Puttalam. The estimated damage cost per ton of SO_2 per million population per day is calculated at $5,560 for the barge mounted plant, $46 for (300MW) coal at Puttalam, and $10,470 for Colombo's auto-diesel emissions. The reduction of 90% of Puttalam's coal emissions by FGD would reduce health damages in Colombo by $41/day! We may therefore conservatively conclude that

- the health damages from the 60MW barge-mounted plant are an order of magnitude greater than from the emissions from a coal-based plant at Puttalam.
- the emissions from the barge mounted plant add 25%-50% to the auto-diesel emissions in the entire western province (depending on how the plant is dispatched)
- the environmental objections to the coal plant at Puttalam are completely irrational given that the probable health damages of oil-based plants are at least an order of magnitude greater.
- the argument that the coal plant requires an FGD system is even more irrational. Reducing sulfur in diesel oil from the present 0.7% to 0.5% is 100-1000 times more cost-effective than installing FGD at Puttalam.

All of the measures examined have net *environmental* benefits (when emissions are monetised), though some options involve trade-offs between emissions. Thus a ban on further imports of 2S motorcycles would (significantly) reduce particulate emissions, though increase NOx emissions: but since PM-10 have far higher damage costs, there is still a net reduction in health damages.

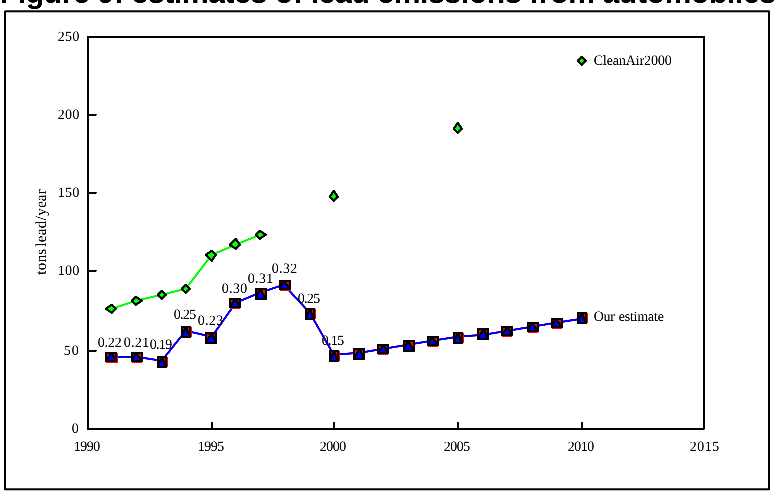
As shown by the example of railway electrification, the traditional focus on *emissions* is misplaced. Given that the electricity for electrification would come from coal-based power generation, sulfur *emissions* would increase (even if low sulfur coal, 0.6% by weight, is used); but the resulting health damages would *decrease*, because the location of the sulfur emissions changes from densely populated areas at more or less ground level (from DMUs) to tall stacks at remote locations (for the coal plant). By the same token, if the incremental electricity were generated from heavy fuel oil at a Colombo urban location (e.g. at the location of the barge-mounted plant, or at Kelanintissa or Sapugaskanda), not only would sulfur emissions increase even more, but the damage costs would be equivalent.

Fuel quality

In both the case of reducing lead in gasoline, and reducing sulfur in diesel, past estimates of benefits – to the extent quantified at all – have been argued on the basis that the specification values are far higher than in other developing countries (0.43gms/l of TEL, 1.1%S in auto-diesel). However, actual lead content, and actual sulfur in diesel, has for many years been considerably lower than these specification values. CPC has historically resisted tighter specifications in order to preserve flexibility in crude acquisition (and the ability to accommodate requests for purchasing crude oil from importers of Sri Lankan tea). The actual past health damages attributable to these pollutants are therefore also less than heretofore supposed.

Figure 9 compares our estimates of lead emissions, based on actual CPC data for the historical period, and 0.15gms/litre of TEL addition for the future against the projections of the Clean Air 2000 Report. Emissions in 2010 are seen to be below the 1991 estimates of the Clean Air 2000 report, and the historical emissions are similarly substantially lower.

Figure 9: estimates of lead emissions from automobiles



Source: Clean Air 2000 Action Plan; our estimates based on CPC historical data plus vehicle fleet forecast presented in Section 3.

However, notwithstanding these observations, we find an overwhelming economic case for the immediate introduction of unleaded gasoline, and for significant reductions in the diesel sulfur content.

Much recent attention has been focused on the use of appropriate lubricants (in the appropriate amounts) in 2S engines in South Asia: emissions from vehicles using straight mineral oil are far higher than the specially formulated "2T" oils designed expressly for 2-Stroke engines. Contrary to the observations in some other studies that suggest 2T lubeoil is not widely available in Sri Lanka, sales data from Caltex (which has 97% of the Sri Lanka lubeoil market), coupled with our estimate of gasoline use in 2stroke motorcycles and 3-wheelers, suggest that 2T oil is indeed being used in about the correct proportion (3%). Indeed, unlike Bangladesh, where 2T oil is reported to be 60% more expensive than straight mineral oil, in Sri Lanka, 2T oil retails for 3 Rs *less* than SAE30 or SAE-40.

Unleaded gasoline

The immediate phasing out of leaded gasoline is the strongest recommendation that emerges from this study. A linear programming optimization of gasoline production at the Sapugaskanda refinery shows that the costs of producing unleaded gasoline are far smaller than heretofore suggested. Indeed, this policy has now been implemented by the new government, and CDC is committed to a complete phaseout of leaded gasoline by [ ].

It needs to be recognized that the much criticized policy of pricing unleaded gasoline above that of leaded gasoline (by Rs5/litre, now reduced to Rs3/litre) was in largely response to the demand for higher octane for luxury vehicles (Mercedes, Saab, etc). The worldwide experience shows clearly that if the goal is the widespread introduction

We reject the arguments that there continues to be a need for leaded gasoline to accommodate older vehicles with soft valve seats that require lead for lubrication. With the bulk of the gasoline fleet of Japanese manufacture, where soft valve seats have not been used for almost 25 years, the number of such vehicles as may remain is extremely small. The experience in Eastern Europe, where car manufacturers continued to make soft-valve seat engines until very recently (and where such vehicles account for a much larger proportion than in Sri Lanka), in any event shows that unleaded gasoline can be successfully introduced.

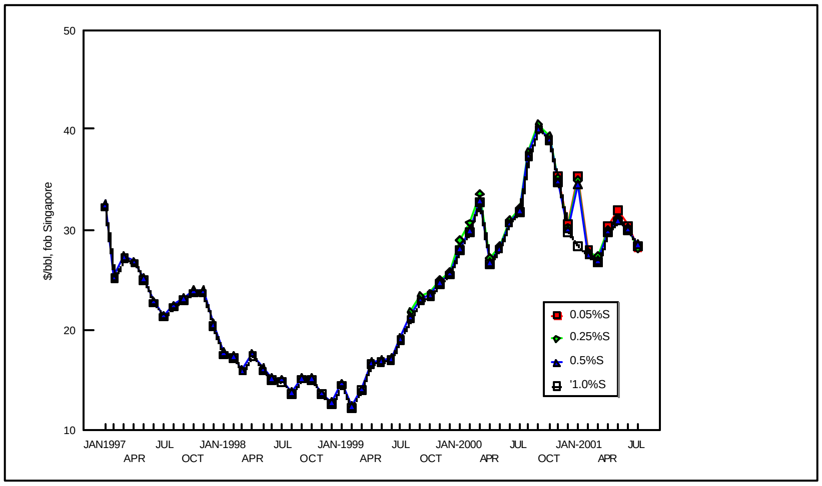
We also reject the arguments that as a poor developing country, Sri Lanka cannot afford the costs of unleaded gasoline. Indicative estimates (under extremely conservative assumptions) suggest that the health damages of leaded gasoline are at least Rs7/litre, which pale in comparison to the incremental cost.

Moreover, once leaded gasoline is eliminated, there is no further need to disconnect the catalytic converters that have long been fitted to new Japanese cars – which not only reduces the cost of vehicle preparation for the Sri Lanka market, but also brings its own further environmental benefits if these devices remain operational rather than discarded.

Reducing sulfur in auto-diesel

As in the case of leaded gasoline, the actual sulfur content in diesel has been significantly lower than the 1.1% of the specification. Nevertheless, the benefits of reducing sulfur in diesel fuel are still significant. On the cost side, the best indication is the differential between gasoil of various sulfur content as revealed by the Singapore spot markets: the difference between 1%S and 0.5% sulfur gasoil has generally been in the range of 10-20 UScents/bbl. As we see in Figure 10, however, these differentials are trivial compared to the variation in overall price levels (that track the world oil price).

Figure 10: gasoil prices and sulfur differentials



Given that the cost of modifying the kerosene unifiner for hydrotreating of gasoil are now sunk (with completion expected shortly), the refinery is now in a position to produce significant quantities of 0.1%S gasoil, which can be blended with imports to almost any desired specification.

There is little doubt that a 0.5%sulfur specification is cost-effective from a social standpoint, using highly conservative values for the health damage of SO_2. If the damage values suggested by the recent World Bank "Six Cities" study were used, reduction to 0.3% sulfur would also be cost-effective.

LPG conversion of gasoline cars

Although the rate of growth of LPG conversion of petrol vehicles has slowed over the past year, we estimate that presently some 10% of the gasoline-engine fleet runs on LPG, of which over 70% involve lower-cost conversions to use bottled gas. This conversion is driven entirely by the distortions of fuel taxation policy: the bulk of the conversions appear to be high-mileage vehicles, notably taxis, for which conversion costs have (at least in the past) been highly profitable (in financial terms).

We find that the main environmental benefit of LPG conversion is the avoidance of lead emissions from leaded gasoline – which even at the new limit of 0.15gms TEL/litre remain substantial. If, as we argue above, leaded gasoline were phased out, and the catalytic converters no longer removed from the imported Japanese vehicles that account for the bulk of the petrol-engined fleet, any remaining environmental benefits are dwarfed by the high economic costs of vehicle conversion and the higher economic costs of imported LPG and filling station costs. This is true even if the new "tanktainer" concept were implemented.

There is significant loss of tax revenue to the government from LPG conversion (given that gasoline is highly taxed, whereas LPG incurs only the 6.5% National security levy). This is effectively a subsidy to taxi fleets (and their high income ridership) and to businesses for whom the conversion costs are justified by high mileage.

The obvious remedy would be to tax auto-LPG at filling stations at a rate commensurate with gasoline, but this would unlikely be effective since it would simply encourage use of bottled gas (unless the tax on bottled gas were also increased, which may be politically difficult). And efforts to prohibit bottled gas for auto use would surely fail, given the large number of vehicles that would be affected.

In fact, the poor overwhelmingly still use fuelwood for cooking, and bottled gas is largely used by middle and high income groups. These are the same groups whose predominant transportation modes are motorcycles and cars. Therefore, if a revenue neutral tax reform were undertaken (by equalizing tax on LPG and gasoline), the distributional impacts would cancel out, with the main benefit that Sri Lanka avoids the uneconomic use of LPG as a transport fuel.

However, these conclusions may not necessarily extend to LPG conversion of *diesel* vehicles, notably buses– which has not heretofore been done in Sri Lanka. This option will be examined in the next phase of research.

GHG emission reduction and carbon trading

It is difficult to envisage that transportation sector projects represent a promising route for joint implementation projects under the Kyoto protocol. While all measures (that reduce fuel consumption) also reduce carbon emissions, among projects that could be adequately isolated to provide credible baseline and carbon reduction verification data, the cost of avoided carbon is often extremely high (because the underlying project has poor economics, as in the case of railway electrification). Some options, such as re-introduction of school bus service, suffer from the additional problem that total lifetime savings are quite small (33,000 tons), which would unlikely warrant the transaction costs.

However, as shown by the analysis of macro-policy options (Section 7), the degree to which a comprehensive transport policy can strengthen the role of public transportation will be key to keeping per capita (or per GDP) emissions at low levels. It is in Sri Lanka's interest to promote a system of tradable carbon emission permits, which are allocated globally on the basis of population or GDP. As an island with no domestic fossil fuel resources, verification of national carbon emissions from the energy sector is straight-forward since it can be calculated from fuel import data can readily be certified.

Figure 11: GHG emissions from the transport sector

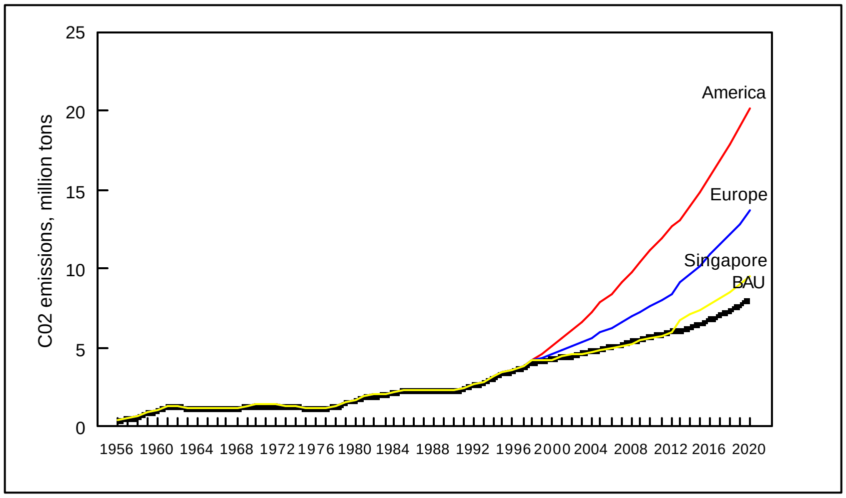


Table 8: GHG emission comparisons

	GHG/capita	*$KgCO_2$/\$GDP*	*$kgC0_2$/\$GDP (PPP adjusted)*
1995			
Sri Lanka	**0.34**	**0.63**	**0.13**
China	2.51	4.72	0.92
Germany	10.83	0.49	0.63
France	6.23	0.29	0.34
India	0.86	2.17	0.73
Indonesia	1.17	1.37	0.34
Japan	9.17	0.36	0.46
Pakistan	0.63	1.62	0.32
USA	19.88	0.85	0.85
former USSR	8.48	5.22	2.61
world Average	**3.92**	**0.94**	**0.75**
2020 Sri Lanka			
high economic growth (6.5%pa)	1.35-1.8		0.16-0.21
medium (5%)	1.09-1.38		0.17-0.22
low(4.5%)	1.00-1.23		0.18-0.22

Note: the ranges for Sri Lanka 2020 are given by the range of the America and BAU scenarios (figure 11).

Nevertheless, even though per capita emissions in Sri Lanka will increase by a factor of six by 2020, even under the worst case American Scenario of car ownership (which would imply huge congestion problems in Sri Lanka's cities) the per capita levels would still be less than 25% of today's world average.

Transportation infrastructure projects

Two of the transportation infrastructure projects (Expressway, dry container port) are win-win, while railway electrification, as noted above, is uneconomic, and cannot be justified by the (small) environmental benefits. However, as shown in Table 9, the proportions of environmental benefits of the Expressway and the dry container port in the total benefit are quite small (3% and <1%, respectively): inclusion of the environmental benefits simply make already good projects slightly better.

Table 9: Percentage of environmental benefit in total social benefit

option	*%-age*
Congestion Fee	1%
School Bus	5%
Tax Equalisation	30%
Unleaded gasoline	120%
Carbon tax (incremental)	40%
Carbon tax (equalisation)	31%
ban2S MC	135%
CKE	3%
Inland Container Port	0%
Railway electrification	2%
Sulfur0.5%	116%
Sulfur0.25%	130%
LPG (v.leaded gasoline)	472%
LPG (tanktainer)	148%
LPG (v.unleaded gasoline)	0%

With respect to our negative conclusions on railway electrification, this applies only to the specific scheme examined, and may not apply to other proposed schemes. In particular the option examined here differs from so-called “light rail” systems, which are less capital intensive than mainline electrification. The light rail option will be examined in the next phase of research.

Mitigation of congestion

The congestion mitigation options (reintroduction of school buses, congestion fee) are also win-win, though again the environmental benefits are modest.

1

Introduction

1.1 Background

The economic and environmental impacts of Sri Lanka's transportation sector have drawn the increasing attention from policymakers and environmentalists. While traffic conditions and urban air quality in Colombo have yet to deteriorate to those encountered in many other Asian cities,[1] particularly over the past five years there has been a significant increase in road traffic congestion in Colombo. Sustained economic growth and lagging investment in public transportation have led to increased vehicle ownership and corresponding growth in transport fuel consumption.[2]

Table 1.1 shows survey results taken on the seven main radial roads from the center of Colombo for the morning peak in 1997, 1999, and 2001. Over the past four years, speeds on all roads have fallen by at least half; moreover, while in 1997 peak conditions were observed

---

1 The World Bank Transport Sector Study notes that

> *Sri Lanka's air pollution problem appears to be currently at manageable levels. Yet based on projected rates of economic, demographic, and vehicular growth, the air pollution situation in Colombo could come to resemble that of more severely affected Asian metropoli. The Clean Air 2000 action plan notes that the transport sector is the biggest contributor of air pollutants in the Colombo metropolitan area . . . thus it is clear that the transport sector's contribution to environmental problems overall in the Colombo metropolitan area is high.*
>
> (World Bank: *Sri Lanka, Transport Sector Study,* South Asia I Infrastructure Division, Report 16269-CE, October 1996, Washington, D.C: hereinafter cited as *World Bank TSS*)

2 The 1992 forecast by the Ceylon Petroleum Corporation (CPC) for the year 2000 was for total diesel consumption of about 900,000 tons, as against an actual diesel consumption of some 1.3 million tons. However, it should be noted that the year 2000 consumption of auto-diesel was forecast at 757,000, as against our estimate of the actual consumption of around 850,000 tons, so the underestimate for diesel used for power generation was far greater: in 1992 the 2000 diesel consumption for power generation was estimated at 135,000 tons, as opposed to an actual of some 480,000 tons. In the early 1990s it had been assumed that the proposed 300MW coal-fired plant would be in operation by the mid-1990s, which has not in fact occurred. The response has been a sharp increase in diesel self-generation as hotels, industry, and commercial enterprises have responded to endemic power cuts by increasing self-generation.

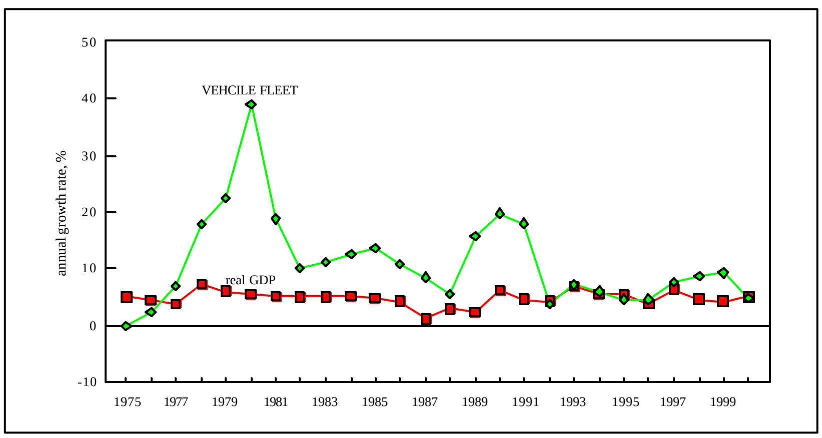
only for roughly two hours during the morning peak, by 2001 these conditions extended until mid-afternoon (in the inward direction); and similarly in the outward direction, the congested period now starts already in mid-afternoon. As we note in Section 3, such reductions in network speeds result in significant increases in local air emissions, because fuel efficiency decreases non-linearly with speed—especially under the stop-go driving conditions of highly congested roads.

Table 1.1: Car journey time survey results (as average speeds, km/hour): inward direction, morning peak

		1997	*1999*	*2001*
Colombo - Galle	Maliban Junction to Dickman Road	28	18	8
Colombo - Ratnapura	Maharagama to Kirulap	32	16	6
Colombo - Kandy	Kadawatha to Orugodawatte	23	22	11
Colombo - Puttalam	Mahabage to Kelani Bridge	18	16	7
Jayawardanapura - Kollupitiya	Battaramulla to Senanayake Junction	23	17	9
Colombo - Horana	Papiliyana to Vilasitha Nivasa Junc	27	17	8
Wellampitiya - Kaduwela	Abatale to Wellampitiya	28	18	9

Source: Transport Studies Planning Centre, Ministry of Transport

Figure 1.1: Growth of the Sri Lanka road vehicle fleet and GDP

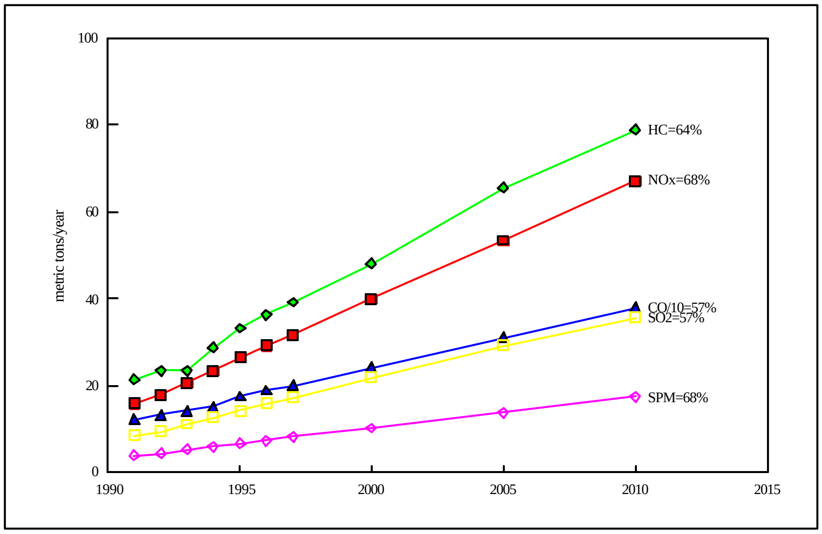


Source: GDP: Central Bank Annual reports; vehicle fleet: TSPC

Sri Lanka expects the continued strong growth in transportation demand that inevitably accompanies economic growth. As shown in Figure 1.1, liberalization of the economy in 1977-78 was followed by an extraordinary increase in the vehicle fleet as physical import controls were relaxed and decades of pent-up demand were released. A second vehicle fleet growth boom—albeit not quite as sharp as the previous one—occurred in 1989-1991, after the end of the civil disturbances of 1986-1989. Since the early 1990s, growth of the fleet has closely tracked GDP growth.

Figure 1.2 shows the projection of transport-sector local air emissions of the Clean Air 2000 Action Plan.[3] This projected air emission increases of 57-68 percent over the decade 2000-2010.

Figure 1.2: Projected transport sector emissions



Source: Clean Air 2000, Action Plan

The transportation sector presently also dominates Sri Lanka's energy-related emissions of greenhouse gases. Even as the fuel mix for power generation (which today is still largely based on hydro) shifts toward thermal generation and coal, the transportation sector will still account for a significant share of greenhouse gas (GHG) emissions for the foreseeable future (Figure 1.3).[4]

Absent appropriate and timely policy interventions, the present trends will inevitably lead to a much higher level of degradation both in the urban environment and the quality of life. Previous estimates of the total costs of congestion (and accidents) in Sri Lanka—though *excluding* the local environmental externalities—amount to roughly 0.l percent of GDP,[5]

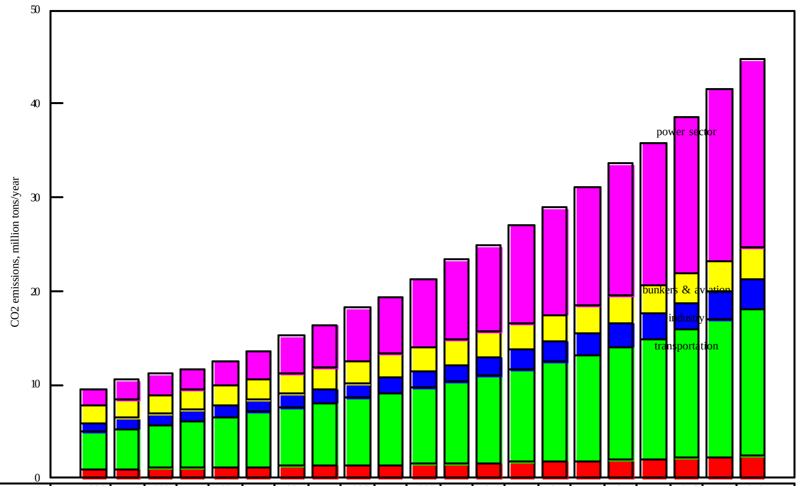
3 Metropolitan Environmental Improvement Program (MEIP), *Clean Air 2000, Action Program*, Colombo, 1993.

4 Until about 1990, thermal generation was required only in drought years. However, with Sri Lanka's hydro resources being largely fully developed (or subject to environmental constraints), the role of thermal generation has increased steadily over the decade, all of it based on either heavy fuel oil or auto diesel. By 2000, 48 percent of total generation was from oil. For a complete discussion, see P. Meier and M. Munasinghe, *Sri Lanka Electric Power Technology Assessment*, World Bank Environment Department, 2001 (hereinafter cited as SLEPTA).

5 World Bank TSS, *op. cit*., para 5.5. The estimates cited in this study range from Rs 550million (Western Province, 1995) to Rs 778 million (Colombo, 2002).

comparable to those of other Asian countries.[6]

Figure 1.3: Projected GHG emissions



	1998		2000		2002		2004		2006		2008		2010		2012		2014		2016		2018
domestic [LPG+Kerosene]	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.3	2.4
transportation	3.9	4.3	4.7	5.0	5.4	5.8	6.2	6.7	7.2	7.7	8.2	8.7	9.3	9.9	10.6	11.3	12.0	12.9	13.7	14.7	15.7
industry	1.0	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.2	2.3	2.4	2.6	2.7	2.9	3.1	3.2
bunkers & aviation	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.4	2.5	2.6	2.7	2.7	2.8	2.9	3.0	3.0	3.1	3.2	3.3
power sector	1.7	2.1	2.3	2.3	2.5	3.0	4.0	4.5	5.6	6.2	7.4	8.6	9.3	10.5	11.4	12.7	14.1	15.2	16.7	18.4	20.1

Source: Authors

It seems prudent, for several reasons, to take action before the situation becomes significantly worse. First, as is true for many environmental issues that involve externalities not captured by markets and prices, prevention of further deterioration through proper planning is often cheaper than ex-post clean-up. Moreover, vested interests in some unfortunate present practices will become more entrenched the longer they are permitted to continue: a good example is the practice of on-street parking on many of Colombo's arterial roads, a major cause of congestion externalities.[7] Second, many potential policy measures have long lead times. For example, since an outright ban on two-stroke motorcycles is not practicable, efforts to lower the proportion of these vehicles in the fleet mix by banning further imports (or by tax disincentives) will take many years before all of the existing fleet of two--stroke motorcycles is retired.

To date, the environmental aspects of Sri Lanka's transportation sector have been

---

6 For example, in Thailand, congestion costs in Bangkok were estimated at $272 million/year, 0.2 percent of Thai 1994 GDP of 1.28 billion. (World Bank, *Thailand: Mitigating Pollution and Congestion Impacts in a High-Growth Economy*, Report 11770-TH, East Asia and Pacific Region, 1994).

7 Kumarage gives an excellent example of externalities caused by inappropriate land use and related parking problems in Dehiwalla on the Galle Road (one of Colombo's seven major radial arterial roads, whose congestion problems are discussed below in Section 8.1). After grape sellers established themselves there, average speeds dropped by about 4 km/hour, as drivers stopped to purchase their produce. This speed reduction on a road that carries 50,000 vehicles per day results in increased gasoline consumption of about 500 litres/day, imposing costs of some Rs 2million/year, equal to about Rs 20,000 for each of the approximately 100 grape sellers (A.S. Kumarage, "Traffic Engineering and Traffic Management," *Journal of the Sri Lanka Energy Managers Association*, 7:1, 1996, pp. 15-18).

examined only on a somewhat ad hoc basis. The work in the early 1990s that led to the adoption of the Colombo Clean Air 2000 programme[8] focused mainly on emissions, but lacked systematic cost-benefit analysis (CBA). Subsequent analyses of measures to reformulate fuel (lower lead in gasoline, lower sulphur in diesel) were limited to financial analysis of the impact on the refinery.[9] After intense criticism of the first Environmental Impact Assessment of the proposed Colombo-Katunayake expressway, a new assessment in 1997 was the first attempt by the Road Development Authority (RDA) to monetize local environmental impacts and incorporate them into CBA—though as we shall see in Section 11, this was not without problems.[10] Transportation sector emissions were examined in the 1996 Greenhouse Gas Emission Inventory,[11] and selected transportation measures were examined in a 1995 World Bank study,[12] but to date there has been no systematic examination of the GHG emissions consequences of a broader range of policy options in the transport sector. An important study of congestion costs was completed in 1999, but this did not extend to valuation of the relevant environmental externalities.[13] Finally, a comparison of the environmental consequences of selected policy options in the road transport sector was published in 2000, but the focus was limited to the trade-off between costs of policy implementation and emissions, and did not extent to benefit valuation.[14] The first (and thus far only) rigorous study of health effects of vehicle pollution in Sri Lanka also appeared in late 2000, but it too was limited in scope, and quantified health damages only for a small group of highly exposed occupations.[15] Another study of hospital attendance for asthma suggested a strong correlation with air pollution levels in

---

8 Metropolitan Environmental Improvement Program (MEIP), *Air Quality Management in Sri Lanka*, Colombo, 1993.

9 See e.g., CPC, Report of the Subcommittee on Fuel Reformulation, 1994.

10 Road Development Authority, *Colombo Katunayake Expressway, Environmental Impact Assessment Report*, Colombo, June 1997.

11 J. Ratnasiri, ed., *Final Report of the Sri Lanka Climate Change Country Study*, Ministry of Forest and Environment, Environment Division, Colombo, 1998.

12 P. Meier, M. Munasinghe, and T. Siyambalapitiya, 1997. *Energy Sector Policy and the Environment: A Case Study of Sri Lanka*, World Bank Environment Department, Washington, D.C., 1993. Two transportation sector options (vehicle inspection and maintenance programs, and reducing the fraction of two-stroke motorcycles) were examined for comparison to power sector options for reducing GHG and local air emissions.

13 D. Jayaweera, *Effective Steps Towards Traffic Calming in Developing Countries: A Case Study for the Metropolitan Region of Colombo in Sri Lanka*, Ph.D. Thesis, MIT, Nov.1999.

14 S. Chandrasiri, *Controlling Automotive Air Pollution: the Case of Colombo City*, Economy and Environment Programme for Southeast Asia, Research Report Series, June 1999.

15 S. Chandrasiri and S. Jayasinghe, *Health Effects of Vehicular Emissions in Colombo*, UC-ISS Project Working Paper Series, 9805, December 1998.

Colombo.[16]

1.2 Approach

In this study we build on past work, and examine a broad selection of sustainable transport sector policy options from the standpoint of a common set of consistently defined attributes. Ideally, sustainable transport development should focus on the economic, environmental and social dimensions of sustainable development[17]. However, in this volume, the first two aspects receive greater attention. The social dimension is examined mainly from the equity viewpoint, due to lack of time and data with regard to other key social indicators. The attributes considered in this study include:

?? *Economic efficiency*: quantified as the net present value (NPV) of lifetime economic costs and benefits, discounted at the opportunity cost of capital taken here at 12 percent. (though several of the policy recommendations, particularly those involving significant capital investment, are tested for robustness to this assumption).

?? *Local environment*: quantified as emissions of the main air pollutants (and monetized using the benefit transfer method).

?? *Global environment*: for which we use emissions of GHGs over the next 20 years as a proxy (and monetized at $20/ton values per ton of carbon).

?? *Equity:* because the main types of vehicles are associated with largely distinct levels of income, we may assess the probable equity implications by enumerating the private costs and tax burdens for each vehicle category. Bus passengers have the lowest incomes; followed by two-stroke motorcycle owners; four-stroke motorcycle owners; and then, at the highest income levels, automobile and dual-purpose vehicle owners. As noted below, the present system of transportation fuel taxation has some perhaps unexpected distributional results.

?? *Government revenue:* as shown in Table 1.2, the transport sector accounts for a significant share of all tax revenue (7 percent), and therefore potential interventions need to be mindful of the impact on government revenue streams.[18] Wherever possible, we suggest reforms that are revenue neutral.

---

16 M. P. Senanayake, R. P. Samarakoddy, R. P. Jayasinghe, A.P. Hettiarachchi, A. P. Sumanasena and J. Kudalugodaarachchi, *Is Colombo Choking its Children: A Case-Control Analysis of Hospital Attendance and Air Pollution*, NBRO and Faculty of Medicine, University of Colombo, 2000.

17 For details, see M. Munasinghe, *Environmental Economics and Sustainble Development*, World Bank, Washington DC, 1993.

18 The bulk of this revenue goes to the Government of Sri Lanka. Only the annual licence fees are collected by the provincial governments. Note that there are (presently) no toll roads in Sri Lanka: the first such road toll road will be the Colombo-Katunayake Expressway.

1.3 Power Systems Modeling

Two standard least-cost power capacity expansion models are used in this study: ENVIROPLAN and WASP. ENVIROPLAN is used for mitigation option screening, benefit-cost analysis, sensitivity studies and risk assessment. This model was developed in the early 1990s for use in a study of environmental issues in the power sector in Sri Lanka,[19] but has since seen a variety of other applications including BCHydro for strategic planning;[20] by USAID for the 1995 Integrated Resource Plan of the Indian State of Andhra Pradesh,[21] by the World Bank in 1997 and 1998 for the economic appraisal of power sector reform programmes in the Indian States of Haryana and Andhra Pradesh,[22] and by the World Bank in an on-going study of environmental issues in the Indian power sector.[23]

Table 1.2: Government revenue from the road sector, 1999

	Rs Million
Import taxes	
Vehicles	2,990
Parts and tires	468
Engines	278
Diesel fuel	1,519
Petrol	4,719
Lubricants	186
Annual vehicle licenses	171
GST, diesel tax, and excise duties	2,340
Other (registration, transfers)	156
Total	**12,363**
Total government revenue	**166,029**
Recurrent government spending on road maintenance (1)	7,871

Source: D. Jayaweera, *Transport Pricing and Charges in Sri Lanka*, Transport Studies and Planning Centre, Colombo, 2000; Government revenue from 1999 Central Bank Annual Report, p.121

(1) Routine and periodic maintenance, rehabilitation of roads and bridges, widening and improvement of roads, provincial council road expenditure

19 See the Annex in Meier and Munasinghe, *op.cit.*, for a more detailed description.

20 BCHydro, *1995 Electricity Plan*, Vancouver, BC, September 1995: Volume C of this Plan presents the economic and trade-off analysis.

21 USAID, *Integrated Resource Plan for Andhra Pradesh*, Report to APSEB, Hyderabad, 1995.

22 P. Meier, *Economic Analysis of the Haryana Power Sector Restructuring and Reform Program*, World Bank, New Delhi, 1997; P. Meier, *Economic Analysis of the Andhra Pradesh Power Sector Restructuring Program*, World Bank, New Delhi, January 1999.

23 P. Meier, *India: Environmental Issues in the Power Sector: A Case Study of Haryana*, World Bank, 1999.

1.4 Scope

We begin, in Section 2, with a discussion of the road vehicle fleet. Estimating the active vehicle fleet proves to be a major challenge, and many past studies have neglected to show the necessary consistency between estimates of the active vehicle fleet, the average annual distances traveled, rates of fuel consumption, and the total quantity of fuel consumed. Only the last quantity is known with any precision, and there exist an infinite number of combinations of these variables that could, in principle, yield the known total quantity of fuel consumed. Fuel characteristics and emission factors are presented in Section 3.

Section 4 examines the present air quality in Colombo, and reviews the one known study of health effects of vehicular pollution (Section 4.2). The emphasis on Colombo arises from the urbanization pattern of the country. In 1998, the Greater Colombo Metropolitan Region (GCMR) area had some 4.8 million inhabitants,[24] about 25 percent of the total 19.4 million population of Sri Lanka.[25] Kurunagala district has the second-highest population outside the GCMR, with 1.5 million inhabitants.[26] It is estimated that 1.7 million persons cross the city boundaries every day; 90 percent of the crossings are made by road.[27]

The section concludes with valuations of local air emission damage costs. Two recent studies, both based on the benefit transfer method, have monetized air emission damages (the 1997 environmental impact statement for the Colombo-Katunayake expressway, and a study of the impacts of the 1996 power shortages). These are compared to estimates in other Asian cities, and to the values derived in more recent World Bank studies.

The econometric analysis necessary for our subsequent examination of fuel price and tax options is presented in Section 5. We examine vehicle ownership elasticities (Section 5.1), classical fuel consumption price, cross-price, and income elasticities (Section 5.2), vehicle operating cost elasticities (Section 5.3), and the response of bus passengers to fare increases (Section 5.4)—for which there is evidence that the inelastic behavior observed in past studies has recently changed.

Section 6 discusses the externalities of traffic congestion. We review briefly the theory and the literature (Section 6.1), and then discuss empirical estimates of the value of time in Sri Lanka (Section 6.2), for time savings are the most important economic benefit of a wide range of transport sector options focused on the reduction of congestion.

With these preliminaries in hand, Section 7 reviews the broad options for the future of

---

24 Comprising 2.2 million in Colombo district, 1.6 million in Gampaha, and 1 million in Kalutara. These three districts comprise the Western Province, which most transport studies equate to the GCMR.

25 Preliminary estimate for 2000 as reported by Central Bank Annual Report 2000.

26 Comparisons with Bangkok are instructive. In 1991, the Bangkok metropolitan area accounted for one-sixth of Thailand's total population, and had 15 times the population of the second largest city, Chiang Mai. (World Bank, 1994).

27 D. Jayaweera, *Effective Steps Towards Traffic Calming in Developing Countries, op. cit*., pg. 29.

the transportation sector. Four scenarios are created, which one may characterize as *uncontrolled* (the "American dream," for which car ownership becomes saturated at 800 cars/1,00 inhabitants); *control of four-wheelers,* which corresponds to the historical situation in Sri Lanka (and which is used as the business-as-usual scenario in this study); *control of four- and two-wheelers* (corresponding to most countries in Europe); and *strict restraint of private vehicles* (which corresponds to the highly restrictive—but also successful—policies adopted in Singapore). These differences are related to a number of factors, such as population density (and the concomitant ability of governments to provide cost-effective mass transit systems), the relative influence of the "road lobby," the cultural perspective toward the advent of the automobile, and economic status. The scenarios are differentiated primarily by passenger vehicles, for the number of freight vehicles—even where road has captured most of the market share from rail—accounts for a small fraction of the total number of road vehicles. Thus in Sri Lanka, where 99 percent of total freight ton-km is by road, lorries account for only 5 percent of the vehicle fleet.

These are followed by the chapters that examine the various types of transport sector interventions. We begin in Section 8 with two options that target the reduction of road congestion: road pricing and the re-introduction of school bus service. Fuel pricing and taxation options are examined in Section 9, while Section 10 examines regulatory options: the phasing out of two-stroke motorcycles (implemented by a ban on further imports), and the conversion of vehicles to liquid petroleum gas (LPG).

Section 11 presents various project investment options: the Colombo-Katunayake expressway; a suburban railway electrification scheme; and a dry container port (to be served by rail), and designed to reduce the number of articulated container lorries on the A3, whose large size and slow speed significantly affect traffic congestion. Section 12 examines issues related to fuel quality: lowering the sulphur content of diesel fuel, and the use of proper lubricants for three-wheelers and two-stroke motorcycles.

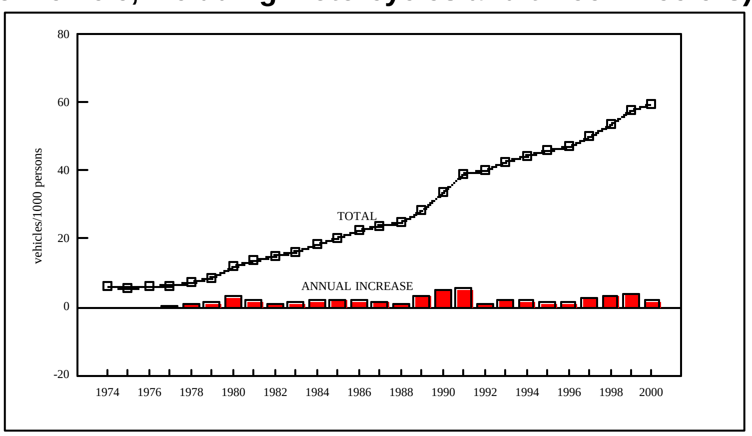
2

The Vehicle Fleet[28]

2.1 Past trends

Sri Lanka has undergone a series of profound changes in its transport sector over the past 30 years. The most significant was the liberalization of the economy in 1977, following a long period of strong import controls under socialist governments that severely restricted automobile ownership.

Figure 2.1: Automobile fleet per 1000 persons (total number of vehicle, including motorcycles and three-wheelers)



The rapid growth of the automobile fleet (Figure 2.1) illustrates the fundamental changes that have occurred following the 1977 liberalization: within five years the number of vehicles per 1,000 persons had almost tripled (from around 5.5 before 1978, to 16 by 1983): the Transportation Studies Policy Centre (TSPC) estimate for 2000 is 60 vehicles per 1,000 persons (for Sri Lanka as a whole).

To be sure, this is still well below that of other Asian countries, as discussed further in Section 7.1. But with a third of the total population accounting for two-thirds of the total

28 The vehicle fleet model described in this section was prepared by A. Kumarage, University of Moratuwa.

estimated vehicle trips that occur in the Colombo metropolitan area, the ownership rates in the Colombo metropolitan region would be roughly double the national figure, i.e., about 170 per 1,000 persons, increasing to 280 per 1,000 in Colombo City. How much further this vehicle ownership pattern will increase is one of the fundamental issues for Sri Lanka's transport policy.

More recent changes have been no less profound. The past decade of steady economic growth has resulted in sharp changes in the fleet mix. For example, Figure 2.2 highlights the changes in taxi service: imports of three-wheelers from India started only after liberalization in 1978, but have grown rapidly during the 1990s. In the early 1980s the typical Colombo taxi was an aged Morris Minor, replaced after liberalization by reconditioned second-hand Japanese cars: the number of petrol taxis peaked at around 8,700 in 1991,[29] falling to 5,900 by 1997.[30] Clearly, the recent explosive growth of three-wheelers has met a need for urban transportation not met by bus service—but the slower speed and limited acceleration of three-wheelers has severely aggravated traffic conditions in Colombo.

A similar picture is true for motorcycles. Again following liberalization in 1978, and during 1989-1991, the motorcycle fleet increased sharply (Figure 2.3). Though the rate of growth has fallen off over the past few years, [31] we estimate that in 2000 there were some 575,000 motorcycles, accounting for 85 percent of all operational road vehicles in Sri Lanka.

Nevertheless, 63 percent of all motorized trips in the Colombo area are made by bus (Table 2.1); buses account for an even higher share of inter-city travel.[32] As shown in Figure 2.4, there has been an important shift from public to private bus service: most of the growth in bus service has been in the private sector (whose passenger-km has doubled over the last decade, as opposed to a 30 percent increase in public buses). However, the quality of data on bus ridership is poor, and these figures are subject to considerable uncertainty.

---

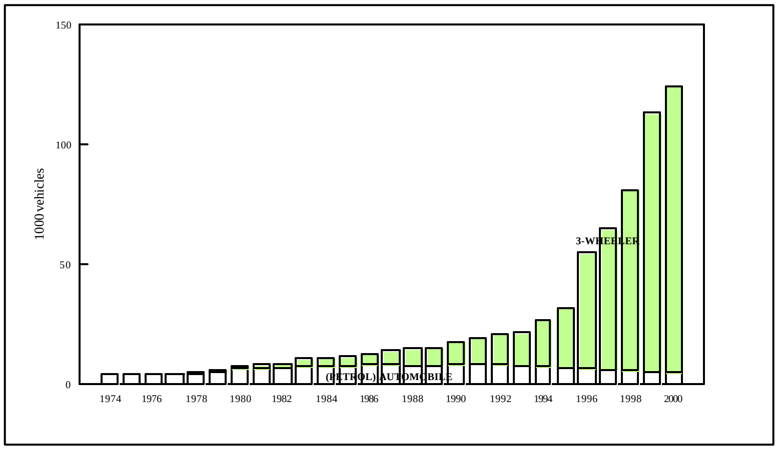
[29] Almost certainly the Natural Resources and Environmental Policy Project (NAREPP) estimate of 10,000 taxis in 1990 (which were assumed to be driven 50,000 km/year, as opposed to 36,000 km/year for passenger cars) is too high. See Table D of M. Walsh, *Motor Vehicle Pollution Control in Sri Lanka, A Preliminary Strategy for Progress in Colombo,* Report to the Natural Resources and Environmental Policy Project, ,Colombo, July 1992, (hereinafter cited as NAREPP).

[30] However, this decrease does not necessarily translate into fewer aggregate vehicle-km by the taxi fleet. A significant share of the Colombo taxi market is now held by radio-cabs, whose utilization factors are likely to be much greater than previously.

[31] Particularly in Colombo, over-capacity has begun to characterise the three-wheeler market.

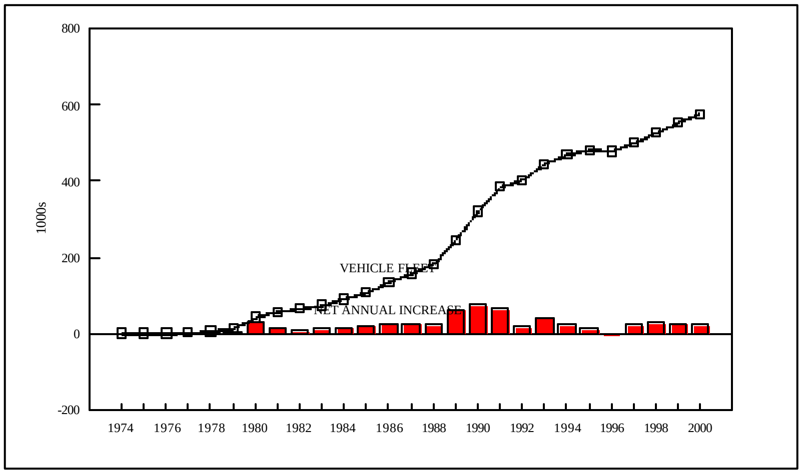
[32] For a history of bus transport in Sri Lanka, see, e.g., J. Diandas, "Notes for Benefit Comparison of Government Sector and Private Sector Supplied Bus Services," in *Aspects of Privatisation in Sri Lanka,* Friedrich Ebert Stiftung, Colombo, 1988; J. Diandas, "Bus Managers and Users vis-à-vis Ownership, Regulation, Competition and Systems," *Proceedings*, European Transport and Planning, 17th Summer Annual Meeting on Transport in Developing Countries, University of Sussex, Sept. 1989; or J. A. Gomez-Ibanez, "Bus Industry Issues and Options," in TSS, op. cit., p.126.

Figure 2.2: Composition of the taxi fleet



Source: TSPC

Figure 2.3: The motorcycle fleet



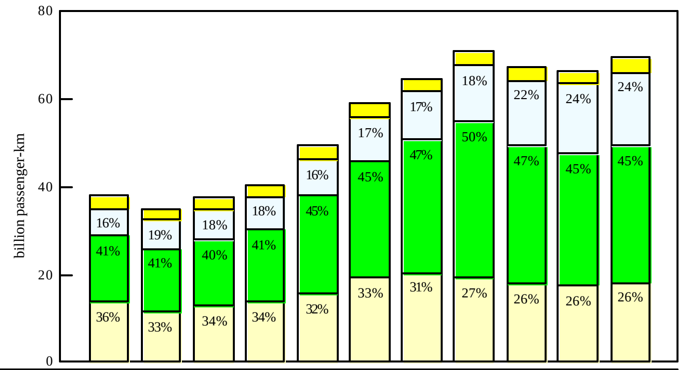
Source: TSPC

Table 2.1: Person-trips by mode in the Colombo Metropolitan area, 1995

	Morning peak		*24-hours*	
	Number, 1,000s	*[%]*	*Number, 1,000s*	*[%]*
Rail	68	7.6	226	5.5
Bus	587	65.2	2601	63
Private car or motorcycle	176	19.5	933	22.5
Taxi, van, three-wheeler	69	7.7	368	8.9
Total	900	100	4128	100

Source: CUTS, op. cit., Vol.1, p.18.[33]

Figure 2.4: Composition of passenger-km by mode



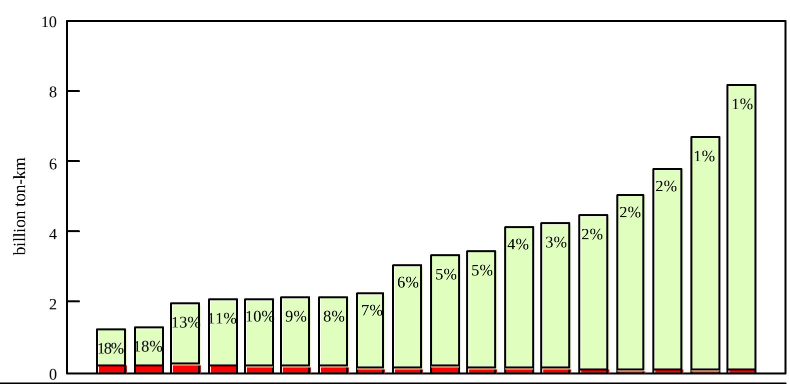
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
SLCTB	14	11	13	14	16	19	20	19	18	18	18
private bus	15	14	15	17	22	27	30	36	32	30	31
private car	6.1	6.5	6.9	7.5	8.1	9.9	11.0	13.0	14.9	15.8	16.7
railway	2.8	2.7	2.6	2.8	3.2	3.3	3.1	3.1	3.1	3.0	3.2

Modal split in percent

Sources: TSPC; Peoplized Bus Companies (from 1990 to 1997), Cluster Bus Companies (from 1997); Provincial Road Passenger Authorities, National Transport Commission, Road; Development Authority, Sri Lankan Railways and Ministry of Transport.

The decline in the railway share of freight has been much more pronounced, with the share of ton-km falling from 18 percent in 1990 to 1 percent in 2000 (Figure 2.5). Unlike the passenger rail system (whose numbers are largely accounted for by the Colombo suburban commuter trips, and whose absolute numbers have continued to grow), there has been an absolute decline in rail freight.from Colombo Port, where the growth of container traffic has led to large numbers of articulated lorries on the A3, one of Colombo's main radial roads. This has led to the proposal for a so-called "dry port" located north of Colombo, designed to move this traffic back to the rail system: we examine this proposal in Section 11.3.

Figure 2.5: Freight demand million ton-km



	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
RAIL	217	224	263	232	204	198	171	164	169	171	159	154	136	108	96	106	94	98
ROAD	1020	1047	1693	1837	1876	1930	1968	2111	2905	3184	3302	4011	4117	4372	4972	5718	6620	8085

33 Other … rcycles and private cars), but the main point remains: rail has the smallest share, buses the largest.

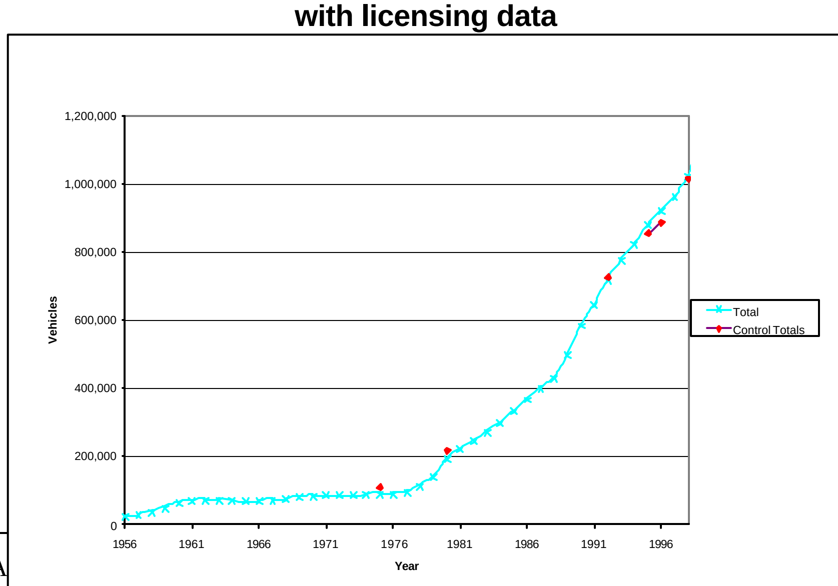
2.2 Vehicle fleet estimates

Estimating the vehicle fleet and its composition is the starting point for analysis. Yet this proves to be an extremely difficult task because of the deficiencies and inconsistencies in the available data, and several past studies have been based upon estimates that are highly questionable. The fundamental difficulty is that while records are kept to reasonable accuracy on new vehicle registrations, there is no (or very little) data on vehicle retirements or vehicles actually on the road, with the inevitable result of overestimating the number of vehicles in the fleet. This is compounded by periodic changes in the classification schemes used by official sources.

It is only recently that rigorous research has been conducted on the composition and evolution of the vehicle fleet to the point at which one may have reasonable confidence in models to project the future growth of vehicles and the concomitant growth of emissions.[34] This work involves careful reconciliation of the available data sources; the formulation of appropriate models of vehicle growth based on hypotheses about survival rates; the calibration of model results with the empirical data (as obtained, for example, from traffic counts); and the reconciliation of estimated vehicle fleets, fuel efficiency, and typical annual distances traveled by each class of vehicle with the total consumption of fuel (known from data published by the Ceylon Petroleum Corporation, (CPC)).

The methodology for this process, as further developed for the purposes of this study, is detailed in Annex 2.1. The result of application of this methodology is shown in Figure 2.6 for the comparison of the estimated total vehicle fleet with licensing data for selected control years.

Figure 2.6: Comparison of estimated vehicle fleet from model with licensing data



34 Notably A[illegible] User Charges Study, Transport Studies and Planning Centre, Colombo, 1992; and A. S. Kumarage and W. Wijertane, *Estimates of Operational Vehicle Fleet in Sri Lanka 1998 Update*, University of Moratuwa, 1999.

2.3 Fuel consumption

In comparison to the power sector, where fuel consumption and emissions for each generator can be estimated with some confidence, fuel consumption in the transportation sector is known with confidence only in the aggregate, since statistics on Sri Lanka's fuel consumption maintained by the CPC are generally reliable. But estimating fuel consumption by vehicle type is a formidable challenge, for there is little actual data, and it is unclear to what extent values published in the international literature are transferable to developing countries. There is a large literature on fuel consumption by vehicle type in North America and Europe, yet this is very difficult to transfer to Sri Lanka. Indeed, fuel consumption (per km traveled) is well known to be dependent upon speed, road, and traffic conditions.

Motorcycle fuel consumption illustrates the problems. All references in the international literature suggest that two-stroke motorcycles are less fuel efficient than four-stroke motorcycles: the ratios of km/litre for four-stroke:two-stroke motorcycles range from 1.30 to 1.65—i.e., that four-stroke motorcycles are between 30 and 65 percent more fuel efficient than two-stroke motorcycles.[35] Yet this is contradicted by at least some anecdotal evidence in Sri Lanka; at a recent seminar, it was two-stroke motorcycles that were reported to have fuel consumption approaching 60 km/litre.[36] Indeed, the km/litre estimates in the literature vary by a factor of two (from 21 to 63 km/litre for four-stroke motorcycles).

Now it may well be that a two-stroke engine of given engine capacity is less efficient (as measured under the controlled conditions of a laboratory test-bed) than a four-stroke machine—but if, as seems likely, most two-stroke motorcycles are of the smallest engine size (50 cc), while most four-stroke machines are 100 cc (and larger), then the actual average consumption of fuel in the fleet of two-stroke machines may yet be less per km than in the fleet of four-stroke machines. Unfortunately, few traffic surveys record whether motorcycles are two-stroke or four-stroke, and the available customs data do not record engine size.

In short, reconciling assumptions for numbers of vehicles, fuel consumption per km traveled, and average km traveled per vehicle involves a great deal of judgment, for there is an infinite number of possible combinations of assumptions that all yield the known total annual fuel consumption i.e., for which, in any given year, for vehicles using a given fuel

$$?_j \, V_j D_j \frac{1}{?_j} \; ? \; Q$$

where V_j = number of vehicles of type j

D_j = km per year in vehicles of type j

35 See detailed data in Table 10.2.

36 Seminar on Environmental Aspects of Transportation, Institute of Policy Studies, Colombo, March 1999.

$?_j$ = fuel consumption, km/litre, of vehicles of type $\boldsymbol{j}$

$\boldsymbol{Q}$ = total annual fuel consumption (from CPC statistics)

One of the problems in undertaking this reconciliation is the vehicle classification scheme itself. For example, since taxis are undoubtedly driven significantly more km/year than other passenger cars, a separate accounting for taxis seems desirable—yet there is little good data on taxi fleets. Moreover, it seems likely that taxis represent the group of motor vehicles that has seen the highest rate of conversion to LPG.

Table 2.2 shows our estimate of the 2000 vehicle fleet by type, average yearly km per vehicle,[37] and average fuel consumption.

Table 2.2: Vehicle fleet and average fuel consumption, 2000

	Fuel	*Vehicle fleet*		*km/litre*	*Fuel cons. 1,000 tons*
Motorcycle-two-stroke	petrol	179,024	5,533	41	18
Motorcycle-four-stroke	petrol	377,799	5,171	41	35
Car	petrol	132,929	8,274	10	94
Dual purpose	petrol	24,955	5,468	8	15
Land vehicle	petrol	1,844	4,881	5	1
Three wheeler	petrol	73,991	19,676	24	49
Total		790,542			213
Car	diesel	20,005	16,759	9	29
Dual purpose	diesel	186,488	14,684	8	298
Bus	diesel	23,948	40,117	3	219
Lorry	diesel	65,373	22,394	3	351
Land vehicle	diesel	73,091	3,652	6	36

[37] The data for average km/vehicle shown here are substantially higher than those reported in the early 1990s, and which were used as a basis for the Metropolitan Environmental Improvement Plan (MEIP). For example, for motorcycles, MEIP assumed 7451 km/year, as opposed to 5100-5500 km used here. For heavy lorries, MEIP assumed 38,000 km/yr, as opposed to our estimate of 22,400; and for cars, MEIP assumed 15,000 km, as opposed to our estimate of 8,275 for gasoline and 16,750 km for diesel cars. The estimates in the NAREPP report are even higher, e.g., 50,000 km/year for passenger cars, and 48,000 km/year for lorries.

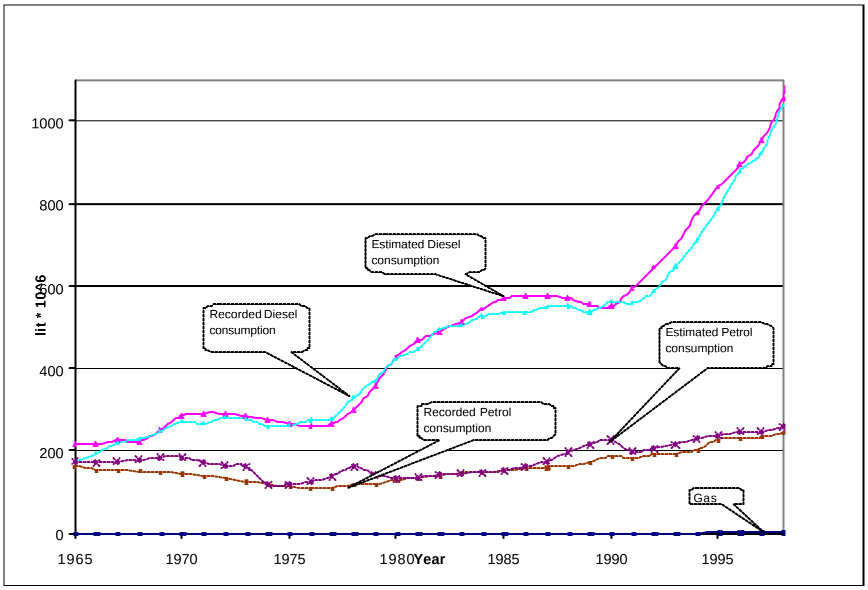
The best evidence that these estimates (together with assumed vehicle fleet and fuel efficiency assumptions) are far too high is that the resulting fuel consumption does not reconcile with the figures of total gasoline and diesel consumption (known with a high degree of accuracy from CPC data). This is unfortunate, for it resulted in estimates of emissions that were also far too high.

For example, from refinery data we know that the average addition of TEL to gasoline was 0.23 gms/litre (significantly less than the erstwhile specification value of 0.43 gms/litre), which when applied to the known quantity of gasoline delivered, results in a total addition of 53 tons. However, the NAREPP study estimated lead emissions as 233 tons, apparently using the specification rather than the actual rate of TEL addition. Even if this estimate is scaled by the ratio of actual to specification TEL addition, the resulting value of 119 tons (i.e., 233 x 0.23 x 0.45) is still double the actual rate based on *known* gasoline consumption.

Three-wheeler	diesel	3,716	22,112	28	2
Total		372,621			936

Figure 2.7 shows the full historical reconciliation of the model with CPC data for gasoline and auto-diesel consumption.

Figure 2.7: Comparison of model estimated fuel consumption with CPC data



Annex 2.1:

Model Calibration[39]

Estimating the registered vehicle fleet

There is no record of the number of operating vehicles in Sri Lanka. An estimation of the present fleet has been obtained through a process of rationalizing and verification to determine the operational fleet by vehicle type as required for analysis in this study.

The basic data is based on the vehicle registration data of the Registrar of Motor Vehicles (RMV). This is available on an annual basis and refers to the number of vehicles that are registered during that year under vehicle types as identified by the RMV. This data has been collated from various published and unpublished sources and a continuous time series database has been built for the period from 1954 to 2000. To facilitate ease of computation, all vehicles that had been registered prior to this date were assumed to have been registered in 1954.

Table 2.3: New vehicle registration

	1994	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Motorcycles	36791	34207	31955	36755	42089	42497	39987
Motor cars	7750	6206	4612	4643	6142	10532	13848
Three-wheelers	4969	12661	13052	10402	16547	14708	11656
Dual pur. veh.	9798	11179	14257	16283	18455	9816	7928
Buses	3823	1701	1479	2069	3348	2611	2298
Lorries	5229	7323	5738	5577	8764	13190	8682
Land vehicles	7160	9124	8340	7652	8415	9499	7530
Total	75520	82401	79433	83381	103760	102853	91929

However, a major problem occurs in correctly identifying the vehicle type in registration data. This arises primarily from the fact that from time to time new vehicle categories were introduced. For example, a separate category called "dual purpose vehicles" was introduced in 1985. Prior to this date all vans, jeeps, and other utility vehicles were registered under the category of cars, lorries, etc. Three wheelers were introduced as a new category in 1991, prior

38 This annex was prepared by A. Kumarage, University of Moratuwa.

39 This annex was prepared by A. Kumarage, University of Moratuwa.

to which they were included with cars. Another inconsistency arises because identical vehicles are classified under different types according to the intended use. For example, some vans are classified as cars, while some station wagons ordinarily classified as cars are classified as dual purpose. Many vans having around 14 seats have been classified as buses as they were originally registered to run public transport services. And, finally, to add to the potential problems, vans that do not have passenger seats are classified as lorries.

In order to reclassify the vehicles into commonly identifiable operational vehicle types, the study adopted the following classes:

- Two-wheelers (motorcycles)
- Three-wheelers
- Cars
- Dual purpose (vans, jeeps, utilities)
- Lorry
- Bus
- Land vehicle

Estimation of the operational vehicle fleet

The operational vehicle fleet is estimated by applying a survival rate for the registered vehicle fleet. The survival rate for a given vehicle type *(Y_x)* after x years since registration has been calibrated in Kumarage (1992) as:

$$Y_x \; ? \; \begin{matrix} ?1 & x \; ? \; n ? \\ ? & ? \\ ?\exp^{?? \, (x ? n)} & x \; ? \; n \; ? \end{matrix}$$

Where ? is a calibration coefficient and ***n*** is constant (in years, before vehicle scrappage begins to take place).

Estimation of annual kms

Kumarage (1992) also discusses the estimation of vehicle-kms operated by each type of vehicle as a function of age of the vehicle and type of vehicle. A calibration following a limited survey has been used to estimate the annual km for a new vehicle, and then to estimate the km operated by an older vehicle through a formulation that considers the impact of age (after ***x*** years) as a negative exponential function. This is given by

$$Z_x \; ? \; C_0 \exp^{(? \, ?x)}$$

Where $\boldsymbol{C_o}$ and ? are calibrated coefficients for each vehicle type and together with ? are shown in Table 2.4.

Table 2.4: Coefficients to determine vehicle survival rates and kilometers operated (1992 and 1998 studies)

Vehicle Type	*?*	*n (years)*	C_o	*?*	F_c *(km/litre)*
Car (p)	0.043	6	34,267	0.069	10.5
Car (d)	0.043	6	37,660	0.044	12.0
Motorcycles	0.099	3	9,996	0.054	40.0
Three-wheelers	0.099	2.5	34,400	0.101	35.0
Dual purpose (d)	0.053	4	63,620	0.096	10.0
Dual purpose (p)	0.096	4	37,340	0.089	8.0
Lorry (d)	0.062	2	53,870	0.029	4.9
Lorry (p)	0.062	2	53,870	0.029	-
Bus (d)	0.100	3	90,617	0.040	5.0
Bus (p)	0.100	3	90,617	0.089	-
Land vehicles (d)	0.069	2	3,180	0	15.0
Land vehicles (p)	0.069	2	3,180	0	-
Trailers	0.046	-	-	-	-

Estimation of fuel consumption

In a subsequent study by Kumarage and Wijeratne (1999), the fuel consumption F_c given in Table 2.4 was used as a control variable to check the results from these calculations. A further revision of consumption rates was undertaken in the present study to adjust for changes to the vehicle fleet during the period 1950 to 2000, in vehicle technology (more fuel-efficient engines), size of carrying capacities (e.g., introduction of container carriers and large buses), and introduction of air conditioning. These changes appear to have caused significant variations in the fuel consumption rate of a given vehicle type.

Model adjustments

Adjustment to Age at Registration: Since government policy on vehicle importation has changed from time to time, the age of vehicles that are imported has also changed. For instance, in recent years, a vast majority of vehicles are imported in a used condition. Presently, only three wheelers can be assumed to be registered in a new or unused condition. For all other vehicle types there are many older vehicles that are registered, in some cases ranging even up to as high as 10 years from time of import. A suitable adjustment to average age at registration has been made based on some limited information available from the RMV, combined with the authors' experience and knowledge of the industry.

Fuel Consumption Rate: The fuel consumption rate for each classification type has also changed over the period of review. Many factors have led to this situation. For example, earlier vehicles were mostly of European origin, while recent vehicles are of Japanese and Indian origin. Most vehicles registered today have air conditioning. Engine capacities have reduced significantly over this period. The carrying sizes of vehicles, particularly lorries and buses, have increased, which we estimated to adjust the consumption rates for each vehicle type over the period 1954-99. A further adjustment was introduced to estimate the increase in fuel consumption with aging of vehicles. This has been estimated by the equation

$$F_x \; ? \; F_o \; ? \, (F_o \; ? \; F_p) x / p$$

Where F_x is the fuel consumption in kms per litre at age x in years

Fo is the fuel consumption at age 0 (new vehicle)

F_p is the fuel consumption at age p years

p is the period of years after which fuel consumption remains constant at F_p

Proportion of Two-Stroke Motorcycles: Both two- and four-stroke motorcycles are used in Sri Lanka. Since fuel consumption and emission factors are significantly different between these two types, an effort was made to estimate this proportion. An estimate had to be made for this study, since the RMV does not record this information at the time of registration. A sample survey of nearly 1,000 motorcycles, identified by series of registration, was used to determine the proportion of two-stroke vehicles in the fleet of motorcycles registered over five-year time periods.

Annual Kms Operated: The model to estimate vehicle-km uses the coefficient C_o, which is theoretically the average annual kms operated by a vehicle in each class; however, this hides significant variations in the notional average values shown in Table 2.2.[40] It was noted that changes in the use of vehicles, variations in fuel prices, other operating costs and, in the case of buses, changes to the management of the industry, have resulted in these values also changing over time and by age cohort. The values of C_o given in Table 2.4 have been adjusted accordingly.

Verification of coefficients

While the general approach followed in earlier studies[41] is valid and relevant for the present task, the requirements of accuracy demand a more detailed validation of the results. In this pursuit, the following validation checks were carried out:

?? Verification between total operational fleet estimated by model and annual licenses obtained

?? Verification between estimated fuel consumption and sales.

Verification between total operational fleet estimated by model and annual licenses obtained: Revenue licenses for motor vehicles are issued annually for the active vehicle population. However, there are some vehicles that operate illegally without renewing the annual

[40] For example, the average value shown for gasoline-powered vehicles of some 8,200 km/year is the result of most privately owned vehicles driving considerably fewer km per year, while cars in the taxi fleet may be driven as much as four times this value.

[41] Notably A. S. Kumarage, *Estimation of Operational Vehicle Fleet*, *op. cit.*

license, and others, such as those with diplomatic licenses, that are not required to renew their registrations. Furthermore, very few licenses have been issued in the North-East province due to the ongoing civil strife. The licensing data for the years 1975, 1980, 1992, 1995, 1996, and 1998 were used for the validation exercise. The values of ? and *n* as given in Table 2.4 were subject to variation in this exercise in attempting to adjust the survival rate for each vehicle category to match the adjusted estimate of the vehicle fleet for the above control years.

Verification between estimated fuel consumption and sales: The Ceylon Petroleum Corporation publishes the annual sale of all fuel by sector of consumption. However, prior to 1995, industrial sales of diesel were not recorded separately. There are also no estimates of nontransport consumption of petrol. It was therefore assumed that 10 percent of diesel consumption prior to 1995 was for nontransport use, while 5 percent of petrol consumption is assumed for the same purpose. Data on fuel sales to the military were not available; hence, the fleet of road vehicles operated by the military was excluded from the verification exercise. A further adjustment was made for petrol vehicles that have been converted to run on liquefied petroleum gas. It was assumed that at present 10 percent of the operating fleet of petrol-driven cars and dual purpose vehicles have been converted to LPG. The data on fuel sales was available from 1960 and thus the comparison was made from that year to 1999.

The resulting exercise of readjusting the coefficients to match with the two control parameters was done by an iterative process. The final outcome of the comparison between the licensing data and the estimated vehicle fleet was given in Figure 2.6, a most satisfactory match having been obtained for six control years. In the second control exercise, the estimated consumption of diesel and petrol has also been reconciled, as shown in Figure 2.7. This has been compared for the period 1964-99 and the adjustments introduced above were helpful in explaining the gaps between the two graphs when the original coefficients from the 1992 study were used.

The final estimates for the coefficients for C_o and ?, together with ?, ***n*** and the fuel consumption rate $\boldsymbol{F_c}$, are given in Table 2.5.

Table 2.5: Coefficients calibrated from the revalidation exercise

Vehicle Type	*?*	*n (years)*	C_o	*?*	F_c *(km/litre)*
Car (p)	0.040	6	These have been computed as age-dependent.	0.069	These have been computed as time-specific and age-dependent
Car (d)	0.040	6		0.044	
Motorcycles	0.060	4		0.054	
Three-wheelers	0.065	3		0.101	
Dual purpose (d)	0.025	6		0.096	
Dual purpose (p)	0.025	6		0.089	
Lorry (d)	0.033	3		0.055	
Lorry (p)	0.033	3		0.055	
Bus (d)	0.085	3		0.040	
Bus (p)	0.085	3		0.089	
Land vehicles (d)	0.0475	3		--	
Land vehicles (p)	0.0475	3		--	

Trailers	0.046	-	--

3

Fuel Prices, Characteristics, and Emission Factors

3.1 Fuel prices

Sri Lanka imports its entire requirement of petroleum fuels, either as crude oil processed at the Sapugaskanda refinery, or as imports of products (Table 3.1).[42] One may note that the data for "auto-diesel" includes that part which is used for power generation: the decline in consumption in 2000 (over 1999), and the very small increase in 2001 (over 2000) reflect changes in power generation use rather than changes in road transportation. The 2001 decline in LPG use is a direct reflection of price increases imposed last year.

The refinery is owned and operated by the Ceylon Petroleum Corporation, which in turn is owned by the Government of Sri Lanka. CPC also has an effective monopoly on the import of diesel fuel for the transportation sector. LPG is imported by Shell Gas Lanka;[43] however, as discussed in Section 10.2, the supply of LPG is being deregulated.

The taxation of crude oil, petroleum products produced at the refinery, and petroleum products imported from the Singapore spot market is complicated, and generally lacks transparency and logic.[44] In the past, imputed subsidies and the cross-subsidies from gasoline to diesel emerged as bookkeeping losses in the CPC accounts. A detailed examination of the many questions that arise in the present system is beyond the scope of this report, and we therefore make the following simplified assumptions for the calculation of taxation flows to the government:

?? The total tax take to the government is calculated as the retail price, less cost, insurance, freight (cif) price of the imported product, less the economic costs of

[42] In 1991, imports of diesel were 170,000 tons, representing only 31 percent of total domestic consumption in that year.

[43] Colombo Gas Company was the state-owned monopoly until its privatization in 1995, when 51 percent of the equity was taken by Shell Gas Lanka Ltd. Its monopoly ended in December 2000.

[44] This problem is discussed later in the report: see e.g., Section 9.1 for a discussion of cross subsidies in diesel and petrol.

distribution, and storage margins, port charges, and so on. If this difference is positive, it represents a tax; if it is negative, it represents a subsidy.

?? There is no need, in this study, to differentiate between customs duty, excise tax, sales tax, VAT, corporate income tax, or defense levy. It is all revenue to the government, and may be considered as a single attribute when examining trade-offs with environmental and economic impacts.[45]

Table 3.1: 1999 production and consumption of transportation fuels [1,000 tons]

	Gasoline	*Auto-diesel*	*LPG*
1999			
Domestic consumption	213	1372	140
Refinery production	295	492	18
Exports (naphtha)	82		
Imports (as % of consumption)		880	122
2000			
Domestic consumption	224	1294	146
Refinery production	213	736	16
Exports (naphtha)	119		
Imports (as % of consumption)	12	557	129
2001			
Domestic consumption	249	1305	139
Refinery production	189	614	15
Exports (naphtha)	90		
Imports (as % of consumption)	60	691	123

Source: CPC

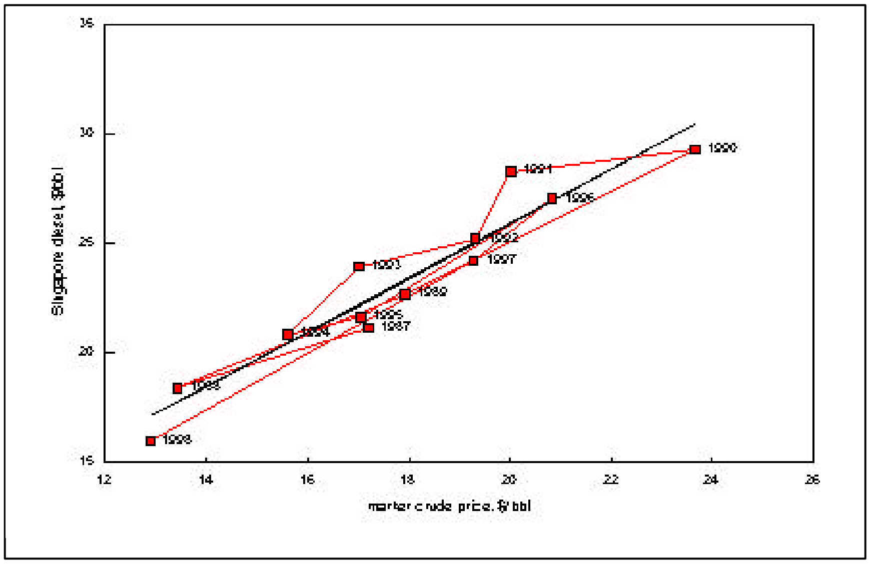
In the case of diesel and LPG, since the marginal barrel as may be reduced (or increased) by the policy options examined in this report is indeed imported, this definition is unambiguous and rigorous. But in the case of gasoline, which is not (presently) imported, there are some potential objections. First, historically the refinery has *exported* naphtha (the principal ingredient of petrol), so one might argue that the relevant opportunity cost is the free on board (fob) price, not the cif price (i.e., Singapore spot *minus* freight, rather than Singapore spot *plus* freight). However, by 2002 most of this surplus naphtha will be used for power generation. Secondly, one might argue that domestic refining lowers the economic cost of gasoline production to below that of the corresponding cif price. However, attempting to assess and forecast CPC's actual refining margins again lies far beyond the scope of this study, and

45 However it is worth noting that simplification and rationalization of the taxation of energy has been recommended by several studies. For example, the World Bank petroleum sector study concluded

> *The present structure of duties, taxies and levies on petroleum and petroleum products is very complex … there is a strong case for simplifying the system of taxation*

therefore the assumption that the relevant opportunity cost for gasoline is the cif price is the only one that is both practicable and reasonable.[46]

Figure 3.1: Singapore spot market price for auto diesel v. Brent crude price (annual averages)



Source: Meier and Munasinghe (2000), based on Platt's Oilgram and Petroleum Intelligence Weekly

Consistent assumptions for the cif prices of transportation fuels are made by relating Singapore spot market prices to the world oil price (for which we use Brent as the marker).[47] For example, Figure 3.1 shows the annual average price of auto-diesel as a function of the annual average Singapore spot gasoil price, for which the statistical relationship was estimated as

[Singapore diesel price, $/bbl]=1.17 + 1.23 [Brent crude price, $/bbl]: R^2=.91

The Singapore prices for diesel and gasoline are shown in Figure 3.2.

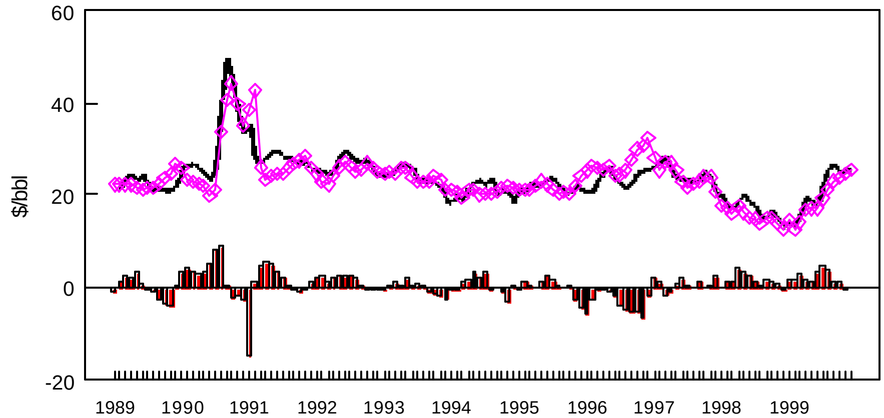
---

[46] Past studies of expanding the Sapugaskanda refinery have shown poor economic returns: a recent proposal to expand from 50,000 bbls/day to 100,000 bbls/day showed only a 5-6 percent IRR on the requisite $350 million investment. Proposals for private refineries (located on the South Coast of Sri Lanka) also failed as a result of inadequate margins. While some of these proposals failed in 1998-1999 during a period of very low crude prices, even the recent increase in world oil prices has failed to lift margins to the point where new greenfield projects would become viable in Sri Lanka. We note that national self-reliance arguments may also play a role in such key public investment decisions.

However, margins at an existing refinery are a different matter altogether: and it does not necessarily follow that margins at Sapugaskanda are necessarily lower than those in Singapore because of its relatively small size and age (or for possible arguments about low productivity). Indeed, margins in Sri Lanka may be positive even when margins in Singapore are negative, because of transportation differentials.

[47] This is discussed in some detail in Meier & Munasinghe (2001), Chapter 2.

Figure 3.2: Singapore diesel and unleaded gasoline prices



Solid line=gasoline. Bars show gasoline – diesel price

Over long-term averages on the Singapore markets, premium (95 octane) unleaded gasoline sells for about 50cents/bbl more than gasoil, though in 1998 and 1999 this increased to around $1.75/bbl (Table 3.2). In this study we assume a long-term differential of $1/bbl.

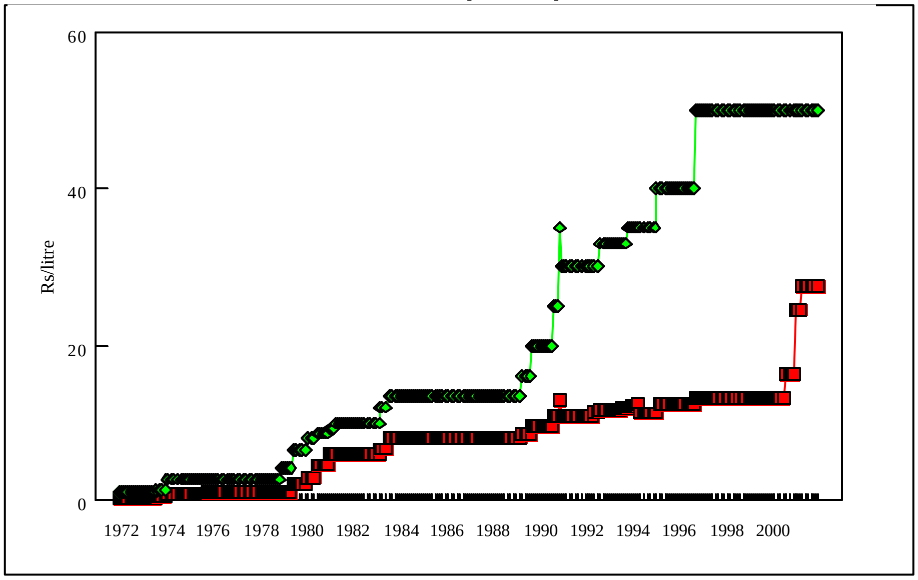
Table 3.2: Comparison of diesel v. gasoline prices (annual averages in $/bbl, Singapore spot prices)

	Gas oil (diesel)	*Premium unleaded RON 95*	*Difference, gasoline-diesel*
1989	22.69	22.53	-0.16
1990	29.32	32.38	3.06
1991	28.29	28.59	0.30
1992	25.24	26.77	1.53
1993	23.98	24.00	0.02
1994	20.86	21.09	0.23
1995	21.64	22.10	0.46
1996	27.07	23.58	-3.39
1997	24.24	24.56	0.32
1998	15.46	17.19	1.73
1999	20.55	22.27	1.72
Average 1989-1999	23.57	24.10	0.53

Source: Petroleum Intelligence Weekly

The monthly evolution of retail prices since 1972 is shown in Figure 3.3: since 1974, only on two occasions have retail prices ever been lowered: in November 1990 (after the short-lived price spike following the Iraqi invasion of Kuwait in August), and in September 1994, when auto-diesel prices were reduced by one Rs/litre.

Figure 3.3: Published prices for auto-diesel and gasoline (Rs/litre, current prices)

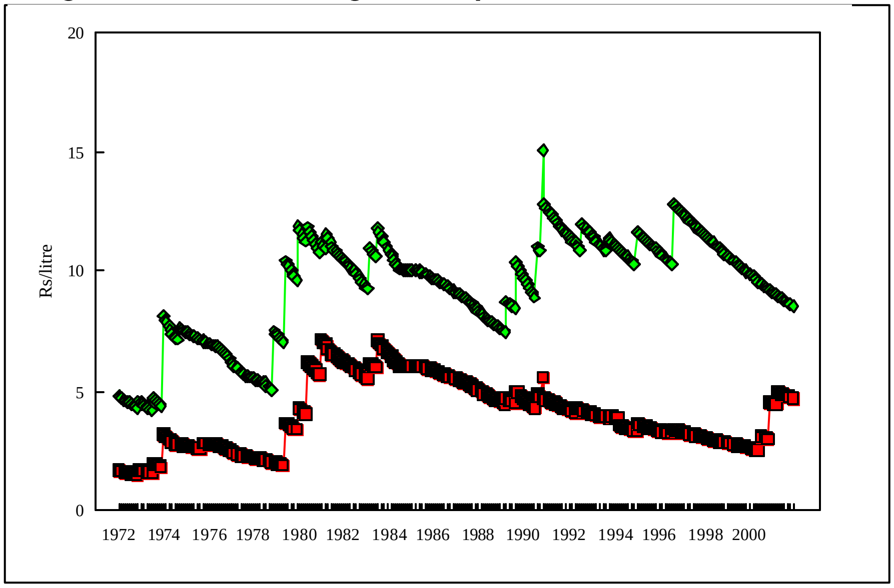


Source: CPC

After almost a decade of relatively unchanged nominal diesel prices, there have been two apparently sharp recent price adjustments (at the end of 2000, and again in April 2001); however, in real terms the situation looks very different, as shown in Figure 3.4. Since the early 1980s (after the second oil price shock), gasoline prices have stayed roughly constant in real terms, except for a period during the late 1980's when they declined significantly. Evidently the government used the opportunity of the price disruption of the 1990 Gulf crisis to bring prices back to their early 1980 levels (in real terms). The recent price increases of 2001 affected only diesel, notwithstanding that gasoline prices have been unchanged (in nominal terms) since 1997.

In the case of diesel, since late 1983 the retail price has experienced a significant and consistent downward trend in real terms, and the recent diesel price adjustment has merely restored the price differential to something approaching the historical norm (Figure 3.5).

Figure 3.4: Diesel and gasoline prices, in constant 1982 Rs.



Source: Retail prices from CPC, converted to constant 1982 prices uses the Central Bank GDP deflator (see Box 5.1 for discussion of deflators in Sri Lanka).

When one takes into account the changes in world oil prices over the same period, the result of the ad hoc pricing policy is significant variations in the tax revenue (Figure 3.6): thus the world oil price increase since late 1998 has led to a decrease of monthly tax revenue of over 30 percent (in real terms).[48] In addition, this mode of price adjustment gives inconsistent signals to road users, signals that should reflect changes in cif price, rather than changes in the government tax take.

Figure 3.5: Differential between diesel and gasoline retail price, constant 1982Rs/litre

48 From Rs 384/month in December 1998 to Rs 260/month by July 2000. In 2001 the world oil price decreased from around $33/bblk to $25/bbl for Brent crude oil, so the tax take has increased again (to an estimated Rs 289million/month in July 2001 in constant 1989Rs).

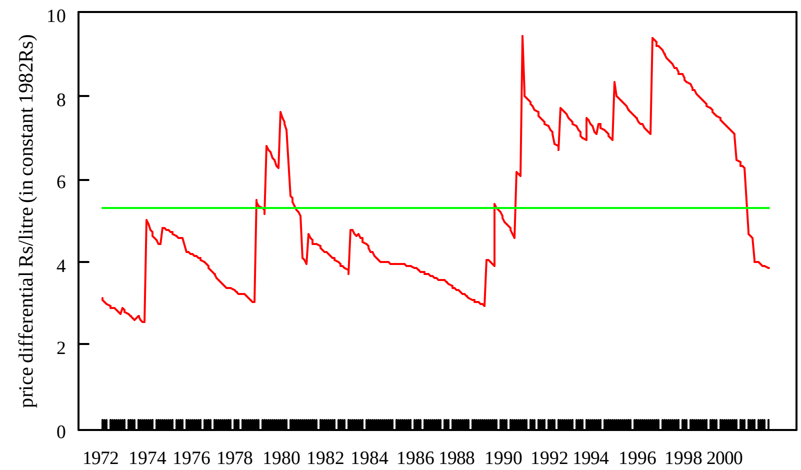
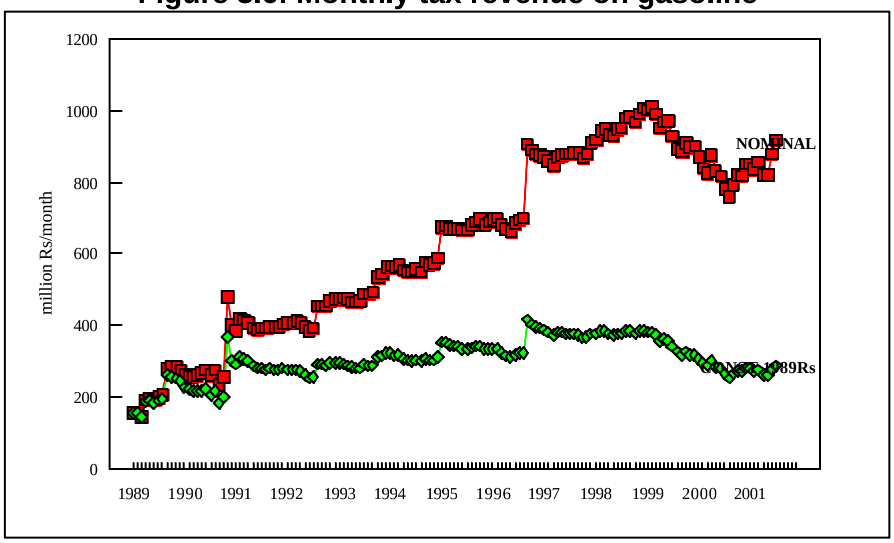


Figure 3.6: Monthly tax revenue on gasoline



Application of the world oil price of late 2001, when the analyses presented in the following sections were done, leads to the simplified price structure shown in Table 3.3. This shows an effective tax rate of Rs 7/litre for diesel, and Rs 27/litre for gasoline.

Table 3.3: Price structure for transportation fuels, December 2001

		Petrol	*Diesel*
World oil price	$/bbl	26.00	26.00
Singapore spot (1)	$/bbl	34.20	33.20
Freight	$/ton	10.00	10.00
Colombo, cif	$/ton	296.00	259.00
	Rs/litre	20.01	17.52
Margins, port charges etc.	Rs/litre	2.70	2.50
Total taxes [by difference]	Rs/litre	27.29	6.98
Retail price	Rs/litre	50.00	27.00

Exchange rate: Rs90/$US; world oil price $26/bbl.

However, in February 2002 the new government adopted a new pricing system, which provides for automatic adjustment of the retail price, and avoids some of the problems noted above. Prices for all products are adjusted in the middle of each month, according to the import parity price based on the average of Platt's Singapore postings over the previous month, and the average exchange Rs/US$ of the previous month.

The new structure is given in Table 3.4: for the same late-2001 world oil price (Brent) of $26/bbl, the retail price increases from Rs 50-59/litre for petrol, and from Rs 27-33/litre for diesel. However, at the time of implementation of the new system, the world oil price had fallen to around 23$/bbl, resulting in *actual* retail prices in April 2002, according to the new pricing formulae, of Rs 52 and Rs 28/bbl for petrol and diesel, respectively.

The previous ad-valorem-based excise duty on petrol, diesel, and kerosene has been replaced by a fixed excise duty charge (for 2002 and 2003) on petrol (Rs 30/litre) and auto diesel (Rs 6.50) – which roughly reflect the 2001 tax takes (shown in Table 3.3).[49] The adjustment is subject to a maximum (monthly) increment of Rs 2.00/litre. It is proposed that once CPC debt is retired, it will be possible to reduce the price of petrol more than diesel, by adjusting the excise duty disproportionately to remain revenue neutral to the government with respect to excise duty. However, whether this equalization will actually occur in 2003 remains to be seen.

Table 3.4: New price structure (as of February 2002)

	$/bbl	*Petrol*	*Diesel*	
WOP	$/bbl	26	26	
Fob Singapore [Platt's]	$/bbl	35.15	33.2	(1)
	[bbls/ton]	8.38	7.52	
Freight $/ton	$/ton	11	11	
Jetty pipeline charge	$/ton	3	3	
Freight & jetty	$/bbl	1.67	1.86	
Cif, $/bbl	$/bbl	36.82	35.01	
	[litres/bbl]	158.90	158.90	
Exchange rate	[Rs/$]	94.83	94.83	average of the previous month
Cif, Rs/litre	Rs/litre	21.97	20.89	
Stamp duty, 1.2 percent	Rs/litre	0.26	0.25	
Landed cost	Rs/litre	22.24	21.15	
Excise duty	Rs/litre	30.00	6.50	fixed amount for 2002 and 2003
Customs duty	Rs/litre			
	Rs/litre	52.24	27.65	

49 Part of the excise duty so collected will be utilized to retire the existing huge debt incurred by CPC in the year 2000 due to the failure of the then government to revise consumer retail prices at the appropriate time. This excise duty is waived for CEB's use of auto-diesel for power generation.

NSL	Rs/litre	1.79	1.70	
GST	Rs/litre			presently only on fuel oil
Tax paid landed cost	Rs/litre	54.02	29.34	
CPC finance charge	Rs/litre	2.54	2.54	fixed amounts for 2002
CPC wholesale costs	Rs/litre	0.24	0.24	for 2002 only
CPC margin	Rs/litre			presently zero on petrol and diesel
CPC wholesale cost	Rs/litre	56.80	32.12	
Marketing + distribution	Rs/litre	1.23	1.23	for 2002 only
Dealer discount	Rs/litre	0.46	0.26	
Consumer retail price	Rs/litre	58.49	33.61	
Last 2001 price	Rs/litre	50.00	27.00	
April 2002 price	Rs/litre	58.00	28.00	new formula

(1) 92RON posting for petrol; 0.5 percent gasoil posting for diesel: average of the previous month.

It is also proposed that, starting in mid-2002, the National Security Levy (NSL) and General Sales Tax (GST) would be replaced by VAT, levied at 10 percent on petrol and auto-diesel, which would further increase the tax take. At the time of writing (June 2002), these proposals are being debated in Parliament, and it is unclear whether (and when) these proposals will actually be implemented.

3.2 Fuel characteristics

Table 3.5 shows our assumptions for the key physical characteristics of transportation fuels.[50]

Table 3.5: Fuel characteristics

	Petrol	Auto-diesel	Log[cal]
Litres/ton	1332	1196	
Carbon content	0.846	0.875	0.846
Bibles/ton	8.38	7.52	8.5
Calorific value; Cal/Kg	10473	10182	10955

Numerous studies have pointed to (and often exaggerated) the problems of lead in gasoline, and sulphur in diesel fuel, problems that are related to the historical desire of CPC to give itself generous specifications, rather than the actual level of emissions.[51] For example, the

50 Characteristics subject to policy interventions (lead in gasoline, sulphur in diesel, etc.) are discussed in later sections of the report. Data in Table 3.5 are from CPC.

51 The principal reason for this is the desire of CPC to preserve maximum flexibility in crude acquisition. The Sapugaskanda refinery does not possess the secondary processing facilities of a typical modern world-scale refinery, and the product mix and quality are therefore much more sensitive to input crudes. Even though direct crude-oil for tea barter arrangements with some Middle Eastern suppliers in the 1970s and early 1980s have been discontinued, CPC is reported to be still subject to occasional government requests that crude be purchased from major purchasers of Sri Lankan tea. However, since

rate of addition of Tetra Ethyl Lead (TEL) to (leaded) gasoline is frequently assumed at the old specification value (of 0.43 gms/litre): this is significantly above the specification values of other countries, as shown in Table 3.6. In fact, as of October 1999, the specification was 0.3 gms/litre.[52]

the Sapugaskanda refinery was designed for Middle Eastern crudes, it seems doubtful that the occasional such purchase would have much impact on average refining margins.

52 CPC Specifications for Lanka 2-star petrol, Technical Committee Meeting, 2 October 1999. The value of 0.43 goes back to the 1980s: in some documents it is quoted as 0.45 gms/litre. In fact prior to the revision of October 1999, the value was 0.4 gms/litre.

Table 3.6: Comparison of lead in leaded gasoline, in gms/litre[53]

		Present
ASEAN (1)	Brunei	0.11
	Cambodia	
	Indonesia	0.3
	Laos	
	Malaysia	0.15
	Myanmar	
	Philippines	0.15
	Singapore	0.01
	Thailand	0.013
	Vietnam	0.4
OTHER	India	
	Bangladesh	
	China (3)	0.35
	Pakistan (2)	0.35(4)
	Sri Lanka	0.43

Source: ASEAN, *Proceedings*, Regional Workshop on Fuel Quality and Alternative Fuels, Delhi, May 2001.

(1) G. Balce, "Overview of Regional Fuel Market and Fuel Quality"

(2) S. M. Zaidi, "Country Experience of Pakistan in Improving Fuel Quality"

(3) Z. Yangsheng, "Improving Fuel Quality in China"

(4) Three refineries produced low lead gasoline (with levels at 0.04, 0.05, and 0.1 g/litre): the largest refinery (ARL) produces gasoline at 0.35 g/litre.

Yet the *actual* addition of TEL, as may readily be calculated from refinery data, has long been significantly lower (Table 3.7), so in fact the difference to other Asian countries has been less than suggested.[54] Moreover, some of the earlier estimates of total lead emissions are

---

53 Specifications for lead in many African countries are much higher than they are in Asia: e.g., in Benin, Cameroon, Chad, Uganda, Zimbabwe, the 1996 value is 0.84 gms/litre. For a complete worldwide list, see, e.g., M. Lovei, Phasing Out Lead from Gasoline: Worldwide Experiences and Policy Implications, World Bank Technical Paper 397, Washington D.C., 1998. Annex A.

54 The 1996 World Bank Transport Sector Study (Vol. I, para. 5.12) is typical:

Leaded gasoline is also used: about 0.43 gms/litre is allowed which is high in comparison to leaded gasoline in other countries

There is no mention of the actual rates of TEL addition. Even the 1994 report of the Sub-Committee on Fuel Reformulation, charged with an examination of fuel formulation issues raised by the Clean Air 2000 program, makes the same statement: " . . . *at present we use about 0.45[sic] gms lead per litre of petrol. This is about 3 times higher when compared to the leaded petrol in other countries.*"

also in demonstrable error due to poor assumptions about the vehicle fleet, fuel efficiency, and annual vehicle-km.[55]

Table 3.7: Actual average TEL additions (based on refinery data)

	Pb gm/litre
1990	0.2348
1991	0.2154
1992	0.2089
1993	0.1863
1994	0.2534
1995	0.2285
1996	0.3033
1997	0.3141
1998	0.3185
1999	0.2500
2000	0.1484
2001 (to June)	0.1059

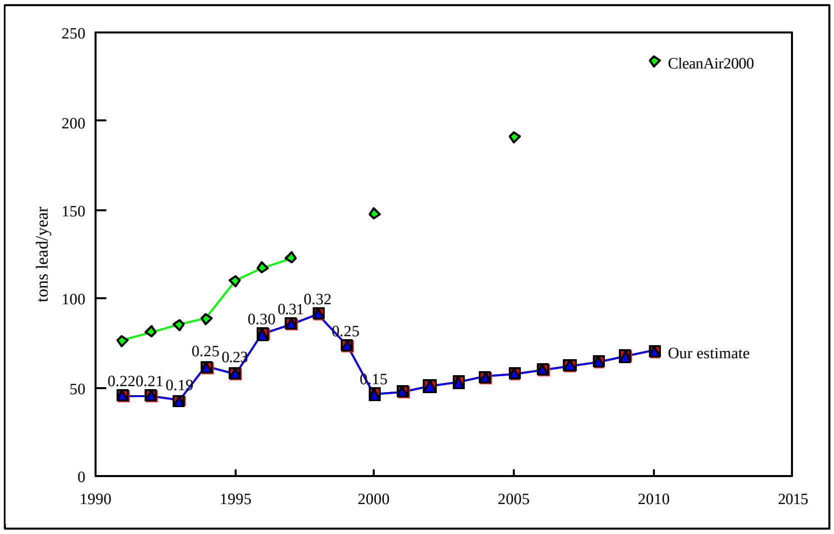
Source: CPC

Figure 3.7 compares our estimates of lead emissions, based on actual CPC data for the historical period, and 0.15 gms/litre of TEL addition for the future. Emissions in 2010 are seen to be below the 1991 estimates of the Clean Air 2000 report, and the historical emissions are similarly substantially lower.[56] Further reductions of lead emissions due to the phasing out of leaded gasoline altogether—a policy now being implemented by the new UNF government—are discussed below in Section 9.2.

55 See above (Section 2.3) for a discussion of the problems in the USAID studies of the early 1990s that were the basis for the Clean Air 2000 program.

56 One of the few sources that accurately reports Sri Lanka's lead emissions (at 0.2 gms/litre) in international comparisons is V. Thomas, "The Elimination of Lead in Gasoline," *Annual Review of Energy and Environment*, 1995, 20:301-324.

Figure 3.7: Estimates of lead emissions from automobiles



Source: Clean Air 2000 Action Plan; our estimates based on CPC historical data plus vehicle fleet forecast presented in Section 3.

3.3 Emission factors

Whatever the uncertainties regarding fuel consumption, estimating emissions is subject to even greater problems. To be sure, for some emissions, such as lead, carbon dioxide, and sulphur oxides, the calculation is straightforward, since it requires knowledge only of the corresponding quantity of (unoxidized) precursor in the fuel, plus some fairly standard assumptions about the fraction oxidized and emitted. However, for a range of other pollutants, notably particulates, NOx, and VOC, calculation by simple stochiometry alone is not possible, since these emissions are dependent upon complex factors of engine design and combustion performance.

Again there is a vast U.S. and European literature on emissions from particular vehicle types, which has been reviewed and summarized by Faiz et al. (1996). And, again, the extent to which U.S. and European test-bed results are transferable to Sri Lanka is debatable—yet absent empirical data from Sri Lanka itself, there is little choice but to use such sources. Problems include:

?? For some vehicle types, such as three-wheelers, there is little data[57]

?? For all classes of vehicles, emissions are strongly dependent upon vehicle speed and traffic conditions

?? Emissions are strongly dependent upon engine maintenance and age of vehicle. Recent findings in the United States that a relatively small proportion of poorly

[57] The paucity of data for south Asian three-wheelers and motorcycles has recently been rectified as part of the World Bank's South Asia Two-Stroke Engine Initiative, which over the past year has published several papers. See, e.g., Kojima, M., C. Brandon and J. Shah, *Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles*, World Bank South Asia Environmental Unit, Washington, D.C., 2000.

maintained older vehicles accounts for the bulk of emissions[58] is likely to be true in Sri Lanka as well.

Table 3.8 shows the emission factors used in Chandrasiri (1999).

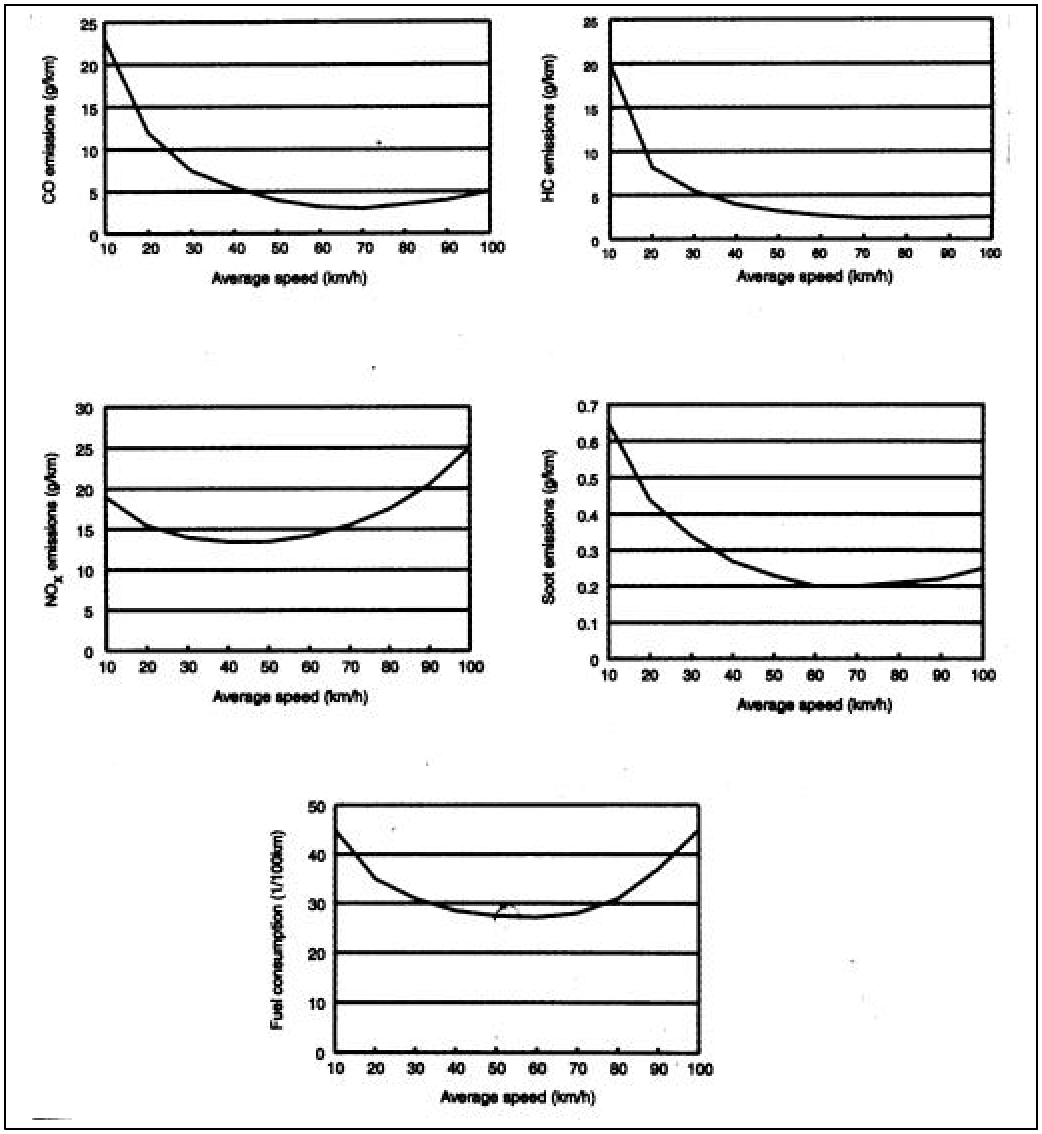
Table 3.8: Emission factors: gms/km

	NOx	*CH4*	*VOC*	*CO*	*N2O*	*PM*
Petrol						
Cars	2.19	0.08	4.63	49.97	0.005	
Dual-purpose	2.94	0.08	4.86	37.12	0.006	0.048
Two-stroke motorcycles	0.08	0.15	15.39	21.97	0.022	0.206
Four-stroke motorcycles	0.3	0.2	3.35	20.0	0.022	0.048
three-wheeler	0.08	0.15	15.39	21.97	0.022	0.206
Diesel						
Cars	0.66	0.005	0.19	0.71	0.01	0.33
Buses	10.56	0.063	1.99	8.89	0.03	0.95
Lorries	10.56	0.063	1.99	8.89	0.03	0.95
Dual-purpose	1.43	0.005	0.42	1.57	0.017	0.37
Land vehicles	10.56	0.063	1.99	8.89	0.017	

Source: Chandrasiri (1999), Annex 2. Based in turn on Faiz et al. *(1996)*.

[58] See, e.g., G. Harvey and E. Deakin, *Transportation and Air Quality*, U.S. Department of Transportation, Federal Highway Administration, Policy Discussion Series #5, August 1992. A study in Denver showed that 30 percent of roadside emissions were attributable to 1 percent of vehicles.

Figure 3.8: Relationship of average speed on emissions and fuel consumption: lorries



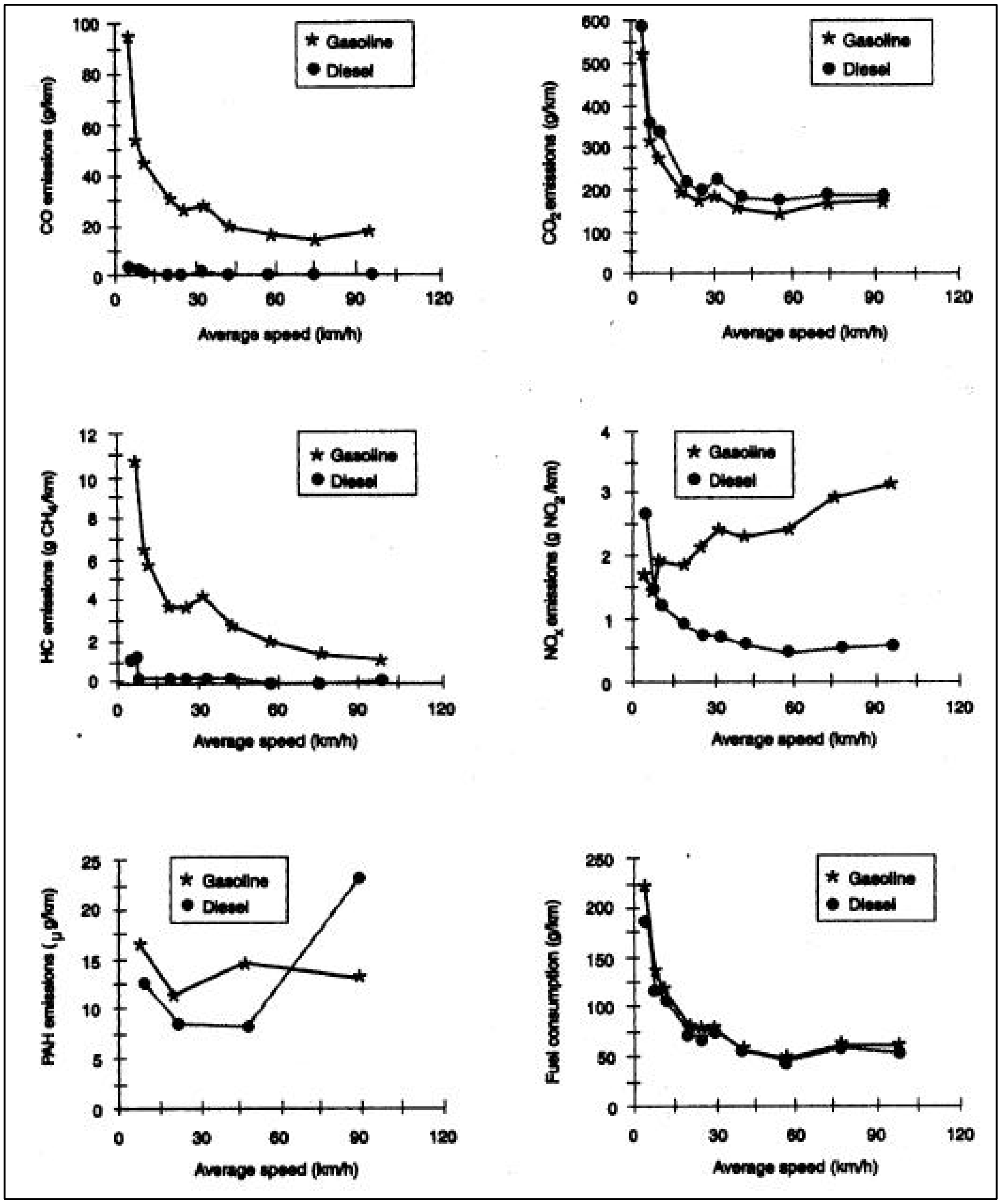
Source: Faiz, et al., Air Pollution from Motor Vehicles, op. cit., p. 42.

Emission factors are strongly influenced by the age of vehicles (which in developing countries is almost always higher than in the developed countries),[59] by the average speed, and by the degree of acceleration and deceleration in the driving cycle. The typical patterns of emissions as a function of vehicle speed are illustrated in Figures 3.5 and 3.6: for most emissions and for fuel consumption, the optimum (lowest) rate is at 50-60 km/hour: at both higher and

59 Indeed, there are essentially no "new" cars in Sri Lanka at all (except for a very small number of high-end luxury cars); as noted [above], most imports are two-to-three year-old reconditioned vehicles from Japan.

lower speeds emission rates increase. CO_2 emissions are not shown, but will be proportional to total fuel consumption (bottom graph in Figure 3.5)

Figure 3.9: Relationship of average speed on emissions and fuel consumption: passenger cars

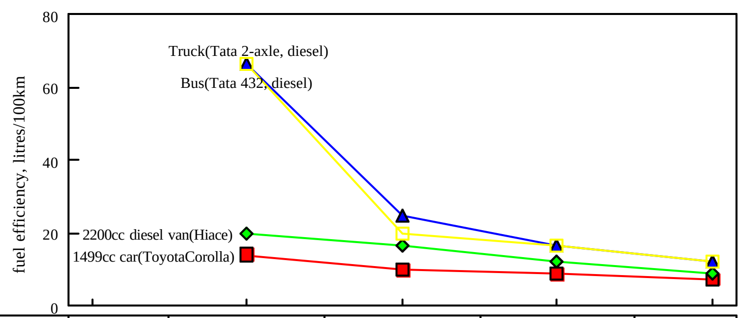


Source: Faiz et al. *Air Pollution from Motor Vehicles, op. cit.*, p. 39; based on European passenger cars without catalysts.

But while the increase at speeds higher than the optimum speed is fairly gradual, there is an exponential increase in emissions as speeds decrease,[60] with emissions at 10 km/hr often double those of 30 km/hr that are often used in published emission factors.[61] Thus, emission factors in the congested urban conditions encountered during peak hours in Colombo are likely to be very much higher than standard values of Table 3.8.

These general relationships are reflected in the recent Sri Lankan survey data, taken in March 2001 on the Colombo-Ratnapura road. As shown in Figure 3.7, particularly for buses and trucks, fuel efficiency falls dramatically at low average speeds. Table 3.9 portrays the same data in terms of km/litre—which falls from 12.5 km/litre at 40 km/h to 1.5 km/litre at 10 km/h for trucks and buses—with fairly obvious implications for diesel particulate emissions.

Figure 3.10: Results of the fuel efficiency survey for typical vehicles



speed, km/hour	10	20	30	40
1499cc car(ToyotaCorolla)	14.3	10.0	8.7	7.7
2200cc diesel van(Hiace)	20.0	16.7	12.5	9.1
Truck(Tata 2-axle, diesel)	66.7	25.0	16.7	12.5
Bus(Tata 432, diesel)	66.7	20.0	16.7	12.5

Table 3.9: Fuel efficiency as km/litre

Speed, km/hour	*10*	*20*	*30*	*40*
1499 cc car (Toyota Corolla)	7	10	11.5	13
2200 cc diesel van (Hiace)	5	6	8	11
Truck (Tata 2-axle, diesel)	1.5	4	6	8
Bus (Tata 432, diesel)	1.5	5	6	8

Source: Figure 3.7

If the benefits of eliminating congestion are to be properly assessed, fuel consumption and emission factors in quantitative models must be speed-dependent. For those pollutants whose emission factors are most likely to be correlated with the characteristics of the fuel, it is

60 Although according to the results summarized in Figure 3.6 [Q: is this reference correct? Figure 3.6 is about monthly tax revenue on gasoline], NOx emissions from gasoline vehicles seem to be an exception to this general pattern.

61 For example, most of the emission factor tables in Faiz et al. *(1999)* are for a speed of 31 km/hour.

clear that the best approach is to estimate emissions on the basis of stochiometry: thus sulphur and lead emissions follow from the sulphur and lead contents of fuel.

Fuel consumption therefore requires knowledge of the vehicle speeds. In the case of projects involving known road segments (such as the Colombo-Katunayake Expressway examined in Section 11.1 or the congestion pricing analysis of Section 8.1 that focuses on Colombo's seven major radial roads), the relationship between speed, traffic volume, and road capacity can be calculated with reasonable accuracy. However, the impact on systemwide average speeds is more difficult to assess, requiring the application of complex, systemwide models. Table 3.10 shows estimates of typical speeds as a function of the volume/capacity ratio.

Table 3.10: Average speeds

Volume/capacity ratio	*Radial arteries*	*Urban street*
0.0 – 0.5	60	50
0.5 – 0.6	55	43.5
0.6 – 0.7	50.5	35
0.7 – 0.8	42	30
0.8 – 0.9	40.5	20.5
0.9 – 1.0	28	17
>1.0	21	12

Source: Jayaweera, *op. cit*, based on journey time survey of June 1999.

Thus the estimation of speed-dependent emission factors requires a number of assumptions, about each of which there may be considerable uncertainty. However, since the general pattern of the relationships involved seems fairly well documented (as for example suggested by Figures 3.5 and 3.6), the error involved in use of the unadjusted emission factors of Table 3.7 is likely to be higher than if we were to use the speed-dependent estimates, notwithstanding the uncertainty of the latter.

3.4 Comparison with the power sector

A comparison of transport sector emissions with emissions from power plants is instructive. Table 3.11 shows daily emissions of SO_2 from the 60MW barge-mounted plant in Colombo harbor, from the first 150 MWcoal-fired unit proposed for Puttalam, and from Colombo's auto-diesel consumption.[62]

62 Which we take here as 60 percent of the estimated year 2000 consumption of 936,000 tons.

Table 3.11 Comparison of daily auto-diesel v. power plant emissions in Colombo

		Barge mounted fuel oil	*Puttalam coal*	*Auto-diesel*
Capacity	[MW]	60	150	
Heat rate	[KCal/kWh]	1954	2293	
Fuel calorific value	[KCal/kg]	10300	6300	
Kwh/day	[kwh/day]	1440000	3600000	
Fuel/day	[10^6 KCal/day]	2814	8255	
	[Kg/day]	273181	1310286	
Tons/day	[tons/day]	273	1310	
Sulphur by weight	[ ]	0.025	0.006	
SO2/day (1)	[tons/day]	13.6	7.86	21.5
Damage cost	[$/ton]	487	6	487
Health damages	[US $/day]	6623	48	10470

SO_2/day for auto diesel based on 0.7 percent sulphur by weight (approximate actual). Assumptions for power plants from P. Meier, Sri Lanka Electric Power Technology Assessment, *op.cit*., Table 3.6

It is evident that the barge-mounted plant is a significant source of SO_2**.** Even if dispatched only during peak hours, say 8 hours a day, it adds 20 percent of the total daily auto-diesel derived SO_2 load in Colombo: but during the period of severe power cuts in 2001-2002, this plant was running 24 hours a day, with a corresponding increase in SO_2 emissions. It may also be seen that the SO_2 damages from the coal plant are a very small fraction of those stemming from auto-diesel SO_2 emissions and the barge-mounted plant.[63]

[63] It is hard to avoid the conclusion that 1) the barge-mounted plant is in the worst possible location (from an environmental point of view), and 2) the environmental concerns regarding the coal-plant at Puttalam, if properly focused on damage costs and not merely emissions, are irrational. These issues are discussed further in P. Meier and M. Munasinghe, *Environmentally Sustainable Energy Development in Sri Lanka: Impacts, Issues and Policy Options*, World Bank, 2002.

4

Air Quality, Health Effects, and Damage Valuations

The main potential environmental concern about continued growth of transportation energy demand is its impact on urban air quality, and the concomitant resulting health damages. In this section three main questions are posed. First, has urban air quality worsened? Second, what is the evidence of growing health damages, and to what extent can this be linked to the growth of transportation fuels? And third, to what extent can these damages be monetized?

We are able to provide only partial answers to these questions, for there are significant gaps in data, and there are few Sri Lankan epidemiological studies that provide clear evidence of causation. The use of the benefit transfer method (that is based on studies elsewhere, and adjusted to the circumstances of Colombo)—and which we adopt in this study for lack of Sri Lankan studies—needs to be applied with due caution.

Nevertheless, even taking a very conservative approach, and bearing in mind the uncertainties introduced by the benefit transfer method, the evidence of (significant and growing) health damages from transportation energy use is sufficiently strong to warrant inclusion of the estimated health damage costs in the cost-benefit calculations.

4.1 Local Air Quality in Colombo[64]

Compared to the air quality data available in other Asian cities, the data for Colombo is quite limited. Systematic monitoring started in 1989 under the auspices of the Environmental Division of the National Building Research Organisation (NBRO).[65] A first study examined 49 locations in the city of Colombo for sulphation rate and dustfall, followed by a second program

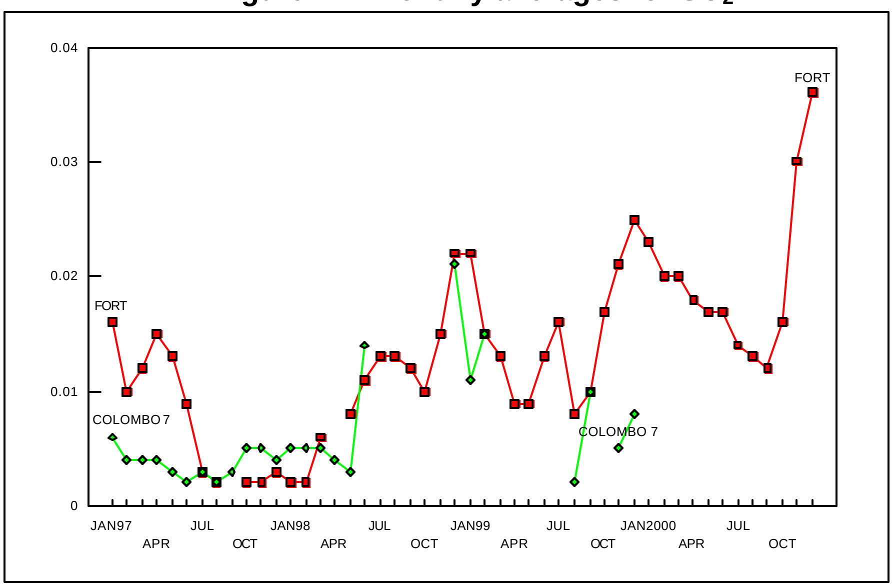
64 We thank P. Samarakoddy of NBRO for his assistance in compiling the air quality data reported in this section.

65 For a complete description of air quality monitoring in Sri Lanka, see, e.g., R. P. Samarakoddy, "Air Quality Monitoring in Sri Lanka," Asian Aerosol Data Synthesis Workshop, Dec.1999, New Delhi. Other organizations active in air quality monitoring include the Sri Lanka Atomic Energy Authority (which collected PM-10 and PM2.5 data in 1995-1996 for urban Colombo, and 1997-1998 in the rural area of Alturas); and the University of Peradiniya, which collected acid rain samples at 12 locations in 1994-1999, and at Nuwera Eliya (in the hill country) since 1996.

at seven representative locations in 1992-1993.[66] In late 1996, NBRO started a long-term monitoring program at two Colombo locations: at Fort, in the center of the city, and at a site in Colombo 7 (Bauddaloka Mawatha, a mainly residential area) as a background station in Colombo. These sites have provided PM-10 once in four days, and continuous monitoring of NOx, CO, SO_2, and ozone (plus corresponding meteorological data). This is the most important source of Colombo air quality data.

Has air quality in Colombo deteriorated, and to what extent can such deterioration be linked to vehicular emissions? Unfortunately, because of differences in sampling methods and locations, the new data from 1996-2000 is difficult to compare with the earlier data from 1989, and 1992-1993. However, the new data set, beginning in late 1996 does permit some preliminary conclusions. Figure 4.1 shows monthly averages from 1996 to 2000 for SO_2. We note the seasonality of the data: the highest concentrations are in November-January, which reflects the impact of fumigation conditions during the NE monsoon—when the prevailing wind direction is exactly opposite to the sea breezes that have W to SW direction, which are typical for the late afternoon-evening hours.

Figure 4.1: Monthly averages for SO_2



Although the Fort station data is unbroken over the four-year period, there are extensive gaps in the available data for the Colombo 7 location, so it is difficult to make judgments about the extent to which the Fort location—clearly a “hot spot”—can be used to gauge average population exposures.

Nevertheless, the Fort data do reflect the growth in vehicular diesel emissions, the main source of SO_2: the winter peaks get worse each year (except 1997, whose winter values show

[66] The various phases of the monitoring program are described in detail at the NBRO website at http://www.nsf.ac.lk/nbro/enviro

no peak at all)[67], most notably in 2000, which is almost certainly due to the start-up of the 60 MW barge mounted plant in Colombo harbor.

Another way of noting the trend is to examine the occurrence of exceedences of the standard. For example, Table 4.1 shows the number of exceedences of the CEA SO_2 standard for one-hour average of 0.08 ppm; once again, we see the dramatic change in the last few months of 2000.

Table 4.1: SO_2: number of daily exceedences/month

	1996	*1997*	*1998*	*1999*	*2000*
January				3	4
February					5
March			2		5
April		3			1
May		2			
June					
July					
August					
September					
October					2
November			3	1	25
December	5		2	1	40
Total	5	5	7	5	82

Source: NBRO AQM Database.

The same general trends are observed for NOx, shown in Figure 4.2: again, the sharp increase in the 2000 winter peak clearly reflects some new emission source (again, most likely the barge-mounted power plant), given the regularity of the cycles in the previous years.

67 However, since the winter peak is observed in the NOx data (see below, Figure 4.4), the most likely explanation is some sampling problem for SO_2 during these months, rather than some unusual weather conditions.

Figure 4.2: Monthly averages for NOx

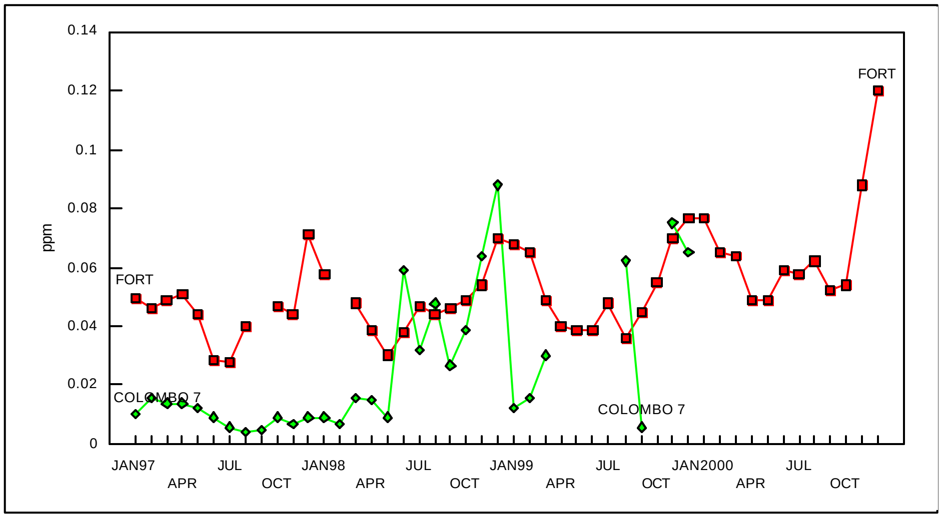
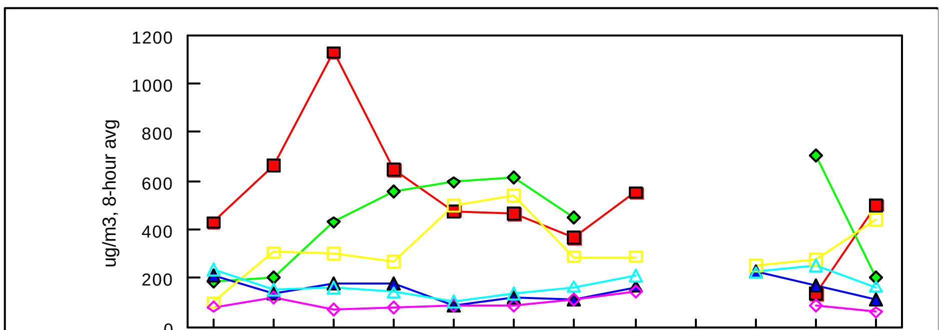


Figure 4.3 shows the particulate data taken at various sites in Colombo in 1992-1993. The seasonalities are less pronounced (except for the Colombo 11 site), but the extent of geographic variation is clear, with average values across sites differing by a factor of 5.

Figure 4.3: Averages of 8-hour SPM, ug/m3



	SEP 92	OCT	NOV	DEC	JAN93	FEB	MAR	APR	MAY	JUNE	JUL	AUG
COL11	427	665	1128	645	477	467	363	554			132	501
COL10	190	199	427	561	594	613	447				707	199
COL5	209	136	173	173	88	115	113	161		229	167	109
COL8	101	304	301	269	498	539	289	286		252	274	443
COL15	84	118	71	77	86	88	109	147			86	57
COL4	235	154	156	141	108	135	162	211		225	250	166

COL11	Traffic Police Station, Colombo 11
COL10	Sarasavipaya, Marinade Junction, Colombo 10
COL5	Lanka Tractors Ltd, Nawala Road, Colombo 5
COL8	ICTAD Sub-office, Baseline Road, Colombo 8
COL15	Aitken Spence (Pvt) Ltd, Sri Wickrema Mawatha, Colombo 15
COL4	Milagiriya Church, Colombo 4
COL7	Sri Lanka Institute of Development Administration, Malalasekera Mawatha, Colombo 7

There are two problems related to particulate data. First, some portion of the measured PM-10 is re-suspended road dust—but there appears to be no information on what proportion actually comes from this source. If this accounts for a large proportion of the particulate matter, then measures to reduce vehicle emissions will be ineffective.

Second is the question of PM-10 precursors. Some part of ambient PM-10 is the result of secondary sulfate particles whose precursors are SO_2 emissions, and therefore reduction of sulphur content in diesel fuel may affect ambient particulate concentrations. However, in general, the formation of secondary sulfates is a phenomenon of long-range transport, involving oxidation over considerable distances, and contributing to ambient PM-10 through dry deposition (and to acid rain during precipitation). Given the strong sea and land breezes that characterize Colombo's climate (as well as rain on more than 50 percent of all days), it seems unlikely that dry deposition of sulfates, originating from sulphur emissions of diesel vehicles, would be a significant contributor to ambient PM-10 in Colombo itself. Nevertheless, this is a topic that needs further research.

4.2 Health effects

There exists to our knowledge only one Sri Lanka-specific study of health damage valuation related expressly to vehicular emissions.[68] Although there are many limitations (as noted by the authors), this is also the only study that is based on clinical data. As shown in Table 4.2 (and Figure 4.4), over the past decade there has been a relentless increase in hospital admissions and deaths related to respiratory disease[69] that tracks very closely with the increase in vehicle emissions of particulate matter.[70] The overwhelming majority of the hospital physicians interviewed asserted that the increase in respiratory diseases was related to vehicle emissions.[71]

---

68 S. Chandrasiri and S. Jayasinghe, *Health Effects of Vehicular Emissions in Colombo,* University of Colombo, ISS Project Working Paper Series, 9805, Dec. 1998.

69 These data are based on countrywide hospital admissions as recorded by the Annual Health Bulletins published by the Ministry of Health. The in-patient data from private sector hospitals was not available, but these account for only a very small proportion of the total (less than 5 percent).

70 Since the bulk of the increase in vehicle emissions is in Colombo, but the health statistics are for the country as a whole, one may expect (as suggested by Figure 4.1) the former to increase faster than the latter. There is also very likely a lag effect.

71 Ninety-four percent of general practitioners (GPs) interviewed noted sharply increased visits for problems of the upper respiratory tract over the past few years, not explainable by other specific causes (Chandrasiri and Jayasinghe, *op. cit.*, Table 13). However, there remains the question of the extent to which these opinions adequately take into account the actual incidence of smoking. We have no data for Sri Lanka, but smoking rates have increased sharply in many other Asian countries.

Table 4.2: Vehicular particulate emissions and hospital admissions/deaths from respiratory diseases

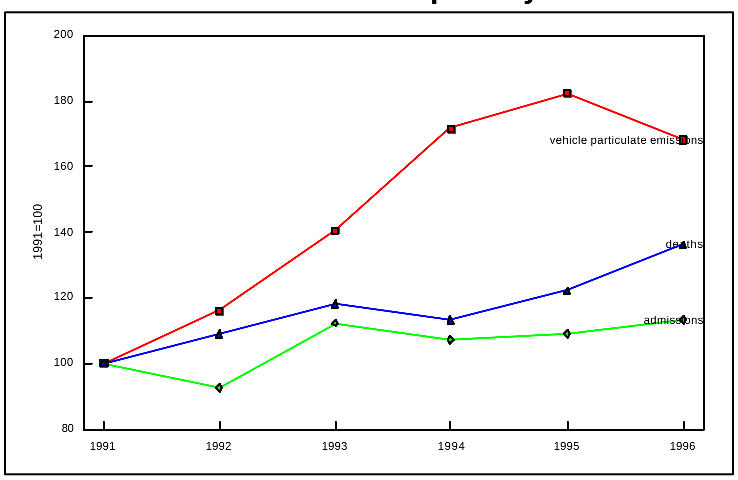
	Vehicular particulate emissions	*Hospital admissions rate (1)*	*Hospital death rate (2)*
1991	435	1435	1217
1992	504	1326	1326
1993	612	1609	1435
1994	746	1539	1379
1995	793	1561	1488
1996	731	1626	1657

(1) Admissions for diseases of the respiratory system (excluding URT diseases, pneumonia, broncho-pneumonia, and influenza), per 100,000 population.

(2) Hospital deaths from the same causes, per 1,000 population.

Source: Chandrasiri and Jayasinghe, *Health Effects of Vehicular Emissions in Colombo, op. cit*., Table 16.

Figure 4.4: Vehicular particulate emissions and hospital admissions/deaths from respiratory diseases



Source: Chandrasiri and Jayasinghe, Health Effects of Vehicular Emissions in Colombo, op.cit., Table 16

These assertions appear to be confirmed by a study of individuals exposed to high emissions levels—trishaw drivers, traffic wardens, and traffic police officers. Controls were matched for age, sex, and social class. Each interviewee was asked about the incidence of symptoms related to respiratory problems (sore throat, wheezing, coughing, shortness of breath, headache and eye pain/irritation, etc.) experienced over the past month, and since starting their occupation.[72] The results (Table 4.3) show that the extent of such complaints in these occupations is significantly higher than that of the control groups.

Table 4.3: Incidence of symptoms/diseases during the last month

	Trishaw drivers n = 50		*Traffic police officers n = 25*		*Traffic wardens n = 25*	
	Test	*Control*	*Test*	*Control*	*Test*	*Control*
Sore throat	6 (12%)	0	2 (8%)	0	2 (8%)	0
Fever	3 (6%)	1 (2%)	3 (12%)	1 (4%)	2 (8%)	1 (4%)
Asthma	0	0	0	0	0	0
Chest pain	0	0	1 (4%)	0	0	0
Shortness of breath	0	0	2(8%)	0	1 (4%)	0
Cough	11 (22%)	0	13 (52%)	0	3 (12%)	0
Sneezing	1 (2%)	0	1 (4%)	0	0	0
Backache	0	0	7 (28%)	0	1 (4%)	0
Pain in upper limb	2 (4%)	0	3 (12%)	0	0	0
Pain in lower limb	0	0	5 (20%)	0	0	0
Abdominal pain	2 (4%)	0	1 (4%)	0	2 (8%)	0
Dizziness	0	0	1 (4%)	0	0	0
Headache	7 (14%)	0	5 (20%)	0	1 (4%)	0
Eye pain/irritation	6 (12%)	0	1 (4%)	0	2 (8%)	0

Source: Chandrasiri and Jayasinghe, Health Effects of Vehicular Emissions in Colombo, op.cit., Appendix 5

There are a number of potential objections to this study (which are again noted by the authors).[73] Most importantly, notwithstanding the correlation in the data, *causation* is far from being established, and individuals' judgments as to what is the cause of their health problems require care.[74] However, when combined with the hospital admissions and death rate statistics, and additional surveys of patients visiting general practitioners working in Colombo, the totality of the evidence does suggest at least some linkages beyond mere correlation.

Another study analyzed hospital admissions of children for asthma attacks, and found significant correlation between the highest daily rates of wheezing requiring immediate

---

72 Information about smoking and alcohol consumption was available only for trishaw drivers—among whom the incidence of smoking (44 percent) was *lower* than the control group (68 percent), so smoking does not explain the much higher rates of complaint.

73 Small sample size, no information on smoking or alcohol consumption for the traffic policemen, etc.

74 In a recent opinion poll in London, 60 percent of respondents cited poor air quality as having the most effect on their health—compared to 27 percent who cited dirty streets (litter, dog droppings); 26 percent who cited smoking; and 14 percent who cited insufficient exercise (Glaister et al., *Transport and Health in London, op.cit.* p.13).

nebulization and the highest daily maximum one-hour averages of SO_2 and NOx (and similar correlation for the minimum rates).[75] However, the relationship between asthma and air pollution is controversial: the U.K. Committee on the Medical effects of Air Pollution (CONEAP)[76] notes

> *"as regards the initiation of asthma, most of the available evidence does not support a causative role for outdoor air pollution . . . factors other than air pollution are influential with regard to the initiation and provocation of asthma [other than the possible effects of biological pollutants such as pollen and fungal spores]"*[77]

4.3 Local damage valuations

In this report we use the benefit-transfer method of damage valuation, whose basis is the extrapolation to Sri Lanka of valuations estimated elsewhere. While there is little doubt that such an approach has its shortcomings,[78] and that country-specific damage valuations would be far preferable, where the latter do not exist there is little choice but to use the former.[79] Indeed,

---

75 Sennanayake, M. P., Samarakoddy, R.P., et al., *Is Colombo Choking its Children: A Case-Control Analysis of Hospital Attendance and Air Pollution*, National Building Research Organisation and Faculty of Medicine, University of Colombo, 1999.

76 U.K. Committee on the Medical Effects of Air Pollution, Department of Health, *Quantification of the Effects of Air Pollution on Health in the U.K.*, 1998.

77 Indeed, in London, between 1976 and 1997, while asthma increased by 300 percent, emissions of air pollutants over the same period *decreased* by 180 percent (Glaister et al., *Transport and Health in London, op.cit*., p.44).

78 A. M. Freeman (*Valuation of Environmental Health Damages in Developing Countries: Some Observations*, EEPSEA Special Paper, Biannual Workshop of the Economy and Environment Programme of Southeast Asia, Bangkok, 2000) lists the main issues as follows: 1) if pollution levels are higher in the developing country than in the country that is the source of the dose-response function, then the transfer involves extrapolation that is outside the range of the data; 2) the evidence is that the elderly are more sensitive to the life-shortening of particulate matter .. . .therefore in developing countries with a younger age structure there may be an overestimate on premature mortality; 3) the amount of time spent outdoors may be different (and lead to an underestimate in tropical countries where individuals spend more of their time outside the home).

79 The potential issues involved in the benefit transfer method have been extensively discussed elsewhere (see e.g. World Bank, 1994, in the case of the Bangkok study). The consensus view in the literature is that it is likely that U.S.-based estimates of the dose-response functions are *conservative* when applied to developing countries. For example, to the extent that people breath more polluted air per period in Colombo than in America because they spend more time outdoors, the U.S. dose response function would underestimate the health effect. Given that that most individuals in Colombo spend a much higher proportion of the day on streets than do most Americans, and that ventilation in urban residences in Colombo is much greater than in air conditioned U.S. houses (or tightly insulated U.S. houses in winter), it is likely that a Colombo resident's exposure to ambient (outdoor) concentrations is much greater (and that exposure to *indoor* sources is lower) than that which determines dose-response in U.S. epidemiological studies.

the approach has been used in a number of recent developing country studies:[80] it has also been used in Sri Lanka (in a study of the impacts of the 1996 power shortage,[81]and in the Environmental Impact Assessment of the Colombo-Katunayake Expressway).[82] Provided the limitations are recognized, the method can provide useful indicative valuations of likely damage valuations.[83]

Particulates, SO_2 and NOx

The damages related to these three pollutants have been studied and monetized in the United States and Europe for some time, particularly for power sector emissions. In the early 1990s a number of U.S. Power Regulatory Commissions required these damage costs to be considered in utility capacity expansion decisions. The benefit-transfer method as presented by the Asian Development Bank (ADB)[84] is based on such studies, and requires the following steps:

1. Specify the base year unit damage values (in US$/ton per 1,000 persons). For this purpose ADB uses the study by Rowe et al. for New York State.[85] The corresponding values are shown in Table 4.5
2. Adjust the price levels to the year 2000 using U.S. GDP growth.

The Bangkok study also notes a number of other reasons why U.S.-based dose-response functions are likely to be conservative, including that the average health status in a developing country is likely to be less (and therefore individuals more susceptible to pollution-induced diseases), and that lower incomes limit the more costly avoidance options available in the U.S..

80 For example, several recent studies of energy sector policies and projects in China have used this approach (for application to an assessment of renewable energy generation, see *Promoting Renewable Energy in China: An Economic Analysis of a Mandated Market Share Policy,* World Bank, April 2001; for an application to a power transmission project, see “Yunnan Dachaoshan Power Transmission Project,” in Abeygunawardena et al., *Environment and Economics in Project Preparation: Ten Asian Cases,* Asian Development Bank, 1999).

81 M. Munasinghe, et al., *Linkages between Economic Policies and the Environment in Sri Lanka*, Lanka International Forum on Environment and Sustainable Development, Working Paper Series, No.1, Colombo, December 1998.

82 Sri Lanka Road Development Authority, *Environmental Impact Assessment Report, Colombo-Katunayake Expressway*, June 1997 (hereinafter cited as CKE-EIS).

83 Thus we are mindful of the admonitions of Freeman, *op.cit*.: “ *. . . analysts should be careful to discuss the issues raised here, properly qualify their results, and be honest about the uncertainties introduced by this practice [of the benefit transfer method].”*

84 Abeygunawardena et al., *Environment and Economics in Project Preparation: Ten Asian Cases*, Asian Development Bank, 1999

85 R. D. Rowe, et al., *The New York Electricity Externality Study*, Oceana Publications, Dobbs Ferry, N.Y., 1995.

3. Multiply the values by the ratio of per capita GDP. In 2000, the per capita GDP in Sri Lanka, adjusted for purchase power parity (PPP)[86], is $3,900; that of the U.S. is $34,000[87]
4. Multiply the values by the estimated population resident within each radius.
5. For future years, adjust by the estimated population growth rate (in each radius) and GDP growth in each radius.

Table 4.4: Damage estimates, 1992 US$/per ton/per 1,000persons

	Local (within 30km)		*Regional (within 30-80 km)*		*Distant (80-500km)*	
	Low	*High*	*Low*	*High*	*Low*	*High*
TSP	0.20	0.30	0.10	0.30	0.04	0.08
SO_2	0.04	0.08	0.02	0.04	0.01	0.02
NOx	0.06	0.08	0.04	0.06	0.01	0.02

The calculations required for steps 2–5, and the values used in this study, are shown in Table 4.5.[88]

86 In this report we use a PPP adjustment factor of 4.56 (based on the data tables in the World Resources 1998-1999, which shows 1995 per capita GDP of $720 at the official exchange rate, $3,290 at PPP).

87 We note some significant errors in the application of the method in the CKE-EIS, which used U.K. damage values as a basis. The ratio of per capita GNP is based on a 1993 estimate of the per capita GNP of Sri Lanka of $600, and that in the U.K. of $2,210. In fact, the 1993 per capita GNP of the U.K. was $18,060 (World Bank, World Tables 1995, Washington, D.C., p. 701). Consequently the calculated damage estimate for Sri Lanka (e.g., Rs 1.5/gram, based on a U.K. value of Rs 4.5/gram, is significantly overstated: if we apply the actual ratio, the value would be Rs 0.15/gm. Even if this figure were adjusted for PPP, the correct value would be 4.57 x 0.15 = Rs 0.68/gm, i.e., *half* the value used by the EIS.

88 There has not been a comprehensive population census for two decades, and official figures are based on small household surveys, which provide little or no information on migration at the district level. The official population annual growth figures for 1998/1999 are 1.26 percent for Colombo city, 1.4 percent for the Colombo metropolitan, and 1.5 percent for the balance of the Island, or 1.4 percent p.a. nationally. However, these are based only on birth and death rates, and do not take into account migration, which accounts for a significant proportion of the growth in Colombo, and for which an additional 2.5 percent per year may well be quite conservative.

Again, comparisons with the 1994 study of congestion costs in Bangkok (World Bank, 1994) are instructive: annual population growth in Bangkok was estimated at 2.2 percent, compared to 1.8 percent for Thailand as a whole (though, as in the case of Sri Lankan data, it is unclear whether these (official) estimates account for natural growth only, or whether they include net migration from rural areas).

Table 4.5: Estimated damage values (using the ADB benefit-transfer approach)

	Local		*Regional*		*Distant*		*Total*	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
1992$/tonUS/1,000persons								
TSP	0.2	0.3	0.1	0.3	0.04	0.08		
SO_2	0.04	0.08	0.02	0.04	0.01	0.02		
NOx	0.06	0.08	0.04	0.06	0.01	0.02		
2000$/tonUS/1,000 persons								
TSP	0.25	0.38	0.13	0.38	0.05	0.10		
SO_2	0.05	0.10	0.03	0.05	0.01	0.03		
NOx	0.08	0.10	0.05	0.08	0.01	0.03		
Sri Lanka 2000$/ton/1,000persons								
TSP	0.0368	0.0551	0.0094	0.0281	0.0030	0.0059		
SO_2	0.0074	0.0147	0.0019	0.0037	0.0007	0.0015		
NOx	0.0110	0.0147	0.0037	0.0056	0.0007	0.0015		
Sri Lanka 2000$/ton								
TSP	180	270	52	157	25	50	258	478
SO_2	36	72	10	21	6	13	53	106
NOx	54	72	21	31	6	13	81	116
Sri Lanka 2020$/ton								
TSP	1365	2047	215	644	44	87	1623	2779
SO_2	273	546	43	86	11	22	327	654
NOx	409	546	86	129	11	22	506	697
Assumptions								
U.S. GDP growth rate	0.03	0.03	0.03	0.03	0.03	0.03		
Sri Lanka 2000GDP/capita (PPP)	4933	4933	2513	2513	1996	1996		
Sri Lanka GDP growth rate	6.4%	6.4%	5.2%	5.2%	3.1%	3.1%		
Population growth	4.0%	4.0%	2.0%	2.0%	-0.3%	-0.3%		
U.S. 2000 GDP/capita	34000	34000	34000	34000	34000	34000		
Sri Lanka 2000 population	4900	4900	5600	5600	8450	8450		
Sri Lanka 2020 GDP/capita	17059	17059	6926	6926	3676	3676		

The valuations derived by Munasinghe et al. (1996) in their evaluation of the impacts of the 1996 power crisis are shown in Table 4.6.[89] Based on more recent studies, discussed below, we believe these significantly underestimate the damages from vehicular sources.

[89] These estimates are based on the classic study by Pace University, *Environmental Costs of Electricity*, Centre for Environmental Legal Studies, Oceana Publications, New York, 1990, and reflect average values for the United States. The Pace estimates suffer from the deficiency that they do not expressly take into account population densities, and, obviously, are applicable primarily to power sector emissions.

Table 4.6: Damage valuations ($/ton)

	Source document (1995)	*Adjusted to 2000 (1)*
NOx	51.8	334
TSP	75	483
SO_2	128	825

Source: Munasinghe et al., *op.cit*, Annex V
(1) Values given in the source document are updated to 2000 (adjusted for inflation and converted to PPP).

A study by the University of Moratuwa[90] also used these damage values to estimate as Rs/litre for different vehicle types.[91] As indicated in Table 4.7, these show very little variation across vehicle types when expressed in Rs/litre: when converted to Rs/km traveled, however, the environmental damages show large variation, as one might expect.

Table 4.7: Damage valuations: University of Moratuwa (1999)

	Rs/litre (1)	*Rs/Vehicle –km (2)*
Car	0.57	0.06
Motorcycle	0.56	0.01
3-wheeler	0.62	0.02
Van	0.65	0.07
Medium bus	0.71	0.14
Large bus	0.79	0.20
Medium lorry	0.71	0.14
Large lorry	0.79	0.23

(1) University of Moratuwa (1999), Table B4-2.
(2) Based on average fuel efficiencies given in Table 2.2.

Chandrasiri and Jayasinghe estimated the value of health damages attributable to particulates in Colombo at between Rs 67-160 million/year, based on limited data on highly exposed occupational groups (traffic wardens, trishaw drivers, traffic policemen).[92] A World Bank assessment calculated the health damages in Colombo attributable to PM-10 at $US30 million, based on an average ambient concentration of 40-50 ?g/m^3.[93] However, it is unclear

[90] University of Moratuwa, *Assessments of Public Investments in the Transport Sector*, Moratuwa, 1999.

[91] Source document values as given in Table 4.7, but updated to 1999 rather than 2000 (and without adjustment for PPP): $262/ton for particulates, $447/ton for SOx and $180/ton for NOx; and $15/ton for CO; *Ibid*, Table B4-1.

[92] S. Chandrasiri and S. Jayasinghe, *Health Effects of Vehicular Emissions in Colombo, op.cit.*, Table 18.

[93] World Bank, *Comments on the Proposed Fuel Quality and Vehicle Emission Standards*, 2000.

from what basis either the average exposure, or the unit health damage, was derived.

The six cities study

Another recent source of damage valuations is the "Six Cities Study,"[94] whose results permit the benefit transfer method for estimating health effects to be applied to vehicular emissions. Since the majority of health effect valuation studies in the United States and Europe relate to power sector emissions (typically from tall stacks in relatively remote locations), there are problems in applying the benefit transfer method to vehicular emissions—emitted at ground level in generally densely populated areas. Based on a study of six cities (Mumbai, Shanghai, Bangkok, Krakow, Santiago, and Manila), this report derives representative damage cost estimates for vehicular emissions of PM_{10}, SO_2, and NOx, which for the four Asian cities are 30-50 times greater per ton than for power plant emissions from high stacks (and even greater for Krakow and Santiago) (Table 4.8).

Table 4.8: Marginal damage costs ($US/ton)

	Power Plant (high stack) [1]	*Large industry (medium stack) [2]*	*Small boilers and vehicular emissions [3]*	*Ratio vehicular: power plant [4]=[3]/[1]*
Mumbai				
PM10	234	1077	7963	34
SO_2	51	236	1747	34
NOx	20	93	668	33
Shanghai				
PM10	161	502	5828	36
SO_2	36	112	1295	36
NOx	11	33	385	35
Manila				
PM10	345	1828	17942	52
SO_2	61	324	3183	52
NOx	24	129	1265	52
Bangkok				
PM10	828	2357	28722	34
SO_2	147	417	5087	34
NOx	57	162	1971	34
Krakow				
PM10	97	682	13255	136
SO_2	18	130	2522	140
NOx	4	29	560	140
Santiago				
PM10	692	4783	88551	128
SO_2	132	911	16864	127

94 K. Lvovsky, G. Hughes, D. Maddison, B. Ostrp and D. Pearce, *Environmental Costs of Fossil Fuels, A Rapid Assessment Method with Application to Six Cities*, World Bank, Environment Department, Paper 78, October 2000.

NOx	35	240	4445	127

Source: K. Lvovsky, G. Hughes, D. Maddison, B. Ostrp, and D. Pearce, *Environmental Costs of Fossil Fuels, A Rapid Assessment Method with Application to Six Cities*, World Bank, Environment Department, Paper 78, October 2000; Table 1.5 (pg.16).

Mindful of the cautions emphasized by the authors of the six cities study, the indicative marginal unit values shown in Table 4.9 still provide useful guidance.

Table 4.9: Unit health damages, US$/ton per 1,000,000 population per US$1,000 of per capita income

One-ton change in emission of: PM10	*High stack (power plants)*	*Medium Stack (large industry)*	*Low stack (boilers and vehicles)*
Range for six cities	20-54	63-348	736-6435
Average	42	214	3114
SO_2			
Range for six cities	3-8	10-56	121-1037
Average	6	33	487
NOx			
Range for six cities	1-3	3-13	29-236
Average	2	9	123

Source: K. Lvovsky et al., Environmental Costs of Fossil Fuels, op.cit., Table 6-3 (pg. 65).

For example, if we apply the *lowest* of the values in the ranges of Table 4.9 to Colombo (with a population of 4.9 million, GDP/capita $4,933), then the values compute to $17,790/ton for PM-10, $2,924/ton for SO_2, and $700/ton for NOx. These are comparable to the values for Manila.

Lead

There are no systematic health damage studies of lead in Sri Lanka.[95] However, there is a vast international literature on the subject, too extensive for detailed review here.[96] In the United States, the cost-benefit ratio of eliminating lead in gasoline was estimated as being in excess of 10;[97] one estimate of the health benefits suggests that reducing the U.S. population's

95 Neither the Chandrasiri and Jayasinghe nor Sennanayake et al. studies included discussion of lead in gasoline (though the former does contain the data on ambient lead measurements taken in 1992/1993).

96 For a good review, see e.g. M. Lovei, *Phasing out Lead from Gasoline*, World Bank Technical Paper 397, Washington, D.C., 1998

97 USEPA, 1985. *Costs and Benefits of Reducing Lead in Gasoline; Final Regulatory Impact Estimate*, Office of Policy Analysis, Washington, D.C. EPA-230-05-85-006.

blood level by 1 ug/dl was $18.9 billion ($1,989) per year.[98] A recent World Bank review of this literature notes that *'the magnitude of these benefits suggests that phasing out lead from gasoline is likely to produce substantial benefits in other countries as well'*[99], a conclusion that is evidently shared by most governments in Asia, who started the process of phasing out lead in gasoline in the 1990's.

Table 4.10 shows the results of the one study in Sri Lanka that measured lead levels in blood,[100] with comparisons from elsewhere (though these need to be used with a great deal of caution, given differences in sample populations, age groups, year of sampling, and so on).[101] Nevertheless, despite these caveats, the high levels of lead in the most exposed groups compared to the control population are evident,[102] although the general levels do appear to be less than half of those in other large Asian Cities.[103]

Mindful of the hazards of extrapolation across countries, we may nevertheless make an order of magnitude estimate for the corresponding health damage in Sri Lanka. If we scale the U.S. estimate by ratio of population and ratio of PPP-adjusted GNP/capita, then a reduction of average concentrations of lead in blood of 1 ?g/dl converts to Rs 19 billion (for the year 2000), about 1.5 percent of GDP.[104] Given year-2000 gasoline consumption of 277 million litres/year, this translates to Rs 68.7/litre of gasoline. Even if this estimate were in error by an order of magnitude, the benefits of unleaded gasoline would still correspond to around Rs 7/litre (under the even more conservative assumption that elimination of all gasoline lead emissions would

98 J. Schwartz, "Societal Benefits of Reducing Lead Exposure," *Environmental Research*, 66, pp. 105-124, 1994. Given a 1989 GDP of around $6,800 billion, this represents 0.25 percent of GDP (which is a very high fraction, given that this represents the damage for just one pollutant!).

99 M. Lovei, *Phasing out Lead from Gasoline, op.cit*., p.6.

100 C. M. Awegoda, M. S.Perera and D. T. Mathhes, *An Assessment of Blood Lead Levels of the Population Exposed to Vehicle Emissions*, Sri Lanka Academy of Science, Abstracts, E2, 1994.

101 The problems of these estimates are discussed in A. M. Freeman, *Valuation of Environmental Health Damages in Developing Countries, Some Observations*, EEPSEA Special Paper, Biannual Workshop of the Economy and Environment Programme of Southeast Asia, Bangkok, Nov. 2000. Freeman expresses particular surprise at the low values for school children, which are evidently significantly lower than in other Asian cities.

102 Since these measurements were made, an additional group of highly exposed individuals may be noted, particularly in Colombo, namely the large numbers of police and army personnel on security duty, largely a roadside occupation. While it may be hoped that this is not a permanent feature of Colombo life, and while one may argue as to whether the incremental (occupational) health risk (compared to the much higher risk of death or injury from terrorists) qualifies as an externality of the transportation sector, it is very likely that the long-term health effects of these individuals' lead exposure are similar to those of the occupational groups that were included in the study.

103 According to the Clean Air 2000 Action plan, average amb ient levels of lead in 1992/1993 were assessed at 0.38 x 10-3 mg/m3 (8-hour avg) during the dry weather periods (*Clean Air 2000*, October 1992. p. 9).

104 i.e., US$17.152 million x (34000/856*4.56 (PPPadjust factor)) x 250/19.4 (population ratio)

reduce blood lead by only 1 ?g/dl).[105] Notwithstanding the uncertainties of this calculation, it does seem to confirm the general conclusion of the World Bank that "*phasing out lead is likely to produce substantial benefits.*"

Table 4.10: Average lead levels in blood

Sri Lanka (Colombo)	*Mean, ug/dL*
School children (4-5 years)	5
Motorcycle riders	12
Street vendors	13
3-wheeler drivers	15
Traffic police	53
Adult control group	9
Other Locations	
Bangkok	40
Manila	20
Jakarta	15

Source: International comparisons from M. Lovei, *Phasing out Lead in Gasoline, op.cit,* Figure 3.
Sri Lanka data from Arewgoda, et al., *An Assessment of Blood Levels, op.cit.*

Summary

We conclude this section with a comparison of the various relevant estimates in the literature, each converted to a year=2000 value for Colombo, shown in Table 4.11.[108] The values used in subsequent sections of this report are based on the Six Cities study.

---

105 Such a high externality value might well raise some doubts. But even higher orders of magnitude have been encountered in other countries: for example, in China, total environmental damages of air and water pollution were estimated at 8 percent of 1995 GDP (see World Bank, *China 2020: Clear Water, Blue Skies*, Washington, D.C., 1997).

106 i.e., US$17.152 million x (34000/856*4.56 (PPPadjust factor)) x 250/19.4 (population ratio)

107 Such a high externality value might well raise some doubts. But even higher orders of magnitude have been encountered in other countries: for example, in China, total environmental damages of air and water pollution were estimated at 8 percent of 1995 GDP (see World Bank, *China 2020: Clear Water, Blue Skies*, Washington, D.C., 1997).

108 Using the corrected values for the CKE study, based on the U.K. value of Rs 4.5/gram, translates to $56,250/ton. Unfortunately, no source is given in the CKE-EIS for this U.K. data point, which also seems unusually high (compared to most other estimates in the literature).

Table 4.11: Comparison of damage valuation estimates (in $/ton)

Basis	*Source*	*Adjusted to Colombo for 2000*
Particulates (1)		
Six Cities study, low value of range	See text: PM-10 as TSP	17,790 14,232
ADB benefit transfer method	Table 4.6	258-478
RDA, CKE environmental assessment	See text	8,500
LIFE	Table 4.7	483
University of Moratuwa		262
SO_2		
Six Cities study, low value of range	See text	2924
ADB benefit transfer method	Table 4.6	53-106
LIFE	Table 4.7	825
University of Moratuwa		447
NOx		
Six Cities study, low value of range	See text	700
ADB benefit transfer method	Table 4.6	506-697
LIFE	Table 4.7	334
University of Moratuwa		180

(1) Only the Six Cities study gives PM-10 health damage costs; the others are for total particulate matter.[109]

Finally, the following should be noted:

?? When the Six Cities study damages are converted to emissions *per ton of fuel* (Table 4.12), the relative importance of NOx to PM-10 increases by a factor of five, as shown in table 4.9,[110] but stays roughly the same for SO_2 (based on a sulphur content of 0.5 percent).

?? The LIFE, University of Moratuwa, and ADB benefit transfer estimates are based on damage estimates for power plant emissions, whose typically high stacks and remote locations result in lower population exposures than those arising from

[109] In the case of *ambient* air quality, the Six Cities study uses a PM10/TSP ratio of 0.55; however emissions of PM-10 are estimated, on average, to be 0.8 of the TSP emission factor for diesel vehicles, and 0.9 of the TSP emission factor for gasoline vehicles (Six Cities study, *op.cit.*, Annex A). The proportion of PM-10 in total TSP from typical power plant stacks is smaller, about 0.6.

[110] The calculations of Table 4.13 are based on average vehicle fleets of average maintenance and age. Obviously, for a poorly maintained bus, belching smoke, the ratios may well be different.

vehicular emissions. For this reason in the valuations of subsequent sections we use the higher values of the Six Cities study.

Table 4.12: Damages per ton of (diesel) fuel

	PM-10	*SO_2*	*NOx*
$ per ton of pollutant	17790	2924	700
Ratio	1	0.16	0.03
Ton pollutant/ton fuel (1)	.012	0.01	0.045
$ per ton of fuel	213	29	31.5
Ratio	1	0.14	0.15

Assumptions: PM-10: 12 kg/ton fuel (Six Cities study), hence 12*0.001=0.012. SOx: 0.5 percent sulphur by weight, hence 2 x 0.005 =0.01 ton SO_2/ton fuel. NOx: emission factor 40.5 kg NOx/ton (Six Cities study), hence 40.5*0.001 = 0.045 ton NOx per ton of fuel.[111]

We recognize that limiting the monetization to PM-10, SO_2, and NOx underestimates the total health damage. A recent study in the U.K.[112] provides some estimate of the relative damage costs: we see that of the total damage cost of 2.424 pence/km for urban diesel emissions, 70 percent is attributable to PM-10, and 82 percent to PM-10, SO_2, and NOx.[113]

111 This NOx emission factor of 0.045 is very close to the 0.0431 emission factor used for diesel buses in a recent study of Delhi (R. K. Bose and V. Srinivasachary, "Policies to Reduce Energy Use and Environmental Emissions in Delhi," *Energy Policy*, 23:3, pp. 1137-1150, 1997. However, the TSP factor used in the Delhi study is given as "0.00143 gms per gm of fuel," roughly ten times smaller than the Six Cities value.

112 S. Glaister, D. Graham and E. Hoskins, *Transport and Health in London: A* Report for the NHS executive, London, October 1999 (http://www.doh.gov.uk/london/transport.pdf)

113 Since unleaded petrol is no longer sold in London, lead does not appear in this table. The sulphur related impacts are low because the sulphur content of U.K. diesel fuel is less than 0.01 percent.

Table 4.13: Health damages in London (diesel vehicles)

	Pence/km	*% of total*
Particulates	1.692	70%
Sulphur dioxide	0.182	8%
NOx	0.113	5%
	1.987	82%
Sulphate aerosol	0.027	1%
Nitrate aerosol	0.219	9%
Ozone from NOx	0.098	4%
Ozone from VOC	0.041	2%
Benzene	0.052	2%
	2.424	100%

Source: Glaister, Graham and Hoslins, Transport and Health in London, op. cit., p.54.

5

Price Elasticities[114]

In this section we examine the influence of prices on the decisions of road users. A first set of questions concerns choices made at the time of vehicle purchase (and particularly on whether to buy a diesel- or gasoline-powered vehicle) –and is likely to be a function of the consumer's perceptions about the cost of operation (a matter, in turn, of expectations about the future price of different fuels at the pump), and first cost. The second set of questions concerns the aggregate response of all road users to changes in fuel prices at the pump. Rates of taxation play as much a role in shaping these decisions as world oil prices and cif prices of automobiles: as we noted in Section 3.1, tax rates on gasoline and diesel fuel are not only very different, but in the case of petrol, far exceed the cif cost (Table 3.3). Similarly, rates of customs and excise duty on vehicle imports show wide variations across different vehicle types, made more complex by provisions for exemptions and concessions to certain types of owners (which are frequently changed).[115]

5.1 Vehicle price elasticities

The demand for vehicles in Sri Lanka has been studied recently.[116] Vehicles are not manufactured in Sri Lanka,[117] so the entire demand is met by imports, of which only 25 percent are new vehicles. Today the typical passenger car import is a reconditioned Japanese vehicle two to three years old. Unfortunately, the available data are of poor quality, because such records as are kept by Sri Lanka Customs do not have the requisite detail on engine capacity, year of manufacture, etc.

---

[114] This section was prepared by S. Chandrasiri, University of Colombo.

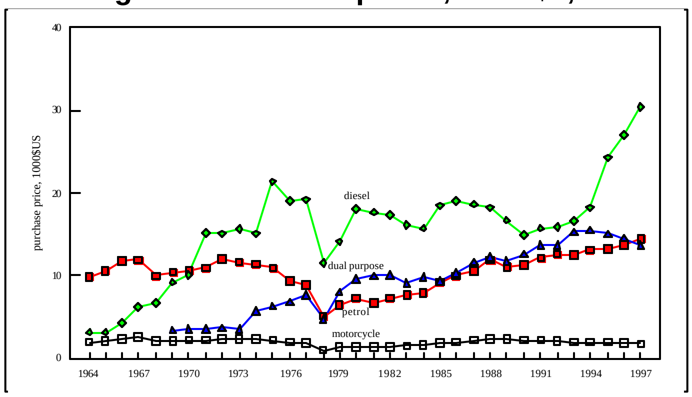
[115] These are noted by Chandrasiri, *Controlling Automotive Air Pollution*, *op.cit*., pg.10. For example, special privileges are extended to state corporations such as the Sri Lanka Transport Board (SLTB), formerly the state monopoly. Special permit schemes for public servants and politicians were terminated in 1994, then reintroduced in 1998, and again rescinded in March 2001.

[116] *Ibid*, p. 8-10.

[117] However, there are four companies (Dimo, Latec, Ceymo, and Ashok Leyland) that assemble trucks and busses in Sri Lanka from body and chassis kits imported from four major sources: U.K., Japan, India, and China.

In Figure 5.1 we show the average nominal price, ex-customs,[118] for the four main types of passenger vehicle, expressed in US$. Several points are worth noting:

Figure 5.1: Vehicle prices, in US$1,000



Source: Based on data from Sri Lanka Customs

?? By expressing prices in US$, most of the price variation reflects changes in taxation.[119]

?? The sharp decline in 1978 reflects the lowering of import duties at the time of liberalization of the economy.

?? The recent (since 1995) increase in the price of diesel vehicles—a reflection of the imposition of so-called "luxury taxes"—is largely cosmetic, for the number of diesel *passenger* cars actually sold is quite small (most of the growth being in "dual-purpose" vehicles),[120] and a significant proportion of those that are imported have benefited from special permits and exemptions.

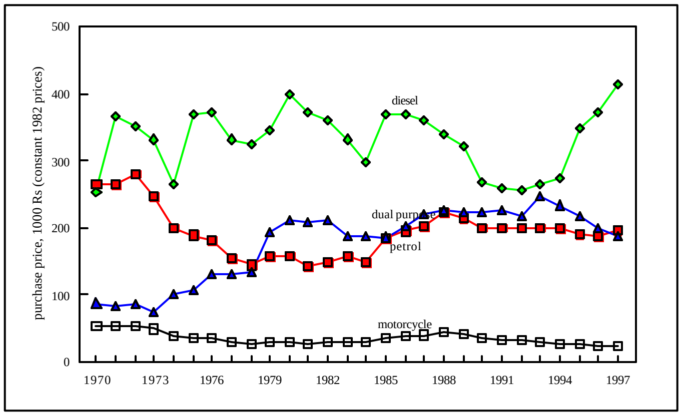
---

118 I.e., CIF plus all duties and taxes, but excluding dealer margins.

119 Nominal cif prices in US$ would of course have increased over this period, so the general trend would be expected to be upward.

120 In 2000, we estimate only some 20,000 diesel passenger cars in the fleet (Table 2.2), as opposed to 132,000 gasoline cars, and 186,000 diesel-powered dual-purpose vehicles.

Figure 5.2: Vehicle prices, in constant 1982 Rs



Source: Authors' estimates based on Sri Lanka Customs: Central Bank for GDP deflator (see Box 5.1)

In Table 5.1 we show a comparison of the taxes levied on diesel and petrol cars, using the same Toyota model differing only by type of engine. The tax burden for the diesel vehicle at the time of purchase is seen to be double that of the gasoline-powered car.

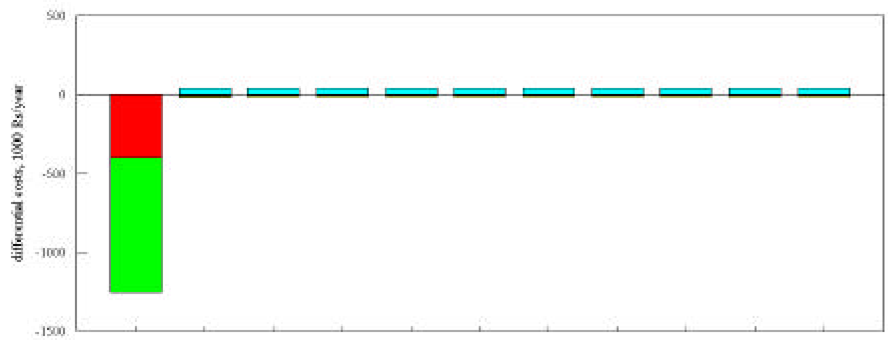
Table 5.1: Comparison of diesel and petrol vehicle price for the Toyota model RAV4

Cost in Rs	*Gasoline*	*Diesel*	*Difference: diesel less gasoline*
Costs at purchase			
CIF	1800000	2200000	400000
Import duty	267000	534000	267000
Defense levy	108489	217000	108511
Excise duty	254400	508800	254400
GST	198721	397400	198679
Stamp duty	21380	42800	21420
Total tax	850092	1700000	849908
Total CIF + tax	2650092	3900000	1249908
Tax [as percent of total]	32%	44%	12%
Annual taxes			
Registration	3500	6500	3000
Diesel tax		10000	10000
Luxury tax		50000	50000
Annual fuel cost			0
Km/year	15000	15000	0
Km/litre	10	10	0
Litres/year	1500	1500	0
Price/litre	50	21.5	-28.5
Annual fuel cost	75000	32250	-42750

Note: Imported as reconditioned, three-year-old vehicles. Luxury tax declines by Rs 10,000/year, reaching zero in the sixth year. Figures are tabulated for taxes and typical prices as of April 2001.

As indicated in Figure 5.3 the annual fuel saving is only Rs 42,750, and indeed at 15,000 km/year (roughly the annual average) the financial rate of return (FRR) is negative (at –10 percent): even at 50,000 km/year (as might be typical for a taxi), the FRR is only 10 percent which, given interest rates at 20 percent, is hardly attractive. While most individuals would be unlikely to make decisions based on such a calculation, it is clear why the (four-wheel) taxi fleet is almost entirely gasoline-powered (and subsequently converted to LPG).[121]

Figure 5.3: Differential costs, petrol v. diesel car



	0	1	2	3	4	5	6	7	8	9	10
cif	-400000										
tax	-849900										
registration		-3000	-3000	-3000	-3000	-3000	-3000	-3000	-3000	-3000	-3000
diesel-tax		-10000	-10000	-10000	-10000	-10000	-10000	-10000	-10000	-10000	-10000
luxury tax		-5000	-4000	-3000	-2000	-1000					
fuel savings		42750	42750	42750	42750	42750	42750	42750	42750	42750	42750
total	-1249900	24750	25750	26750	27750	28750	29750	29750	29750	29750	29750
IRR	-10%										

Based on the vehicle price series shown in Figure 5.2, Chandrasiri has estimated vehicle ownership elasticities using the model[122]

$$\boldsymbol{V} \text{ ? } \boldsymbol{aP}^{?} \text{ ? } ^{\boldsymbol{k}}\boldsymbol{U}^{?}\, \boldsymbol{Y} \qquad \text{Eq.[5.1]}$$

where *V*=number of vehicles/adult population
P=fuel price
? ?vehicle price
U=user charges (registration fees, etc)?
? ,***k***,? = elasticities, as estimated for each vehicle class as shown in Table 5.2
Y = per capita income

As shown in Table 5.2, in some cases statistically significant coefficients have the wrong sign. However, this can be explained by the highly distorted character of the market. For example, contrary to expectations, vehicle price variable is positive and significant for both diesel cars and lorries, but the data does not take into account the permit scheme for diesel cars and special duty concessions offered for certain types of diesel trucks. Similarly, positive

---

121 Though as we see below in Section 10.2, a large part of the taxi fleet has converted to LPG.

122 Chandrasiri, Controlling Automotive Air Pollution, op.cit., pp. 9-10, but with addition of the income variable.

coefficients of tax rates for petrol cars and dual-purpose vehicles are consistent with their ownership by the high income segment of the population (reflecting status and convenience, rather than price—factors hard to specify in an econometric model). The poor quality of the customs data made it difficult to fit alternative models,[123] and the indicated results are about the best that can presently be achieved.

Table 5.2: Vehicle elasticities

Type of vehicle	*Time coverage*	*Const*	*Fuel price* ***P***	*Vehicle price ? ?*	*Income* ***Y***	*Tax rates* ***U***	$\bar{R}^2$
Petrol cars	1968-2000	6.08	.013	**-.125**	**.433**	**.334**	.822
		(9.94)	(0.300)	(2.04)	(4.31)	(5.40)	
Diesel cars	1978-2000	2.42	**-.508**	**.454**	**.300**	**-.524**	.977
		(2.97)	(3.73)	(2.30)	(2.40)	(4.79)	
Diesel buses	1970-2000	4.75	.142	**-.161**	**.403**	**-.148**	.931
		(9.69)	(1.18)	(1.54)	(5.41)	(1.58)	
Diesel lorries	1968-2000	5.34	**-.214**	**.172**	**.278**	**-.280**	.972
		(10.78)	(2.83)	(2.10)	(3.51)	(3.33)	
Diesel – dual-purpose	1968-2000	-29.59	-.281	-.631	**3.96**	**.975**	.958
		94.58)	(0.489)	(.847)	(3.93)	(1.40)	
Motorcycles	1978-2000	-1.24	**-.516**	**.770**	**.920**	-.176	.969
		(0.431)	(1.88)	(2.65)	(1.83)	(0.467)	

Ordinary least squares (OLS) estimates. **Boldface**=statistically significant
T-values in parentheses.

5.2 Aggregate fuel demand

Several estimates of Sri Lanka transportation fuel price elasticities are described in the literature (Table 5.3).[124] However, many of the earlier estimates are limited to the period 1970-1985, and do not properly capture the major changes in road transport consequent to liberalization of the economy in 1977. The estimates by Meier et al.[125] do include the early years

---

[123] Each vehicle category covers a very wide range of engine capacity, make, condition of vehicle, age, and features such as air conditioning.

[124] In all cases, except where noted, the dependent variable is consumption per vehicle. We note that several U.S. studies use consumption *per driver* (see, e.g., D. Greene, "Vehicle Use and Fuel Economy: How Big is the Rebound Effect?" *Energy Journal*, 13:1, pp. 117-143, 1992).

[125] P. Meier, M. Munasinghe and T. Siyambalapitiya, "Energy Sector Policy and the Environment: A Case Study of Sri Lanka," World Bank Environment Department, Washington, D.C., 1993.

of liberalization, but their time series is still relatively short and extends only to 1991.[126]

Table 5.3: Estimates of own-price elasticity

	Time series	*Petrol (gasoline)*	*Diesel*
Sri Lanka			
deSilva (1)	1970-1985	-0.55	-1.21
Samaraweera (2)	1970-1985	-0.387	-0.26
Ranasinghe (3)	1970-1985	-0.508	-0.034
Meier et al. *(4)*	1973-1991	-1.14 (long-run)	
		-0.334 (short-run)	
McRae (5)	1973-1987	-0.337	
Jayaweera (8)		-0.163 (long run)	-0.339 (long run)
		-0.115 (short run)	-0.154 (short run)
Other countries			
Philippines (6)	1973-1987	-.391	
Thailand (6)	1973-1987	-.304	
Malaysia (6)	1973-1987	-.125	
S.Korea (6)	1973-1987	-.496	
S. Korea (5)	1973-1997	-0.866 (long-run)(*)	
		-0.385 (short-run)(*)	
Indonesia (6)	1973-1987	-.197	
India (6)	1973-1987	-.321	
Taiwan (6)	1973-1987	+0.024	
Taiwan (7)	1954-1985	-1.362 (long-run)	
		-0.245 (short run)	
Taiwan (5)	1973-1992	-0.519 (long-run)*	
		-0.124 (short-run)*	

(*) Demand for gasoline and diesel taken together.

(1) A. P. D. S. de Silva, "Impact of Energy Price Changes on Transport," in E. N. Wijeratne, ed., *Energy Pricing Options in Sri Lanka,* ILO, 1989.

(2) C. P. Samaraweera, "Determinants of Petroleum Demand in Sri Lanka," in E. N. Wijeratne, *op.cit*.

(3) A. P. Ranasinghe, "Impact of Fuel Price Changes on Transport," in E. N. Wijeratne, ed., *op.cit.*

(4) P.Meier, M. Munasinghe and T.Siyambalapitiya, "Energy Sector Policy and Environment: A Case Study of Sri Lanka," World Bank Environment Department, Washington D.C. 1993.

(5) S. Banaszak, S., U. Chakravorty and P. Leung, "Demand for Ground Transportation Fuel and Pricing Policy in Asian Tigers: A Comparative Study of Korea and Taiwan," *Energy Journal*, 20:2, pp.145-165, 1999.

(6) R. McRae, "Gasoline Demand in Developing Asian Countries," *Energy Journal*, 15:1, 143, 1994.

(7) C.Garbacz, "Gasoline, Diesel and Motor Fuel Demand in Taiwan," *Energy Journal*, 10:2, 143, 1989.

(8) D. Jayaweera, *Effective Steps Towards Traffic Calming in Developing Countries: A Case Study for Metropolitan Region of Colombo in Sri Lanka*, Ph.D. Thesis, MIT, Nov.1999.

[126] However, this study used the so-called vehicle use lagged endogenous model, which models demand as the autoregressive function $Q_t=f(Q_{t-1}, P, Y, \ldots)$, and which allows separate estimation of long and short run elasticities.

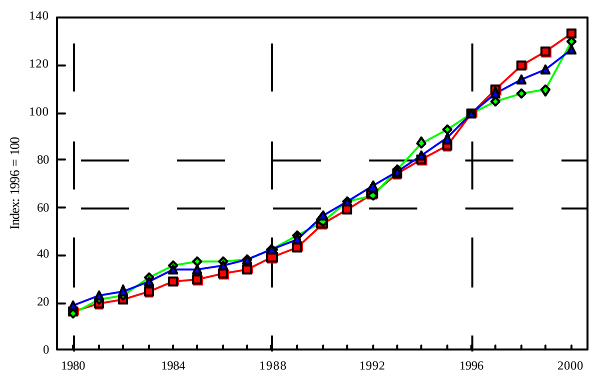
Box 5.1: Price indices

In Sri Lanka inflation is generally measured by four different price indicators: the Colombo ConsumerPrice Index (CCPI);[127] the Greater Colombo Price Index (GCPI); the Wholesale Price Index (WPI); and the Implicit Gross Domestic Price Deflator (GDPD). Of these four indicators the CCPI, which is computed by the Department of Census and Statistics, is considered as the official price index.

Colombo Consumer Price Index(CCPI)

The GCPI commenced in 1989 (with base January to June 1989 = 100). In relative terms, the GCPI has a much wider coverage than CCPI in terms of geographic area and number of commodity groups. [128] The WPI, commenced in 1974, is a measure of price movement at the primary marketing level. It has a much bigger commodity coverage and is a good indicator of cost of production. It also places more weight on internationally traded commodities and is therefore more volatile than the consumer price indices. The fourth indicator, GDPD, has the widest coverage of all indicators as it includes all goods and services of domestic origin weighted by their respective contribution to total value added.

Comparison of indices



Specification problems abound. In the case of gasoline demand studies, definition of the independent variable as consumption per vehicle runs into the problem of rapid changes in the

127 The CCPI is computed on a monthly basis with weights derived from the average expenditure patterns of 455 working-class households as observed in the Colombo Family Budget Survey 1949/50. The base is 1952=100. The CCPI has been subject to a wide range of criticisms both on theoretical and empirical grounds. The CCPI in Sri Lanka is heavily influenced by administered prices of various items included in the basket. Accordingly, the Central Bank of Sri Lanka has argued that in order to isolate "core inflation" from "headline inflation" as reflected in the original price indices, the effect of administered prices needs to be removed from the basket of the CCPI and the price change in the residual basket needs to be treated as a measure of inflation.

128 The GCCPI has the following percentage weights: Food and Drinks 69.3; Liquor, Tobacco, and Betel and Areca Nuts 3.8; Housing 8.9; Fuel and Light 5.4; Clothing and Footwear 2.8; Personal Care and Health Services, Household Goods and Services 4.9; Transport and Communication 2.8; Miscellaneous 2.1. The weights are based on the Labor Force and Socioeconomic Survey of 1985/86 revalued at January-June 1989 prices.

vehicle mix, notably the significant growth in motorcycles (whose demand per vehicle is a small fraction of that of automobiles).[129] Some studies add a variable for vehicles per capita, whose elasticity is almost always strongly negative:[130] in McRae's Sri Lanka estimates, the demand elasticity with respect to vehicle/capita has a value of -0.504. Among past Sri Lanka studies, only Meier et al. includes a variable for fraction of motorcycles in the vehicle mix (with a corresponding elasticity of -0.17).

Among the various studies of Asian countries in the literature, the most rigorously specified is the study by Garbacz for Taiwan,[131] who estimated the model

$$AUTO \, ? \, a_1 PGAS^{a_2} PBUS^{a_3} INCOME^{a_4} AUTO^{a_5} MCYCLE^{a_6}$$

$$MCYCLE \, ? \, b_1 PGAS^{b_2} PBUS^{b_3} INCOME^{b_4} AUTO^{b_5} MCYCLE^{b_6}$$

$$GAS(t) \, ? \, c_1 GAS(t \, ? \, 1)^{c_2} PGAS^{c_3} INCOME^{c_4} AUTO^{c_5} MCYCLE^{c_6} TAXI^{c_7}$$

where ***AUTO,MCYCLE*** = number of automobiles and motorcycles (per capita)

PGAS=gasoline price (per litre)

GAS(t)=gasoline consumption per capita (at time t)

TAXI=number of taxicabs per capita

INCOME =personal disposable income per capita

PBUS=bus price per passenger km

However, even this study was unable to include vehicle price variables—though it is worth noting that this study of Taiwan, and the Sri Lanka study by Meier et al., show similar results for both long- and short-run elasticities (see Table 5.3), and both are consistent with the value of –1.05 for long-run elasticity reported by Dahl and Sterner as the average value across developing countries.[132]

Since gasoline and diesel are partial substitutes, rigorous estimation of price effects need to take into account the relevant cross-price elasticities. Therefore price and income elasticities must be estimated simultaneously. There are two ways of doing this: (1) combine gasoline and diesel consumption, and use a price variable that is the weighted diesel and gasoline price; or (2) simultaneous estimation of the two equations.

---

[129] The 1994 study by McRae, *op.cit*., for example, which examined aggregate gasoline demand in several developing Asian countries, does not once mention the words motorcycles or three-wheelers!

[130] McRae, *op.cit*., notes *" . . more vehicles per capita are expected to reduce utilization, so the expected sign for the variable is negative."*

[131] C. Garbacz, "Gasoline, Diesel and Motorfuel Demand in Taiwan," *Energy Journal*, 10:2, 153, 1989.

[132] C. Dahl and J. Sterner, "Analysing Gasoline Demand Elasticities: A Survey," *Energy Policy*, July, pp. 203-210, 1991.

The former approach was taken by Banaszak for Taiwan and S. Korea;[133] the latter was taken by Chandrasiri for Sri Lanka,[134] who applied the SURE method[135] to the simultaneous equations:

$$\boldsymbol{Q_p} \ ? \ \boldsymbol{k_1 Y^{a_p} P_p^{ß_p} P_d^{?}} \qquad \text{Eq.[5.2]}$$

$$\boldsymbol{Q_d} \ ? \ \boldsymbol{k_2 Y^{a_d} P_d^{ß_d} P_p^{?}}$$

where $\boldsymbol{Q}_{\mathrm{d}}$ = diesel demand (sales/#vehicles)

$\boldsymbol{Q_p}$ = gasoline demand (sales/#vehicles)

$\boldsymbol{Y}$ = per capita GDP (at constant prices)

$?_p$ = own-price elasticity for petrol

$?_d$ = own-price elasticity for diesel

$?_p$ = income elasticity, petrol

$?_d$ = income elasticity, diesel demand

? = diesel demand, cross-price elasticity gasoline price

? = gasoline demand, cross-price elasticity diesel price

$\boldsymbol{k_1}$, $\boldsymbol{k_2}$ = constants

The results – estimated for the time series 1960–1997—are given in Table 5.4 below.

Table 5.4: Elasticity estimates

Type of fuel	*k*	*Income elasticities*	*Own-price elasticities*	*Cross-price elasticities*	$\overline{R}^2$ / R^2
Gasoline	+1.76	$?_p$ =.296	$?_p$ = -.078	? = +.250	0.67
	(9.71)[a]	(6.78)	(1.49)	(5.23)	
Diesel	+1.83	$?_d$ =.129	$?_d$ = -0.136	? = +.105	0.88
	(8.80)	(2.58)	(2.48)	(1.75)	

[a] Figures in parentheses are t-statistics.

Source: Chandrasiri, *Estimating Automotive Air Pollution, op.cit.* Table 8.

133 S. Banaszak, U. Chakravorty, and P. S. Leung, "Demand for Ground Transportation Fuel and Pricing Policy in Asian Tigers: A Comparative Study of Korea and Taiwan," *Energy Journal*, 20:2, 145.

134 S. Chandrasiri, *Controlling Automotive Air Pollution: The Case of Colombo City*, Economy and Environment Programme for Southeast Asia, Research Report Series, June 1999.

135 In this technique (SURE=seemingly unrelated regression equations) the equations are estimated simultaneously to avoid problems when the error terms across equations are correlated, which is the case in fuel demand equations linked by cross-price elasticities. For details see, e.g., H. Lutkepohl, *Introduction to Multiple Time Series Analysis*, Springer-Verlag, New York, 1991.

These estimates suggest that substantial increases in price will be necessary to discourage consumer demand for auto fuel: a 10 percent increase in gasoline price may reduce the demand for gasoline by less than 1 percent (0.78 percent) and increase the demand for diesel by 1.05 percent. Similarly, a 10 percent increase in diesel price may reduce the demand for diesel by 1.36 percent and increase the demand for gasoline by 2.5 percent. Indeed, these values are significantly below most other estimates for Sri Lanka.

However, the consensus view of the international literature favors the so-called "lagged endogenous model," which, say for the case of gasoline demand, has the general functional form[136]

$$Q(g)_t \; ? \; kQ(g)^{?}_{t?1} Y^{?}_t P(g)^{?}_t P(d)^{?}_t V^{?}_t \qquad \text{Eq.[5.3]}$$

where $Q(g)_t$ = gasoline demand (gasoline sales/#vehicles) at time t

$P(g)_t$ = gasoline price at time t

$P(d)_t$ = diesel price at time t

Y = per capita GDP (at constant prices)

V = vehicle mix variable (e.g., fraction of motorcycles)

? = short-run own-price elasticity

? ???= income elasticity

? = cross-price elasticity for diesel

? = lag coefficient

k = constant[137]

from which the long-run price elasticity ? ***** computes to

$$?^{*} \; ? \; \frac{?}{(1 \, ? \, ?)} \qquad \text{Eq.[5.4]}$$

For the gasoline equation, the relevant vehicle mix variable is the fraction of motorcycles, while for the diesel equation, the fraction of light diesel vehicles is the relevant variable.[138] The results are shown in Table 5.5, where we compare the Ordinary Least Squares (OLS) and Seemingly Unrelated Regression Estimate (SURE) estimates.

---

136 This is the form used by Meier et al, Energy Sector Policy and the Environment, op.cit., and Jayaweera, Effective Steps Towards Traffic Calming, op.cit.

137 For the geometrically distributed lags in the partial adjustment model, the lag coefficient should be less than unity (and, therefore, from Eq. [5.4] the long run elasticity should be higher than the short run elasticity).

138 Alternatively, one could adjust the number of vehicles to automobile equivalents (in the gasoline equations), or heavy vehicle equivalents (in the diesel equation).

Table 5.5: Comparison of SURE and OLS estimates

Variable	Petrol		Diesel	
	OLS	*SURE*	*OLS*	*SURE*
CNST	.412	.365	1.94	2.08
	(.226)	(0.207)	(2.00)	(2.21)
Petrol price	**-.151**	**-.155**	.045	.039
	(1.82)	(1.90)	(0.833)	(0.740)
Diesel price	.091	.089	-.070	-.630
	(1.02)	(1.01)	(1.18)	(1.06)
Tax rates	-.059	-.054	**-.144**	**-.156**
	(.317)	(0.300)	(1.96)	(2.17)
Lag effect ???	**.704**	**.693**	**.765**	**.758**
	(6.38)	(6.35)	(7.46)	(7.62)
Fraction of MCs	**-.100**	**-.099**		
	(2.18)	(2.18)		
Fraction of heavy duty vehicles			**-.151**	**-.168**
			(1.37)	(1.54)
R^2	.962	.962	.979	.979

Boldface=statistically significant; t-value in parentheses; Time series: 1968-2000

The lag variables have the correct sign and magnitude (for the hypothesized distributed lag model), and the results of SURE and OLS are surprisingly close. The vehicle fleet variables (fraction of MCs in gasoline), and fraction of heavy vehicles in diesel are significant (and also have the correct sign). However, we note that the diesel own-price elasticity is not significant, which is hardly surprising given the impact of vehicle taxes that may as much as double the cif price at time of purchase. Thus we may summarize the elasticity values as shown in Table 5.6.

Table 5.6: Short- and long-run price elasticities

	Gasoline	*Diesel*
(Own) price		
Short-run	**-0.16**	-0.07
Long-run	**-0.51**	-0.29
Cross price	0.09	0.045

Boldface: statistically significant

Of course, this finding is not very helpful for predicting the impact of increases in the diesel fuel price (e.g., as in Section 9). However, as is evident from the diesel fuel price over the past two decades, with very little variation in real price (except a gradual downward drift), it is hardly surprising that an econometric estimate would have difficulty in identifying a clear price response.

The wide variation in the elasticity values reported in the literature is a reflection of the shortcomings of the data series used in these studies. Whatever values are used need to be treated with great care, and policy conclusions that depend upon them need to be subjected to careful sensitivity analysis.

5.3 Vehicle-km elasticities [139]

A different approach—one that also requires a more detailed database—is to derive vehicle-km elasticities. These measure the change in vehicle-km traveled in response to changes in total (private) vehicle operating costs (including fuel, lubricants, and maintenance), and which will be different for different vehicle classes.[140] The results are shown in Table 5.7. These vehicle-km elasticities are used in the analysis of congestion tolls of Section 8.1.

Table 5.7: Vehicle-km elasticities

Vehicle category	*Elasticity of the average private cost*
Cars (diesel/petrol)	-0.349
Light truck (diesel)	-0.230
Medium truck (diesel)	-0.443
Heavy truck (diesel)	-0.260
Medium buses (diesel0	-0.150
Large buses (diesel)	-0.130
Motorcycles (petrol)	-0.462

Source: Authors' estimates

5.4 Public transport fare elasticities[141]

Previous estimates of the price elasticities of public transport modes show low price elasticities (Table 5.8) and negative cross-price elasticities, suggesting that the different modes provide complementary rather than substitute services.[142] The most significant bus fare increases (in constant terms) occurred in 1974, 1980, and 1987, with relatively little shift to railway service.

Figure 5.4 shows average rail and bus-fares per km during the 1990s, together with total passenger-km: monthly data is available only for 2001. Rail ridership has increased significantly following the recent bus fare increases.

---

139 Sections 5.3 and 5.4 were prepared by D. Jayaweera, Transport Planning Studies Centre.

140 The elasticities were estimated using data for 1988 to 2000 and estimated in log-linear form using OLS.

141 For a good succinct chronology of bus transport in Sri Lanka, see e.g., Kumarage, *Review of Household Income and Public Transport, op. cit*., Box 3.1

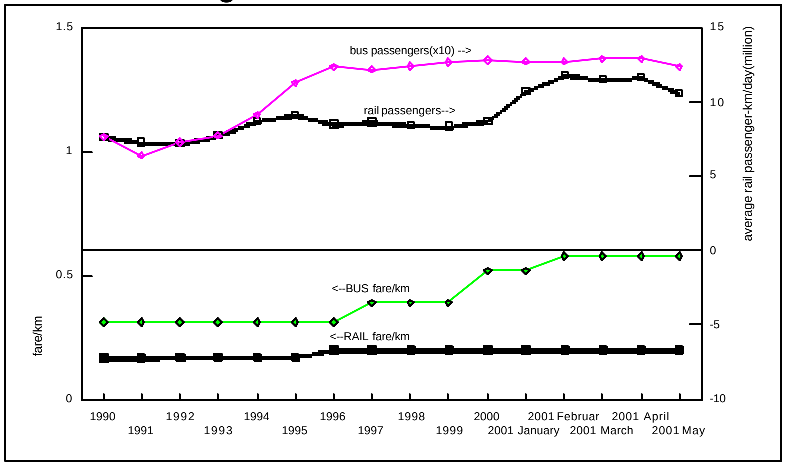
142 Dheerasinghe, K. G. D. D. and D. S. Jayaweera, 1997. *Economic, Social and Environmental Demands on Transport: Past Performance and Emerging Challenges*, in Sri Lanka, Transport Sector Study, Volume II, South Asia I Infrastructure Division, World Bank Report 16269-CE, Washington, D.C.: pg.75.

Table 5.8: Estimated price elasticities

Mode	
Peoplized bus	-0.08
Private bus	-0.07
Rail	-0.04

Source: Dheerasinghe, K. G. D. D. and D. S. Jayaweera, 1997. *Economic, Social and Environmental Demands on Transport: Past performance and Emerging Challenges, in Sri Lanka*, Transport Sector Study, Volume II, South Asia I Infrastructure Division, World Bank Report 16269-CE, Washington, D.C., p. 75.

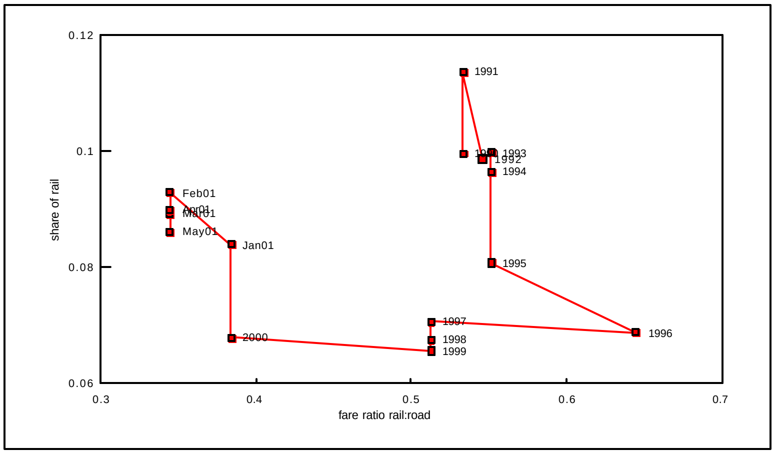
Figure 5.4: Bus and rail fares



Source: TSPC

However, as suggested by Figure 5.5, which shows the share of daily passenger-km held by rail as a function of the ratio of average fares, it seems evident that factors other than price play an important role. While rail ridership has recently increased following the bus fare increases of 2000 and 2001, the econometric elasticity estimates are not robust.

Figure 5.5: Rail market share v. ratio of fares



Source: TSPC

6

Traffic Congestion Externalities

If there is a unifying theme to this study it is that of congestion externalities. Alleviating the rapidly increasing congestion of Colombo's roads is the driving force for many of the options and policies we examine below—the Colombo-Katunayake Expressway (Section 11.1), the dry container port (11.3), the reintroduction of school buses (8.3), railway electrification (11.2), and road pricing itself (8.1).

Figure 6.1 illustrates the fundamental relationship between speed, cost, and traffic flow. In Figure 6.1A, starting at low flows (V_1) and an empty road, speed is S_1. As the number of additional vehicles joins the flow, speeds gradually decline, reaching S_{max} at the flow V_{max}. Beyond this point, additional vehicles entering the road result in a *reduction* in flow, reaching near zero flow and near zero speed (S_o) as gridlock approaches.

Figure 6.1: Speed and cost v. traffic

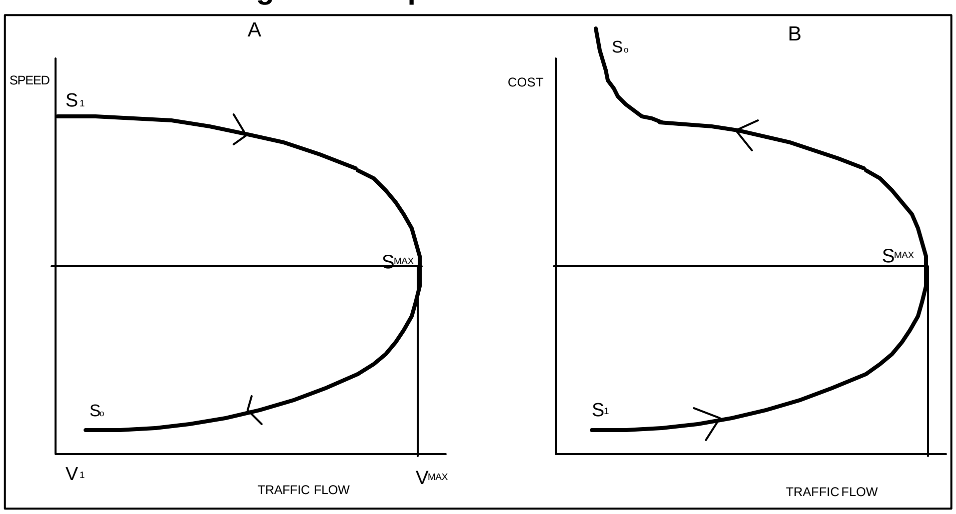


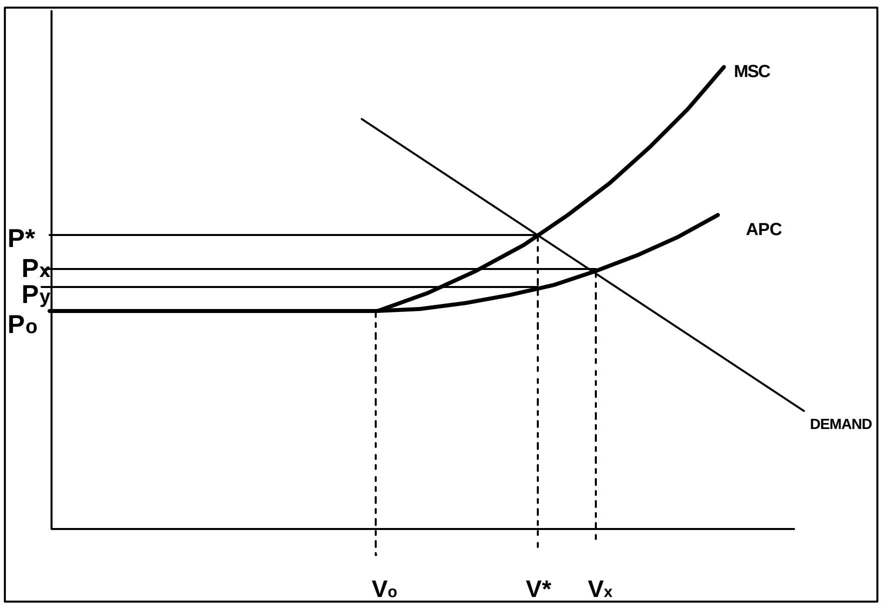
Figure 6.1B shows the corresponding average private cost (***APC***) curve faced by the individual motorist. As speeds decline, private cost to the motorist increases (because as speeds fall, time per trip, and the value of time per trip increase; and because as speeds decline, fuel efficiency decreases). As more vehicles enter the road beyond V_{max}, costs continue to increase (tending to infinity as total gridlock approaches). In the subsequent discussion of theory, in the

interests of clarity we do not draw the backward bending part of the cost curve —optimal solutions will not lie in this domain, for these will always lie on the *lower* part of the cost curve.[143]

6.1 Theory

Traffic congestion occurs because the marginal user considers only his own private costs when making a decision to undertake a particular trip at a particular time, ignoring any costs imposed on others. Figure 6.2 illustrates the theory. Up to some given traffic volume (V_o), equal to the capacity of the road, the private cost is (roughly) constant (P_o). Below this value, an additional vehicle does not reduce the speed of other vehicles already on the road.

Figure 6.2: Optimal pricing and congestion



But with further traffic increases, the volume-to-capacity ratio exceeds one, speeds begin to decrease, and therefore the individual user's private costs increase, both because to cover a given distance requires more time (which has a cost to the individual), and because fuel efficiency is lower as speeds decrease (which increases the individual's fuel costs). Therefore, beyond V_o, the private cost (***APC***) curve slopes upward, intersecting the demand curve at V_x, P_x.

Beyond V_o, however, the marginal user imposes these same externalities on the other road users as well, for the decrease in speed is experienced by all. The marginal social cost (***MSC***) curve therefore lies higher than the private cost (***APC***). Thus the societal optimal traffic

[143] Some discussions of the issue e.g., Chin (2000) and Jayaweera (1999), use the term "average variable cost, AVC" for this quantity; we prefer the term average *private* cost (APC) to stress the difference between private and social costs.

volume is at ***V*, P****—where the demand curve intersects the ***MSC*** (rather than ***APC***). Welfare theory argues for a "Pigouvian" tax[144] on the use of congested roads in the amount $? = P^* - P_Y$, at which point the private users' total cost (private cost plus tax) exactly equals the social cost (and which also equals the marginal social benefit represented by the demand curve).

But these externalities (lost time to private users and increased fuel bills) are not the only ones we need to consider.[145] Indeed, we may list five main externalities imposed by the marginal road user—time costs, additional fuel costs, accidents, environmental pollution, and road damage[146]—of which only the first two are considered above.[147] The question then becomes to what extent are the latter three externalities also speed-dependent. In addition, less easy to quantify is the general inconvenience imposed by motorists on pedestrians and bus passengers—to which the recent concept of "traffic calming" to force speed reduction is a direct response.

Since lower speeds imply higher rates of emissions per km traveled (for all road users), there are unquestionably *additional* environmental externalities associated with congestion. In other words, while the environmental externalities are constant (in the speed range up to V_o), beyond V_o the environmental costs increase with increasing congestion (i.e., with decreasing speeds). Thus we may redraw Figure 6.2 as shown in Figure 6.3: Environmental damages result in an upward shift of the marginal social cost (***MSC***) curve of $?E_o$ up to V_o, and thereafter grow (non-linearly), reaching, say, $?E_x$ at V_x.

Thus the original toll ?? (from Figure 6.2), shown in Figure 6.3 as ***[AB],*** increases to

$?_e$ ***(= [XY]) >> ??(= [AB])***

where $?_e$ is the optimal toll including consideration of environmental externalities.

In the case of road damage, one might argue that the effect of congestion is to *reduce* damage, since these are generally related to the *square* of the speed. But this is true only once a certain

144 Following Pigou's dassic study that laid the theoretical foundation for road congestion pricing (A. Pigou, *The Economics of Welfare*, MacMillan, London, 1924).

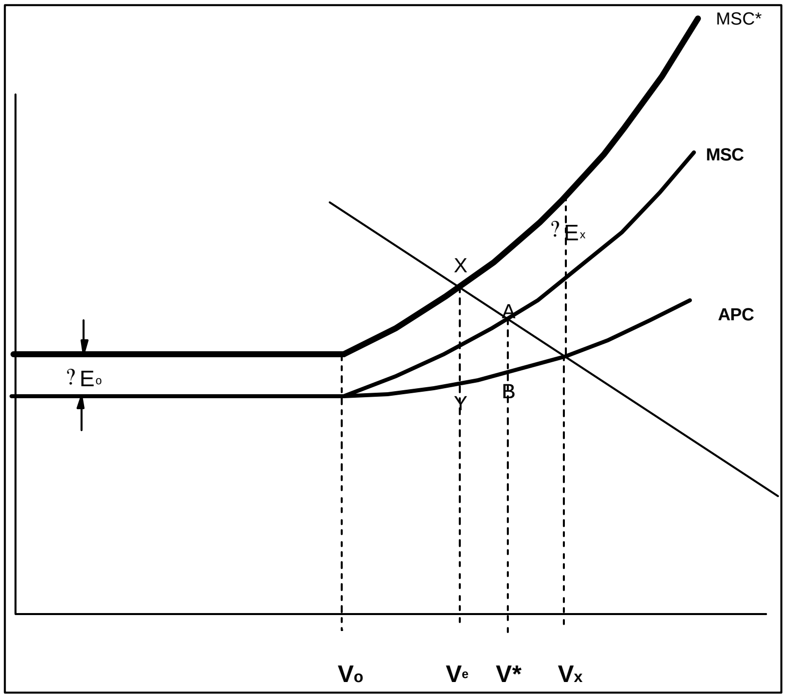
145 D. Newberry, "Pricing and Congestion: Economic Principles Relevant to Pricing Roads," *Oxford Review of Economic Policy*, 6:2, 1990.

146 Road damage/maintenance costs also divide into two main categories: those dependent upon road use (largely caused by high axle loadings of heavy lorries), and those related to weather. While Newberry argues that in hot dry climates the proportion of damage attributable to road use will be higher (60-80 percent) than in freezing temperate climates (20-60 percent), in Sri Lanka it is much more difficult to make this distinction—for here it is the combination of poorly enforced axle load limitations, heavy monsoonal rains, and poor surfaces that causes most of the road damage.

147 Some externalities may not be so apparent. For example, faster traffic may cause inconvenience to non-motorists, like pedestrians, bicyclists, bus passengers, etc. The latter may absorb these costs, in the form of greater vigilance, delays, and annoyance. The recent concept of "traffic calming" is aimed at reducing vehicle speeds, to make life easier for non-motorists.

threshold is exceeded, and at low urban speeds, congested or not, this is not a significant effect.[148]

Figure 6.3: Environmental costs of congestion



Newberry has argued (in the case of the United Kingdom) that accident externalities could be as large as all other externalities taken together.[149] On the other hand a French study suggests that the years of life lost to road accidents are two orders of magnitude greater than those attributable to air pollution,[150] and a recent study of London concludes that the direct costs to the UK National Health Service attributable to traffic accidents is at least 12 times as great as those as might be attributed to air pollution.[151] Certainly the rates of road accidents in

148 In any event, this effect is taken into account by the more sophisticated models for calculating vehicle operating and damage costs.

149 Newberry, *op.cit*., pg. 25.

150 Academie des Sciences, *Pollution atmospherique due au transport*, Rapport Etage I, Paris, France, 1996. This study suggests the following order of magnitude comparisons of lives lost, with smoking as a yardstick (1,000,000); traffic accidents (100,000s); passive smoking (10,000); long-term carcinogenic effects of air pollution from transport (1,000s), direct effects of particulates from transport (100s). (For a review of this study in English, see Glaister et al., *Transport and Health in London, op. cit*., p. 21.)

151 Glaister et al., *Transport and Health in London, op.cit*., p. 4. Indeed, the authors conclude that the dramatic improvements in London's air quality since the 1950s (when deadly "peasouper" fogs were responsible for thousands of deaths) have not been matched by improvements to the cleanliness of London's streets: today this likely constitutes a greater direct health risk from the encouragement of

Sri Lanka compare unfavorably with those in other countries.[152] Calculations in the environmental impact assessment for the Colombo-Katunayake Expressway (discussed in Section 11.1) estimate the benefit of reduced accidents (avoided fatalities) at Rs 3-12 million/year, as opposed to benefits of Rs 16-34 million from reduced emissions of air pollutants.[153]

The question of whether accidents constitute an externality of congestion depends upon whether accident rates vary non-linearly with volume of traffic (in which case they do constitute a congestion externality), or whether accident rates vary linearly (in which case the marginal vehicle does not increase accident rates for everyone else, and therefore there is no externality).[154]

Indeed, the question of how to recover from private users the costs of congestion is not unrelated to broader questions of how to design a system of charges for road use (i.e., how to recover public costs even for an uncongested road). Indeed, this is in turn related to the broader question of taxes on fuel, parking, and vehicle purchases. The most widely held view in South Asia (at least among politicians) is that the purpose of differential taxation of diesel and gasoline is income redistribution, under the theory that diesel is widely used by farmers and buses (the former assumed to be poor, the latter assumed to serve the poor, and therefore both worthy of subsidy), while gasoline is used by passenger car owners (assumed to be wealthy, and who therefore deserve to be taxed).[155] Since the poor are more numerous than the wealthy (a few

rats and other disease-carrying vermin. But with respect to air pollution, London is now one of the cleanest mega-cities of the world (*Ibid*., p. 28)

152 Accident and fatality rates are significantly higher in Sri Lanka compared to its South Asian neighbors:

		Fatalities/10,000 vehicles	*Vehicles/ 10,000 persons*	*Fatalities per 100,000 persons*
Malaysia	1992	7.0	3523	24.5
Thailand	1993	8.4	1927	16.3
Indonesia	1990/1992	10.6	571	6.1
Sri Lanka	1992	20.0	501	10.0

Source: TSS, Table 19, p. 49

153 After correcting for an error in the calculations of unit damages in the application of the benefit transfer method (which are discussed below in Section 8.1).

154 One might also consider differentiated measures: fatalities per vehicle-km reflects driver responsibility, whereas passenger risk is better reflected in fatalities per passenger-km (especially relevant to Sri Lanka where fatal bus accidents are frequent in the hill country).

155 These are largely the same arguments heard from the same politicians (especially in India) in the case of electricity—justifying cross-subsidies from industrial customers (who pay confiscatory tariffs, and are often the first to be disconnected during shortages) to farmers. But as recent empirical studies show, the presumptions are just as fallacious as in the case of transport fuels: in fact the so-called "free power for farmers" imposes a range of externalities upon them (and others) whose net effect is to make them effectively worse off than if they paid some reasonable tariff. In any event, the principal beneficiaries of "free power" for irrigation are not the rural poor, but relatively wealthy farmers with large land-holdings,

million dependant upon farming, compared to 200,000 passenger car owners), the political logic of this argument is attractive to decisionmakers.

However, others (e.g., Newberry, *op. cit*) have advanced a different argument: In general, policies should be designed to achieve production efficiency, with discretionary taxes falling on final consumers.

Neither argument is likely correct in the case of Sri Lanka: as we shall see, the gasoline:diesel dichotomy neither matches rich:poor, nor final:intermediate production. These arguments may have been correct in the past (particularly in the case of Sri Lanka during the *dirigiste* socialist economy before 1978, when import controls could be used to make it so), but they are certainly not true today, as we shall show in the detailed analyses that follow.[156] For example, the high taxes levied on gasoline fall disproportionately on (low- and middle-income) motorcycle owners and users of 3-wheelers, while the relatively affluent urban elites have shifted overwhelmingly to diesel vehicles (while avoiding the high vehicle import taxes on luxury vehicles through special exemptions and concessions granted to favored groups). Moreover, at least in the case of private bus operators, high diesel costs are inevitably passed to their low-income passengers through fare increases.

6.2 The value of time: empirical estimates

For a very wide range of options examined in this report—particularly those focused on reducing congestion—time savings account for the largest proportion of economic benefits. Both absolute as well as relative values are of interest, since different road users—drivers, bus passengers, car passengers—have significantly different incomes, and would likely value their time at different levels.[157]

---

who can deal with the power shortages (that result from bankrupt utilities) by installing their own diesel-sets.

156 Nor is it likely that Newberry's dichotomy applies as it once did in Europe. In 1990 diesel vehicles accounted for 14 percent of sales; today they account for a third (in 2000, total sales fell by 5 percent, but diesel sales increased by 5 percent). Diesel engines get better mileage and in most EU countries diesel is up to 25 percent cheaper than gasoline. However, unlike Sri Lanka, where any rents are captured by government through high vehicle import taxes, in Europe the lagging supply of diesel vehicles has enabled car manufacturers to price diesel vehicles at substantial mark-ups to actual incremental costs (Business Week, May 14, 2001).

157 In some cases, it is the individual's personal opportunity cost of time that would decide whether he would pay the expressway toll in exchange for the time savings (or whether a bus passenger would choose expressway service rather than a slower stopping service on the A30 in exchange for a slightly higher fare). How that opportunity cost is related to an individual's salary is an empirical question, about which there is, in Sri Lanka, no data (since there are no toll roads in operation that would allow estimation of the trade-offs made by users). Absent such evidence, average salary is surely the best guide.

In the case of drivers, the *individual's* valuation is irrelevant, for as (mostly) salaried individuals, they may be assumed to be indifferent to the speed at which their vehicle travels. However, their employers

Table 6.1 shows average monthly incomes of employed drivers and passengers, which may be used as a rough guide for relative values. In subsequent sections we use the value of car passenger time as the exogenous variable, with that of other users linked by the proportions implied by the values in Table 6.1. The car passenger value of time is escalated at the assumed real GDP growth rate (which we take as 5 percent per year in the reference case).[158]

Table 6.1: Average monthly income of drivers and passengers (1999)

	Rs/month
Car passengers	21,465
Van passenger	9,037
Motorcyclists	4,770
Public transport passengers	3,387
Nonmotorized users	1,849

Source: Kumarage (1999), Table B1.1.

If we escalate the passenger salary by 5 percent, the 2001 value is 23,365 Rs/month, equal to Rs 134/hour.[159] A similar definition of the value of travel time appears to have been used by the Colombo Urban Transport Study (CUTS),[160] for their estimate (at 1998 prices) is Rs 111/hour for car passengers.[161]

Several studies suggest that the value of time is related to trip purpose (Table 6.2) for which some data is available in Sri Lanka: the value of time for business (and commuting) is arguably greater than that for leisure time.[162] Kumarage et al. (1999) summarizes the value of

---

would not be indifferent: and it is reasonable to assume that the opportunity cost *they* place on driver time is equal to salary (plus fringe benefits and employment taxes).

In the case of bus passengers, many of whom are wage-earners, the consequence of road congestion is longer commute times, which reduces leisure time (or sleep) rather than hours on the job. Again there is no data for what opportunity costs such passengers place on their leisure time, but it is not unreasonable to assume it would be related to income.

158 A March 1996 survey showed that bus passengers had significantly lower average incomes (Rs 2,900) than both suburban rail passengers (Rs 4,900) or office van passengers (Rs 4,900) (D. Jayaweera, "Are Current User Charges in Roads Adequate," in TSS, *op. cit*., Vol. II, p. 438). The TSS deduces that this unexpected result is a consequence of the fact that a majority of Colombo suburban rail passengers are civil servants, whose employing departments pay 75 percent of the season ticket cost.

159 Assuming 22 working days per month and 8 hours/day.

160 Colombo Urban Transport Study, Stage I, Working Paper #8, Halcrow-Fox Associates, Colombo, 1996.

161 Which corresponds exactly to the figure given in Table 6.1 for monthly car passenger salary. This is the figure used by the University of Moratuwa study.

162 Clearly the fraction of car passengers whose trips are part of their business activity is less than one. Indeed, with the advent of the cellular phone, much business is conducted from automobiles, necessarily implying a reduction of the opportunity cost of being stuck in congested traffic.

time savings as shown in Table 6.3.

Table 6.2: Trip purpose, morning peak

	[%]
Work (commuting)	43
Education	21
Business	16
Recreation	5
Social	9
Other	6

Source: University of Moratuwa, Origin-Destination Survey, May 1998.

Table 6.3: Value of travel time savings (in 1999 Rs per hour per user)

User group	*Urban*	*Rural*	*Intercity*	*All sectors*[163]
Car	100.06	78.62	135.81	106.50
Van	51.15	37.62	51.15	48.44
Motorcycle	19.05	27.00	14.29	19.22
Public transport	10.83	12.41	12.41	11.62
Nonmotorized modes	6.78	8.62	0.00	7.39
All motorized modes (AV)[164]	24.61	23.01[165]	28.81	25.55

However Jayaweera's estimates of the values of time are substantially lower, as shown in Table 6.4:[166] his average value of time (for car passengers) is only Rs 26.5/hr (Rs 30/hr at 2000 price levels). This is significantly below the Rs 111/hour value used by the Colombo Urban Transport Study, and below the value of Rs 66/hr used by the CKE-EIS.[167]

---

163 Assumed as been composed of 50 percent urban, 20 percent rural and 30 percent intercity travel.

164 Assumed as being composed of 10 percent share for cars, vans, and motorcycles respectively and 70 percent for public transport.

165 If non-motorised travel is considered, for example in rural transport, this should change. If 50 percent of travel is assumed to be by non-motorised means, then the average value of travel time savings would be Rs 15.31 per hour.

166 The older literature is reviewed in a 1987 report by the United Kingdom Institute of Transport Studies (The Value of Travel Time Savings), which noted, inter alia, that

"higher absolute values of time are associated with higher levels of income . . . there thus appears to be some justification for custom in benefit cost studies using values for time for future saving which are adjusted for future changes in disposable income."

See also Jayaweera, op. cit., pp. 44-46.

167 This is comparable to the time value per hour for the vehicle as a whole (i.e., passenger(s) + driver) of Rs 66/hour used in the CKE-EIS (see Table 3.11). It might be argued that higher values are justified for

Table 6.4: Value of time

	Value of time (1) *Rs/hour*	*Ratio to value of time for car passenger*	*Ratio based only on salary*
Car passenger	26.5	1	1
Van passenger	21.4	0.81	0.79
Bus passenger	8.8	0.33	0.18
Car driver	16.8	0.63	0.22
Van driver	13.0	0.49	0.24
Bus driver	16.4	0.62	0.48
Truck driver	19.3	0.73	0.54

Source: Jayaweera (1999), *op. cit*., Table 5.8 and Table 5.2, *supra*.

(1) The source document expresses the value of time per one-km length trip at a speed of 42 km; therefore we multiply his figures by 42 to obtain values per hour.

Evidently there are significant differences among the various estimates of the value of travel time. For example, in the case of car passengers (and owner-drivers), the values range from Rs 26.50/hour (Table 6.4) to Rs 106.50/hour (Table 6.5). These differences are attributable to a range of assumptions (e.g., the extent to which social costs are added to salaries; the degree to which a salary-based valuation is applicable to commuting travel) that are the subject of intense debate in the literature. In this report we take the lower of the values, and then calculate the switching value. In almost all of the policies examined in the following sections, the switching value lies below this lower estimate, which shows robustness to this assumption.

The average value of time for goods vehicles was provided by the Transportation Policy Centre, which uses the following values in their studies: Rs 186/hour for industrial inputs; Rs 154/hour for intermediate goods, and Rs 196/hour for finished goods. To take into account some proportion of trips made empty, we have used an average of Rs 150/hour (to which we add driver's time as noted above).[168]

the expressway/A30 corridor, since the proportion of higher-valued business trips is likely to be higher than the Colombo averages as determined by the University of Moratuwa studies.

168 D. Jayaweera, Project Completion Report, CUTS, Nov. 1999.

7

Transportation Futures[169]

The desire of individuals to own and use a motor vehicle appears universal.[170] As incomes increase and technological advancements reduce the cost of producing a motor vehicle, more and more persons find the financial means for owning and operating one.

However, motor vehicles do not come without their share of physical and environmental limitations. In the first place, they require road space to operate freely, parking spaces at residences and work places, and protection for their users as well as for others sharing the same road space. Increase of motor vehicles often outstrips the provision of road space in many countries. The result is traffic congestion and wastage of resources. Poorly designed roads and lack of adequate enforcement also result in high costs arising from accidents. Motor vehicles also require a vast array of supporting services such as garages, service stations, and petrol stations, all of which require physical land space. At the same time, motor vehicles are often identified as the primary cause of environmental pollution, particularly air quality, in cities. Different motor vehicles emit different amounts of pollutants that contribute to many local health problems, particularly respiratory diseases and lead poisoning, and global problems related to increasing emissions of greenhouse gases.

As a result, increasing attention is being paid to the manner in which the global vehicle fleet is anticipated to grow in the future and its possible impact on air quality and the environment. Presently, there are few global strategies to manage this growth.[171] It is noted, however, that different countries and cities adopt different strategies in dealing with the motor vehicle. In general, their policies toward the motor vehicle are reflections of their cultural

---

[169] This chapter was prepared by A. Kumarage, University of Moratuwa.

[170] However, for an opposing view, see e.g. A. Schafer and D. Victor, "Global Passenger Travel: Implications for Carbon Dioxide," *Energy*, 24, pp. 657-679, 1999, who argue that in developed countries, automobile travel will begin to decline by 2050.

[171] A few of such global strategy studies have recently appeared in connexion with GHG emissions reduction policy: see e.g., L. Schipper, *Flexing the Link: Transport Sector Policy and GHG Emissions*, World Bank, Washington, D.C., 1999, and Shafer and Victor, *op. cit*. (who show that absent policy actions to drastically improve energy efficiency in transportation over the next decade, the goal of stabilization of carbon emissions is technically impossible (absent some new zero-carbon technology).

perspective toward the advent of the automobile, of their available resources, of the relative influence of the "road lobby," of the extent of air quality problems, and of their economic status.

The objective of this section is to postulate some alternative transportation futures for Sri Lanka in light of worldwide experience. Despite some potential objections to historical determinism and the validity of cross-cultural comparisons, we believe there are useful lessons in the worldwide experience, and that trends observed elsewhere in countries that have already achieved higher levels of income have relevance to Sri Lanka.

7.1 World trends in vehicle ownership[172]

The relationships between vehicle ownership and per capita incomes differ vastly from country to country. In other words, the rates of vehicle ownership of two countries when they have the same income levels are observed to be quite different. The work of Newman and Kenworthy[173] presents some insights into the parameters that appear to significantly influence the level of vehicle ownership. These can be identified as

?? Population density
?? Penetration by public transport
?? Cost of vehicles, fuel, and parking, relative to income level
?? Taxation levels on private vehicles and
?? Restraint on vehicle ownership and use.

It is observed that in countries that have lower population density, penetration by public transport is difficult, and consequently these countries will tend to have higher vehicle ownership rates compared to others. In this respect, countries in Asia in particular appear to have lower trends when compared to countries such as the United Kingdom Australia and Canada. Figure 7.1 shows a comparison of international data for car and van ownership as a function of per capita income.

India, Sri Lanka, and other developing nations have historically levied high taxation on the ownership and use of private vehicles and thus the growth rates have been further reduced. Strong restraints of vehicle ownership by the government have recently been introduced in countries such as Singapore and Hong Kong, but these differ fundamentally to the restraints

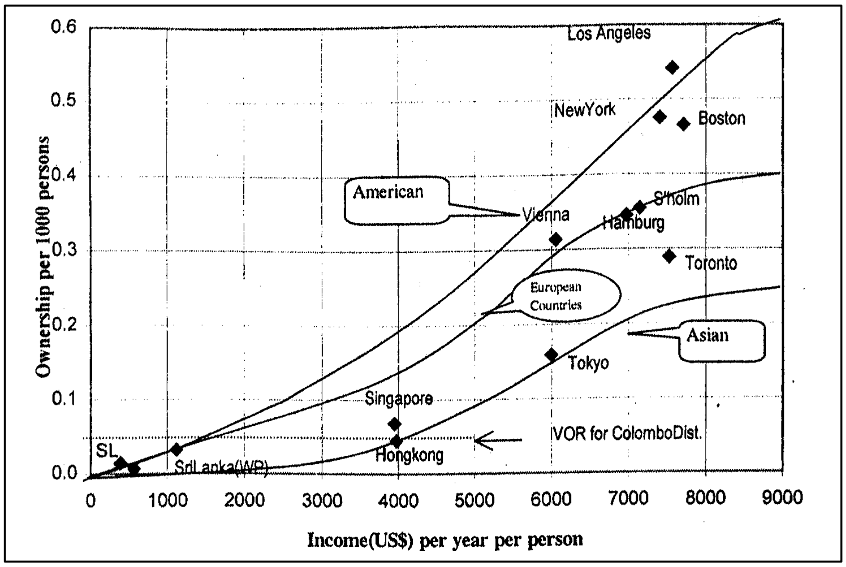
---

[172] A wide range of studies was examined for this exercise. The World Bank's Urban Transport Strategy Review (TSS, *op. cit*.) presents the growth of the vehicle ownership rates (usually measured as vehicles owned per 1,000 persons) for France, Spain, and Japan for the time period 1950s to 1995 as it relates to incomes of those countries during this period. It also gives the relative positions of several other selected countries as well. Shoup and Stark (2000) trace the growth of the U.S. vehicle fleet from 1900 to 1995. By tracing the growth of per capita incomes for the same period the relationship between the growth of incomes and vehicle ownership in the U.S. too could be established. In a similar manner, Singapore's vehicle growth as a function of its per capita income has also been traced using data from the Singapore Department of Statistics (2000). The vehicle fleet in the U.K. was studied using the database at www.Statsbase.gov.uk/statbase/timezone.asp.

[173] Newman and Kenworthy, *Cities and their Traffic*, Gower Publications, 1990.

imposed by the erstwhile socialist governments of Sri Lanka. The new generation of constraints is based on market-based instruments to allocate shortages—in Singapore's case by the auctioning of a limited number of permits and through road pricing (whose revenues are used to improve public transportation)—whilst in the old days of socialist import controls in Sri Lanka, bureaucratic discretion was the instrument of allocation.

Figure 7.1: Vehicle ownership trends and likely saturation levels as a function of income



Source: A. S. Kumarage, "Managing the Demand for Cars in Cities," *Proceedings*, National Conference, "Cities for All," World Habitat Day 1999, Sri Lanka, 1999, Figure 2.

Ownership trends need to be studied for different vehicle types. Two- and three-wheelers (i.e., motorcycles and "tuk-tuks" or "trishaws" as they are called in different countries), which are popular modes of private transport in Asia, have patterns quite different than those of four-wheeled private vehicles made up of cars, saloons, station wagons, double cabs, and passenger vans. Commercial vehicles made up of trucks, delivery vans, buses, taxis, and agricultural vehicles have yet different trends.

In the sections that follow, we aggregate two- and three-wheelers, and include (4-wheel) taxis with passenger cars, a classification scheme that follows income levels. Three-wheelers provide taxi service largely to the same income class as motorcycle riders, while four-wheel taxis are used almost exclusively by those who can also afford their own passenger car (and by tourists and for business trips).

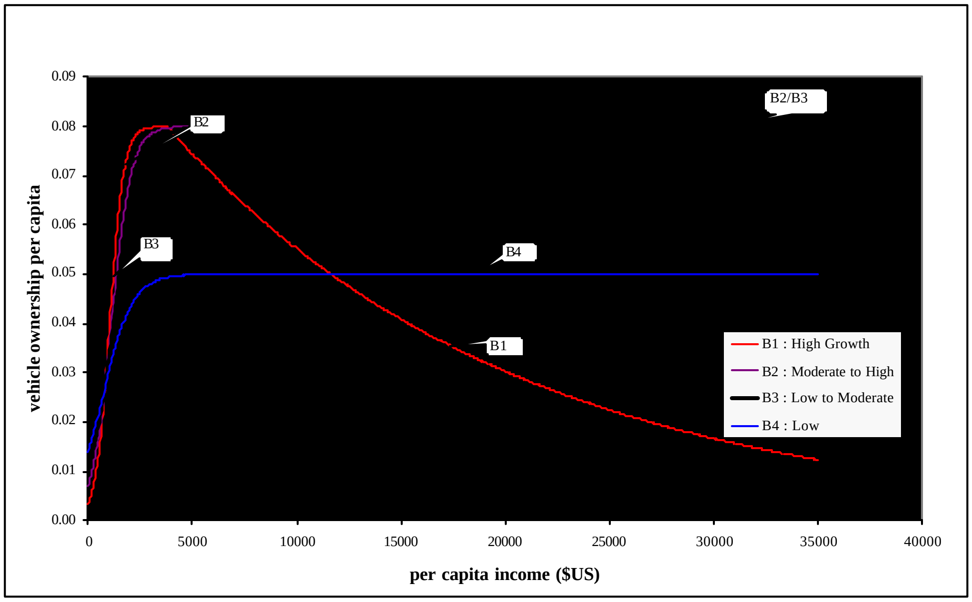
Two- and three-wheeled vehicles

Motorized two-wheelers—i.e., motorcycles—are to be found in most countries. However, they appear in particularly large numbers in Asia and in other third world countries. Only a few countries in Europe (notably Italy) have motorcycles in such large numbers. Three-wheelers are surrogates for taxis in low-to middle-income countries, though their ridership includes few of the poor (whose main mode of transportation is the bus).[174] The growth in ownership of two- and three-wheelers is observed to be very different between countries. As such, the analysis identifies four probable but distinctly different trends for two- and three-wheeler vehicle ownership rates (VOR) with respect to per capita income. These are identified as curves B1, B2, B3, and B4 in Figure 7.2, which have the general functional form

$$B(I) = \frac{k_1}{\left(1 + a e^{-b(I-d)}\right)}$$

where $\boldsymbol{k_1}$, $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{d}$ are constants, and $\boldsymbol{I}$ is the per capita income in \$US.[175]

Figure 7.2: VOR and income for two- and three-wheeled vehicles



With respect to the increase in incomes, curve B1 represents countries and economies where there is a rapid increase in ownership of two- and three-wheelers up to income levels of around US\$2,000-3,000 per capita. Thereafter, there is a gradual decrease when the additional income necessary to own and use a four-wheeled vehicle is found to be only marginal, in order

---

174 For example, in Sri Lanka, the average bus fare is less than Rs 1/km, compared to Rs 25/km for three-wheelers (see Kumarage, *Review of Household Income*, *op. cit.*, for a detailed review of fares).

175 The values of these coefficients are as follows:

B1: $\boldsymbol{k_1}$=0.08; $\boldsymbol{a}$=100; $\boldsymbol{b}$=-0.003; $\boldsymbol{d}$=500

B2: $\boldsymbol{k_1}$=0.08; $\boldsymbol{a}$=30; $\boldsymbol{b}$=-0.0021; $\boldsymbol{d}$=500

B3: $\boldsymbol{k_1}$=0.08; $\boldsymbol{a}$=10; $\boldsymbol{b}$=-0.0015; $\boldsymbol{d}$=300

B4: $\boldsymbol{k_1}$=0.05; $\boldsymbol{a}$=40; $\boldsymbol{b}$=-0.0014; $\boldsymbol{d}$=1950 to effect a rapid transition from two to four wheels. This indicates situations where the tax levels on four-wheel vehicles and fuel are low and there are no external restraints on vehicle ownership.

The curve B2 illustrates a situation where the rate of increase is lower than B1 and peaks at higher income levels of around US$3,000 per capita. This represents a situation where the need for the use of private two- and three-wheeler transport may be delayed due to higher population density in that country, which may allow a higher proportion of travel by non-motorized means such as walking and bicycling. Higher densities also give a potential for improved public transport services. Unlike the B1 curve, this curve does not diminish sharply as it represents situations where governments would typically set tax levels on cars and vans much higher than for two-and three-wheelers. In this situation it could be expected for curve B2 to show a saturation level, which is represented by a situation in which a dynamic equilibrium is maintained between those who are moving from two- and three-wheelers to four-wheelers and those who are moving from non-motorized travel and public transport to two- and three-wheelers. The B1 curve for two-wheelers is typically found in North America and Australia, while most parts of Europe can be expected to follow curves similar to B2, where population density is higher and public transport is more widely used.[176]

The VOR represented by curve B3 has an even slower growth trajectory for two- and three-wheelers with respect to per capita income, though the trend is similar to B2. These are countries that have made owning and operating four-wheelers much more expensive compared to owning and operating two- and three-wheelers. Most countries in Asia demonstrate growth in VOR of two-and three-wheelers along this curve.

The fourth curve labeled B4 has the lowest trajectory with respect to per capita incomes but is similar in shape to curves B2 and B3. This curve typically represents countries that have a restrictive policy on motorcycles due to either congestion or environmental factors, particularly air pollution. Singapore, Philippines, Japan, and Hong Kong are examples where such restraints exist either as explicit prohibitions on the ownership or use or implicitly through higher fees, parking charges, fuel and registration taxes, etc. Beijing simply bans motorcycles from its urban center. It should also be noted that each of these examples is also generally characterized by good to excellent public transport systems that provide a satisfactory alternative to private vehicles (Singapore and Beijing, for example, have excellent metro systems).

---

[176] However, many inner cities in America and in Europe now show increased use of bicycles by the health conscious, and of motorcycles and bicycles by courier and delivery services. Motorcycles in North America are frequently used by high-income individuals for purposes of recreation or (at the high end) of conspicuous consumption. Indeed, new proposals for congestion pricing notwithstanding, recent studies of London show that traffic in the inner city core has remained largely unchanged in the 1990s—while bicycle traffic—after a drop in the early 1980s, has grown sharply since 1987 (by 40 percent in central London, and by 20 percent in Inner London). See Glaister et al., *Transport and Health, op. cit*., p.18.

Four-wheeled vehicles

These vehicles are conventional four-wheeled saloons and the increasingly popular multi-purpose passenger vehicles termed as vans, pickups, RAVs, etc. These vehicles, unlike two- and three-wheelers, have a steady trend linked to personal incomes, differing only in the scale of increase between countries.

Similar to the set of curves that defined growth in ownership of two- and three-wheeler curves, another set of four curves is identifiable to illustrate the growth in ownership rates of four-wheelers. The highest elasticity to income for four-wheelers is observed in the United States, which promoted early motorization and where saturation appears to be reached around 700 to 800 vehicles per 1,000 population—which implies three vehicles for a typical family with two children.[177] The United States has low population density, low penetration by public transport, and a culture geared to private vehicle use as the primary mode of transport. This is coupled with low taxes on fuel and vehicles. This trend is denoted as curve C1 in Figure 7.3

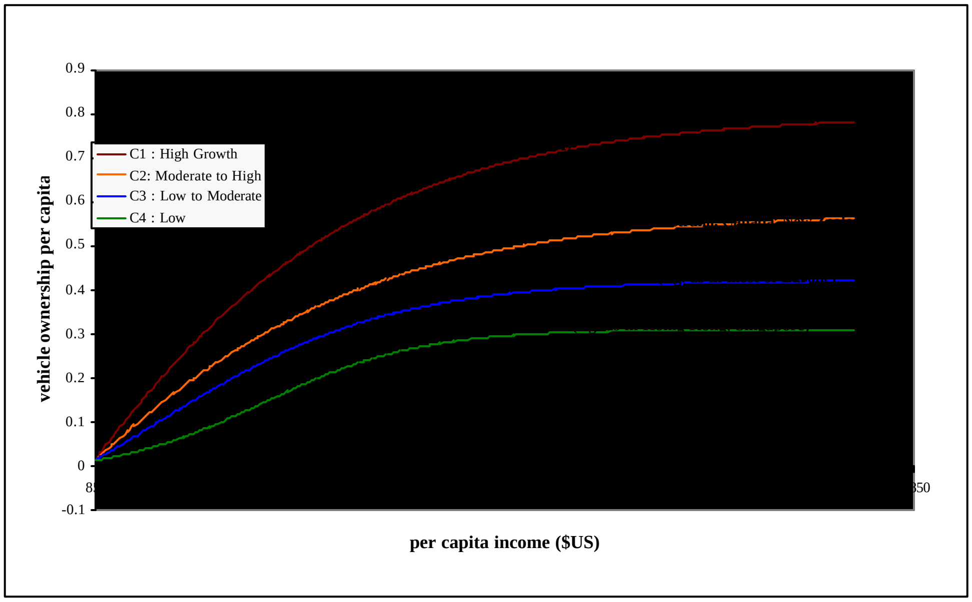
The curve C2 shows a lower elasticity to per capita incomes, and has a lower trajectory when compared to curve C1. In counties where growth in four-wheeled vehicles follows this curve, the VOR for cars and vans appears to saturate around 500-650 vehicles per 1,000 population, i.e., around one car per family. These are mostly to be found in Australia, Canada, and New Zealand, where population densities are low but motorization has been slower, and where taxes on fuel and vehicles are slightly higher than in they are in the United States.

The third curve, identified as C3 for VOR of four-wheeler vehicles, is to be found in most European countries, where tax levels are considerably higher and other measures are introduced to restrict the use of the car while taking explicit steps to promote public transport. These are also countries with higher population densities that make service by public transport more appropriate. Saturation in these situations is generally around 350-500 vehicles per 1,000 population.

---

[177] In many affluent suburban areas of the U.S., the norm for new house construction now includes a three-car garage (rather than the earlier two-car garage). In addition to a car each for both parents, the more affluent families increasingly also have a passenger van for weekend and recreational use, while teenagers still living at home often also have their own cars.

Figure 7.3: VOR and income for four-wheeled (passenger) vehicles



Those countries that have extremely restrictive vehicle ownership policies such as Singapore and Hong Kong represent the curve C4. In this instance, due to very high population densities, large vehicle fleets would be unmanageable. Therefore, through a series of measures aimed at discouraging vehicle ownership and encouraging public transport, the VOR of four-wheelers in particular is kept very low. This curve shown as C4 can be expected to saturate around 200-300 vehicles per 1,000 population.[178]

Commercial vehicles

Commercial vehicles include those used for goods transport, agricultural purposes, and for passenger transport for fee or fare, such as buses. These also show a very steady trend linked to economic growth. Figure 7.4 shows a steady increase in VOR of commercial vehicles. The growth appears to be steady over all income rages, but can be assumed to vary with the

---

[178] These curves again have the general functional form

$$c = \left(\frac{k_1}{1 + a e^{b(I - d)}}\right) + k_2$$

where I is the per capita income in US$. The values for the four curves C1 to C4 are as follows:

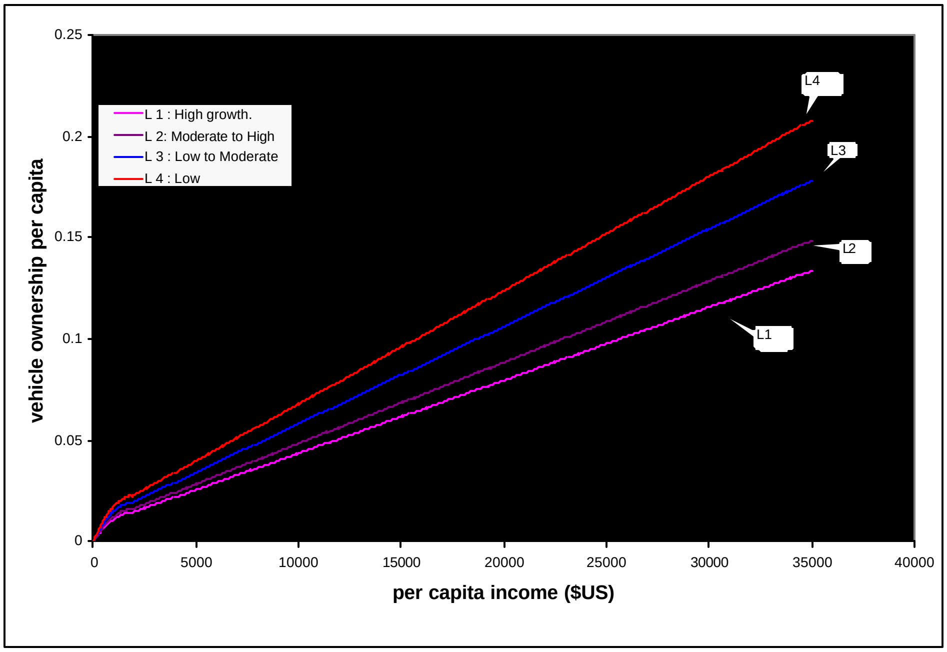
C1: $\boldsymbol{k_1}$=2.6; $\boldsymbol{k_2}$=-1.802; ***a***=0.25; ***b***=-0.000133; ***d***=5,000

C2: $\boldsymbol{k_1}$=1.7; $\boldsymbol{k_2}$=-1.125; ***a***=0.25; ***b***=-0.000133; ***d***=6,000

C3: $\boldsymbol{k_1}$=0.65; $\boldsymbol{k_2}$=-0.227; ***a***=0.4; ***b***=-0.0002; ***d***=8,000

C4:: $\boldsymbol{k_1}$=0.33; $\boldsymbol{k_2}$=-0.0188; ***a***=0.56; ***b***=-0.0003; ***d***=10,000 level and quality of public transport. Thus four trends corresponding to the earlier set of curves have been identified as L1, L2, L3, and L4, respectively. The lowest growth rate is represented by curve L1, which corresponds to B1 and C1 (which were actually the highest growth rates for two-wheelers and four-wheelers, respectively). This is because, as the curves B1 and C1 indicate, as private ownership levels increase rapidly, the need for public transport vehicles would diminish marginally. These four curves are shown in Figure 7.4.[179]

Figure 7.4: VOR and income for commercial vehicles (trucks and buses)



The trends in vehicle ownership of these three vehicle categories in Sri Lanka for the period 1958 onward have been analyzed in this study. Sri Lanka appears to closely follow the curve B2/B3 for two- and three-wheeled vehicles and C2/C3 for four-wheeled vehicles. It follows the curve L2 for commercial vehicles. This trend seems most logical when considering the relatively high taxation policies on fuel and cars, the higher population density, and the dominance of public transport that have characterized the transport sector in Sri Lanka for the last 50 years.

---

179 The four curves L1, L2, L3 and L4 are defined as follows:

$L2 = -2 * 10^{-16} * I + 2 * 10^{-12} * I - 9 * 10^{-9} * I + 2 * 10^{-5} * I - 0.0001$

$L1 = 0.9 * L2$

$L3 = 1.2 * L2$

$L4 = 1.4 * L2$

7.2 Scenarios for the future

There is uncertainty about how the transport sector will evolve in Sri Lanka, not least because of the uncertainties of public policy that will have a significant influence. While population density is one of the key determining factors, over which there may be little influence, the Singapore experience shows clearly the importance of a consistent government policy pursued over long time periods.

To illustrate the potential long-term impacts of the interaction of government policies, economic growth, and the main characteristics of the transport system, we have developed four general scenarios for Sri Lanka. These roughly span the range of what is observed in other countries as economic development proceeds—bounded, at one extreme, by the vehicle ownership picture in the United States, and, at the other, by that of Singapore and Hong Kong.[180] Each of the following scenarios reflects a set of assumptions about government policy in the sector.

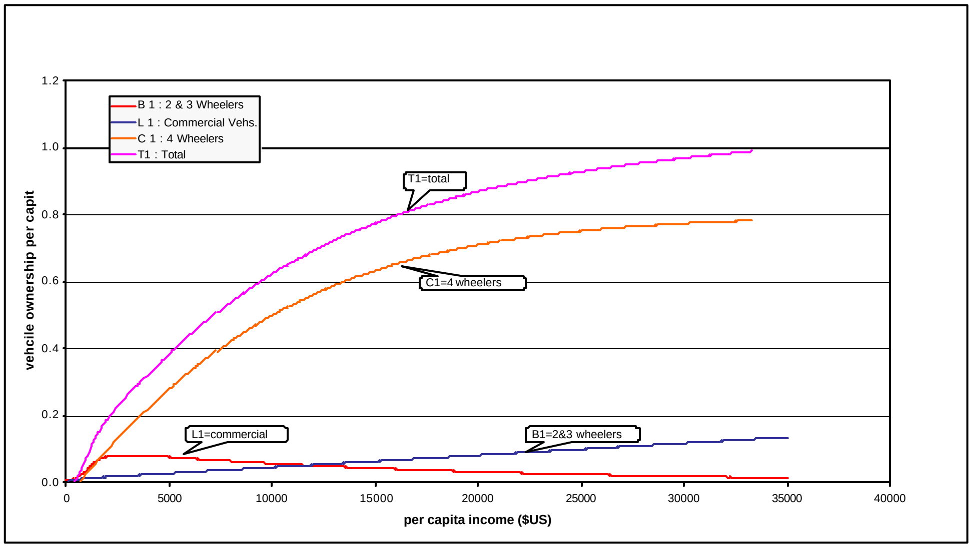
Transport policy option 1: uncontrolled

Under this scenario it is assumed that there would be no restrictions of vehicle ownership or use placed through vehicle and fuel taxes. This simulates the growth of vehicle ownership similar to trends seen in the United States. This is represented by the curves B1 (low tax on two-wheelers), C1 (very low—almost no—tax on cars and vans) and implies that public transport would rapidly diminish in importance denoted by curve L1. This cannot be said to be suitable for Sri Lanka, as its population density is high and the public transport penetration is currently very good. However, continuous neglect of public transport and ignoring the need for facilities for non-motorized travel can shift the growth rates toward these trends. The set of curves (B1, C1, L1) that illustrate this scenario, together with the total vehicle ownership (T1), is given in Figure 7.5.

---

180 For a full discussion of the history and experience of Singapore's efforts to control congestion, see, e.g., R. S. Toh, "Experimental Measures to Curb Road Congestion in Singapore: Pricing and Quotas," *Logistics and Transportation Review*, 28:3, pp.289-317, 1996.

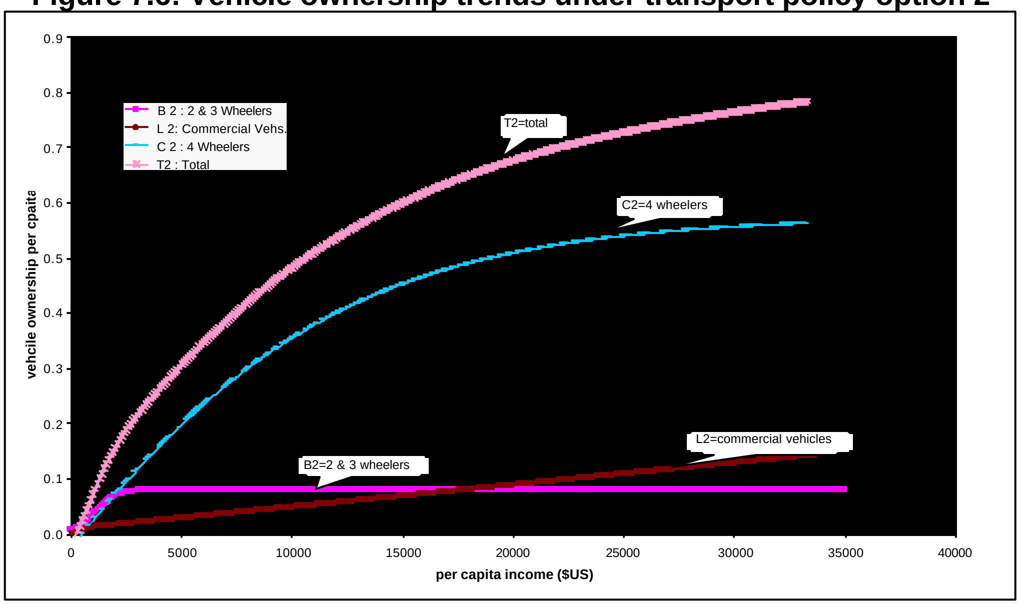
Figure 7.5: Vehicle ownership trends under transport policy option 1



Transport policy option 2: control of four-wheelers

In this scenario it is assumed that four-wheel vehicles (particularly cars and vans) would be somewhat controlled through marginally higher taxes than those of the United States. However, this situation implies that, although cars and vans are discouraged, two- and three-wheeled vehicles are encouraged in place of public transport. This situation is represented by curves B2 and C2. The dominant mode of transport would still be public transport. The corresponding curve for commercial vehicles is designated as L2. This is perhaps the scenario that closest represents the immediate past performance of the transport sector in Sri Lanka over the last 20 years. The continuation of this scenario is illustrated in Figure 7.6.

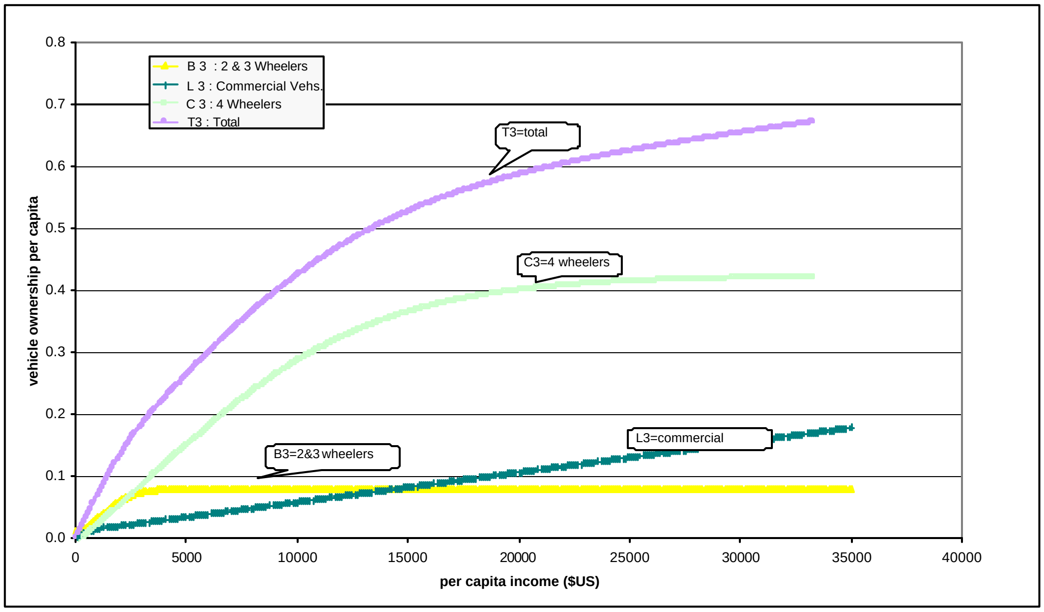
Figure 7.6: Vehicle ownership trends under transport policy option 2



Transport policy option 3: control of two- and four-wheelers

This option, represented by curves B3 and C3, means much higher taxes on all modes of private vehicles, but with an alternative emphasis on maintaining a good public transport system. This is illustrated in Figure 7.7 and closely represents Sri Lanka's ownership patterns prior to liberalization of the economy.

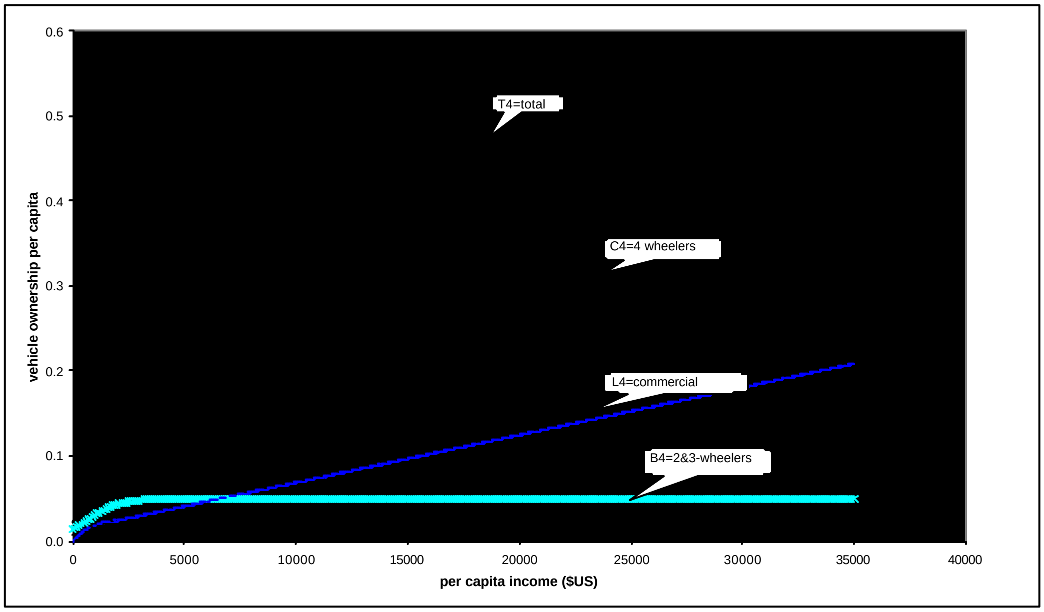
Figure 7.7: Vehicle ownership trends under transport policy option 3



Transport policy option 4: restraint of private vehicles

This option represents a more rigorous restraint of motor vehicles by physical and fiscal measures such as permits, quotas, and tolls. These are similar to measures presently employed in countries like Singapore and Hong Kong. In this instance, the curves to be used for forecasting would follow B4 and C4. Public transport would have the highest growth rates illustrated by curve L4, as shown in Figure 7.8.

Figure 7.8: Vehicle ownership trends under transport policy option 4



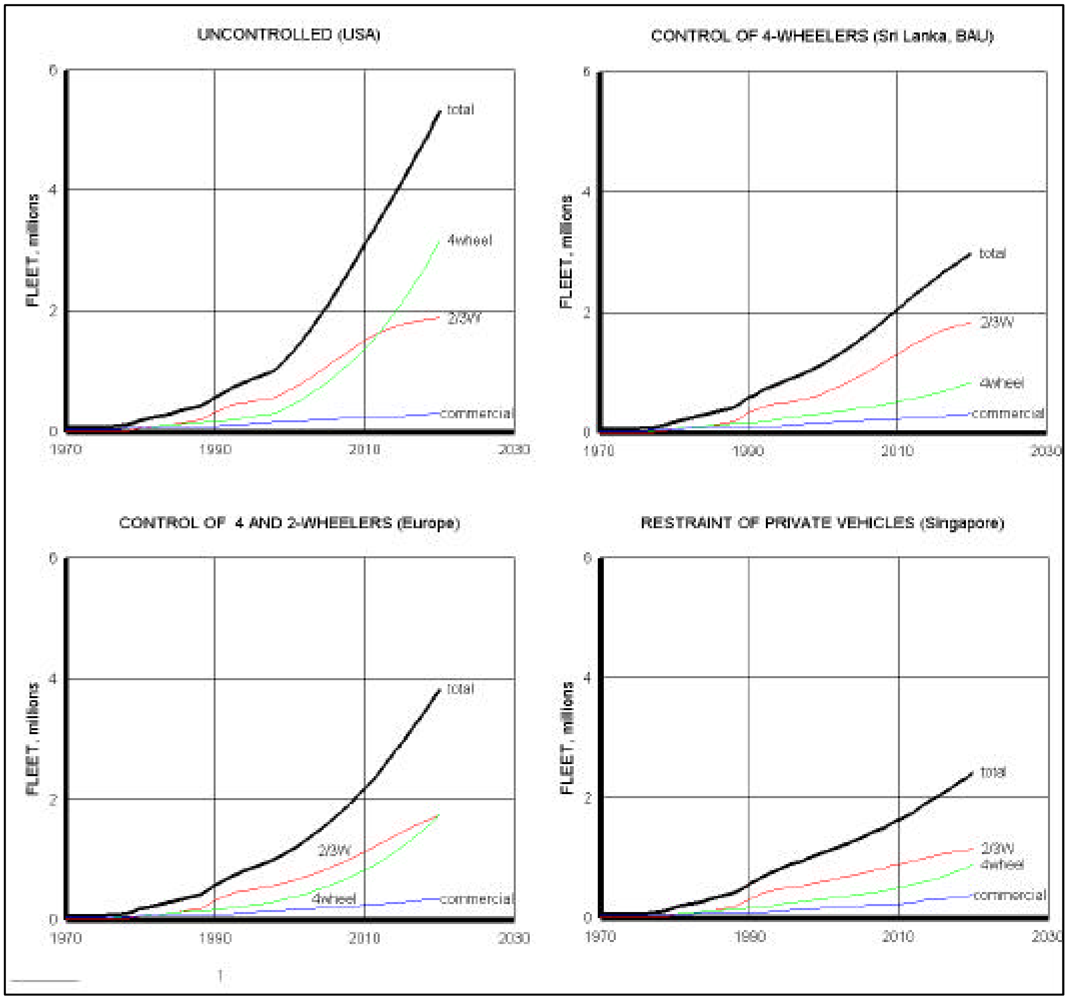
7.3 Forecasts

Each of these four vehicle fleet scenarios has been calculated for each of three different scenarios for economic growth:[181]

- Optimistic (6.5 percent annual GDP growth): shown in Figure 7.9
- Moderate (5.0 percent annual GDP growth): shown in Figure 7.10
- Low (4.5 percent annual GDP growth): shown in Figure 7.11

[181] The per capita incomes have been estimated by deducting from the GDP growth rates assumed as above, the annual population growth of 1 percent for the period 2000-2010 and 0.5 percent beyond.

Figure 7.9: Vehicle fleets: high economic growth (6.5 percent average annual GDP growth)



The fleet of two- and three-wheelers is estimated to peak at around 1.8 million units under each of the three economic growth rate cases if the tax levels on two- and three-wheelers is low, as at present. For higher tax levels, the fleet is estimated to increase to these same levels though at a slower rate. It is only under restraint conditions (Singapore) that a lower number of two- and three-wheeled vehicles could be envisaged at around 1.3 million units.

In the case of four-wheelers (cars and vans), the largest estimate is for 3.2 million by the year 2020 under the uncontrolled (US) scenario, where public transport deteriorates and there is no control of the growth of private vehicles. The estimate for the year 2020 reduces progressively with increasing tax levels and reducing economic growth rates to a low projection of 600,000 units by the year 2020.

The fleet of commercial vehicles is estimated to be between 250,000 and 325,000 units, with the higher levels to be realized under the combination of higher economic growth and improved public transport policy that characterize the European and Singapore scenarios.

Figure 7.10: Vehicle fleets: moderate economic growth (5 percent average annual GDP growth)

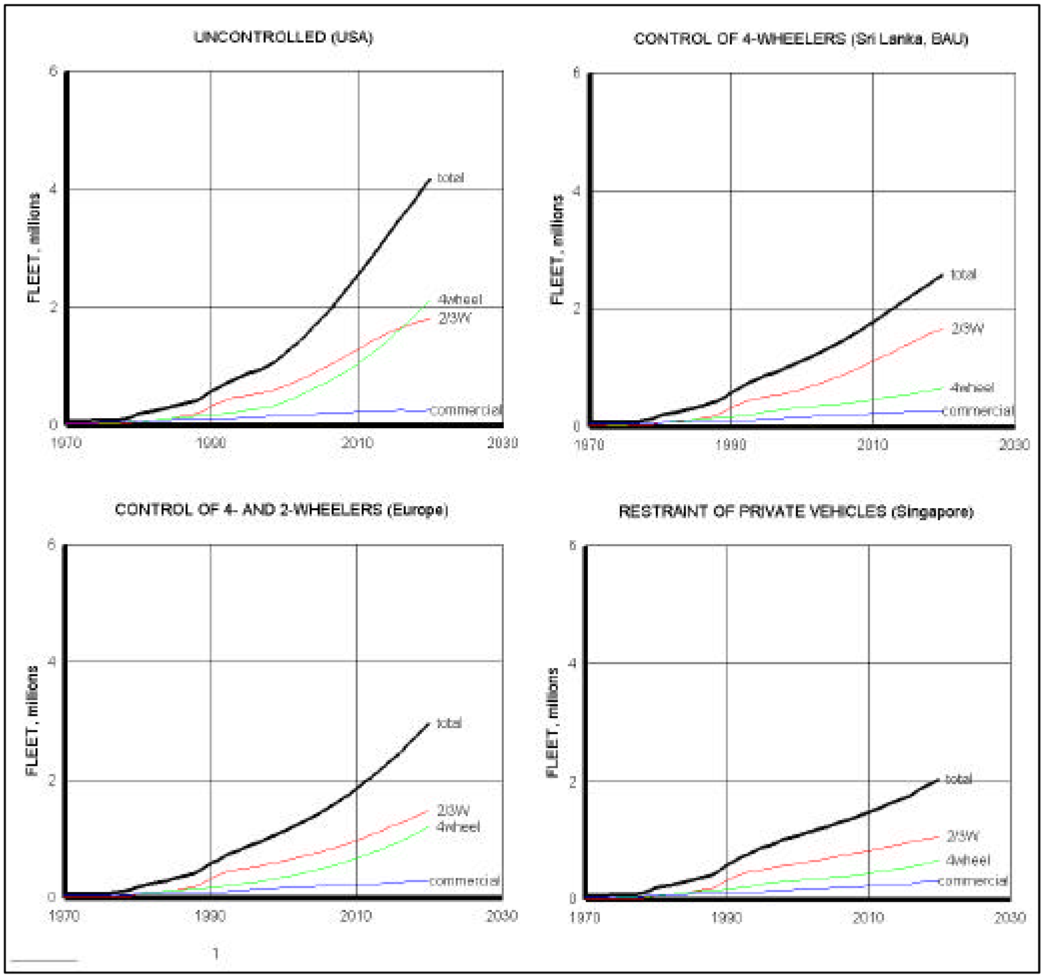
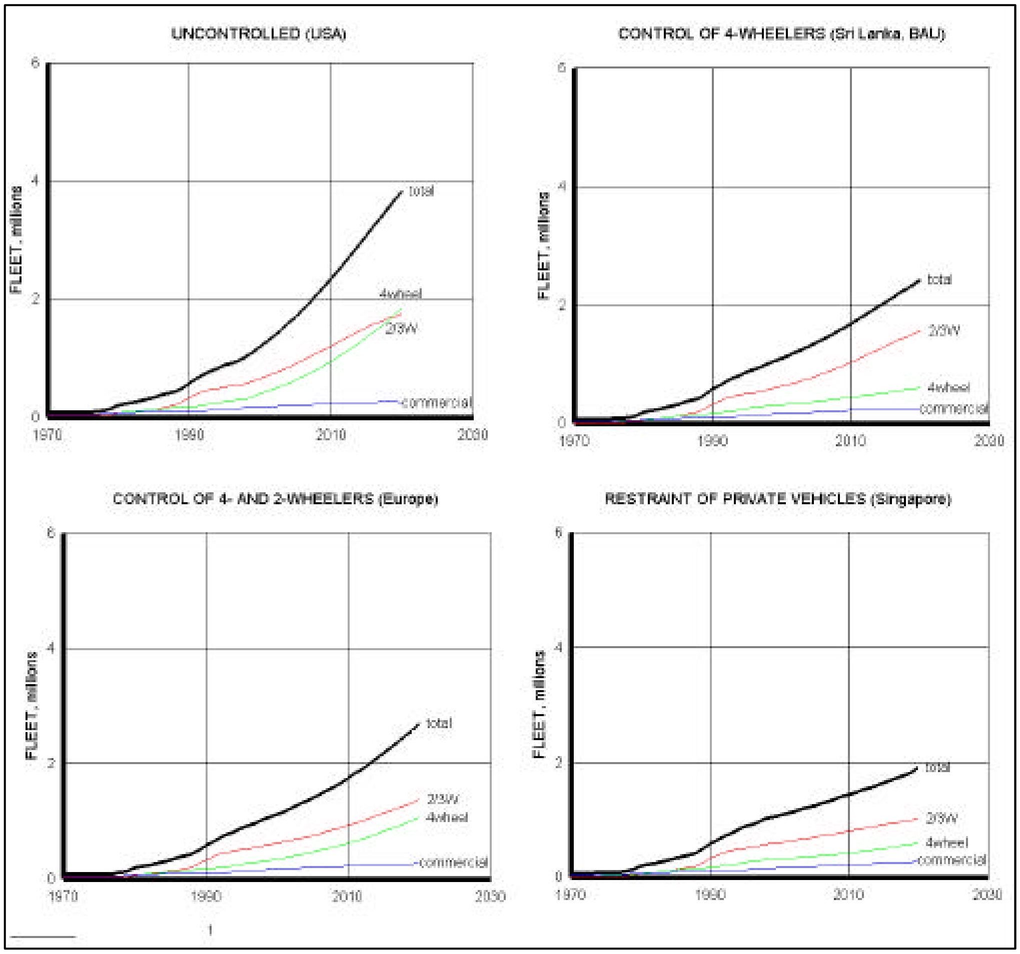


Figure 7.11: Vehicle fleets: low economic growth (4.5 percent average annual GDP growth)



7.4 Policy implications

Table 7.1 shows the operational fleet in the year 2020 under the various economic and transport policy scenarios. The baseline scenario— corresponding to an average annual 5 percent GDP growth rate and a continuation of the present policies—implies a roughly two-and-a-half-fold increase in vehicles over the next 20 years, to 2.5 million from the present vehicle fleet of 1.1 million.

Table 7.1: Operational vehicle fleet (all vehicles) -year 2020

	Transport scenario			
	Uncontrolled (USA)	*Control of 4-wheelers (Sri Lanka, BAU)*	*Control of 2- and 3-wheelers (Europe)*	*Restraint of private vehicles (Singapore)*
6.5% GDP growth	5,340,173	2,984,790	3,833,764	2,434,594
5% GDP growth	4,195,480	**2,587,242**	2,974,857	2,039,929
4.5% GDP growth	3,831,565	2,424,144	2,703,996	1,921,676

Note: Reference scenario in **Bold**

Operated vehicle kms (Table 7.2) show a somewhat smaller increase, from the present 11.8 million km to 20.3 million—implying that the average km/vehicle decreases over time. This is a trend already observed in Sri Lanka as well as in other countries.

Table 7.2: Vehicle kms operated (all vehicles-million kms) -year 2020

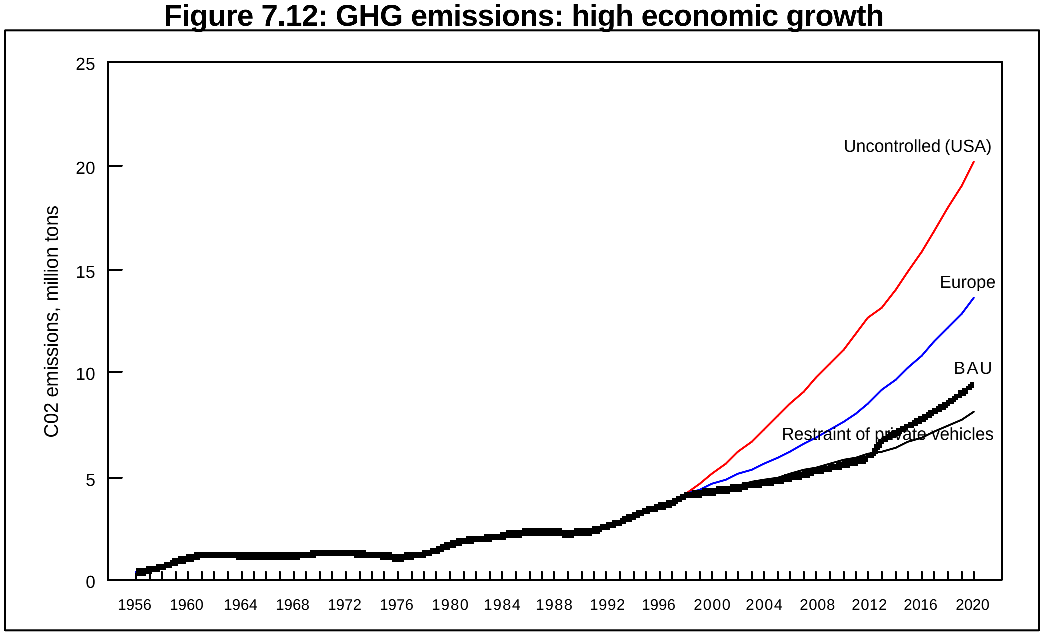
	Transport scenario			
	Uncontrolled (USA)	*Control of 4-wheelers (Sri Lanka, BAU)*	*Control of 2- and 3-wheelers (Europe)*	*Restraint of private vehicles (Singapore)*
6.5% GDP growth	56,185	24,528	37,795	22,774
5% GDP growth	40,736	20,388	27,378	17,592
4.5% GDP growth	36,198	18,856	24,343	16,245

Attainment of this future will require significant efforts by the government to ensure the viability of public transport, for failure to do so would inevitably result in movement toward option number 3, with even higher, European-style levels of auto ownership, anda predictable worsening of congestion in the Colombo area. The most important question that arises concerns the link between the transport scenario and economic growth: would the higher levels of congestion associated with the European scenario of vehicle ownership make the achievement of higher rates of economic growth less likely?

GHG emission implications

The environmental implications are no less profound. In Figure 7.12 we show GHG emissions from the transportation sector for the four transportation futures for the high economic growth case.

Figure 7.12: GHG emissions: high economic growth



The emissions in year 2020 in terms of per capita and per unit of GDP are shown in Table 7.3.

Table 7.3: CO_2 emissions from the transportation sector, 2020

			America	*BAU*	*Europe*	*Singapore*
GHG emissions (1)						
High (6.5%)		[mill tons]	47.2	35.1	40.6	36.5
Medium (5%)		[mill tons]	35.8	28.3	31.7	29.1
Low (4.5%)		[mill tons]	32.1	25.8	28.6	26.5
GDP growth rate:	GDP/capita					
High (6.5%)	8572	[$USbill]	223	223	223	223
Medium (5%)	6274	[$USbill]	163	163	163	163
Low (4.5%)	5649	[$USbill]	147	147	147	147
KgCO2/$GDP(@ppp)						
High (6.5%)		[Kg/$GDP]	0.21	0.16	0.18	0.16
Medium (5%)		[Kg/$GDP]	0.22	0.17	0.19	0.18
Low (4.5%)		[Kg/$GDP]	0.22	0.18	0.19	0.18
GHG emissions per capita						
High (6.5%)		[Kg/capita]	1.81	1.35	1.56	1.40
Medium (5%)		[Kg/capita]	1.38	1.09	1.22	1.12
lLw (4.5%)		[Kg/capita]	1.23	0.99	1.10	1.02

(1) Including power sector emissions

While these GHG emissions show significant increases over their present levels, when expressed in terms of emissions per capita, or emissions per unit of GDP, Sri Lanka will still be far below the present world averages, as shown in Table 7.4. Even under the most pessimistic scenario from the point of view of increasing road congestion, at least GHG emissions would not increase to a point where Sri Lanka's ability to benefit from carbon offset trading would be compromised.

Table 7.4: International comparisons: GHG emissions per capita and per GDP

	GHG/capita	*$KgCO_2$/ $GDP*	*$kgC0_2$/$GDP PPP adjusted*
1995			
Sri Lanka	**0.34**	**0.63**	**0.13**
Pakistan	0.63	1.62	0.32
India	0.86	2.17	0.73
Indonesia	1.17	1.37	0.34
China	2.51	4.72	0.92
France	6.23	0.29	0.34
Former USSR	8.48	5.22	2.61
Japan	9.17	0.36	0.46
Germany	10.83	0.49	0.63
USA	19.88	0.85	0.85
World average	**3.92**	**0.94**	**0.75**
2020 Sri Lanka			
High economic growth (6.5%pa)	1.35-1.8		0.16-0.21
Medium (5%)	1.09-1.38		0.17-0.22
lLw (4.5%)	1.00-1.23		0.18-0.22

1995 data: IEA CO_2 database

2020 Power sector emissions estimated at 22 million tons (see P. Meier and M. Munasinghe, *Global Overlay of GHG Mitigation Options in the Sri Lanka Power Sector*, Environment Department, World Bank, Oct. 1999): these are added to the transportation sector emissions shown in Table 7.4

8

Reduction of Road Congestion

In this section we examine two options expressly targeted at the reduction of road congestion. Following the model of similar schemes in Europe and Singapore, in Section 8.1 we discuss the option of a congestion toll on vehicles entering the central Colombo area during peak hours, and in Section 8.2 we discuss the reintroduction of school bus service: since each bus would replace five vans presently ferrying children to school, this would relieve congestion during peak hours.

The measures analyzed here represent a sample of a much larger set of anti-congestion measures that might be considered.[182] Others include

- Bus lanes[183]
- More one-way streets, possibly retaining a "contra-flow" bus lane (this might be done with Galle and Duplication Roads, with, say Galle Road taking southbound traffic, plus a contra-flow northbound bus lane, and Duplication Road non-bus northbound traffic)[184]
- Truck bans during certain hours.[185]

---

[182] We may also take brief note of some options, which the international experience suggests are ***not*** likely to be successful. For example, Mexico City tried to restrict usage of private vehicles on one or two days a week depending upon licence plates. Many households responded by buying second vehicles, which tended to be older (and more polluting), with little impact on congestion. See World Bank (1992).

[183] A study of bus lanes is underway at the University of Moratuwa.

[184] Contra-flow bus lanes have been successfully used in Bangkok, where they have been found much easier to enforce than in the case of "with-flow" lanes (World Bank, 1994). They have also been used to great effect in London (e.g., in the case of Piccadilly, which carries east-bound traffic plus a contra-flow westbound bus lane). In London "with-flow" bus lanes are frequently blocked by parked delivery vehicles, while "contra-flow" bus lanes are very rarely obstructed.

[185] This strategy is widely employed in other Asian cities. Delhi enforces a ban on heavy lorries from 6 a.m. to 9 p.m. (which is enforced by checkpoints on the main arterial roads at the city boundaries); Bangkok bans all truck traffic from the city centre during morning and evening peak hours and heavy trucks only

8.1 Congestion pricing[186]

As noted above, urban traffic congestion, particularly in the rapidly growing major metropolitan areas of developing countries, is imposing increasing economic and environmental costs. Traditional methods of curtailing congestion, particularly on the supply side, have largely failed: reduction of congestion following expansion and improvements of roads is typically short-lived,[187] and is constrained by increasingly tight fiscal, physical, and environmental constraints. However, demand side options, particularly pricing,[188] offer a more promising long-term solution, as evidenced by the successful pricing scheme in Singapore,[189] one of the few large Asian cities free of major road congestion.[190]

Is there traffic congestion in Colombo?[191] Whatever the anecdotal evidence, there is a rigorous definition: congestion can be said to occur at the point at which an additional vehicle entering a road segment causes the normal speed of other vehicles to decrease, thereby imposing a cost not only on that additional vehicle, but on *all* vehicles using that road segment. Based on a definition of congestion as occurring whenever average speeds of 30km/hr cannot be maintained, the Colombo Urban Transport Study[192] estimates the costs of congestion at Rs 11 billion/year.[193] This is clearly significant and, absent policy reforms, will inexorably rise.

---

during weeknights and weekends (World Bank, 1994); Beijing has similar restrictions (and presently also bans motorcycles).

186 This section was prepared by D. Jayaweera, Transportation Policy Studies Centre, Colombo

187 As noted by Jayaweera, *op. cit*., "every large congested city harbours a reservoir of potential peak period drivers (latent demand)—who are deterred from adding to congestion only by congestion itself. Once a new highway eases congestion, these drivers, who may now be travelling in other modes, or at other times of the day—will move into the empty spaces, thus driving congestion levels back up."

188 Jayaweera, *op. cit*., notes the distinction between road pricing and congestion pricing as follows: Road pricing refers to a well-defined charge for particular trips at well-specified places or times—conventional road tolls being the typical example (and in general unrelated to the specific problem of congestion externalities). On the other hand, congestion pricing refers to schemes in which the price charged is targeted to the users who cause the greatest problem—namely those who travel at already congested peak hours.

189 Peak hour speeds in Singapore are typically 25 km/h during the evening peak, and 30 km/h in the morning peak, compared to speeds of 10 km/h in New York, 12 km/h in London, and less than 10 km/h in Bangkok (Chin, 2000).

190 The international experience with congestion pricing, including that of Hong Kong and Singapore, as well as several European cities, is reviewed in Jayaweera (1999).

191 See also D. Jayaweera, *Is There Significant Travel Congestion in Colombo?* paper presented at the Annual Meeting of the Chartered Institute of Transport, Colombo, October 1997.

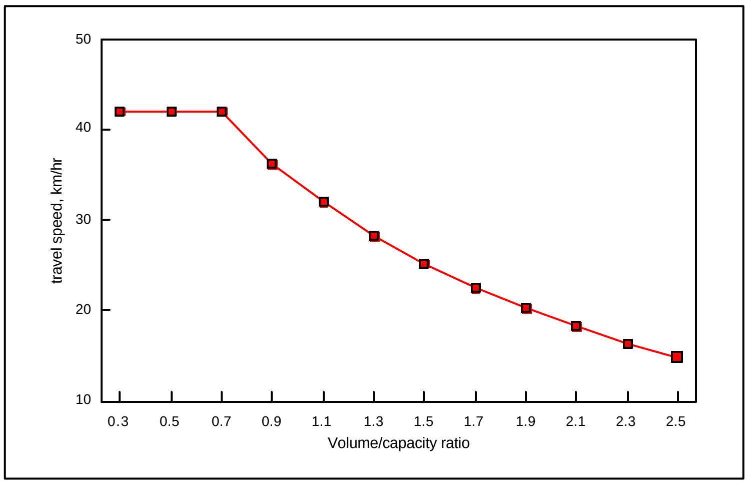
192 W. S. Atkins and University of Moratuwa, *A Masterplan for the Development of Transport in the Colombo Metropolitan Region*, Colombo Urban Transport Study, Stage 2: Working Paper 25, June 1999.

193 This represents about 1.5 percent of the 1996 GDP of Rs768 billion.

Already average speeds in the GCMR have dropped to about 22 kms/hour, from 10-15 km/hour in the center to around 45 km/hour at the periphery of the GCMR.

The relationship between speed and the volume/capacity (V/C) ratio is illustrated in Figure 8.1, for a road whose design speed is 42 km. With increasing V/C ratio, speeds decrease and travel times increase, a decrease that normally begins once V/C ratios are above 1; however, in Sri Lanka, the usual assumptions on road design—upon which the calculations of this curve depend—are not present. Pedestrians on the right–of-way, and spillover of activities normally occurring on the hard shoulder, and so forth, result in declining speeds already at a V/C ratio of 0.7.

Figure 8.1: Relationship of travel speed to the volume/ capacity ratio (for a 42-km/hr design speed)

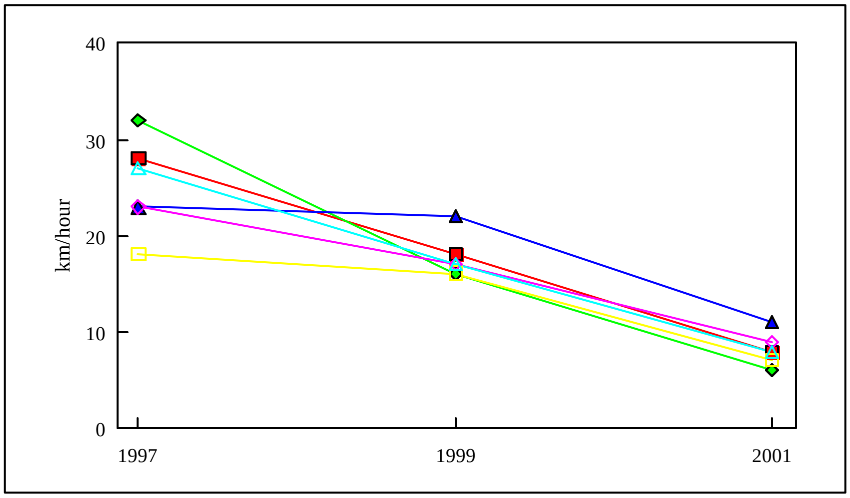


Source: Based on data in Jayaweera, *op. cit.*

The rapid decline of average speeds on many of Colombo's radial roads over the past few years is shown in Figure 8.2.[194]

[194] These new travel time surveys require that the V/C curves (as in Figure 8.1) be recalibrated. However, this recalibration work is still underway at the TSPC, and the new curves were not available to our study.

Figure 8.2: Reduction in average speeds 1997-2001: main radial roads, peak hour



Source: Table 1.1

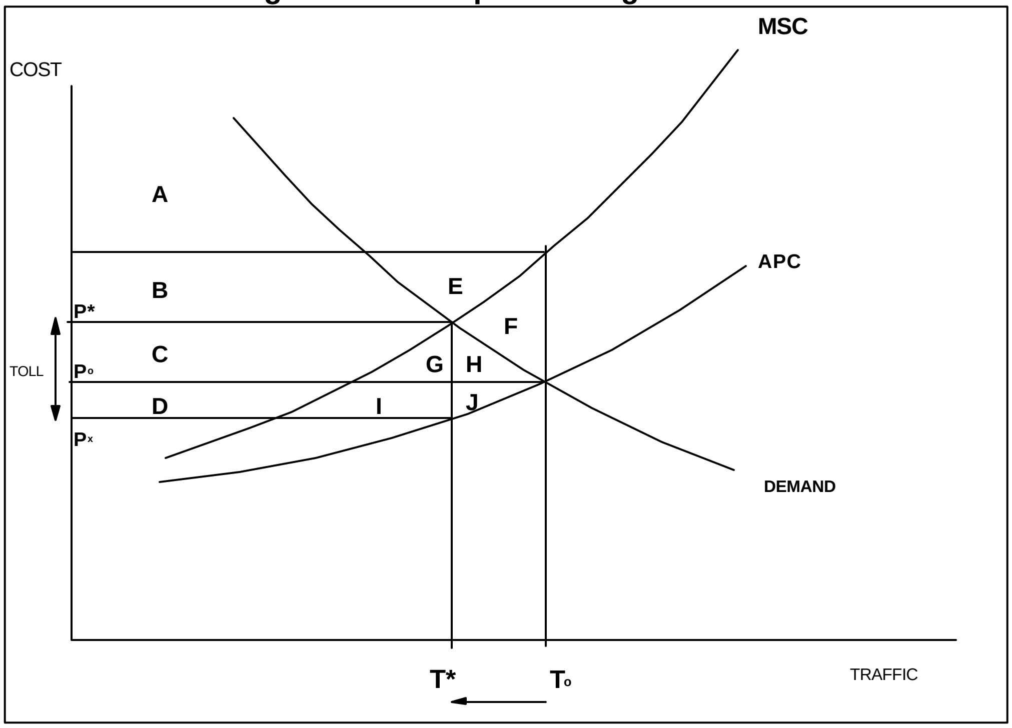
A microeconomic analysis of congestion pricing in Colombo was undertaken by Jayaweera.[195] That study derived the optimal value of a congestion toll by setting it equal to the difference between marginal social cost and average private cost (see section on theory, below). In this section we extend this microeconomic work to a calculation of the aggregate economic effects, and to an estimation of the related environmental benefits.

Theory

The theory of congestion pricing is straightforward, and is illustrated in Figure 8.3. Initially, the traffic volume is $\boldsymbol{T_o}$, which reflects the intersection of the demand curve with the average private cost curve (***APC***). However, the social optimum lies at the intersection of the social cost curve (***MSC***) and the demand curve, with the smaller traffic volume ***T*.*** The social cost curve includes the environmental costs associated with the air emissions, plus that part of road maintenance costs incurred by government that is not recovered by fuel taxes (that are included in the **APC**).

[195] D. Jayaweera, *Effective Steps Towards Traffic Calming in Developing Countries: A Case Study for Metropolitan Region of Colombo in Sri Lanka*, Ph.D. Thesis, MIT, Nov. 1999.

Figure 8.3: The optimal congestion toll



The optimal toll, ?? is then the difference between ***P**** and ***P***$_{x,}$ i.e., the difference between the ***MSC*** and ***APC*** at the optimal traffic level.

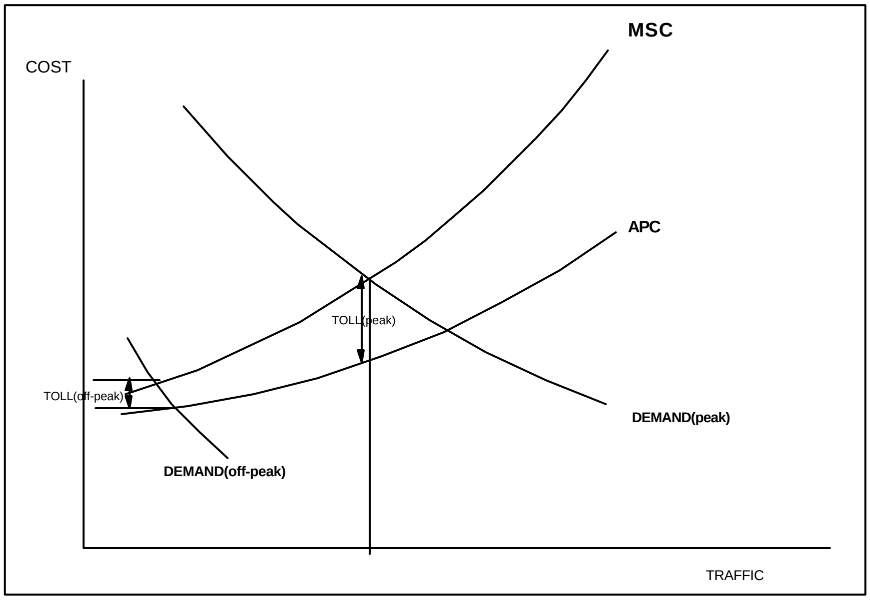
The net economic benefits follow from consideration of the various areas indicated in Figure 8.3. Consumers suffer the loss of surplus given by the area **[C+G+H**]. The social costs reduce from **[B+E+F+H+G+C**] to **[C+G+D+I**], the latter exactly equal to the toll revenue. It therefore follows that the net economic (social) benefit of the toll is **[B+E+F]-[D+I+J],** which is necessarily greater than one.[196] In the model we make a much more detailed disaggregation of the various elements of vehicle operating costs and environment, but the principles remain the same.[197]

As we shall see below, the traffic demand during off-peak hours is typically very much smaller, implying that the off-peak demand curve lies far to the left (Figure 8.4). The optimal toll would be correspondingly smaller, if not zero, as indicated in Figure 8.4. In fact, the present situation is that before 7 a.m., and after 9 p.m., the actual traffic is well below the capacity, which means that the optimal toll for this period is zero.

[196] Except in the (unlikely) case of inelastic demand curves, in which case the loss of consumer surplus is exactly equal to the toll revenue, in turn exactly equal to the social costs not captured in private costs.

[197] See e.g. Table 8.4, below.

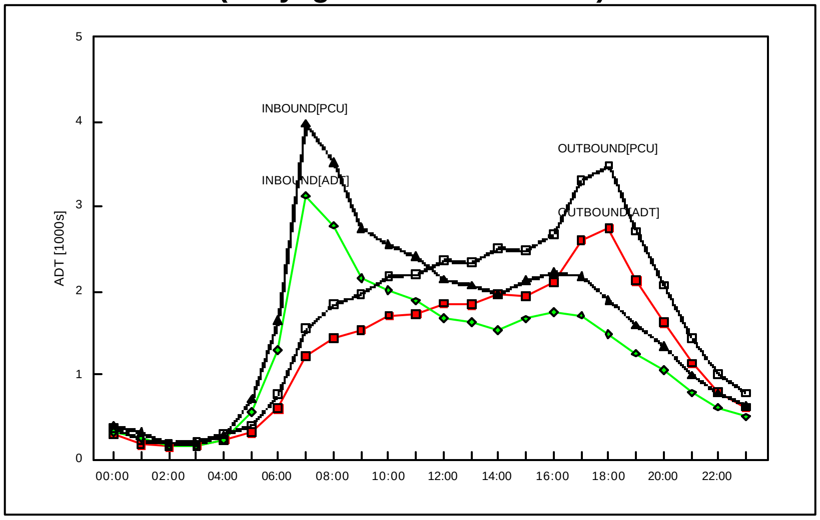
Figure 8.4: Peak v. off-peak



The colombo traffic situation

The bulk of the traffic entering the city of Colombo enters on main radial seven roads (see Map 8.1), which all connect with the central business district (CBD). These roads all exhibit very strong peak-hour traffic: Figure 8.5 shows typical inbound and outbound patterns.

Figure 8.5: Hourly average daily traffic by hour for the A3 (Peliyagoda-Puttalam Road)



Source: Traffic Data from the traffic and planning division of the RDA and PCU factors from the PCU study, TSPC, 1993; and D. Jayaweera, *Effective Steps Towards Traffic Calming, op. cit.*

PCU equivalents as per Table 8.1.

Map 8.1: Colombo's main radial roads

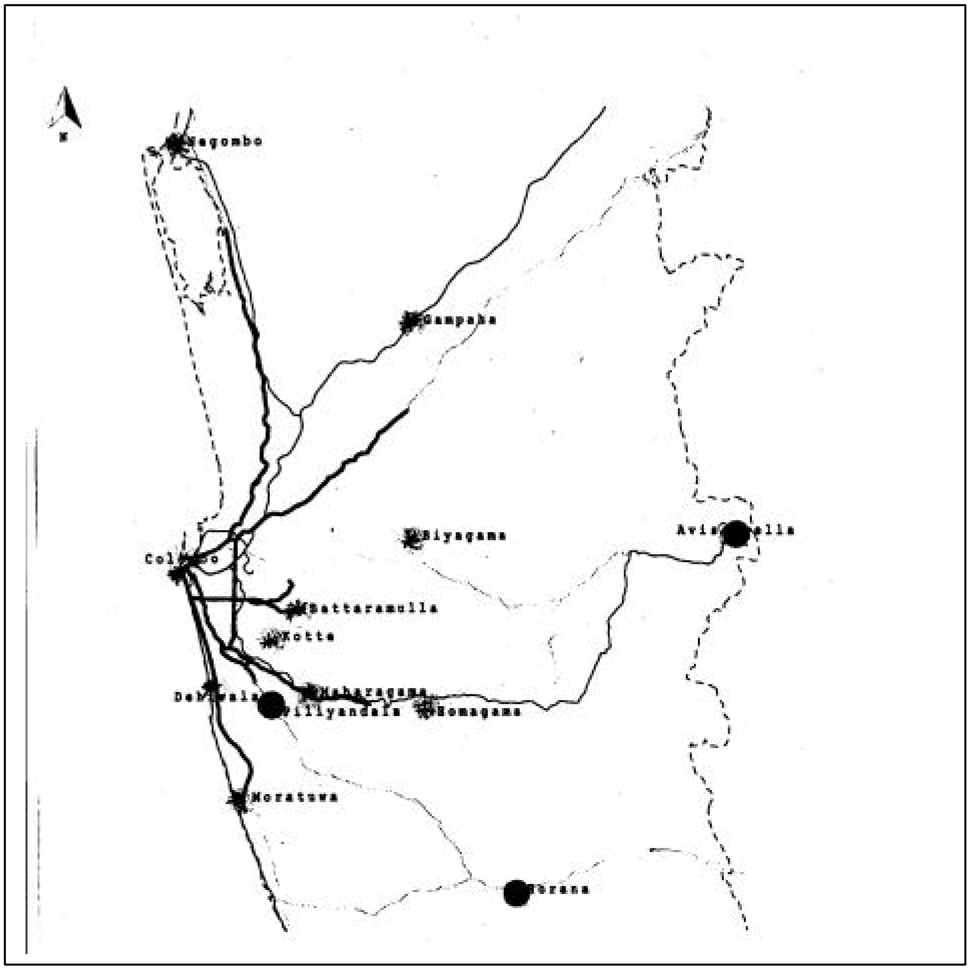
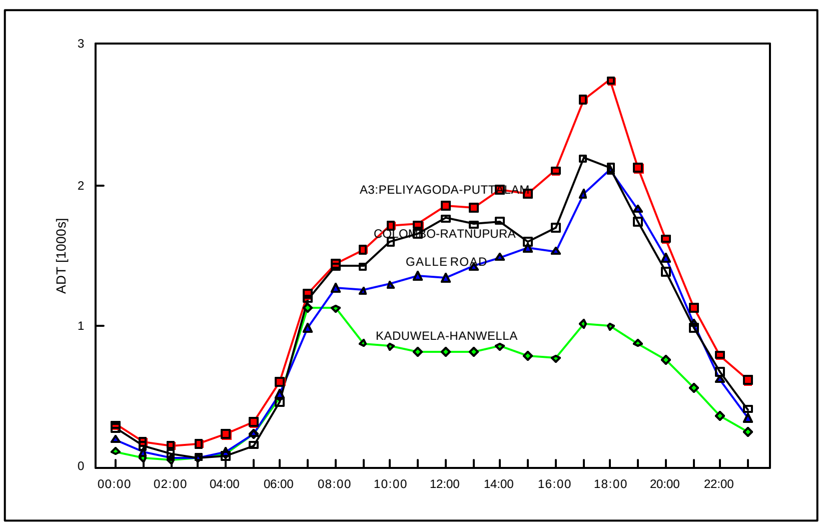


Figure 8.6: Comparison of traffic patterns on radial roads (outbound direction)



Assumptions and model calculations

For each hour of the day the traffic is converted to Passenger Car Units (PCU)[198] (Table 8.1), and compared to the design capacity per lane (see Table 8.2), from which we calculate the volume-capacity ratio in each hour, $\mathbf{VC_t}$ i.e.,

$$VC_t ? \frac{PCU_t}{PCU(design)}$$

Vehicle speeds can then be calculated using the travel speed to volume/capacity ratio given in Figure 8.1.[199]

Table 8.1: PCU equivalents and average VOC (radial roads)

	PCU equivalents	*Elasticity*	*Average VOC, Rs/km*
Passenger car	1	-0.349	15.41
Small truck/van	1.2	-0.230	10.29
Medium truck	1.4	-0.443	17.32
Heavy truck	2.2	-0.260	18.44
Medium bus	1.2	-0.150	18.40
Large bus	1.6	-0.130	20.35
Motorcycles	0.7	-0.462	5.72

Source: Jayaweera, Effective Steps Towards Traffic Calming, op. cit., Table 6.1.

198 PCU measures the amount of road capacity required by a particular vehicle type in comparison to that required by a passenger car. The PCU value generally depends upon traffic conditions, and may therefore be different for inner city, radial, and trunk roads. Values of PCU will also depend upon driver and pedestrian behavior, and the condition of roads and vehicles. See Jayaweera, *op. cit*., for detailed discussion of the determinants of PCU values.

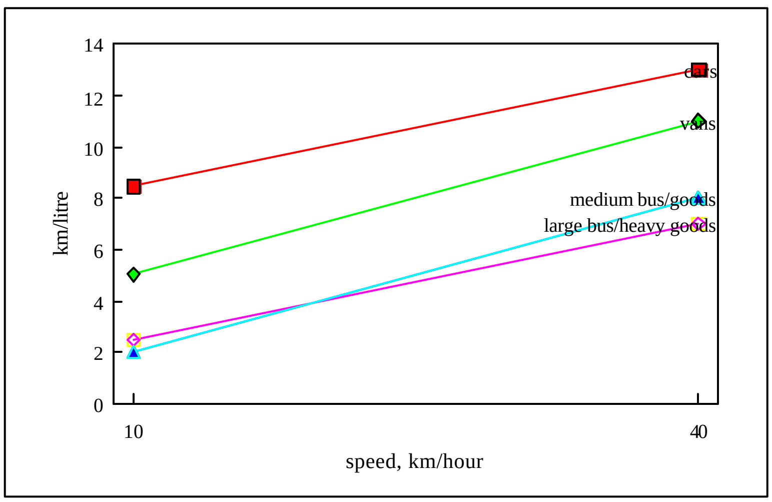
199 In the model, this is calculated by a polynomial equation fitted to this curve, namely, for a 42 km/h design speed, *speed (kmph)* = $\mathbf{52.2 - 29.4\ VC + 5.74\ VC^2}$

Table 8.2: Road data

		GDP growth	*Traffic growth*	*Lanes per direction*	*Assumed trip length, km*	*Design capacity PCU/lane*
Peliyagoda - Puttalam Road (Welisara to Puttalam)	outbound	1.057	1.046	2	5.7	984
	inbound	1.057	1.046	2	5.7	984
	both directions	1.057	1.049	1	5.7	652
Colombo - Galle	outbound	1.050	1.040	2	5.7	984
	inbound	1.050	1.040	2	5.7	984
Colombo – Ratnapura - Beragala Road	outbound	1.059	1.052	2	5.7	1093
	inbound	1.059	1.052	2	5.7	1093
Colombo - Horana Road	both directions	1.058	1.048	1	5.7	734
Kollupitiya – Sri Jayawardanapura Road	outbound	1.052	1.049	2	5.7	984
	inbound	1.052	1.049	2	5.7	984
Colombo - Kandy Road	outbound	1.056	1.045	2	5.7	1253
Colombo - Kandy Road	inbound	1.056	1.045	2	5.7	1253

Given vehicle speed and the average trip length, one can then calculate the value of time, fuel consumption, and vehicle operating costs, from which also follow emissions. Figure 8.7 shows the linear approximations used in the model to relate fuel consumption to vehicle speed, extrapolated from field data collected by TSPC in February 2001.

Figure 8.7: Fuel consumption v. vehicle speed



Source: Table 1.1 (in turn from TSPC data)

In the case of the toll, the number of trips is adjusted according to the assumed elasticity to vehicle operating costs (discussed above in Section 5.3), based on average VOCs for each vehicle type. Thus the change in number of trips, *?* ***N*** is given by

$$\frac{Vkm(toll)}{Vkm(o)} ? \; ?\frac{VOC(o) ? ?*}{VOC(o)}?^{?}$$

$$?* ? \frac{?}{2L}$$

$$Vkm(o) ? \; N(o)2L$$

$$Vkm(toll) ? \; N(toll)2L$$

and $?N \; ? \; N(o) ? N(toll)$

where $??$= daily toll

$?*$ = toll per km

L = assumed one-way trip length

$VOC(o)$ = vehicle operating cost per km

$?$ = elasticity (as given in Table 8.1)

Table 8.3 shows the graduated toll proposal of Jayaweera and the flat rate proposal of the Colombo Municipal Council.[200] Jayaweera's proposal for a graduated toll is based on his theoretically rigorous analysis that takes into account the differences in externality costs imposed by different vehicle classes—and is used in this report as the reference case. Clearly, there is some uncertainty about whether the response to a toll will conform to the historically estimated responses to changes in VOC.[201] Figure 8.8 shows typical changes in road speeds in response to a toll, as calculated in our model using the elasticities of Table 8.1.[202]

Table 8.3: Proposed tolls (daily equivalent)

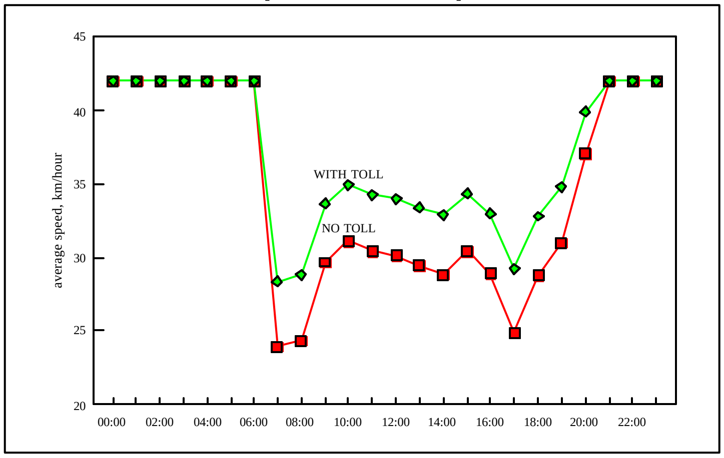
	Jayaweera	*Colombo Council*
Car	25	8
Light truck	20	8
Medium truck	20	8
Heavy truck	40	8
Medium bus	0	
Light bus	0	
Motorcycles	10	8

200 See Annex 8.1. This proposal anticipates a monthly sticker of Rs 200, based on 25 days/month, i.e., Rs 8/day (though the proposal states the daily toll is Rs10 "with a 20 percent concession")

201 This uncertainty is not limited to Colombo: the assumption that the proposed daily congestion charge for central London of 5 pounds would reduce traffic by 15 percent is highly controversial.

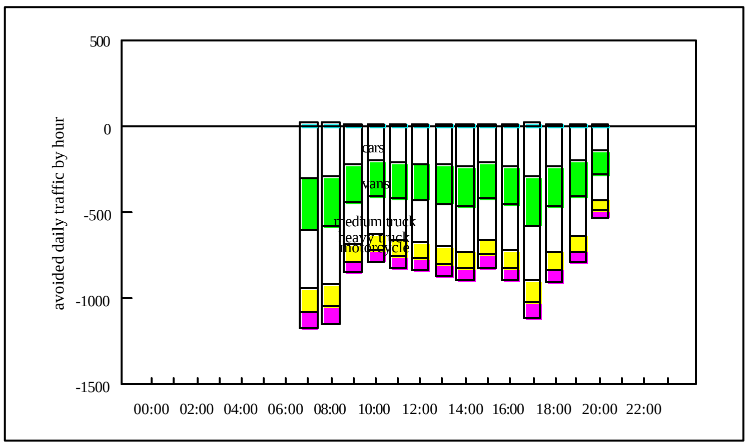
202 It is evident that the calculation of expected revenue by the Colombo Municipal Council (see Annex 8.1) does not take into account any reduction of traffic due to the elasticity effect—indeed, from their perspective the proposal is entirely one of raising revenue for road maintenance.

Figure 8.8: Impact of congestion toll on speed (A3, outbound)



The corresponding pattern of avoided trips is shown in Figure 8.9. There are a small number of *additional* bus trips induced by the toll—a ratio of roughly one additional bus trip for every 40 *avoided* motorcycle or passenger car trips[203]—but, clearly, these barely affect the overall savings.

Figure 8.9: Avoided traffic (base case tolls, A3)



Economic analysis

The calculation of the main economic and financial flows is straightforward, but care must be taken to account for welfare losses that depend upon behavioral assumptions in response to the toll. In the case of passenger trips (cars, vans, and motorcycles), there are four potential responses:

1. Make the trip at the usual hour, and pay the toll
2. Forego the trip entirely

203 Assuming average occupancies of 28 passengers in medium buses, and 45 in large buses.

3. Take public transport (i.e., shift from car, van, or motorcycle to buses)[204]
4. Avoid the toll by entering the city before 7 a.m., remain in the city, and leave the city after the toll period ends at 8 p.m. However, since the toll will not be collected at booths, but instead require the display of stickers during the peak hours, the requirement to be parked (and not be observed on the road) is onerous, and it may safely be assumed that the effect of this response would be quite small (and is ignored in the model).

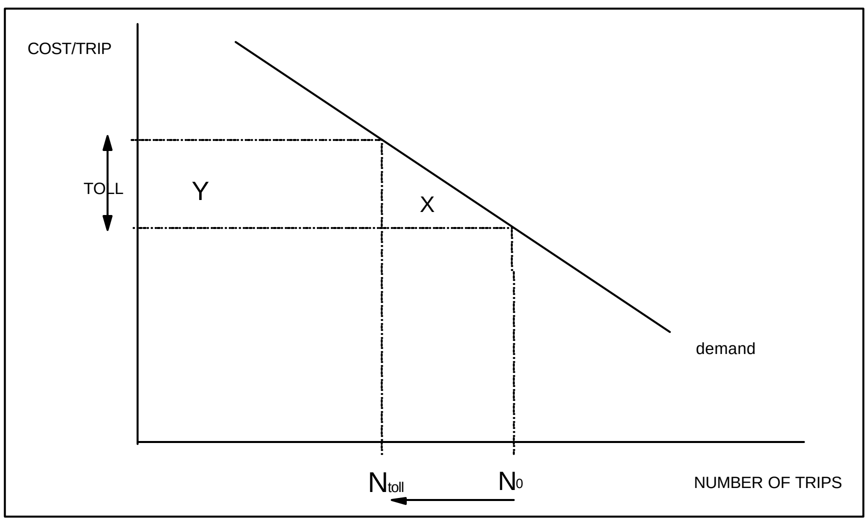
Figure 8.10 shows the loss of consumer surplus implied by the reduction in the number of trips in response to the toll. The total loss of surplus is the area ***Y + X***, namely

$$\boldsymbol{X} \; ? \; \frac{??\boldsymbol{N_0} \; ? \; \boldsymbol{N_{toll}}?}{\boldsymbol{2}}$$

$$\boldsymbol{Y} \; ? \; ?\boldsymbol{N_{toll}}$$

where $\boldsymbol{T}$, $\boldsymbol{N_o}$, and $\boldsymbol{N_{toll}}$ are as defined above. Thus $\boldsymbol{Y}$ is the toll revenue collected by the government, and $\boldsymbol{X}$ is the deadweight loss.

Figure 8.10: Welfare losses



This can be taken only as a rough approximation of the various effects, which are quite complicated in the case of those who shift to public transport. Since the original decision to commute by car or motorcycle is motivated by a combination of the desire to avoid the longer trip times associated with public transport, and to enhance personal comfort, convenience, and display of status, those who shift to public transport will experience some loss of utility (which may or may not be offset by the lower cost of public transport).[205]

[204] It is possible that some would also take the train rather than buses (see Section 5.4), though we ignore this potential effect since we have no data to estimate it.

[205] Indeed, although the buses themselves experience the same time savings as the cars consequent to higher speeds, because of the general need to wait for buses at bus stops, and the time involved in

Table 8.4 shows the physical environmental impacts as a function of key assumptions: the level of the toll and the assumed elasticity to the toll. It is evident that if the road user response to tolls is the same as the historical VOC elasticity, then the reductions in traffic in response to a Rs 25 daily toll will be modest, no more than 2.2 percent in total, with a 3.9 percent reduction in car traffic, and a 5.6 percent reduction in motorcycle traffic. The same is true of the reduction of air emissions, which is small. To obtain, say, a 20 percent reduction in car traffic would require a Rs 75-toll, and a much greater response to the toll than the estimated VOC elasticities suggest.

Table 8.4: Physical impacts of the congestion charge

		Toll=Rs 75		*Toll=Rs 25*	
		Low-elast	*High-elast*	*Low elast*	*High elast*
Cars	[%]	-10.1%	-19.1%	-3.9%	-7.7%
Light truck	[%]	-7.9%	-15.0%	-3.1%	-6.1%
Medium truck	[%]	-9.7%	-18.3%	-3.7%	-7.2%
Heavy truck	[%]	-9.7%	-18.3%	-3.9%	-7.6%
Medium buses	[%]	0.3%	0.5%	0.1%	0.2%
Large buses	[%]	0.6%	1.0%	0.3%	0.5%
Motorcycle	[%]	-14.0%	-25.7%	-5.6%	-10.8%
Total	[%]	-5.7%	-10.7%	-2.2%	-4.3%
Environment					
GHG emission [lifetime]	[1000 tons]	17.0	33.0	6.4	12.8
Year 2010 reductions					
PM-10	[tons]	1	2	0	1
SOx	[tons]	7	13	3	5
NOx	[tons]	39	75	15	29

Low elasticity= VOC elasticity values per table 8.1.
High elasticity= 2 x VOC values.

Table 8.5 shows the distribution of costs and benefits for the reference case, the case of

walking from home to the bus stop, and from the Colombo bus stop to the place of work, there may be no net time savings for the person who shifts from car or motorcycle to bus. Since the number of car passengers who shift from cars to buses is small compared to the number of existing bus passengers, we simply assume such additional utility losses are captured in the (simple) calculation depicted in Figure 8.10.

It is true that bus fares are certainly at significantly lower levels than the corresponding costs of a car trip, but this is evidently not a consideration for those who can afford the comfort of automobiles (as opposed to what is perceived as the discomfort of buses). The direct savings (i.e., actual private VOC v. bus fare) are likely to be much smaller than the value assigned by such individuals to their time; therefore this (small) gain can also safely be ignored in the calculations of aggregate economic benefits.

the toll structure proposed by Jayaweera. It is evident that the big winners are (low income) bus passengers—because of the large number of passengers in each bus, increases in bus speeds have disproportionately large impacts on aggregate time savings, and therefore on economic benefits as a whole.

Table 8.5: Impact of the congestion charge, year 2010 (passenger car toll=Rs 25)

	Road users						*Environment*		
	Low Inc. (bus)	*Med- Inc. (MC)*	*High-Inc. (car)*	*Freight (lorry)*	*Govt*	*Total*	*Local*	*Global*	*Total*
	[1]	*[2]*	*[3]*	*[4]*	*[5]*	*[6]*	*[7]*	*[8]*	*[9]*
Time savings	578	21	489	354		1442			1442
Tolls	0	-99	-1280	-593	1972	0			0
Gasoline fuel tax		0	8		-8	0			0
Diesel fuel tax	5		1	2	-9	0			0
Diesel savings	87			47		134			134
Petrol savings		0	19			20			20
Deadweight losses	0	-7	-56	-27		-90			-90
Admin costs					-30	-30			-30
Commissions					-197	-197			-197
Environment									
PM10						0	2		2
SOx						0	2		2
NOx						0	3		3
GHG emissions						0		1	1
Total	671	-85	-819	-217	1728	1278	7	1	1286

While the impact on car users (column [3]) is (obviously) negative, the overall balance is positive—in other words, the time savings to other user groups (like bus passengers) exceed the additional toll costs to car passengers. In the case of trucks, while the impact is negative (at the proposed toll structure), the absolute incremental cost is small, so the case that the imposition of tolls would increase commodity prices would be hard to sustain.[206]

Table 8.6 shows the corresponding results in NPV terms over 20 years (at a 10 percent discount rate). It is evident that road pricing in the form of a congestion toll has a significant positive economic impact. The inclusion of environmental benefits raises benefits only by less than 1 percent; however, as a win-win option these environmental benefits are achieved at no

---

[206] However, the lack of substantive merit is rarely a reason for vested interests to resist protest. The impact of the price rise of diesel fuel is discussed further in Section 9 in relation to fuel tax equalization.

incremental cost.

Table 8.6: Impact of toll, NPV at 10 percent, Rs million (at constant 2000 price levels)

	Road users						*Environment*		
	Low Inc.	*Med-Inc.*	*High Inc.*	*Busin*	*Govt*	*Total*	*Local*	*Global*	*Total*
Time savings	4666	173	3996	354		9189			9189
Tolls	0	-778	-10031	-4643	15452	0			0
Gasoline fuel tax		2	57		-59	0			0
Diesel fuel tax	38		6		-43	0			0
Diesel savings	646			350		997			997
Petrol savings		1	142			144			144
Deadweight loss	0	-55	-442	-212		-709			-709
Administration costs					-259	-259			-259
Commissions					-1545	-1545			-1545
Environment									
PM10						0	11		11
SOx						0	16		16
NOx						0	22		22
GHG emissions						0		21	21
Total	5350	-656	-6272	-4150	13545	7816	50	21	7887

Figure 8.11 shows a sensitivity analysis of net economic benefits to the level of the congestion charge (for 2001).[207] The optimum toll corresponds to a passenger car toll of about Rs 30/day, which is somewhat higher than the theoretical value of Rs 25 determined by Jayaweera on the basis of a microeconomic analysis. The reason is that buses are exempted in the policy proposal, so the toll for remaining vehicles has to be increased somewhat to have the same overall impact on congestion. However, the results of this aggregate (macro)-model clearly confirm the theory.

[207] The daily congestion charge shown is for passenger cars: tolls for other vehicles are scaled in proportion to the values shown in Table 8.3 (e.g. when the passenger car toll is Rs 25, the motorcycle toll is Rs 10; when the passenger car toll is set at Rs 50, the motorcycle toll is set at Rs 29, and so on).

Figure 8.11: Congestion toll winners and losers

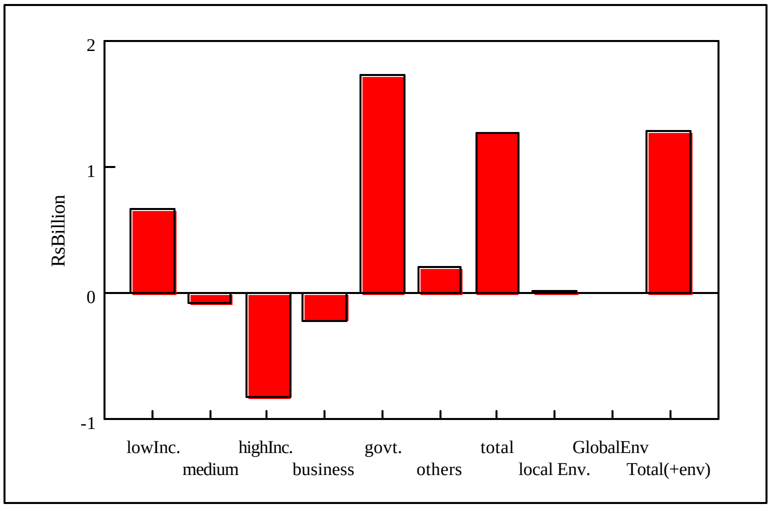
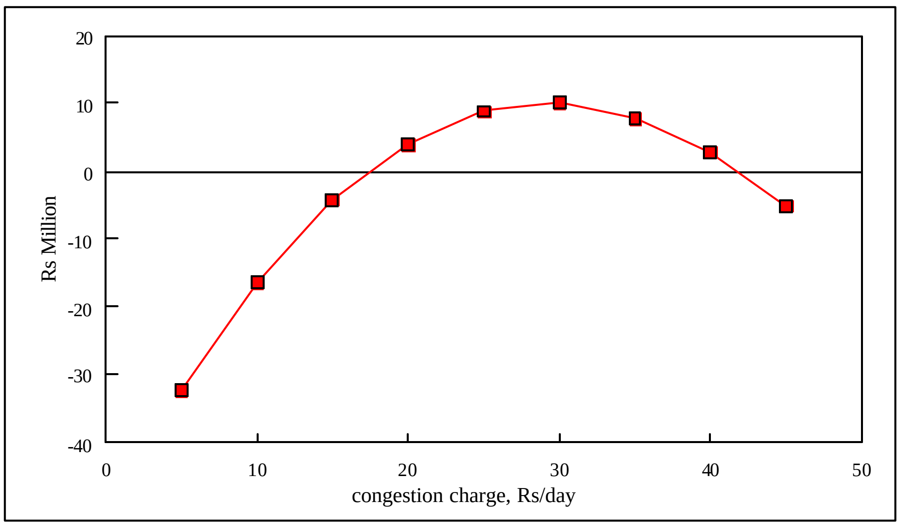


Figure 8.12: Sensitivity of net economic benefits as a function of the congestion charge



8.2 Reintroduction of full school bus schedules[208]

Till the early 1980s Colombo City had a reasonably well-patronized school bus service operated by the state-owned Sri Lanka Transport Board. However, with the introduction of private buses and the "peoplization" of the state-owned bus operations, school bus services have been neglected in favor of more remunerative services. This vacuum has been largely filled by private vans that offer a charter service for a monthly fee. There are presently only some 50 to 60 school buses operating to and from Colombo City, compared to an estimated 2,167

208 This section was prepared by A. Kumarage, University of Moratuwa

vans.[209] As shown in Table 8.7, the number has increased significantly since 1996.

Table 8.7: School vans arriving in Colombo city (estimate for 2000)

	Corridor	*Count at*	*1996 study by Transport Studies & Planning Centre*			*2000 estimate*
			Vans	Passengers /van	Passengers	Vans
1	Kandy Rd	Kelanitissa Br	377	15.0	5,661	505
2	Galle Rd	Dehiwala Br	295	16.1	4,760	395
3	Parliament Rd	Castle St Hospital	236	18.4	4,338	316
4	Negombo Rd	Japan (Victoria) Br	218	15.3	3,339	292
5	Horana Rd	Pamankade Br	165	13.7	2,265	221
6	High Level Rd	Kirulapana Br	165	13.7	2,260	220
7	Kolonnawa Rd	Dematagoda Jn	61	17.8	1,083	82
8	Nawala Rd	Narahenpita Jn	51	12.5	638	68
9	Cotta Rd	Ayurveda Hospital	44	15.5	682	59
10	Low Level Rd	Orugodawatte Jn	7	16.6	116	9
	Total		1,619	15.5	25,142	2,167

These school vans have caused a number of traffic and parking related problems that have drawn the attention of policymakers in the transport sector. Presently, there is an attempt to reintroduce school buses on a large scale. Discussions with school principals have revealed that approximately 50 percent of the students (and teachers) traveling in these vans would transfer to a regular and dependable school bus service and that each bus would carry on average 80 students. Thus each bus would replace 5 school vans. If we assume that a bus has an equivalent passenger car unit (PCU) value of 2.5, and a van 1.0,[210] then net result is a 50 percent savings in road space.

If one were to consider replacing private cars that carry one or two students, then the savings would be significantly greater, in the range of around 95 percent of the road space. However, it is believed that shifting students from private cars to buses would be rather difficult and, hence, even if some shift could very well take place, a conservative estimate has been assumed in this study by making the entire shift to be from school vans only.

---

[209] *Study of Transportation Services Provided by School and Office Vans*, Transport Studies and Planning Center, May 1996 (Published in TSS, *op. cit*., Volume II, pp.146-202). This earlier study was limited to gathering physical data, and presented no benefit cost analysis (or quantitative estimates of the impact on reducing road congestion).

[210] Kumarage A.S., "Estimates of Passenger Car Units," *Proceedings Annual Sessions*, Institute of Engineers Sri Lanka, 1993. In the inner-city areas where school vans cause congestion, the PCU values are higher than those for radial roads noted in Table 8.1.

Methodology and assumptions

The analysis follows the following methodology:

- ?? Estimate of present traffic flow rate on the roads and speeds given in Table 8.7.
- ?? Estimate the fuel consumption of the traffic flow inclusive of the vans under present conditions.
- ?? Estimate the traffic flow rate on the roads with the new policy alternative.
- ?? Estimate the fuel consumption of the traffic flow excluding the displaced vehicles but including the additional buses.
- ?? Aggregate the savings in fuel consumption for a year.

The following assumptions are made:

- ?? That all the school vans (and the buses) travel during the morning traffic hour of 7 a.m. to 8 a.m. and during the afternoon between 2 p.m. and 3 p.m.
- ?? That the vans travel an average distance of 20 kms.
- ?? That the traffic flow rate and fuel consumption rates would be made for the point at which traffic flow data is available, which is at the boundary to the City of Colombo.
- ?? That the daily flow during the morning traffic hour from 7 to 8 a.m. would be 4.5 percent of the total daily flow (in both directions) and that during the afternoon school peak hour from 2 to 3 p.m. it would be 4 percent of the total daily flow.
- ?? That the traffic flow would have grown at 4 percent p.a. at each of these locations since the last survey in 1995, the values of which are given in Table 8.8.

Table 8.8: Estimated daily flows at the CMC boundary and modal splits (1995)

	Traffic flow per day (both directions)			
	Buses	*Other vehicles*	*Total vehicles*	*Pass. car units*
Galle Road – Dehiwela Bridge	7,255	43,795	51,051	55,364
Horana Road – Pamankade Bridge	2,131	35,839	37,970	35,790
High Level Road – Kirullapone Bridge	5,054	30,722	35,776	38,748
Negombo Road – SLJF Bridge	4,828	47,400	52,229	52,361
Kandy Road – New Kelani Bridge	6,644	44,543	51,187	54,472
Low Level Road - Orugodawatte	1,399	12,924	14,323	14,484
Dematagoda Road	1,293	9,189	10,482	11,043
Parliament Road – Castle Street	856	31,859	32,715	29,220
Cotta Road - Borella	5,181	16,229	21,410	26,748
Nawala Road	357	16,491	16,848	14,909

The flow characteristics, including computation of speed for each of the roads, are given in Table 8.9. Under the policy alternative, we made the assumption that 50 percent of the school children presently traveling by school vans would transfer to a school bus service. Accordingly, the traffic flow changes for the morning peak under the present status and under the policy alternative are given in Table 8.10. Similarly, Table 8.11 gives the situation for the afternoon peak hour.

Table 8.9: Flow conditions under present status (2001)

Corridor	*Flow/ day*	*Flow/h (a.m. peak)*	*Flow/hr(p.m. peak)*	*Std lanes- per direct.*		*Flow/hr/ lane (a.m. peak)*	*Flow/hr /lane (p.m. peak)*	*Speed (km/hr) (a.m. peak)*	*Speed (km/hr) (p.m. peak)*
Galle Road	55,364	2,491	1,938	1.75	69,205	1,780	1,384	12	18
Horana Road	35,790	611	253	1	44,738	2,013	1,566	8	15
High Level Road	38,748	1,744	1,356	2	48,435	1,090	848	23	26
Negombo Road	52,361	356	1,833	1.75	65,451	1,683	1,309	13	19
Kandy Road	54,472	451	1,907	1.75	68,090	1,751	1,362	12	18
Low Level Road	14,484	652	507	0.9	8,105	905	704	26	29
Dematagoda Road	11,043	497	387	0.7	13,804	887	690	26	29
Parliament Road	29,220	1,315	1,023	2	36,525	822	639	27	30
Cotta Road	26,748	1,204	36	0.7	3,435	2,149	1,672	6	13
Nawala Road	14,909	671	522	0.8	18,636	1,048	815	23	27

Table 8.10: Traffic flow conditions a.m. peak hour (with and without policy alternative)

Corridor	*Speed kms/hr*	*Motor cycles*	*3Ws*	*Cars*	*Vans*	*Buses*	*Goods*	*Total*
PRESENT STATUS								
Galle Road	11.5	498	374	374	623	249	374	2,491
Horana Road	7.8	322	242	242	403	161	242	1,611
High Level Road	22.6	349	262	262	436	174	262	1,744
Negombo Road	13.1	471	353	353	589	236	353	2,356
Kandy Road	12.0	490	368	368	613	245	368	2,451
Low Level Road	25.5	130	98	98	163	65	98	652
Dematagoda Road	25.8	99	75	75	124	50	75	497
Parliament Road	26.9	263	197	197	329	131	197	1,315
Cotta Road	5.6	241	181	181	301	120	181	1,204
Nawala Road	23.2	134	101	101	168	67	101	671
SCHOOL BUS ALTERNATIVE								
Galle Road	12.4	498	374	374	425	289	374	2,333
Horana Road	8.7	322	242	242	292	183	242	1,522
High Level Road	23.0	349	262	262	326	196	262	1,656
Negombo Road	13.7	471	353	353	443	265	353	2,239
Kandy Road	13.1	490	368	368	360	296	368	2,249
Low Level Road	25.6	130	98	98	158	66	98	648
Dematagoda Road	26.3	99	75	75	83	58	75	464
Parliament Road	27.5	263	197	197	171	163	197	1,189
Cotta Road	5.9	241	181	181	271	126	181	1,180
Nawala Road	23.6	134	101	101	134	74	101	644

Table 8.11: Traffic flow conditions, p.m. peak hour (with and without policy alternative)

Corridor	*Speed kms/hr*	*Motor cycles*	*3Ws*	*Cars*	*Vans*	*Buses*	*Goods*	*Total*
PRESENT STATUS								
Galle Road	17.9	388	291	291	484	194	291	1,938
Horana Road	14.9	251	188	188	313	125	188	1,253
High Level Road	26.4	271	203	203	339	136	203	1,356
Negombo Road	19.1	367	275	275	458	183	275	1,833
Kandy Road	18.2	381	286	286	477	191	286	1,907
Low Level Road	28.7	101	76	76	127	51	76	507
Dematagoda Road	29.0	77	58	58	97	39	58	387
Parliament Road	29.8	205	153	153	256	102	153	1,023
Cotta Road	13.3	187	140	140	234	94	140	936
Nawala Road	27.0	104	78	78	130	52	78	522
SCHOOL BUS ALTERNATIVE								
Galle Road	18.8	388	291	291	287	233	291	1,780
Horana Road	15.8	251	188	188	203	147	188	1,164
High Level Road	26.9	271	203	203	229	158	203	1,268
Negombo Road	19.7	367	275	275	312	212	275	1,716
Kandy Road	19.4	381	286	286	224	241	286	1,705
Low Level Road	28.8	101	76	76	122	52	76	503
Dematagoda Road	29.4	77	58	58	56	47	58	354
Parliament Road	30.4	205	153	153	98	134	153	896
Cotta Road	13.6	187	140	140	205	100	140	913
Nawala Road	27.3	104	78	78	96	59	78	495

Fuel consumption rates for different vehicles types in Sri Lanka were given in Figure 3.7.[211] Based on these rates the total fuel used for a 20 km length of roadway per day is given in Tables 8.12 and 8.13 for the morning and afternoon peaks, respectively.

[211] Halcrow Fox Associates, *Colombo Urban Transport Study*, Working Paper 8: Transport Costs, December 1995.

8.12: Fuel used for a.m. peak hour (with and without policy alternative)

Corridor	*Speed kms/hr*	*Motor cycles*	*3Ws*	*Cars*	*Vans*	*Buses*	*Goods*
PRESENT SITUATION							
Galle Road	17.2	373	352	1,018	2,113	1,848	2,772
Horana Road	14.2	262	247	717	1,478	1,283	1,925
High Level Road	26.1	225	211	608	1,288	1,154	1,731
Negombo Road	18.5	343	323	935	1,946	1,707	2,561
Kandy Road	17.6	364	343	992	2,062	1,805	2,707
Low Level Road	28.4	82	77	221	471	425	637
Dematagoda Road	28.6	62	58	168	358	323	485
Parliament Road	29.5	163	153	440	941	852	1,278
Cotta Road	12.5	209	197	571	1,172	1,014	1,521
Nawala Road	26.6	86	81	232	493	442	664
Total		**2,169**	**2,042**	**5,901**	**12,321**	**10,854**	**16,281**
SCHOOL BUS ALTERNATIVE							
Galle Road	19.0	359	338	976	1,390	2,071	2,682
Horana Road	16.0	249	234	679	1,020	1,395	1,840
High Level Road	26.9	222	209	601	955	1,292	1,720
Negombo Road	19.8	334	315	909	1,427	1,878	2,506
Kandy Road	19.9	347	327	943	1,159	2,093	2,603
Low Level Road	28.5	82	77	220	457	430	637
Dematagoda Road	29.6	62	58	166	238	375	483
Parliament Road	30.7	161	152	434	484	1,051	1,271
Cotta Road	13.2	203	192	556	1,032	1,039	1,486
Nawala Road	27.3	85	80	230	390	485	660
		2,104	**1,981**	**5,716**	**8,552**	**12,108**	**15,887**

Table 8.13: Fuel used for p.m. peak hour (with and without policy alternative)

Corridor	*Speed kms/hr*	*Motor cycles*	*3Ws*	*Cars*	*Vans*	*Buses*	*Goods*
PRESENT STATUS							
Galle Road	19.8	275	259	748	1,562	1,375	2,062
Horana Road	17.1	188	177	513	1,065	931	1,397
High Level Road	27.6	172	161	464	987	888	1,332
Negombo Road	20.9	255	240	693	1,450	1,280	1,920
Kandy Road	20.1	269	253	731	1,528	1,346	2,019
Low Level Road	29.7	63	59	169	362	328	492
Dematagoda Road	29.9	48	45	129	276	250	375
Parliament Road	30.6	125	118	338	725	659	989
Cotta Road	15.5	147	138	400	827	721	1,081
Nawala Road	28.1	66	62	177	378	341	511
Total		**1,607**	**1,512**	**4,362**	**9,159**	**8,119**	**12,178**
SCHOOL BUS ALTERNATIVE							
Galle Road	21.6	266	251	723	898	1,614	2,011
Horana Road	18.9	181	170	493	664	1,060	1,352
High Level Road	28.5	170	160	459	661	1,027	1,325
Negombo Road	22.2	249	235	676	968	1,459	1,888
Kandy Road	22.4	259	243	701	693	1,652	1,959
Low Level Road	29.8	63	59	169	349	334	492
Dematagoda Road	30.8	47	44	127	158	302	373
Parliament Road	31.9	124	117	334	274	859	984
Cotta Road	16.2	144	136	392	710	754	1,064
Nawala Road	28.8	65	61	176	278	384	509
		1,568	**1,476**	**4,251**	**5,653**	**9,444**	**11,958**

If we assume that all motorcycles, three-wheelers, and cars are gasoline-driven and that vans, buses, and trucks are diesel-driven, the overall savings in fuel use per day computes as shown in Table 8.14.

Table 8.14: Fuel saved with policy alternative

	a.m. peak	*p.m. peak*	*Total*
PRESENT STATUS FUEL USED PER DAY (litres)			
Diesel	39,456	29,456	68,911
Gasoline	10,112	7,481	17,593
Total	49,568	36,937	86,505
SCHOOL BUS POLICY FUEL USED PER DAY (litres)			
Diesel	36,548	27,056	63,604
Gasoline	9,800	7,295	17,095
Total	46,348	34,350	80,699
SAVINGS PER DAY (litres)			
Diesel	2,908	2,400	5,308
Gasoline	312	187	499
Total	3,220	2,586	5,806
SAVINGS (%)			
Diesel	7.4	8.1	7.7
Gasoline	3.1	2.5	2.8
Total	6.5	7.0	6.7

There are approximately 210 schooldays per year. Thus the annual savings can be estimated by multiplying the daily savings by 210, resulting in a total savings of 1.11 million liters of diesel and 105,000 liters of petrol.

Economic analysis

In order to estimate the overall economic savings (in addition to the above fuel savings), we also need to consider changes in VOCs and the value of travel time savings.[212] These were estimated as economic costs using the HDM III and TransPlan V3 models.

The vehicle operating cost for a typical corridor in Colombo is given in Table 8.15. It can be seen the VOC takes a similar pattern to fuel consumption, decreasing with speed to an optimal amount at speeds varying for vehicle type ranging between 45 to 80 kms/hr. The value of travel time savings given in Table 6.4, and based on the vehicle occupancy rates in Table 8.16.[213]

212 Adapted from the computations in *Assessment of Public Investment in Transport Sector*, Final Report, University of Moratuwa, December 1999.

213 For details of the calculations, see A. Kumarage, *Assessment of Public Investments in the Transport Sector*, Appendix B2, University of Moratuwa, 1999.

Table 8.15: Estimated vehicle operating cost at road roughness (IRI =3.00) in Rs/km

Speed	*Car*	*M C*	*3W*	*Utility /van*	*Medium bus*	*Large bus*	*Medium2-axle lorry*	*Large 2-axle lorry*	*Large 3-axle lorry*
10	12.7	3.49	9.47	15.17	27.38	30.02	21.55	27.35	34.82
15	10.5	3.02	7.77	11.93	20.99	22.55	16.50	20.76	27.59
20	9.69	2.79	6.92	10.31	17.77	18.80	13.97	17.46	23.95
25	9.21	2.67	6.42	9.36	15.84	15.56	12.46	15.49	21.78
30	8.90	2.59	6.09	8.73	14.56	15.08	11.46	14.20	20.35
35	8.69	2.54	5.85	8.30	13.66	14.04	10.77	13.30	19.36
40	8.54	2.50	5.67	7.98	12.99	13.29	10.26	12.65	18.64
45	8.43	2.48	5.54	7.74	12.49	12.73	9.89	12.17	18.11
50	8.44	2.49	5.48	7.57	12.11	12.32	9.60	11.83	17.73
55	8.46	2.50	5.44	7.44	11.81	12.01	9.39	11.58	17.45
60	8.48	2.51	5.40	7.34	11.59	11.79	9.23	11.42	17.26
65	8.50	2.53	5.37	7.27	11.42	11.64	9.12	11.32	17.15
70	8.53	2.54	5.35	7.22	11.29	11.55	9.05	11.29	17.10
75	8.56	2.56	5.34	7.19	11.20	11.51	9.00	11.32	17.12
80	8.59	2.57	5.33	7.18	11.15	11.53	8.99	11.40	17.19
85	8.63	2.59	5.33	7.19	11.13	11.59	9.00	11.53	17.32
90	8.67	2.60	5.33	7.21	11.15	11.69	9.03	11.73	17.51
95	8.71	2.62	5.33	7.25	11.18	11.85	9.08	11.98	-
100	8.75	2.64	5.34	7.29	11.25	12.04	9.16	12.29	-

Table 8.16: Vehicle occupancy rates (without crew)

User group	*Urban*[214]	*Rural*[215]	*Intercity*[216]
Car	2.0-2.2	2.0-3.0	2.0-3.0
Van	2.2- 3.8	2.4- 3.8	3.0- 6.0
Motor-cycle	1.15-1.35	1.20-1.35	1.4-1.6
Bus transport	30-50	20-40	35- 45

The economics of the present school van service are opaque.[217] The 1996 survey showed that the average cost of school van service was Rs 570/month, only slightly lower than that charged by office vans (Rs 650/month).[218] The survey also suggested that most school vans

214 Source: Colombo Traffic Study (UoM, 1995); TransPlan Database (UoM, 1999).

215 No data exists, assumed.

216 Source: TransPlan Database (UoM, 1999).

217 School and office vans are eligible for concessionary diesel tax, but this requires production of a certificate that the van has been registered as a school van; operators are not compelled by law to insure passengers. TSS, *op. cit*., p. 152.

218 TSS, *op. cit*., p. 150. This is significantly higher than the corresponding bus fare. If we take Rs5.50 as the normal fare (without transfer) for a 10 km trip, then the average bus fare cost would be some Rs 240/month.

were used only for this purpose. If indeed these vans were to be replaced by new school buses (and if these were also used only for school bus service), then use of average VOCs may underestimate the economic costs.[219] In the case of the school buses run by public bus companies, students are charged 10 percent of the normal fare, and the government provides a 55 percent subsidy, with the balance of 35 percent covered by the operator.[220]

Based on these details, we may then calculate the total economic cost and the savings as shown in Table 8.17. It may be seen that there are significant cost savings amounting to Rs 731,570 per day. For a total of 210 school days, this would work out to Rs 153.6million/year.

Table 8.17: Economic costs with and without policy alternative

	Morning peak	*Afternoon peak*	*Total*
PRESENT STATUS COST PER DAY (Rs)			
Vehicle operating cost	2,952,305	2,078,772	5,031,077
Travel time cost	1,961,871	1,340,662	3,302,533
Total	**4,914,176**	**3,419,434**	**8,333,610**
SCHOOL BUS POLICY COST PER DAY (Rs)			
Vehicle operating cost	2,704,579	1,965,449	4,670,028
Travel time cost	1,742,469	1,189,543	2,932,012
Total	**4,447,048**	**3,154,992**	**7,602,040**
SAVINGS PER DAY (Rs)			
Vehicle operating cost	247,726	113,323	361,049
Travel time cost	219,402	151,119	370,521
Total	**467,128**	**264,442**	**731,570**

Environmental consequences

The reduction in air emissions is given in Table 8.18.

Table 8.18: Reduction in air emissions (tons)

	Annual (2010)	*Lifetime*
Local		
TSP	0.8	
SOx (1)	40.9	
NOx	9.3	
Global		

219 Based on the 5:1 ratio of buses to vans, this would call for around 430 new buses. The capital cost of a new large bus may be taken at Rs 2 million (Kumarage, *Assessment of Public Investments, op. cit*., pp. 4-30), thereby incurring an up-front capital cost of Rs 860 million.

220 It is this apparent loss that explains the reluctance of bus companies to provide school bus service: though why under these conditions any bus service would remain at all is unclear.

Carbon	879	18450

(1) Assumes sulphur content of diesel fuel at 0.5 percent by weight.

Table 8.19 shows the benefits and costs of this policy option, expressed as NPVs over an assumed 20-year time horizon. Environmental benefits account for some 7 percent of the total economic benefits: this is obviously a win-win policy option.[221]

The distributional impacts are difficult to disaggregate. All other things being equal, it would be reasonable to assume that if one bus replaces five vans, some reduction in both the government subsidy and the fees charged to students would be achievable.[222] Precisely how the (economic) vehicle operating cost savings would be distributed among bus operators, students, and government is difficult to say. We also show as undetermined the time savings to the students themselves: these may be hard to express in monetary terms (since, for the vast majority, there is no opportunity cost implied from lost earnings); however, there is certainly *some* gain in utility consequent to fewer hours spent per day en route to and from school.

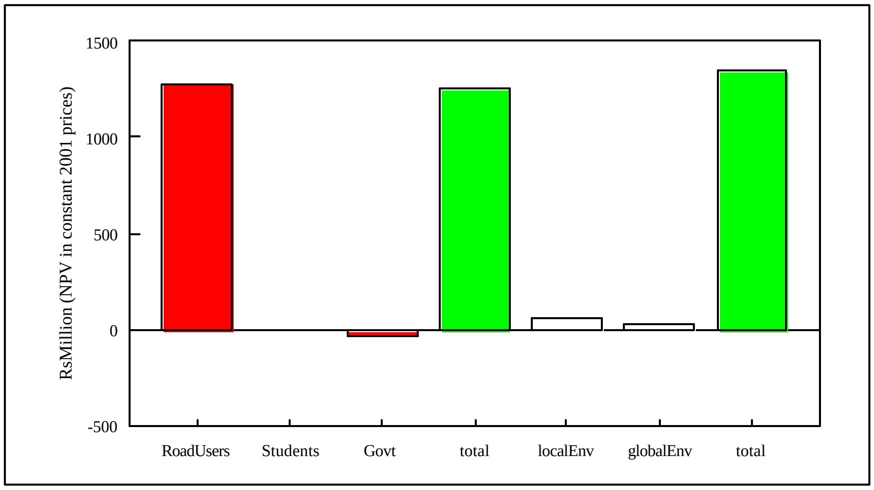
Table 8.19: Benefits and costs, NPV, million Rs (at constant 2001 price levels)

	Road users	*Students*	*Govt.*	*Total*	*Local envir.*	*Global envir.*	*Total*
VOC savings	736			736			736
Time savings	512	x		512			512
Fuel taxes	30		-30	0			0
Fees	x	x	x	0			0
Environment							
PM-10				0	13		13
NOx				0	25		25
SOx				0	24		24
Carbon				0		33	33
Total	1277	x	-30	1247	61	33	1342

Positive entries=benefit; negative entry=cost
x = undetermined
Note: fuel savings are included in VOC savings.

[221] Note that even if the capital costs of new buses were factored (see text discussion, above), the net economic benefits would be reduced by Rs 860million, which still leaves a net economic benefit (before environment) of Rs 787million.

[222] The costs of the present van service constitute a significant burden on many parents. While there is no systematic data, Kumarage, *Review of Household Income and Public Transport*, *op. cit*., gives an example of a family who spend Rs 400/month to send their daughter to school by van because of poor bus service, compared to a monthly daily commuting bill of Rs 800/month (p. 7-2). For this distance (in mid-2000), the normal bus fare would have been Rs 5.50 per trip, or Rs 5.50 x 22 x 2 = Rs 242/month, so the van cost is substantially greater.



The example of a possible reintroduction of school buses as the primary mode of school transport illustrates the existence of economic and environmental cost savings in almost all transport activities. This raises the question of the degree to which policy in other areas is adequately coordinated. For example, education policy calls for all children attending government schools to live within a two-km radius, which is evidently not the case, given the large numbers of school children arriving every day. The option to have these “popular” and “good” schools dispersed in suburban and provincial areas is a possible policy alternative to circumvent the present congestion problems.

This example also questions the wisdom of the urban planning practice of maintaining homogenous land use areas that result in schools being concentrated in one part of the city. The traffic peaks created by this concentration disrupt the remaining traffic in these areas, often to the point of gridlock. One option would be to open branch schools to accommodate the expected growth.

In managing transport demand itself, this example clearly shows how the state should take leadership in providing initiative and direction in the transport sector. This does not necessarily mean the state should make the corresponding investments, and there is no reason why the state cannot provide the structure for the private sector to operate a reliable school bus service. But in the present policy vacuum, there are inadequate funds for the state-owned transport companies to provide the service, while on the other hand, the private sector remains unorganized and unable to gain enough credibility to give parents and school authorities the confidence required for entrusting the lives of children to their care.

Annex 8.1

Report of the Committee of the Colombo Municipal Council for Introduction of Road Taxes

1.0 Introduction

Road taxes have been introduced in many countries for the purpose of reducing traffic congestion in cities or parts of cities. Colombo being the commercial capital of Sri Lanka presently faces many traffic problems due to various activities. Traffic congestion in many parts of the city could well be observed during peak periods. More than 160,000 vehicles on average enter the city in a weekday. Due to the lack of an efficient facilitated and punctual public transport system, many people use private cars to commute to the city. Use of limited space on city roads is dominated by cars with single occupancy. One option to control this is the introduction of road taxes and simultaneously improving the standard of the public transport system. In many countries this is adopted on a toll basis to recover the charges at entries and exits to roads or areas intended to be restricted. However, for Colombo, this would have to be structured as a road tax as the recovery of charges is to be monitored both at city boundaries and within the city on a random basis due to inadequate infrastructure facilities to introduce a toll system. Taxation systems on roads have been very successful and sustainable in other countries. A well-enforced and monitored road taxation system would no doubt effectively function in the city of Colombo also.

2.0 Purpose of Road Taxation

The main purpose of introducing a road taxation system for Colombo is to ease the prevailing traffic congestion in many parts of the city. Many cars with one occupant entering the city contribute to the traffic congestion. With considerable improvements in the public transport system and the introduction of a road taxation system for some categories of vehicles, commuters will tend to change their mode of transport and transfer to a public transport system. On the other hand, the Colombo Municipal Council spends millions of Rupees to maintain the city road network at an acceptable standard. The contribution of the city ratepayers to this event is enormous. However the road network of Colombo is also used by many outsiders who do not contribute to maintaining the roads of Colombo. Hence it is fair to levy a charge to CMC from such road users also so that the standard of the road network can be further improved.

Recently traffic count data collected by the Road Development Authority at the city boundaries and marked on a map of the city of Colombo is attached in the annex.

3.0 Vehicles to be Exempted from Taxation

In most of the countries abroad, taxation systems are adopted for all types of vehicles. In a developing country like Sri Lanka, however, we should consider implement taxes for selected types of vehicles, as imposing taxes for some types of vehicles may indirectly increase the cost of living of some people. Hence public transport services, school vans, police, military, fire, funeral vehicles, and vehicles related to health services should be exempt from taxation. The committee recommends the following list of vehicles to be initially exempted from taxation.

1. All vehicles providing public transport services.
2. High occupancy vehicles such as school vans and vans carrying office workers.
3. Hearses and ambulances.
4. Vehicles belonging to the Sri Lanka police, military services, and fire brigade vehicles.
5. Vehicles owned by Colombo Municipal Council.
6. Any other type of vehicle considered to be exempt from taxation at the Discretion of the Municipal Commissioner.

The committee recommends vehicles described in items 2, 5, and 6 above be exempted from road taxes to display a sticker issued by the Colombo Municipal Council at the left-hand upper corner below the revenue license on the front windscreen whenever they travel on roads within the administrative limits of Colombo. Other vehicle categories are easily identifiable in the process of monitoring and hence it is not necessary to display stickers on them.

As a pilot project, the committee recommends implementing the road taxation system initially only for the cars that use Colombo roads. Once the Colombo Municipal Council is satisfied with the monitoring and the enforcement system and once solutions are found for the practical problems that may arise initially, the road taxation system may well be extended for vehicle categories such as vans, lorries, commercial vehicles, containers, three-wheelers, motor bicycles, and machinery vehicles. These vehicle categories, as those are easily identifiable. A model of the sticker intended to be displayed is printed in the annex.

4.0 Method of Charging

In many countries, electronic methods have been adopted for levying road taxes from vehicles. Such techniques, generally called ETC (Electronic Toll Collection) systems, are technically very advanced and involve high capital costs. Extensive improvements to road infrastructure in Colombo are also needed to cope up with such a system. Hence, the committee does not recommend going for such a system in Colombo at this stage. Instead, the committee recommends a ticket system on a prepaid basis. A daily ticket is recommended for those who randomly visit Colombo. A monthly ticket is also recommended to cater to regular motorists visiting Colombo for work and other purposes. The daily ticket is designed so that a space is provided for the issuer to write the date boldly and conspicuously prior to issue. It is recommended to print the monthly ticket with the relevant month also readily printed on it in bold letters. This ticket should be printed in 12 different colors for 12 months. Models of a daily ticket and a monthly ticket are printed in the annex. It is recommended to issue these tickets at reputed banks, petrol sheds, and supermarkets in Colombo and the suburbs. The Colombo Municipal Council would sell these tickets to such organizations on a commission basis. The committee recommends a 10 percent commission in this arrangement. In addition, it is recommended to establish road tax ticket stalls in the Colombo suburbs with the participation of private sector companies. The Colombo Municipal Council will sell tickets to these stallholders on a commission of 10 percent. It is the responsibility of the private sector companies to obtain permission from the relevant authorities to keep these stalls at predetermined locations. The Colombo Municipal Council would help them administratively in obtaining such permissions. All motorists should display the ticket at the left-hand upper corner below the revenue license on their front windscreen when they enter the city and when traveling within the city. The Colombo Municipal Council should freely issue a pouch to each motorists to display the ticket or sticker. The committee recommends that this scheme be implemented from Monday to Saturday except public holidays, as traffic congestion in Colombo is not that severe on Sundays and public holidays. The committee also recommends that the scheme be implemented from 6:00 a.m. to 8:00 p.m. only.

5.0 Financial Aspects

The committee recommends levying a charge of 10 Rupees from each car that enters the city of Colombo. As per traffic counts conducted by the Road Development Authority in the year 1999, the total daily inflow of cars to Colombo is 29,500 on average. Hence with the initial implementation of the scheme, approximate total annual income of the Colombo Municipal Council would be Rupees 88,500,00 (i.e., Rupees 29,500 x 10 x 25 x 12). The committee also recommends the price of the monthly ticket to be Rupees 200, which is the total price for 25 days on the basis of 10 rupees per day with a concession of 20 percent.

6.0 Enforcement

A road taxation system cannot be made viable unless it is properly enforced. The committee recommends obtaining help from the Traffic Police for monitoring and enforcing the system. Traffic Policemen can capture motorists without tickets at the city boundaries and anywhere within the city of Colombo on a random basis, as they capture violators of traffic rules and regulations. A spot fine of Rupees 250 at a time is recommended for a motorist without a ticket or a sticker in case of an exempted vehicle. The committee recommends facilitating motorists to pay the fine at the Town Hall. A system to pay fines without any delay should be established at the Town Hall. Any motorist refusing to pay the fine would be prosecuted. The committee recommends that 20 percent of the fine be given to the Traffic Policemen who captured the violator as a reward.

7.0 Other Collaborative Organizations

The Colombo Municipal Council should effectively negotiate with following collaborative organizations prior to implementing the scheme:

1. The Ministry of Transport to obtain ministerial support to implement a scheme related to transport.
2. The city Traffic Police to enforce laws related to road taxation systems.
3. The Department of Registration of Motor Vehicles.
4. The Road Development Authority.
5. Local authorities at Colombo suburbs.
6. Banks and owners of petrol sheds in Colombo and the suburbs.
7. Private sector companies, to obtain help in establishing road tax ticket-selling counters.
8. Sri Lanka Central Transport Board.
9. Western Provincial Council Passenger Transport Authority.

8.0 Publicity Programs

The committee recommends starting publicity programs on implementation of the road taxation system in Colombo at least one month prior to the effective date of the scheme. Government and private media such as television, radio, and newspapers could be used for publicity programs.

9.0 Changes to Municipal Bylaws

The committee recommends arrangements to established bylaws in this regard as follows:

1. No person shall drive a motor vehicle within the administrative limits of the council without a valid permit or ticket issued in that behalf by the council.
2. A fee as determined by the commissioner from time to time with the consent of the council shall be charged for the permit or the ticket issued.
3. A driver of a motor vehicle shall affix the said permit or the ticket on the left-hand top corner of windscreen of the vehicle.
4. A driver of a motor vehicle shall always display the said permit or the ticket during the time specified by the commissioner.
5. Whoever shall contravene any provisions of these bylaws shall be guilty of an offence and shall on conviction be liable to a penalty not exceeding Rs 250/- and 20 percent of such fine recovered shall be credited to the laity traffic police.
6. The following motor vehicle or any other vehicle as determined by the commissioner shall exempt from obtaining such permit or ticket.
    a. All vehicles providing public transport services.
    b. Hearses and ambulances.
    c. Vehicles belonging to Sri Lanka Police, Military Service and Fire Brigade.

d. Vehicles belonging to the council.
e. Motor vehicle has the same meaning as given in the Motor Traffic Act.

9

Tax and Price Reform

In this chapter we examine tax instruments as a method of effecting changes in the transportation sector. We examine the broader aspects of fuel and vehicle taxation, as well as the use of taxes to reduce environmental externalities.

9.1 Tax equalization on gasoline and diesel fuel

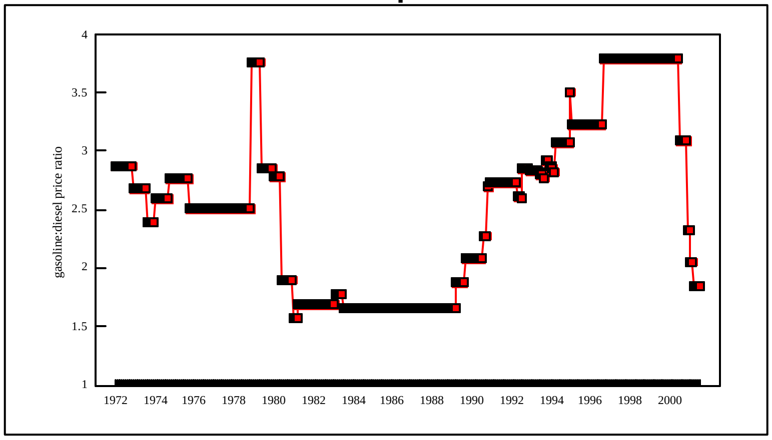
The historical tax differentials on diesel and gasoline (both on fuel and on vehicle import duties) have had a seriously distorting impact on the fleet mix, as well as on the economics of the refinery. High taxes levied on gasoline have resulted in a relative low gasoline demand, with the result that for several decades, naphtha has had to be exported (at a loss), while diesel has had to be imported.[1] As shown in Figure 9.1, the ratio of gasoline to diesel price has varied over the past 30 years from 3.5 to 1.5. This may be compared to rough equivalence of Singapore prices (see above, Figure 3.2).

As in many other countries, the ostensible rationale for the high level of tax on gasoline is that gasoline is mainly a fuel used by those with relatively high incomes, while diesel is mainly a fuel used by buses that transport those with relatively low incomes, and lorries that transport various goods including foodstuffs. That may have been the case before liberalization, when car ownership was indeed limited to a very small segment of the population, and diesel vehicles limited to buses, trucks, and tractors.

---

[1] However, hopefully with the completion of the naphtha-fired combustion turbine at Kelanitissa, in the future surplus naphtha will be absorbed by the power sector. For a discussion of the economics of naphtha use in power generation, see Meier, *Sri Lanka Electric Power Technology Assessment, op.cit*, Section 4.1.

Figure 9.1: Historical ratio of retail gasoline to diesel price



But with the dramatic changes in vehicle mix, such a rationale, as elsewhere, can no longer be sustained—as is readily evident from a breakdown of gasoline consumption by vehicle type (Table 9.1). Gasoline *cars* account for only 36.5 percent of total gasoline sales (and hence of gasoline taxes), while motorcycles and three-wheelers account for 58 percent, obviously the personal transportation mode used by lower income workers.

Table 9.1: Breakdown of gasoline use by vehicle class, 2000

	1,000 tons	*[Percent]*
Autos	72	36.5
Vans	10	
Land Vehicles	1	
Motorcycles	59	30
Three-wheelers	55	28
Total	197	

New data on vehicle ownership by income distribution is instructive, as shown in Table 9.2. Motorcycles are the dominant vehicles for 98 percent of earning households; only in the top 2 percent (earning more than Rs.25,000/month) are cars the dominant vehicle.

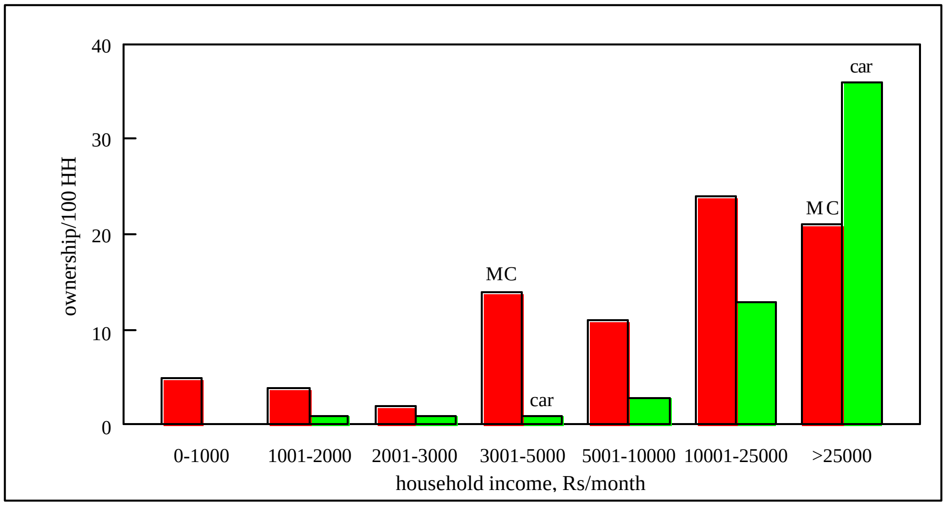
Table 9.2: Vehicle ownership by income class

		0-1,000	*1,001-2,000*	*2,001-3,000*	*3,001-5,000*	*5,001-10,000*	*10,001-25,000*	*>25,000*
Veh/100 HH								
MC		5	4	2	14	11	24	21
Cars		0	1	1	1	3	13	36
Income distribution	35%	4.3%	6.2%	7.2%	8.6%	6.2%	1.8%	0.7%

As percent	12.3%	17.7%	20.6%	24.6%	17.7%	5.1%	2.0%

In sum, there is little evidence that the present tax structure on transportation fuels is progressive. In fact, the present tax structure disproportionately favors the better off, most importantly the owners of so-called dual-purpose vehicles, whose consumption of diesel just in this category (232,000 tons in 2000) exceeds the total consumption of petrol (Figure 9.2).

Figure 9.2: Vehicle ownership per 100 households by income



Source: Kumarage, Review of Household Income and Public Transport, op. cit., Table 6.6.

In addition to the distributional rationale for equalization of diesel and gasoline taxes, there is also an environmental rationale. In the case of petrol, the main local air emission of concern in Sri Lanka is lead, and particulates from 2-stroke engines, emissions that would increase in any tax-induced shift to gasoline vehicles. But these issues are more easily solved[2] than the main local air emissions problem from diesel engines, namely the high emissions of particulates from heavy vehicles.

Finally there is the further rationale of better matching road user charges to public costs for road maintenance. As noted by Jayaweera,[3] two-axle trucks have the heaviest axle loads, and contribute most to road damage: as shown in Table 9.3, a two-axle medium truck (the most common type in Sri Lanka) imposes road maintenance costs of Rs 7/vehicle-km, as opposed to Rs 1.35/vehicle km for passenger cars. It is evident that while the gasoline tax on passenger cars is 210 percent of the road maintenance costs imposed, the diesel fuel tax paid by trucks is between 6 and 22 percent. But trucks are exempt from the special diesel tax, pay essentially no tax on diesel fuel, and pay disproportionately lower rates of import duty and annual license fees.

2 E.g., by introducing unleaded gasoline (Section 9.2) or limiting two-stroke-motorcycles (Section 10.2).

3 D. Jayaweera, *Transport Pricing and Charges in Sri Lanka, op. cit.*, p.15.

Table 9.3: Road maintenance costs imposed by different vehicle types vs. fuel tax revenue

	Road maintenance cost Rs/vehicle km	*Km/litres*	*Litres/km*	*Fuel tax/km*	*Ratio*
	[1]	*[2]*	*[3]*	*[4]*	*[5]=[4]/[1]*
Passenger cars (gasoline)	1.35	10	0.10	2.83	210%
Passenger cars (diesel)	1.35	10	0.10	0.29	21%
Vans/4WD/dualpurpose	1.94	8	0.13	0.36	19%
Buses	3.25	3	0.33	0.96	30%
Small trucks	2.66	5	0.20	0.58	22%
Medium trucks (2-axle)	7.06	4	0.25	0.72	10%
Medium trucks (3-axle)	11.39	4	0.25	0.72	6%
Articulated truck	8.77	3.5	0.29	0.83	9%

Source: Col[1] from Jayaweera, *op. cit.*, pg.40; col[2] from Table 2.2.

In short, there is a range of arguments for rationalization of fuel taxation, options for which we examine in this section:[4]

?? Raise the tax on diesel to the same rate as levied on petrol.
?? Decrease the tax on gasoline to the same rate as levied on diesel.
?? Lower the tax rate on gasoline *and* increase the tax on diesel.

The first option raises significant revenues for the government, but the corresponding increase in diesel fuel would be politically unacceptable. The second option would imply a significant revenue loss to the government, and may therefore also be discarded.[5] However, the

4 This is, to be sure, a limited proposal for reform. Others have called for fundamental changes in the tax structure, not just for auto-fuels, but for all petroleum products and crude oil. The World Bank *Petroleum Sector Study* (Energy and Project Finance Division, Country Department I, South Asia Region, Sept 2, 1996) recommended that the government introduce a simplified taxation system, replacing the profusion of customs duties, taxes, and levies with a single sales tax of the final retail price (p. 21).

This study also proposed (p. 20) that:

The tax differential between gasoline and diesel be corrected by re-establishing a more appropriate ratio between the two prices so as to reflect the true cost to the economy

and suggested a 10 percent increase in the price of diesel. However, this study did not provide any detailed economic analysis supporting such a proposal, except to note that such a 10 percent increase " . . . *would result in a correspondent increase in wholesale prices for basic food commodities in the range of only 0.1 percent to 0.15 percent.*" This estimate was apparently based on a Central Bank estimate that the fuel cost per kg of rice transported was 0.11/kg, and a 1994 rice price of Rs12/kg, and "*… . . . thus [the] fuel transportation cost for rice is equivalent to only 0.9 percent of the wholesale price.*" See Box 9.1, below, for further discussion.

5 However, we do provide below the calculations for the first two options to show the magnitudes of revenue gain/loss involved.

third option can easily be structured so that it is revenue-neutral to the government, and therefore merits detailed consideration.

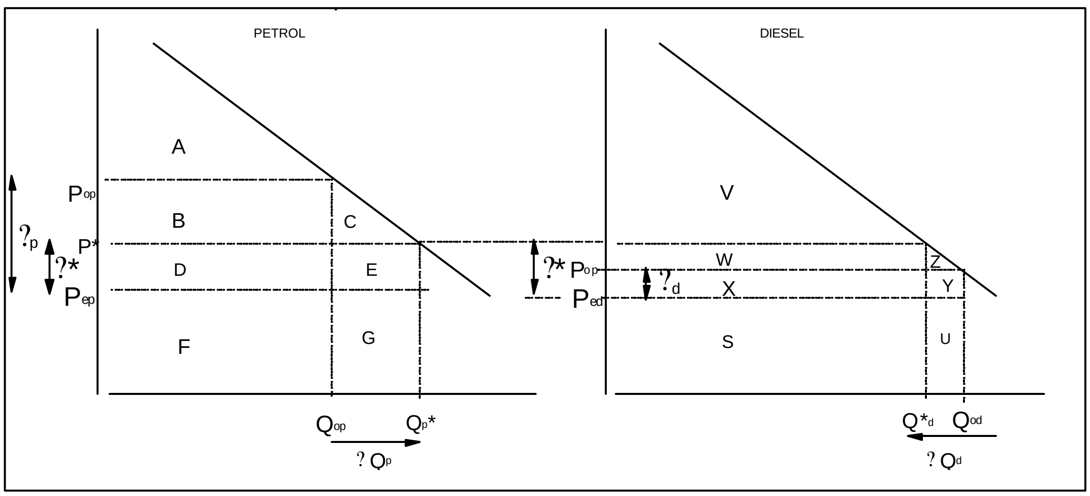
Theory

Consider the demand for gasoline and diesel shown in Figure 9.3. At present, tax is levied at ?$_p$ and ?$_d$ on gasoline and diesel, respectively, with retail prices of P_{op} and P_{od} at quantities Q_{op} and Q_{od}, respectively. If the tax rate is equalized, i.e.,

???????????$_p$ = ?$_d$??? ???

then diesel consumption *decreases* by ? Q_d, and gasoline consumption *increases* by ? Q_p

Figure 9.3: Tax equalization



Under revenue neutrality, the tax revenue before the tax change must equal the revenue with the common tax rate ?*, and therefore

[B+D] **+** ***[X+Y]*** **=** ***[D + E]*** **+** ***[W+X]***

old tax on gasoline old tax on diesel new tax on gasoline new tax on diesel

Q_{op}??$_p$ + Q_{od} ?$_d$ = ? ? ?Q_p? ??????????? ????????Q_d?

Hence ?? follows as

??????? [Q_{op}??$_p$ + Q_{od} ?$_d$]/ [Q_p? ??? ?Q_d? ?

where the new quantities Q_p? ?and??Q_d? ??are given by application of the price elasticity model discussed in Section 5.2.

However, while the impact on government revenue is (by definition) revenue neutral, the net impact on consumers will be given by the change in consumer surplus (for each user group, which will vary according to the balance of its use of petrol and diesel), and even in aggregate may be non-zero. This is shown by Table 9.4, which enumerates the net economic benefits before and after equalization. The net (aggregate) impact on consumers calculates to B+C-W-Z, whose magnitude will be determined by the relative price elasticities involved.

Table 9.4: Net economic benefits of tax equalization

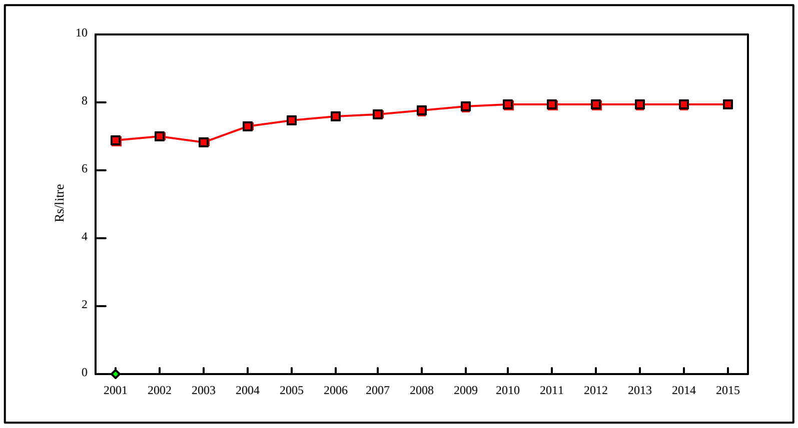
	Before equalization	*After equalization*	*Net change*
Gasoline			
consumer benefit	***A+B+D+F***	***A+B+C+D+E+F+G***	***G+C+E***
-resource cost	***-F***	***-F-G***	***-G***
net economic benefit	***A+B+D***	***A+B+C+D+E***	***C+E***
distributed among:			
consumers	***A***	***A+B+C***	***B+C***
government[tax]	***B+D***	***D+E***	***E-B***
Diesel			
consumer benefit	***V+W+X+S+Z+Y+U***	***V+W+X+S***	***-Z-Y-U***
-resource cost	***-S-U***	***-S***	***U***
net economic benefit	***V+W+X+Z+Y***	***V+W+X***	***-Z-Y***
distributed among:			
consumers	***V+W+Z***	***V***	***-W-Z***
government[tax]	***X+Y***	***W+X***	***W-Y***
Total			
consumers	***A+V+W+Z***	***A+B+C+V***	***B+C-W-Z***
government[tax]	***B+D+X+Y***	***D+E+W+Z***	***0 [by definition]***

Results

Figure 9.4 shows the results of a tax equalization on diesel and gasoline under revenue neutrality to the government, expressed as NPVs (at 12 percent over 25 years), assuming a world oil price of 26$/bbl and current retail prices. The resultant rate of (equal) tax is about Rs 7 per litre: it increases slightly from year to year to maintain the net revenue, because the differences in elasticity values for the two fuels cause shifts in the mix.

Imposition of a diesel tax of Rs 7-8/litre would doubtless be vociferously opposed by the freight industry, which will overlook the fact that, at present, diesel vehicles do not pay an equitable share of road damages, and will argue instead that consumer prices, particularly for food, would increase. However, as suggested in Box 9.1, this argument would be hard to sustain.

Figure 9.4: Equalized tax rate



Box 9.1: Impacts of diesel fuel taxes on food costs

The question of the impact of diesel fuel prices on marketing costs of vegetables was examined in a 1994 study,[6] using beans as an example.[7] Though that study analyzed the benefit of a diesel price *decrease* (of March 1994), it found that a Rs 1/litre decrease in diesel prices would result in a decrease in delivered cost of vegetables of 1.4 to 2.4 cents per kg, less than 0.06 percent of the retail price of Rs 25/kg. This was based on the fuel consumption of a round trip from Colombo to N'Eliya (a distance of 360 km up and down, consuming 72 litres) for a savings of Rs 72 per round trip (for a one Rs decrease in price). For 5,000 kg of vegetables (say 100 bags @ 50kg), this calculates to 1.4 cents/kg (with greater savings at lesser loads). Transportation costs were assessed at 7 percent of the total marketing cost of beans.

Since 1994 diesel prices have increased from 11.40 to Rs 21.50/litre, and retail bean prices from Rs 25 to 57/kg. In constant 1994 Rs, today's price of beans computes to Rs 36, and the retail diesel price Rs 13.4/litre, from which it is evident that the real price of beans has increased much more than the real price of diesel.

The physical environmental impacts are shown in Table 9.5. There is a net decrease in fuel use, a consequence of the differences in the assumed price and cross-price elasticities. While gasoline cars and vans are immediate substitutes for their diesel counterparts, it would be much more difficult for lorry-owners to shift to gasoline vehicles (since these are largely unavailable in the Indian market that is the principal source), so lorry-operators can indeed be expected to utilize their vehicles more efficiently if the price of diesel increases (and hence the net savings in total fuel).[8]

---

6 A.D.V. de S. Indraratna, *Economic and Environmental Implications of Petrol/Diesel Pricing*, University of Colombo, November 1994.

7 In 1994 the retail price of beans was Rs 25/kg. Average Pettah Market retail prices for the month of April 2001 were as follows: beans Rs 57/kg; cabbage Rs 38/kg; tomatoes Rs 39/kg, red onions Rs 82/kg, big onions Rs 34/kg, N'Eliya potatoes Rs 64/kg, dhal Rs 54/kg. It may be seen that beans are a representative product for the analysis.

8 The presumption here is that indeed surplus naphtha would have been used by the power sector for power generation, so the economic cost of the additional gasoline imports is taken at the Singapore

Table 9.5: Physical environmental impacts of tax equalization

		Valuation	*2010*				*Lifetime savings*	
		$/ton	*Baseline*	*+Policy*	*Delta*	*Percent [baseline]*	*Discounted*	*Undisc*
Petrol	[1,000 tons]		275	304	29	11%		
Diesel	[1,000 tons]		928	838	-91	-10%		
Emissions								
PM-10	[tons]	17790	990	944	-46	-5%	318	
SOx	[tons]	2924	9282	8377	-905	-10%	6156	
NOx	[tons]	700	49278	46858	-2420	-5%	16682	
Carbon	[1,000 tons]	20	1045	981	-63	-6%	-697	-2073

Assumptions: World oil price: 26$/bbl; price elasticities from Jayaweera (1999).

The distributional impacts of this equalization are shown in Table 9.6. The net economic benefits of tax equalization are large. First, there are substantial reductions in road maintenance costs consequent to the reduction in vehicle-km from the heavier diesel vehicles, so the impact on government is positive despite fuel tax revenues remaining unchanged. Second, we see significant environmental benefits, bringing the net economic benefit to Rs 15.8 billion (in NPV terms).[9]

price plus freight (rather than at Singapore minus freight which would be the relevant cost if naphtha is exported)

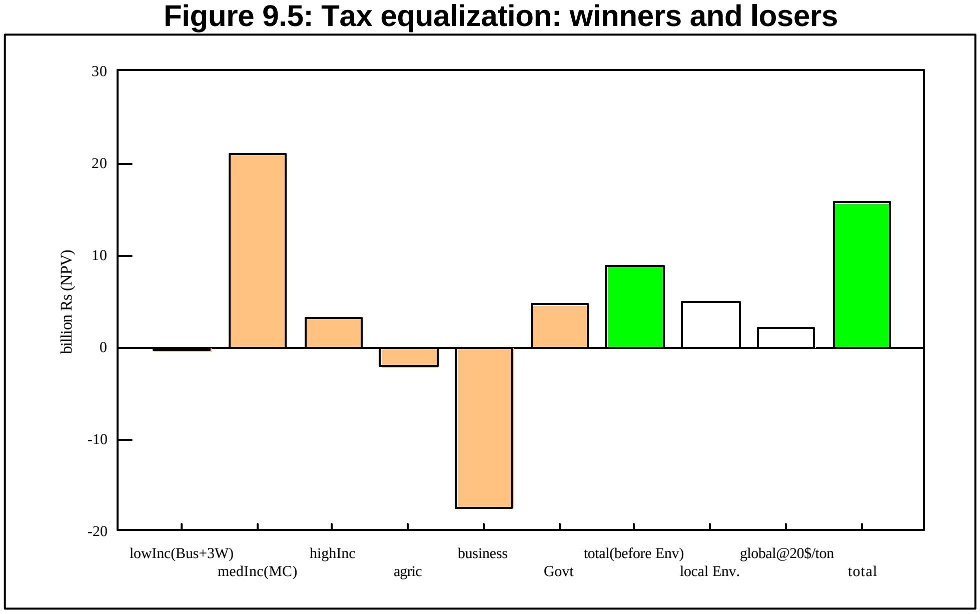
9 Note that, unlike in the case of measures discussed in other sections, fuel savings (or changes in fuel consumption) do not appear in this table (even though there would undoubtedly be lower diesel consumption and somewhat more gasoline consumption). However, since there is an equivalent loss of benefit (area under the demand curve), the two cancel out. However in the case, say, of the expressway project, fuel savings are counted as an economic gain, because these are achieved without diminution of consumer benefits.

Table 9.6: Impact of tax equalization (Rs Million, NPV)

	Road users					*Govt.*	*Total*	*Environment*		*Total*
	Low-Inc	*Med-Inc*	*High-Inc*	*Agric*	*Freight*			*Local*	*Global*	
Tax changes										
Diesel tax	-14890		-13221	-2140	-18571	48822	0			0
Petrol tax	13410	17878	14965	266	2302	-48822	0			0
d[consumer impacts]										
Area[C](petrol)	264	353	291	5	45		958			958
Area[B](petrol)	15445	20593	17233	307	2652		56229			56229
Area[Z](diesel)	-928		-818	-133	-1153		-3033			-3033
Area[W](diesel)	-15199		-13496	-2184	-18957		-49836			-49836
d[road maintenance]										
Diesel						8576	8576			8576
Gasoline						-3968	-3968			-3968
Environment										
PM-10							0	770		770
SOx							0	2459		2459
NOx							0	1591		1591
Carbon reduction							0		2073	2073
Net impact	-418	20946	3210	-2006	-17414	4608	8927	4820	2073	15820
Baseline fuel bill	91176	43845	94484	9038	73120					
Net impact as percent	0%	48%	3%	22%	24%					

Positive numbers=benefits; negative numbers=costs

Figure 9.5: Tax equalization: winners and losers



In this presentation we make the following assignments:

?? Low income = bus and three-wheeler passengers
?? Medium income = motorcycle owners
?? High-income = owners of cars and dual-purpose vehicles
?? Business=owners and operators of lorries.

It is evident, from Figure 6, that equalization of tax rates has little effect on either low-income or high-income road users: their net impact, expressed as a percentage of their baseline fuel-bill, is less than 4 percent. In the case of low-income users, bus passengers would suffer the impact of higher diesel fuel prices, but these are also the most typical users of three-wheelers, who would experience a fuel cost savings of about the same amount.

Thus, the principal beneficiaries are motorcycle users, and the principal losers are lorry owners and land vehicle users. In fact, it is clear that the present tax structure is such that the cross-subsidies are not from high income to low income road users, as may be supposed, *but from motorcycle owners (i.e., medium income) to agriculture and lorry operators*. It seems very unlikely that this is the intended effect of the present fuel tax structure.

Table 9.7: Sensitivity of results to price elasticity

Assumptions						
World oil price		21	26	31	26	31
Elasticity		Chandra siri	Chandra siri	Chandra siri	Jayaweer a	Jayaweera
Gasoline price elasticity	[ ]	-0.078	-0.078	-0.078	-0.163	-0.163
Diesel price elasticity	[ ]	-0.136	-0.136	-0.136	-0.339	-0.339
Tax rates						
Present gasoline tax	[Rs/litre]	34	31	28	31	28
Present diesel tax	[Rs/litre]	7	3	0	3	0
Equalized tax	[Rs/litre]	13	10	7	10	7
Change in 2010						
Gasoline consumption	[1000tons]	12	12	12	29	26
Diesel consumption	[1000tons]	-33	-33	-32	-91	-81
Change in 2010 emissions						
PM-10	[tons]	-16	-15	-15	-46	-42
SOx	[tons]	-329	-327	-324	-905	-809
NOx	[tons]	-824	-812	-800	-2420	-2192
Carbon	[1000tons]	-22	-22	-21	-63	-57

As one might expect, the results are sensitive to the elasticity assumptions and the world oil price: the results of Table 9.6 use those of Jayaweera (1999), which are about in the middle of the range. Table 9.7 illustrates the sensitivity of results to different elasticity and world oil price assumptions.

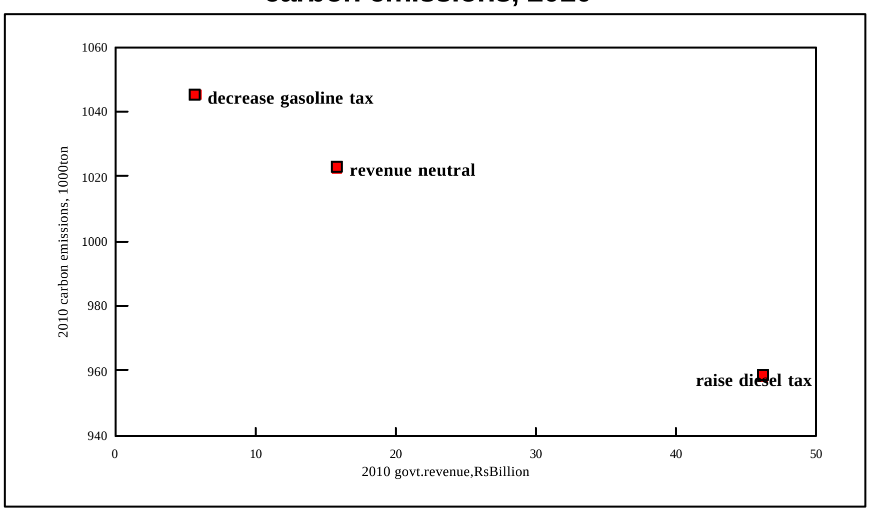
With regard to the other two options for equalizing taxes, if one increases the diesel tax to the same level as that of gasoline, then this would clearly bring larger environmental benefits and greater revenues to the government, but unacceptable increases in private costs. The alternative of reducing the gasoline tax to that of diesel (i.e., to essentially zero) is even more unfeasible, given the loss of government revenue involved (however popular such a measure might be to road users). Nevertheless, for comparative purposes, the three equalization options above are compared to the present situation in Table 9.8.

Table 9.8: Revenue and environmental impacts of tax equalization options: impacts in year 2010

			Change		
		Present	***Revenue neutral tax ~Rs 7/litre***	*Increase diesel tax to that of petrol*	*Reduce gasoline tax to that of diesel*
Gasoline consumption	1000tons	**275**	**+12**	+12	18
Diesel consumption	1000tons	**928**	**-33**	-99	-15
Government revenue	[Rs Billion]	**15.7**	**0**	+30	-10
Carbon emissions	[1000 tons]	**1045**	**-22**	-86	+1

As may be seen in Figure 9.6, the trade-off is as expected: the higher the aggregate level of tax, the lower the carbon emissions; therefore, raising the diesel tax to that of gasoline results in a tripling of government revenue, a 10 percent reduction in carbon, but an unacceptable impact on road users; conversely, if the tax on gasoline is reduced to that of diesel, there is a Rs 10 billion loss in revenue, which is unacceptable to the government. In short, equalization under revenue neutrality, in which diesel and gasoline are taxed at the same rate, provides a good reduction in carbon emissions without affecting the *aggregate* consumer burden (though with the distributional impacts noted above).

Figure 9.6: Tradeoff between government revenue and carbon emissions, 2010



Pricing reform: unleaded gasoline[10]

In the past, Sri Lanka has been criticized for its gasoline lead content, for which the specification has long been 0.43gms/litre. Unleaded gasoline was introduced in June 1997, with the hope that by 2000, unleaded might account for 30 percent of sales.[11] But sales have been disappointing, as shown in Table 9.9; in 2000, less than 2 percent of total gasoline sales were unleaded. Several explanations for low sales are likely:

?? Few outlets sell unleaded gasoline (only 12 of 639 outlets in Sri Lanka provide unleaded petrol, mainly in Colombo);

?? Price differential between leaded and unleaded (which sells at Rs 53/litre as opposed to Rs 50/litre for leaded);[12]

?? Conversion of vehicles that need 95 octane unleaded to LPG (whose octane is also about 95).

Table 9.9: Sales of unleaded gasoline

	1997	*1998*	*1999*	*2000*
Total petrol [tons]	194,828	204,351	213,068	224,379
Unleaded gasoline [tons]	1,582	3,068	3,476	4,160
Percent unleaded gasoline	0.8%	1.5%	1.6%	1.9%
Average TEL, gms Pb/litre	0.314	0.318	0.25	0.148

CPC has argued that to the extent that unleaded gasoline involves higher production costs (of about Rs 1.25), the higher sales price is justified. Moreover, to add unleaded gasoline at an outlet costs about Rs 475,000 per station (for the tank, dispensing machine, construction, etc.).[13] There are also additional tank-farm costs at the storage facility end.

However, it must be understood that the introduction of unleaded gasoline by CPC was in response to a perceived *customer demand* for high-octane (95) unleaded petrol, rather than to environmental concerns per se. This demand was from high-end (luxury) vehicles,[14] whose owners' ability and willingness to pay for the incremental cost is clear. Therefore, to the extent that *customer demand* was the rationale, the price premium for unleaded is not unreasonable, given its higher octane.

---

[10] This section was prepared with the assistance of A. Abeywardena, Ceylon Petroleum Corporation.

[11] See *Report of the Subcommittee on Fuel Reformulation*, 1994, para 6.1.

[12] Initially, the price differential was Rs5/litre, which was subsequently reduced to Rs3/litre.

[13] This estimate, say 500,000 x 300 (say 50 percent of all outlets) = Rs 150 million is considerably higher than that assumed by the Subcommittee on Fuel Reformulation (Rs 35million).

[14] Typically of European manufacture (e.g., Volvo, Mercedes).

Following a decision of the new UNF government, additive lead blending was discontinued in April 2002, and the lead content of 90 research octane number (RON) leaded petrol will drop to about 0.013 gms/litre (the level previously accepted for unleaded petrol). Effective mid-July 2002, there will be only two grades of petrol on the market, both unleaded. The following analysis therefore serves to document the economic and health benefits of the new policy.

Dispelling the myths

Most of the traditional objections to the introduction of unleaded gasoline have been heard in Sri Lanka:

- ?? that as a poor developing country, the costs are too high;
- ?? that Sri Lanka has a large fleet of older vehicles designed for leaded gasoline that depend upon lead as a lubricant (to avoid so-called "valve seat recession" in older cars that have soft valves and valve seats);[15]
- ?? that if unleaded gasoline is produced by running reformers at higher severity, it will have a higher content of benzene (a known carcinogen).[16]

These arguments have little if any merit.[17] The health effects of lead in gasoline have been demonstrated beyond reasonable doubt, and arguments to the contrary (for example, that the observed decline of lead concentrations in blood are attributable to declining use of other lead compounds, such as lead-based paints, rather than to the introduction of unleaded gasoline) have been convincingly rejected.[18] We have already noted that a conservative order of magnitude estimate for the health damage for lead in gasoline is around 7 Rs/litre gasoline, much higher than the estimated incremental cost of around 1-3 Rs/litre (as presented below). Finally, many international sources also argue that even aside from the health benefits, the incremental costs of unleaded gasoline are largely offset by reduced engine maintenance costs.

With respect to valve seat recession, there is broad consensus in the literature that this is a greatly exaggerated problem, and to the extent it has any validity at all, applies primarily to the former Soviet Union and Eastern European countries where car manufacturers did not introduce

15 CPC, *Environmental Concerns as a Result of Increase in Use of Petroleum Fuels*, May 1992: "The old cars in use in Sri Lanka will need minimum lead level of 0.15 gm/litre to ensure valve lubrication." In fact, a number of studies show that minimum levels are far less than this figure, around 0.05-0.07 gms/litre.

16 Subcommittee on Fuel Reformulation, *op. cit*., "*use of unleaded petrol without a catalytic converter will increase the aromatic organic compounds coming to the atmosphere from petrol*."

17 Similar myths have arisen in most developing countries. For example, in the context of the Philippines (which plans to phase out lead this year), they are rehearsed, and answered, at the website www.motorista.com.ph/motortips/tips_102099.html. See also Shell-Philippines website www.shell.com/ph-en/content/0,4600,31743-57201,00.html.

18 See e.g., the literature review by V. M. Thomas, "Elimination of Lead in Gasoline," *Annual Review of Energy and Environment*, 20: 301-324, 1995.

hardened valve seats until very recently.[19] For the past twenty years, the overwhelming majority of gasoline vehicles in Sri Lanka have been imported (as two-to-three–year-old reconditioned) vehicles from Japan, where leaded gasoline was phased out in 1980, and where all models have long had hardened valve seats.

Moreover, upon import, their catalytic converters are removed in order to use leaded gasoline (the avoided costs of which constitute a further economic benefit of unleaded gasoline). Indeed, all domestic Japanese engines were designed to use unleaded gasoline from 1975 onwards, and these constitute the bulk of the present gasoline car vehicle stock in Sri Lanka.[20] Moreover, in a number of countries, leaded gasoline has been phased out despite a large number of vehicles with soft valve seats: for example, in the Slovak Republic, 70 percent of the fleet had soft seats at the time of conversion, a problem solved by use of a special-purpose additive.

With regard to the benzene issue, two points are worth noting.[21] The first is that the health impacts of benzene exposure are far smaller than those of lead exposure: the United States Environmental Protection Agency (USEPA) estimated that, for the U.S., 47 cases of leukaemia deaths could be attributed to benzene in gasoline, as opposed to 4,000-5,000 deaths avoided by the reduction of lead in gasoline.[22] Second, the most significant share of gasoline-related exposures to benzene is related to evaporation in garages, during driving, and at filling stations; and that, in any event, the main source of exposure to benzene in the population is from smoking.

Technical aspects of unleaded gasoline production

Figure 9.7 illustrates the relevant parts of the refinery involved in production of gasoline. Previously, gasoline was blended from two stocks: platformate, typically of 92 octane, and light, straight-run naphtha, typically of 67 octane, blended to produce gasoline of around 84 octane, and brought to 90 octane by the addition of around 0.25gms/litre of tetra ethyl lead (TEL).

---

[19] See, e.g., M. Lovei, *Phasing out Lead from Gasoline in Central and Eastern Europe*, World Bank, 1997; and UNEP, *Global Opportunities for Reducing the Use of Leaded Gasoline*, 1998. As one might expect, many of these arguments have been advanced by the world's leading supplier of lead additives.

[20] Finally, as noted by Shell-Philippines, *op. cit.*, most cars designed for leaded gasoline have "lead memory" that typically affords protection for a further 10,000 to 20,000 km after a switch to unleaded gasoline. The very small percentage of older soft valve cars that remain in Sri Lanka (such as vintage Morris Minors) are unlikely to be driven very much, and are consequently unlikely to experience significant damage. These few vehicles could easily use some other suitable additive to provide the additional lubrication.

[21] For a more detailed discussion see, e.g., M. Lovei, *Phasing out Lead from Gasoline*, Box 4, "The Benzene Myth."

[22] USEPA, *Costs and Benefits of Reducing Lead in Gasoline*, *op. cit.*

Figure 9.8 shows the effect of TEL addition to different blendstocks on RON. Note the non-linear response: the first 0.1gm/litre typically raises the RON by a much larger amount than from 0.1 to 0.2gm/litre.

Figure 9.7: Gasoline production

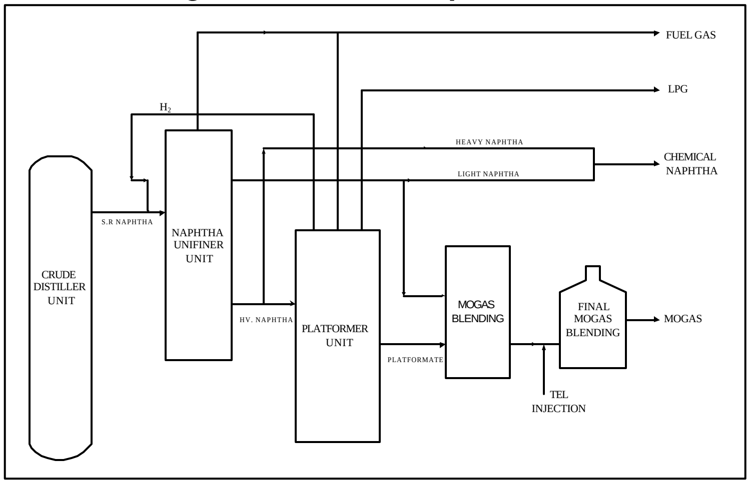
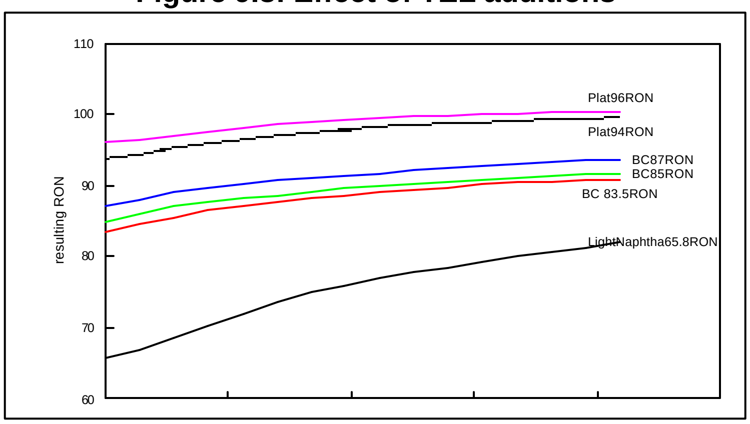


Figure 9.8: Effect of TEL additions



The higher cost to CPC of making unleaded gasoline derives in part from the need to run the platformer at higher severity (though a by-product is more hydrogen, which has its uses for gasoil desulphurisation). Also, since smaller amounts of light naphtha are required for blending, it increases the amount of the surplus that must be exported (at a significantly lower price than gasoline) —though that is no longer true once the naphtha can be used for power generation. Finally, the volume of unleaded gasoline that can so be produced is also reduced, which may necessitate importing gasoline (at the same time as naphtha is exported).[23]

[23] Obviously this raises broader questions of the profitability of refining at Sapugaskanda, and whether all products should simply be imported in whatever proportions required by the domestic market. However, these questions lie beyond the scope of this study.

In Figures 9.9 and 9.10 we show an optimization analysis of the costs of producing 90 Octane leaded and unleaded gasoline. This analysis uses the TEL blending curves of Figure 9.8, and uses average 2000 border prices for the inputs.

Figure 9.9: Optimization of leaded gasoline production

Platformer Yield % wt

Severity	92 RON	93 RON	94 RON	95 RON	96 RON	97 RON	98 RON
H2	6.77	5.22	4.27	5.66	5.89	6.00	6.12
Fuel Gas	2.10	3.43	4.15	4.66	5.48	5.95	6.42
LPG	7.50	8.57	9.67	9.83	9.95	10.01	10.07
Platformate	83.55	82.78	81.91	79.85	78.68	78.04	77.39
Platformate Density	0.7750	0.7824	0.7843	0.7862	0.7881	0.7910	0.7980
SRF Kg/MT	46.00	46.73	47	47.19	49.8	52.41	55.03
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	IMPORTS			PLATFORMER THROUGHPUT							BLENDING
	IMP92UL	IMP95UL	IMP97UL	HN92PL	HN93PL	HN94PL	HN95PL	HN96PL	HN97PL	HN98PL	L.Naphtha
Quantity (MT)	23705	0	0	0	0	179200	0	0	0	0	49636
PRICE (US$/bbl)	32.30	33.55	34.72	27.26	27.26	27.26	27.26	27.26	27.26	27.26	
RON	92	95	97	92	93	94	95	96	97	98	
RVP	5	5	5		5	5	5	5	5	5	
Density	0.74	0.754	0.76	0.7750	0.7824	0.7843	0.7862	0.7881	0.7910	0.7980	
TOTAL COST US $	6E+06	0	0								
M3	32034	0	0	0	0	228484	0	0	0	0	

NAPHTHA AVAILABILITY	QT(MT)	US $/bbl	RON	RVP(psi)	Density	COST US $
L. Naphtha	146000		67.0	13.0	0.6750	
H.Naphtha	179200				0.7550	
FOR BLENDING						
L. Naphtha	49636		67.0	13.0	0.6750	
Platformate	146783		94.0	5.0	0.7843	
B/C production	196410		86.4	7.1	0.7535	
Fuel Oil Price		152.30 US $/MT				
Platformer Unit Capacity	217000					
Platformate Unit Costs						
H. Naphtha - Feed	179200	27.26 US $/bbl				40,696,189
Fuel(FO/FG) SRF MT	8422	160.32 US $/MT				1,350,244
Less Production from Platformer						
Fuel Gas	7436.0	104.36 US $/MT				1,371,072
LPG	17329	350.00 US $/MT				6,065,024
L. Naphtha - For Blending	49636	27.26 US $/bbl				12,608,176
Total Cost of Refinery Mogas	196410					47,218,513
Mogas Requirement	220123.36		87.0	9.0		
Imported UL Mogas	23705.03 MT					6,467,712
Refinery Production	196410.33 MT					47,218,513
Mogas Pool (Ref + Imp) 87 RON	220123.36 MT		87.0	7.0		53,686,225
TEL requirement (MT)	96.640	8129.00 US $/MT				785,583
Leaded 90 RON Mogas Pool	220220.00 MT		90.0	7.0		54,471,808
Average Price Of Mogas		**29.59** US $/bbl				
Pb GM/litre		**0.130** gms/litre				

TEL B Litres /M3 requirement to boost 87 RON B/C to 90 RON: 0.1891

* B/C - Blending Component (Blend of L. Naphtha & Platformate)

Figure 9.10: Optimization of unleaded gasoline production

Platformer Yield % wt

Severity	92 RON	93 RON	94 RON	95 RON	96 RON	97 RON	98 RON
H2	6.77	5.22	4.27	5.66	5.89	6.00	6.12
Fuel Gas	2.10	3.43	4.15	4.66	5.48	5.95	6.42
LPG	7.50	8.57	9.67	9.83	9.95	10.01	10.07
Platformate	83.55	82.78	81.91	79.85	78.68	78.04	77.39
Platformate Density	0.7750	0.7824	0.7843	0.7862	0.7881	0.7910	0.7980
SRF Kg/MT	46.00	46.73	47	47.19	49.8	52.41	55.03
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	IMPORTS				PLATFORMER THROUGHPUT						BLEND IN
	IMP92UL	IMP95UL	IMP97UL	HN92PL	HN93PL	HN94PL	HN95PL	HN96PL	HN97PL	HN98PL	L.Naphtha
Quantity (MT)	47676	0	0	0	0	179200	0	0	0	0	25761
PRICE (US$/bbl)	32.30	33.55	34.72	27.26	27.26	27.26	27.26	27.26	27.26	27.26	
RON	92	95	97	92	93	94	95	96	97	98	
RVP	5	5	5		5	5	5	5	5	5	
Density	0.74	0.754	0.76	0.7750	0.7824	0.7843	0.7862	0.7881	0.7910	0.7980	
TOTAL COST US $	1E+07	0	0								

NAPHTHA AVAILABILITY	QT(MT)	PRICE		RON	RVP(psi)	Density	COST US $
L. Naphtha	146000			67.0	13.0	0.6750	
H.Naphtha	179200					0.7550	
FOR BLENDING							
L. Naphtha	25761			67.0	13.0	0.6750	
Platformate	146783			94.0	5.0	0.7843	
B/C production	172544			89.4	6.4	0.7658	
Fuel Oil Price		152.30	US $/MT				
Platformer Unit Capacity	217000						
Platformer Unit Costs							
H. Naphtha - Feed	179200	27.26	US $/bbl				40,696,189
Fuel(FO/FG) SRF MT	8422	160.32	US $/MT				1,350,244
Less Production from Platformer							
Fuel Gas	7436.8	184.36	US $/MT				1,371,072
LPG	17329	350.00	US $/MT				6,065,024
L. Naphtha - For Blending	25761	27.26	US $/bbl				6,543,655
Total Cost of Refinery Mogas	172544						41,153,992
				MIN	MAX		
Mogas Requirement	220220			90.0	9.0		
Imported UL Mogas	47676.35	MT					13,008,079
Total Mogas Pool	220220.00	MT		90.0	6.1		54,162,071
Average Price Of Mogas(UL)		29.72	US $/bbl				

These preliminary studies show that the incremental difference between leaded and unleaded gasoline (at the same RON) is much smaller than the difference between octane levels. At 90 RON the incremental cost of unleaded gasoline is only Rs 0.08/litre (see Table 9.10), while at 95 RON the incremental cost of unleaded is higher (Rs 0.14 - 0.22/litre).[24] However, the difference between 90 RON and 95 RON is between $1.20 and 1.40$/bbl (about Rs .67 to .80/litre).

[24] This is significantly lower than earlier estimates by CPC of additional costs of Rs 1.25/litre. However, the basis for those earlier estimates is unclear.

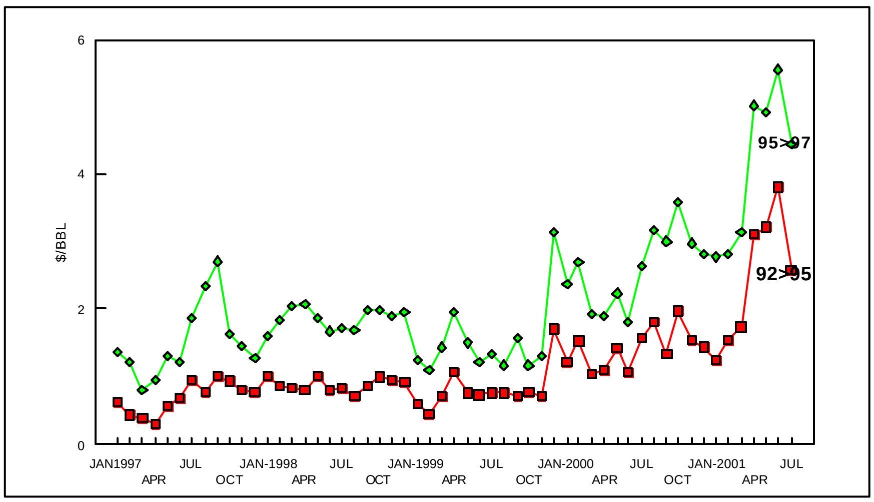
Table 9.10: Incremental costs of unleaded gasoline

		90RON	*95RON*	*95RO (with platformer constraint)(1)*
Cost of unleaded gasoline	US $/bbl	29.72	30.96	31.16
Delta (octane improvement)	US $/bbl		1.24	1.44
Cost of leaded gasoline	US $/bbl	29.59	30.77	30.77
Delta (octane improvement)	US $/bbl		1.18	1.18
Incremental cost	US $/bbl	0.13	0.26	0.39
	Rs/$bbl	12.06	23.4	35.1
	Rs/litre	0.08	.14	.22
	US cents/litre	0.085	.16	.25

(1) Platformer severity limited to maximum of 96 Octane.

The incremental production costs of 95 RON over 90 RON at Sapugaskanda are also consistent with the premia observed on Singapore spot markets, shown in Figure 9.11.[25] For most of 1997-1999, the cost of moving from 92 RON to 95 RON was around 1$/bbl (or 0.6Rs/litre at 90Rs/$); this has more than doubled in recent months. 97 Octane commands even higher premia.

Figure 9.11: Octane premia (Singapore spot market prices)



25 Platt's no longer quotes 90 RON leaded or unleaded gasoline, so a direct comparison with Singapore is difficult.

Tax incentives

The efficacy of an appropriate taxation scheme to the introduction of unleaded gasoline is evident from the Hong Kong experience. According to Walsh,[26] when Hong Kong introduced unleaded gasoline in spring 1991, prices were modified to make unleaded gasoline cheaper to the consumer than leaded. As a result, unleaded sales soared from zero to over 50 percent within the first month. If indeed unleaded petrol is priced less than leaded petrol, then no rational consumer would use the latter, and unleaded gasoline consumption would be constrained only by the ability of CPC to supply adequate unleaded gasoline, and, perhaps more importantly, by the number of stations offering unleaded.

The relationship between price differentials and market share is well established statistically. A World Bank study[27] showed the relationship between market share for unleaded (***Y***), price differential (***P***), and share of the fleet with soft valve seats (***V***) as

$$\boldsymbol{Y=61.7 + 3.41\,P - 1.19\,V};\ R^2=0.78$$

Thus a 1 percent increase in the price differential resulted in a 3.5 percent increase in the market share for unleaded.

We know of no examples in Asia of where unleaded gasoline was successfully introduced while selling at a higher price than leaded. For example, in Thailand, leaded gasoline was phased out over a four-year period (1991-1995), with differential tax rates used to secure the desired result (Figure 9.12).[28] Although the ex-refinery price of unleaded is higher (by about 15 percent), the retail price of unleaded is lower by about 2.5 percent.[29]

---

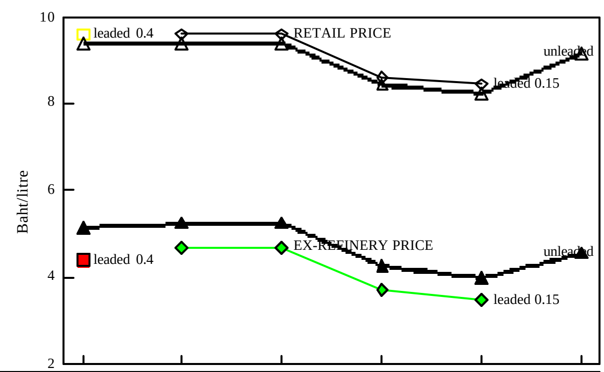
26 M. Walsh, *Motor Vehicle Pollution Control in Sri Lanka: A Preliminary Strategy for Progress in Colombo*, NAREPP, Colombo, July 1992, p.31.

27 M. Lovei, *Phasing Out Lead from Gasoline, op. cit*., Annex B.

28 P. Vivekaphirat, "Experience of Thailand in Improving Fuel Quality," *Proceedings*, Regional Workshop: Fuel Quality and Alternative Fuels, Delhi, May 2001. In addition to normal taxes, the Thai "oil fund" was used as a cross-subsidy measure in this tax equalization.

29 The impact on ambient lead levels was dramatic, falling from about 0.5 microgram/m3 in 1990 to less than 0.05 by 1997; and roadside levels falling from 2 micrograms/m3 to about the same ambient value of 0.05. (*Ibid*, p.27)

Figure 9.12: Implementing unleaded gasoline in Thailand [Baht/litre]



	1991	1992	1993	1993	1994	1995
leaded 0.4	4.4					
leaded 0.15		4.7	4.67	3.7	3.5	
unleaded	5.1	5.3	5.25	4.2	4.0	4.6
leaded 0.4	9.59					
leaded 0.15		9.59	9.59	8.62	8.44	
unleaded	9.38	9.41	9.41	8.43	8.24	9.18

Source: Vivekaphirat (2001), p.18.

Several aspects of the Thai experience seem worth noting. First, the differential between unleaded and leaded gasoline does not have to be large: even a small price advantage to unleaded (e.g., of 2.5 percent) is sufficient to induce motorists to choose unleaded, always assuming there is a sufficient number of retail outlets to supply it. Second, the volatility in world oil prices far exceeds the ex-refinery production cost differential of 15 percent, equal to about 2 U.S. cents/litre.[30] In 1995, the average Singapore spot price for gasoline was around 23.5 $/bbl, or 14.8 U.S. cents/litre; it then fell to 13/bbl (8 cents/litre) in December 1998, increasing to 38$/bbl (24 cents/bbl) in August 2000. Therefore, even if the entire price differential were passed onto the consumer, it would be a modest increase compared to any adjustments required by cif prices.

To be sure, in Sri Lanka, changes in the retail price (under the previous system) were made infrequently, and did not respond to short-term changes in world price. However, the present Rs 3/litre differential between leaded and unleaded may be compared to the last retail gasoline price increase of Rs 10/litre in 1996. And at Rs 3/litre to cover CPC and incremental infrastructure costs, the total annual incremental cost is Rs 450 million per year,[31] representing about 6 percent of present fuel tax revenue on gasoline (Rs 7.76 billion). But our analysis suggests that the Rs 3/litre differential is not justified to remove lead from gasoline (though it may be justified to cover incremental costs of supplying high octane fuel to owners of luxury vehicles).

---

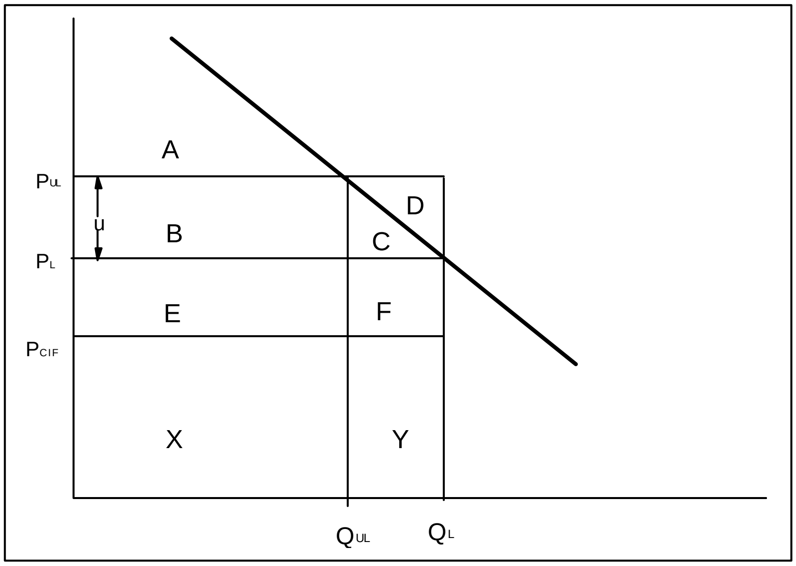
30 In the 1990-1996 time period (before the crisis in 1997), the exchange rate was around 25.3Baht/$.

31 Assuming 255 million litres of gasoline consumed in year 2000.

Theory

The calculation of costs and benefits of introducing unleaded gasoline is shown in Figure 9.13. Initially, consumption of leaded gasoline is Q_L, and the leaded price of P_L, which equals (ignoring for simplicity the margins) the sum of (all) gasoline taxes ? plus the cif price P_{CIF}. In this case we also assume that the incremental cost is passed onto the consumer (as is now the case in Sri Lanka).

Figure 9.13: Costs and benefits of introducing unleaded gasoline



Suppose the cost of producing unleaded gasoline at the Sapugaskanda refinery is u, and that this price is passed to the consumer, i.e.,

$$P_{UL} = P_L + u$$

Consumption will reduce from Q_L to Q_{UL}. We can then tabulate the situation before and after introduction of unleaded gasoline as shown in Table 9.11. Note that the total consumer benefit in each case is the area under the demand curve. It is assumed here (to simplify the figure) that the environmental damage cost per litre is exactly equal to the incremental cost of unleaded gasoline, u: actual calculation may of course show otherwise (and therefore either increase or decrease the quantity D-F).

Table 9.11: Economic benefit of unleaded gasoline

	Leaded [1]	*Unleaded [2]*	*Net impact [2]-[1]*
Consumer benefit	***A+B+C+E+F+X+Y***	***A+B+E+X***	***-C-F-Y***
Refinery cost of UL		***-B***	***-B***
Fuel cost	***-X-Y***	***-X***	***+Y***
Total (before environment)	***A+B+C+E+F***	***A+E***	***-B-C-F***
Environmental	***-B-C-D***	***0***	***B+C+D***
net economic benefit	***A+E+F-D***	***A+E***	***D-F***
Distributed as			
Consumers	***A+B+C***	***A***	***-B-C***
Government	***E+F***	***E***	***-F***
Environment	***-B-C-D***	***0***	***B+C+D***

Table 9.12 rearranges the terms in the usual way, in which the affected interests are shown by columns of the table, and which shows just the *changes* in each case. We assume here that the CPC makes no margin on the additional cost (i.e., that its incremental cost exactly equals the incremental price of unleaded).

Table 9.12: Unleaded gasoline, winners and losers (unleaded cost passed to consumer)

	Consumers	*Govt*	*CPC*	*Total*	*Environment*	*Total*
Area C	***-C***			***-C***		***-C***
Price increase	***-B***		***B***			
Refinery cost			***-B***	***-B***		***-B***
Tax		***-F***		***-F***		***-F***
Environment					***B+C+D***	***B+C+D***
Total	***-B-C***	***-F***	***0***	***-B-C-F***	***B+C+D***	***D-F***

But what happens if the incremental cost is absorbed by the government by a reduction in tax? If there is no increase in (consumer) price, the quantity consumed remains the same ($\boldsymbol{Q_{UL}} = \boldsymbol{Q_L}$), in which case the results are somewhat different, as shown in Table 9.13: Consumers are unaffected, and there is no net economic benefit.

Table 9.13: Unleaded gasoline, winners and losers (incremental cost covered by subsidy)

	Consumers	*Govt*	*CPC*	*Total*	*Environment*	*Total*
Area C						
Price increase		***-B-C-D***	***-B-C-D***			
Refinery cost			***-B-C-D***	***-B-C-D***		***-B-C-D***
Fuel cost						

Tax						
Environment					***B+C+D***	***B+C+D***
Total	***0***	***-B***	***0***	***-B-C-D***	***B+C+D***	***0***

In other words, it is better for the consumer to pay the increased cost of unleaded gasoline (assuming ***D>F***) than for the government to do so (net economic benefit=zero)—a standard result of welfare economics. However, if consumers continue to be offered lower-priced leaded gasoline, the net benefit (***D-F***) is also unrealized, thereby warranting the subsidy in the short-term (during the transition) in the interests of realizing the long-term benefit.

Results

Table 9.14 shows the results of the analysis, under the following assumptions:

?? An incremental production cost at the refinery of Rs 0.8/litre (assuming the platformer is limited to maximum severity of 96 octane).

?? Lead health damage equivalent to Rs 7/litre.

?? Infrastructure development costs based on a three-year programme to extend service of two grades of gasoline to an additional 400 filling stations.[32] This adds about Rs 0.25/litre to the cost.

The environmental benefits are great compared to the economic costs. Moreover, the increased costs experienced by consumers (assuming the incremental costs are passed onto them) are small, less than two percent of the present fuel bill: but when the health benefits are apportioned back to road users, benefits particularly to motorcycle riders are large. In addition, the occupational groups most affected by present lead exposure—trishaw drivers, traffic wardens, and policemen—would be directly benefited.

[32] Assuming Rs 500,000 per filling station plus another Rs 500,000 for each filling station as CPC's incremental development cost (for storage and handling).

Table 9.14: Impact of unleaded gasoline

	Road users					*CPC*	*Govt*	*Total*	*Environment*		*Total*
	Low-Inc	*Med-Inc*	*High-Inc*	*Agric*	*Busin*				*Local*	*Global*	
Economic costs								0			0
Area[C](petrol)	-37	-49	-42	-1	-7			-135			-135
Price increase	-756	-1048	-698	-12	-109	2623		-0			-0
Refinery costs[B]						-2623		-2623			-2623
Infrastructure costs						-298		-298			-298
Tax impacts							-241	-241			-241
Environment								0			0
Lead								0	19535		19535
PM-10								0	10		10
Sox								0	-13		-13
NOx								0	17		17
Carbon reduction								0		14	14
Net impact	-792	-1098	-739	-13	-115	-298	-241	-3297	19549	14	16266
Apportioned health impact											
Diesel											
Petrol	5632	7815	5199	91	811						
Net impact	4840	6717	4460	78	696						
Baseline fuel bill	122900	50998	127271	12947	105586						
Net impact as percent	-1%	-2%	-1%t	-0%	-0%						
Percent(after health)	4%	13%	4%	1%	1%						

Conclusions

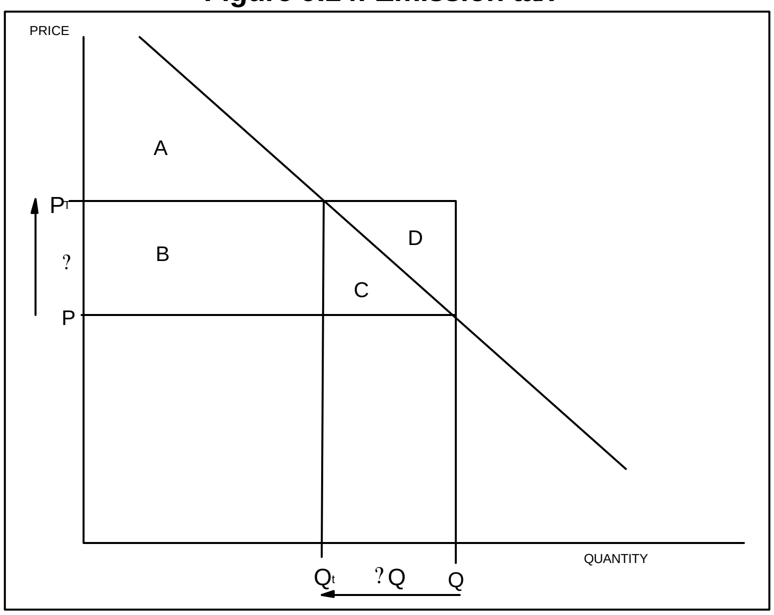
It is hard to avoid the conclusion that the introduction of unleaded gasoline is highly cost-effective. The switching value for the damage costs is around Rs1/litre, which is a small fraction of our already very conservative estimate of Rs 7/litre (in turn only five percent of the value based on U.S. studies adjusted for population and GDP). Moreover, we show very small incremental refining costs. Experience in other countries shows little problem with old cars (that are said to require lead for lubrication), so the costs of duplicating infrastructure could be eliminated by simply phasing out leaded gasoline straight away. Since most gasoline-vehicles in Sri Lanka are of Japanese domestic origin, where lead was phased out 20 years ago, and vehicles have had hard valve seats for the same period, the number of vehicles that actually require such lubrication is very small. These vehicles could be supplied with a special-purpose additive at a minute fraction of the cost of duplicating infrastructure (as shown by the successful experience in the Slovak Republic). Of course, a modern supply system would need to offer two grades of gasoline (say 92 and 95 unleaded). But to charge these incremental infrastructure and octane costs to the environmental account is hardly reasonable.

Clearly these results need to be confirmed by a detailed refinery optimization study, which goes beyond the scope of this report. However, the analysis presented here suggests large benefits to Sri Lanka of immediately eliminating leaded gasoline.

Carbon tax

The theory—and rationale—of an emission tax is straightforward. Consider the demand curve for transportation fuels of Figure 9.14, with fuel price ***P***, and quantity consumed ***Q***, say, expressed in tons. Suppose consumption of one ton of fuel resulted in an air emission damage of *?* Rs/ton. The total damage is therefore ***Q****??*, equal to the area ***B+C+D.*** Then if a tax were levied on the fuel at a rate equal to the externality damage, the price would rise to $\boldsymbol{P_T = P + t}$, with a corresponding decrease in the quantity consumed to $\boldsymbol{Q_T = Q -}$ *?* ***Q***.

Figure 9.14: Emission tax



It is easy to see that this tax increases welfare: winners and losers are as indicated in Table 9.15: the sum of avoided environmental damages and government revenue exceeds the loss of consumer surplus by the area ***D***.

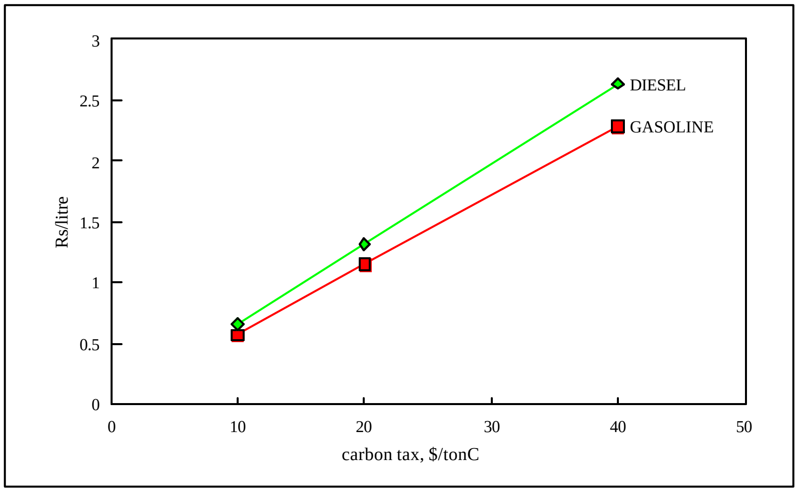
Table 9.15: Winners and losers

	Consumers	*Government*	*Environment*	*Total*
Tax		**+ *B***		**+*B***
Consumer surplus	***-B – C***			**+*B-C***
Environmental damage			***C + D***	***C + D***
Total	***-B - C***	**+ *B***	***C + D***	***D***

Positive=gain, negative=loss.

There are several ways in which a carbon tax could be implemented. The first is as an *incremental* tax: for which the retail price impact is as shown in Figure 9.15. Thus, a carbon tax pegged at \$20/tonC results in an (additional) tax of Rs 1.14/litre for gasoline, and Rs 1.32/litre for diesel.[33]

Figure 9.15: Incremental price impact as a function of carbon value



Exchange rate:Rs90/\$US.

With the carbon tax set as such an *incremental* tax, the physical impacts are as shown in Table 9.16.

Table 9.16: Physical impacts, incremental carbon tax

		Valuation	*2010*			*Lifetime savings*		
		\$/ton	*Baseline*	*+Policy*	*Delta*	*Percent [baseline]*	*Discounted*	*Undisc*
Petrol	[1000tons]		275	275	-0	-0%		
Diesel	[1000tons]		928	910	-18	-2%		
Emissions								
PM-10	[tons]	17790	990	975	-15	-1%	106	
SOx	[tons]	2924	9282	9101	-181	-2%	1310	
NOx	[tons]	700	49278	48536	-742	-2%	5360	
Carbon reduction	[1000tons]	20	1045	1027	-18	-2%	-206	-601

---

33 The difference follows from slightly different carbon contents, and different densities (see Table 3.4). For example, for diesel, the tax computes to

$$20\left(\frac{\$}{tonC}\right) \times 0.875\left(\frac{tonC}{tonFuel}\right) \times 90\left(\frac{Rs}{\$}\right) \times \frac{1}{1196}\left(\frac{ton}{litres}\right) = 1.32\left(\frac{Rs}{litre}\right)$$

Table 9.17: Impacts of incremental carbon tax ($20/ton): NPV (Rs Billion)

	Road users					*Govt*	*Total*	*Environment*		*Total*
	Low-Inc	*Med-Inc*	*High-Inc*	*Agric*	*Freight*			*Local*	*Global*	
Tax changes										
Diesel tax	-3438		-3085	-494	-4311	11329	0			0
Petrol tax	-737	-984	-820	-15	-126	2682	0			0
d[consumer impacts]										
Area[C](petrol)	-7	-9	-8	-0	-1		-25			-25
Area[B](petrol)	-751	-1002	-835	-15	-129		-2731			-2731
Area[Z](diesel)	-68		-61	-10	-85		-223			-223
Area[W](diesel)	-3504		-3144	-504	-4393		-11544			-11544
Carbon Tax receipts						14011	14011			14011
d[road maintenance]										
Diesel						1827	1827			1827
Gasoline						26	26			26
Environment										
PM-10							0	255		255
SOx							0	517		517
NOx							0	507		507
Carbon reduction							0		601	601
Net impact	-4329	-1011	-4047	-529	-4607	15863	1340	1279	601	3220
Baseline fuel bill	91176	43845	94484	9038	73120					
Net impact as %	-5%	-2%	-4%	-6%	-6%					

low-I:=three-wheelers & buses; **med-I**=motorcycles; **high I**=cars and dual-purpose vehicles.
Assumptions: World oil price: US$26 /bbl, Rs 90/$US

The impacts of this tax are positive even without environmental benefits being taken into consideration, because the deadweight losses associated with the tax[34] are offset by reduction of another externality, namely the reduction in road damage costs.

The second option is to raise the entire tax revenue on auto fuels as a carbon tax, which is similar in concept to the previously discussed tax equalization scheme, but here, rather than setting an equal tax in Rs/litre, the tax on gasoline to diesel is set in the ratio of 1.14:1.32 (i.e., in the proportion of the ratio of carbon emissions), such that the same total revenue is raised. One would expect carbon emissions under this approach to be lower than if the tax rate is set in the ratio 1:1 (as assumed above in Section 9.1): this is indeed the case, as illustrated in Table 9.18, that shows an additional 70,000 tons of lifetime carbon reduction.[35]

---

34 I.e., the incremental tax receipts (Rs 14,011 million) are less than the change in consumer surplus (Rs 14,523 million).

35 From 2.07 million (in Table 9.6) to 2.14 million in (Table 9.19).

Table 9.18: Physical impacts: carbon-based equalization

		Valuation	*2010*				*Lifetime savings*	
		$/ton	*Baseline*	*+Policy*	*Delta*	*Percent [baseline]*	*Discounted*	*Undisc.*
Petrol	[1000tons]		275	306	31	11%		
Diesel	[1000tons]		928	834	-94	-10 %		
Emissions								
PM-10	[tons]	17790	990	942	-48	-5%	328	
SOx	[tons]	2924	9282	8341	-941	-10%	6390	
NOx	[tons]	700	49278	46777	-2500	-5%	17212	
Carbon reduction	[1000tons]	20	1045	979	-66	-6%	-720	-2143

The distributional impacts are generally similar as in the simple equalization scheme, as shown in Table 9.19. With the slightly greater impact on diesel vehicles, there is also a further reduction in road maintenance costs of Rs 200 million.[36]

Table 9.19: Distributional impacts, carbon-based tax equalization: NPV (Rs Million)

	Road users					*Govt*	*Total*	*Environment*		*Total*
	Low-Inc	*Med-Inc*	*High-Inc*	*Agric*	*Freight*			*Local*	*Global*	
Tax changes										
Diesel tax	-15491		-13750	-2226	-19317	50785	0			0
Petrol tax	13950	18601	15562	277	2395	-50785	0			0
d[consumer impacts]										
Area[C](petrol)	248	332	274	5	42		901			901
Area[B](petrol)	16089	21454	17944	319	2761		58567			58567
Area[Z](diesel)	-999		-881	-144	-1242		-3265			-3265
Area[W](diesel)	-15811		-14035	-2272	-19718		-51836			-51836
Carbon tax						0	0			0
d[road maintenance]										
Diesel						8902	8902			8902
Gasoline						-4169	-4169			-4169
Environment										
PM-10							0	794		794
SOx							0	2553		2553
NOx							0	1642		1642
Carbon reduction							0		2143	2143
Net impact	-474	21786	3302	-2092	-18156	4733	9100	4989	2143	16232
Baseline fuel bill	91176	43845	94484	9038	73120					
Net impact as	-1%	50%	3%	-23%	-25%					

[36] From Rs4.6 billion (in Table 9.5) to Rs 4.8 billion (in Table 9.12).

percent

low-I:=3-wheelers&buses; **med-I**=motorcycles; **high I**=cars and dual-purpose vehicles

In conclusion, we may summarize as follows:

?? Equalization of fuel taxes is economically efficient, even without consideration of environmental benefits. Indeed, to the extent that diesel vehicles cause more road damage than do gasoline vehicles, one could argue that the diesel fuel tax should be higher than that levied on gasoline, but that is unlikely to be politically achievable.

?? The present rates of fuel tax imply a cross-subsidy from motorcycle owners—the larger group of road users—to the freight industry (and agriculture). Equalization redresses this cross-subsidy.

?? There are significant environmental benefits to equalization. An equalization based on relatively carbon emissions brings even higher benefits, and is the option that we recommend.

?? The previous pricing policy for unleaded gasoline (at a price higher than that of leaded gasoline) was unlikely to have achieved its objective of displacing leaded gasoline. A small price advantage for unleaded gasoline is essential for consumers to prefer this fuel, as is well demonstrated by the Thai experience. Fortunately, with leaded gasoline now being phased out completely, this point is now moot.

10

Regulatory Options

In this section we examine a group of measures that we call "regulatory" simply to distinguish them from those that involve tax and price policy (already discussed in Section 9). Thus the reduction of two-stroke-motorcycles would be accomplished by a ban on further imports; and conversion of vehicles to LPG would be accomplished by an enforcement regime based upon administrative rules and legislation.

10.1 Ban two-stroke motorcycles

Two-stroke (2S) motorcycles have higher emissions and lower fuel efficiency than four stroke (4S) engines.[37] Nevertheless, because of a slight advantage in initial cost, they have captured a significant share of total sales. We estimate that of the total number of around 550,000 motorcycles in Sri Lanka in 2000, about one-third are two-stroke.[38] However, because emissions from two-stroke machines are significantly higher per km than for four-stroke, two-stroke machines account for a disproportionate quantity of total emissions (Table 10.1). Chandrasiri has estimated that in Colombo, 2-stroke motorcycles emit ten times the total particulate emissions of four-stroke machines.[39] Indeed, we estimate that in 2000, two-stroke motorcycles account for 4 percent of passenger-km but 8 percent[40] of particulate emissions.[41]

---

37 However, as noted by Faiz et al.,[37] "the data on motorcycle emissions are scarce. Available data pertain mostly to uncontrolled U.S. motorcycles, though limited information is also available from Europe and Thailand." However, the recent study by Kojima et al. (2000) fills many of the earlier gaps.

38 See Table 2.2. Most of the earlier estimates of the proportion of two-stroke motorcycles in the mix prove to be guesses, mainly because customs data do not record the type of engine. Walsh, *op. cit*, estimated the fraction of two-stroke motorcycles as 40 percent; Chandrasiri (1999) at 60 percent. Our estimate is based upon an actual sampling (see Annex 2.1).

Nevertheless, this proportion of two-stroke motorcycles in Sri Lanka is substantially lower than that reported in other Asian cities. For example, in Bangkok in 1994, two-stroke motorcycles were reported to account for 90 percent of the total (World Bank, 1994).

39 Chandrasiri (1999), Annex 3. Two-stroke motorcycles in Colombo were estimated to emit 229 tons of particulates/year, as opposed to 29 tons from four-stroke machines.

40 See Table 12.5, below, for a detailed breakdown of 2000 particulate emissions by vehicle type.

Table 10.1: Motorcycle fuel emissions: gms/vehicle-km

	Two-stroke	*Four-stroke*
SPM	0.21	0.029
CO	17	20
HC	9.9	2.39
NO2	0.075	0.15

Source: Faiz et al. (1990)

Higher emissions from two-stroke machine have two causes: first, they have somewhat lower fuel efficiency, and therefore for carbon, lead, and sulphur, higher emissions per km are roughly equal to the difference in average fuel efficiency. However, as shown in Table 10.2, the data on fuel efficiency of motorcycles show wide variations, both in terms of km/litre, and in the *ratio* of efficiencies.[42]

Table 10.2: Motorcycle fuel economy

	Litres/ 100km	*Mpg*	*Km/litre*	*Ratio: two: four-stroke*
Two-stroke				
Bangkok (1)	2.5		40	
USA (1)	4.7		21	
Sri Lanka (MEIP)		37.7	16	
OTA		50	22	
Europe (4) >50cc			25	
<50cc			42	
Four-stroke				
Bangkok (1)	1.6		63	1.56
USA (1)	2.9		34	1.62
Sri Lanka (MEIP)		49	21	1.30
OTA		67	29	1.34
Europe (4)>50cc			20	1.25

Sources : (1) Chan and Weaver, 1994 (as cited in Faiz*, op. cit.)*
(2) OTA: Overseas Transport Authority
(3) MEIP: Metropolitan Environment Improvement Program
(4) Faiz et al., Tables A2.1.3 and A2.1.4.

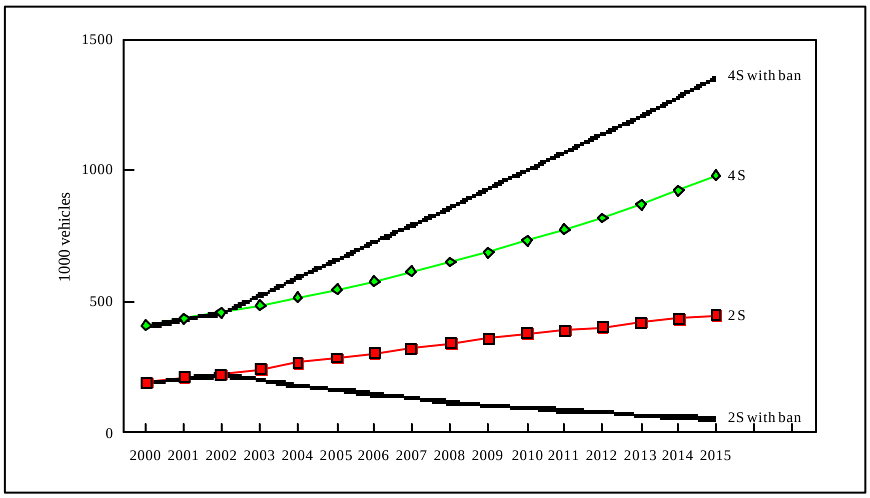
[41] In Bangkok, prior to the introduction of standards, two-stroke motorcycles were estimated to account for 87 percent of particulates, 20 percent of lead, and 50 percent of hydrocarbon emissions from transport sources (World Bank, 1994).

[42] One obvious explanation for the variation is that these are estimated fleet average figures, which do not take into account the variation in engine sizes within and between the two categories.

Second, two-stroke engines have inherently higher emissions of particulates because lubricating oil is added directly to petrol, and there tends to be a higher fraction of unburnt oil in the exhaust than there is in four-stroke engines.

Therefore, on grounds of both fuel economy, and the disproportionate contribution to emissions, banning two-stroke machines represents a potential policy option.[43] Because the ban on two-stroke motorcycles would most easily be implemented by a ban on further imports, depending upon assumptions about retirement, it would be some years before the stock of two-stroke motorcycles declined—and consequently the benefits to fuel savings and emissions would increase gradually over time. Figure 10.1 shows the projection of the stock of motorcycles with and without the ban.[44]

Figure 10.1: Projections of motorcycle vehicles, with and without two-stroke ban (starting in 2003)



A bewildering variety of motorcycle models can be found on the market, and the information provided to the consumer regarding the fuel-economy benefits of four-stroke machines is rarely precise, and often inconsistent.[45] Moreover, a significant proportion of

43 The efficacy of banning motorcycles from urban areas is nowhere more evident than in Beijing—not just two-stroke motorcycles, but *all* motorcycles have been banned from Central Beijing (which, together with extensive conversions of buses and taxis to LPG, have significantly reduced automotive emissions in the downtown areas).

44 The growth assumptions are taken from the vehicle fleet projections of Section 2.2, which specify only the annual number of vehicles. If we assume the average life of a motorcycle at 15 years, then the annual retirement rate is 6.7 percent; hence, if the growth in the number of vehicles is, say, 8 percent, the growth in the number of *new* vehicles is 8+6.7 percent=14.7 percent. This is a simplification, particularly in a period of a rapidly growing vehicle stock: more accurately, one would have to model the survival distribution of each age-cohort separately. However, by taking a relatively long assumed lifetime, one can avoid this complication.

45 As revealed by our informal survey of four large dealerships in summer 2000, when a research assistant posed as a potential buyer of a motorcycle. Fuel efficiency is almost never mentioned in newspaper

motorcycles is imported second-hand (from Japan and other East Asian countries), and account for the bulk of the offered supply.[46] Among the cheapest two-stroke models on the market are those from China, although anecdotal evidence suggests that potential consumers (and dealers) do perceive a significant quality difference between high-end Suzuki and Honda models, and those from China.

The prices (and price differentials) among different types of motorcycles are strongly dependent upon engine capacity, as shown in Figure 10.2. The average price of a two-stroke motorcycle offered by dealers in summer 2000 was Rs 59,500, as opposed to Rs 87,700 for four-stroke motorcycle, a difference of Rs 28,200 ($350).[47] These prices include taxes and duty: all motorcycle imports (both new and used) are subject to an import duty of 10 percent computed at CIF cost irrespective of variations in engine capacity: they are also subject to a 10-percent excise duty and 6.5 percent NSL. A simple regression analysis with four-stroke motorcycle taken as a 0/1 dummy variable showed that four-stroke motorcycles added Rs 18,000 ($225) to the selling price (i.e., when engine capacity is factored out).

However, such differentials need to be evaluated with caution, for the offerings of dealers may or may not translate into actual market share. Unfortunately, the database maintained by the customs authorities does not distinguish between two-stroke and four-stroke machines, and therefore we can make no independent consistency check on our assumptions.

A different approach was taken by Chandrasiri,[48] who based his estimate of a Rs 6,000-difference on the international literature,[49] which in turn is based upon engineering estimates of what the difference in manufacturing costs (between machines of otherwise comparable characteristics) *ought* to be. This estimate is significantly lower than that derived above.

---

advertising (unlike electricity-powered household appliances, whose efficiency rating is increasingly a feature of Colombo consumer advertising).

46 This is similar to gasoline automobiles, a large proportion of which are of Japanese manufacture two to threeyears old. Only four of the 20 four-stroke motorcycles offered in one newspaper advertisement were new machines.

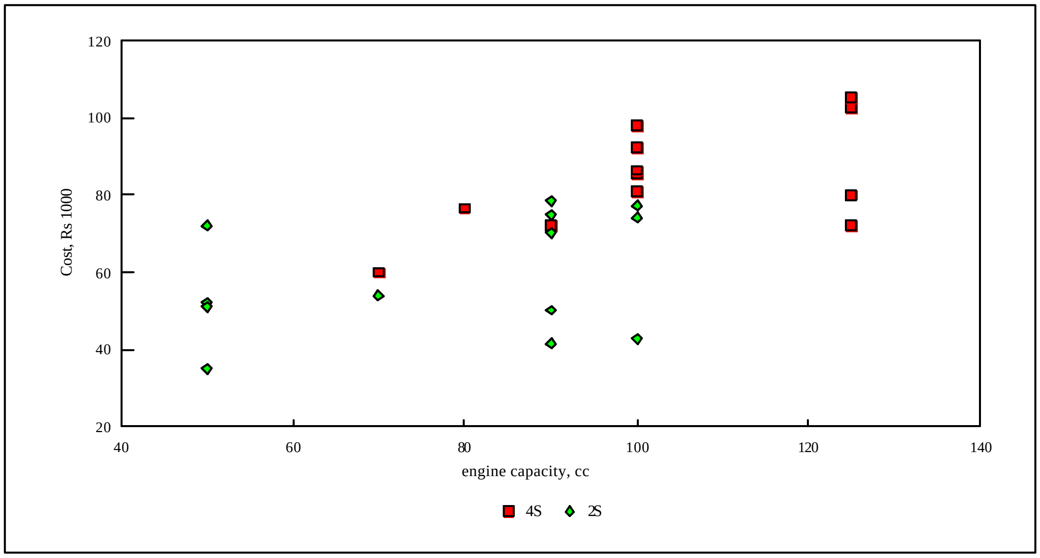
47 These averages reflect the listed prices of 20 four-stroke and 21 two-stroke motorcycles offered in an advertisement in the Daily News, on Nov. 21, 2000.

These are substantially larger differences than those reported elsewhere. For example, the Bangkok study (World Bank, 1994) estimates that the cost of replacing two-stroke by cleaner alternatives (either four-stroke or advanced two-stroke engines with timed fuel injection and crankcase lubrication) at $30-60/machine. It is unclear what these estimates are based on.

48 Chandrasiri, *Health Effects, op. cit*., p.54.

49 Notably Faiz, *Air Pollution from Motor Vehicles, op. cit*.

Figure 10.2: Motorcycle prices and engine capacity[50]



While there may well be some uncertainty about the exact magnitude of the difference, it certainly seems reasonable that a significant differential on vehicles of comparable quality, age, and engine capacity does exist. Therefore, a ban on further imports of new two-stroke motorcycles would doubtless impose private costs upon the lower–income end of motorcycle buyers. Monthly payments quoted in advertisements (based on 20 percent down payment, balance payable over 36 months), ranged from Rs 1,436-2,533/month for two-stroke, but Rs 2,227-3,760 /month for four-stroke.[53] The probable response to a ban would be a combination of:

?? an increase in the price of existing second-hand two-stroke motorcycles
?? decisions by some potential buyers to defer purchase (and to continue to use buses)
?? the import of a greater proportion of four-stroke motorcycles with smaller engine sizes.

---

50 Retail price, excluding 2500Rs stamp duty and registration, and excluding Rs 900 for the number plate. The data are for machines offered in newspaper advertisements in November 2000.

51 Chandrasiri, *Health Effects*, *op. cit*., p.54.

52 Notably Faiz, *Air Pollution from Motor Vehicles*, *op. cit*.

53 Although the University of Moratuwa road user salary survey (Table 6.3) does not report the income of motorcycle riders, it seems reasonable to suppose that their income would be somewhat higher than that of bus passengers (Rs 3,800/month), though obviously significantly lower than car passengers. Even if their income were between Rs 5,000 and Rs 8,000/month, the difference in monthly payments is material.

We may also note that the interest rate implied by the advertised monthly payments is 2.25 percent per month, i.e., about 27 percent per year! That is 7 percent above commercial bank lending rates, reflecting the risks of lending to lower-income borrowers, or profiteering, or both.

These various points are translated into the following specific assumptions for the model simulations:

- ?? average price increase for models of comparable engine size and age = Rs 6,000[54]
- ?? vehicle price elasticity ($?_v$) of –0.24.[55] This elasticity determines the proportion of potential buyers of two-stroke motorcycles who do ***not*** buy a four-stroke motorcycle (and are assumed to remain as bus passengers).
- ?? ban on further imports is assumed to start in 2003
- ?? the average price increase faced by former two-stroke motorcycle buyers is Rs 6,000 on the assumed baseline of Rs 60,000, i.e., 10 percent. Application of the price elasticity implies that the quantity (of four-stroke motorcycles) purchased falls by 2.3 percent.[56]

Theory

The distributional impacts of the ban are illustrated in Figure 10.3. There will be a first group of potential two-stroke-motorcycle buyers, who may be presumed to be at the lower end of the income distribution, who, when faced with the higher investment costs of four-stroke machines, are unable to afford the down-payment. They experience a loss of consumer surplus, $?\boldsymbol{C_s}$, equal to the areas [***B+C***] in Figure 10.3A, namely

$$?C_s = +(P_c4S-P_c2S)\,N_{4S} + ½\,(N_{2S} - N_{4S})(P_c4S-P_c2S)$$

$$= \;?Pc\,N_{4S} + ½\,?Pc\,?N$$

where ?N is given by application of the vehicle price elasticity $?_v$

$$?N = [(P_c2S + ??Pc)/?P_c2S]^{?v}$$

and where

P_c2S, Pc4S = purchase cost of 2 and four-stroke motorcycles, respectively

P_o2S, P_o4S = operating cost of 2 and four-stroke motorcycles, respectively

Q(2S), Q(4S) = vehicle-kms, 2 and four-stroke motorcycles, respectively

N_{2S}, N_{4S} = number of 2 and four-stroke motorcycles purchased

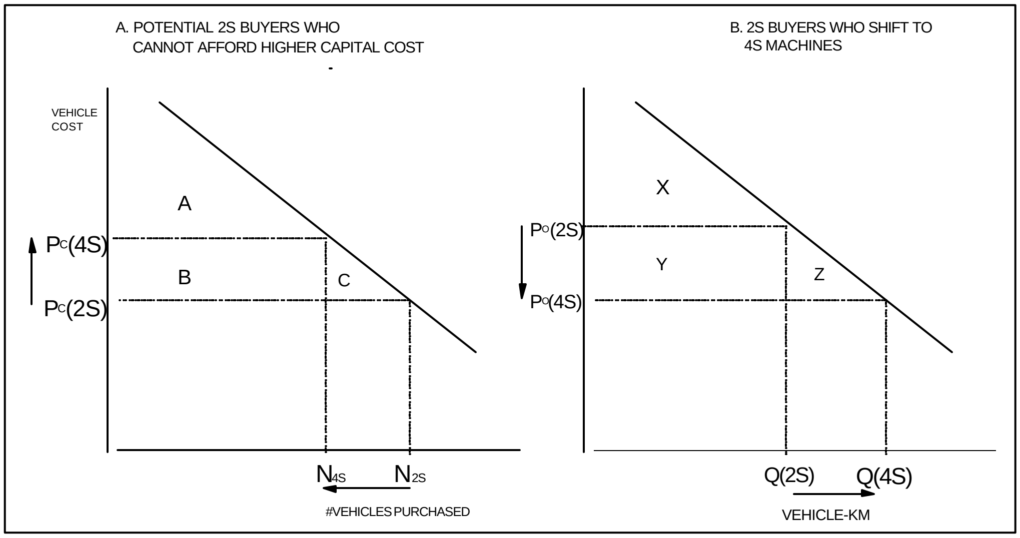
---

54 i.e., consistent with Chandrasiri, *op. cit.*

55 This is 50 percent higher than the average motorcycle vehicle price elasticity estimated by Chandrasiri (-.162). We take a higher value on the grounds that lower-income two-stroke buyers would likely be more sensitive to vehicle price than the average four-stroke buyer.

56 i.e., $1.1^{-0.24}=0.977$

Figure 10.3: Consumer surplus changes



On the other hand, those buyers who *can* afford the higher down-payment in fact experience an increase in consumer surplus, since the higher up-front cost is offset by fuel savings, so in effect they experience a decrease in their transportation cost (per km traveled over the assumed lifetime of the motorcycle). Their gain is the area ***Y + Z*** in Figure 10.3B, calculated analogously.

There is, however, a further complication, namely that of finance costs. The vast majority of motorcycle purchasers will need loans. While some might be sufficiently well informed to avail themselves of finance schemes at lower effective interest rates, a substantial number will experience the high finance charges offered in "easy payment" plans by the dealers, which in November 2000 were over 26 percent. Since the accounting scheme in our model is in constant Rs, the annual payments need to be deflated by the assumed inflation rate (taken as 6 percent). However, the *real* interest rate to consumers would still be 20 percent. While some part of the difference to the opportunity cost of capital is accounted for by transaction costs of the financial institutions, the rest is, in effect, a transfer payment from motorcycle buyers to sources of retail loans.[57]

Results

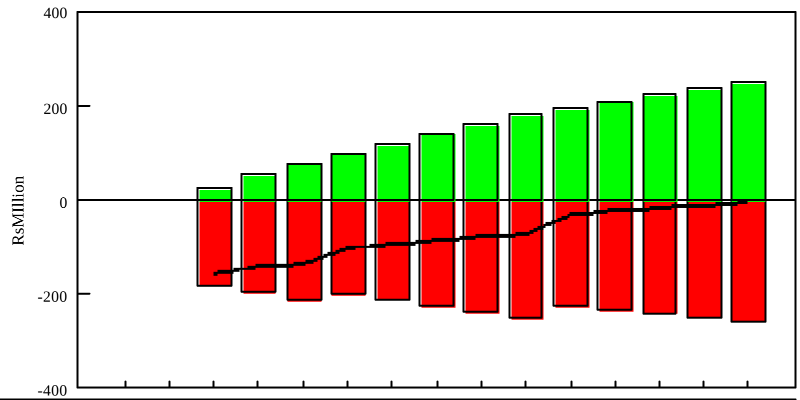
Even leaving aside the welfare losses, and under very optimistic assumptions about the incremental costs ($50/unit on a cif basis), the economic benefits (before environmental benefits)

---

57 Of course it might be argued that this transfer payment is on account of the risks in lending to low-income borrowers; and that in fact this payment is in effect returned to those borrowers who default. We have no data on default rates on lending for motorcycle loans; but since the difference has to be accounted for somewhere in our accounting scheme, we record it under transfers to financial institutions (who clearly benefit from the greater level of lending associated with more expensive vehicles).

is negative, with an NPV of –Rs 400million (see Figure 10.4). At the assumed value of $85/unit, the loss increases to Rs 1.4 billion.

Figure 10.4: Economic flows



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
capital cost			-181	-196	-212	-200	-212	-224	-237	-251	-224	-232	-239	-247	-256
fuel savings			26	56	78	99	120	141	161	182	196	210	224	238	251
total			-155	-140	-134	-101	-91	-83	-76	-69	-28	-21	-15	-10	-4

Assumptions: World Oil Price (WOP) = $25/bbl; incremental capital cost $30/unit.

The physical environmental impacts, to be sure, are strongly positive, as indicated in Table 10.3, although NOx emissions increase.

Table 10.3: Physical impacts of two-stroke motorcycle ban, 2010

	Emission factors, gm/km		*Baseline emissions (1)*	*Savings with two-stroke motorcycle ban*
	Two-stroke	*Four-stroke*		
PM-10	0.2	0.02	542	-328
NOx	0.08	0.3	1547	+387
VOC	15.4	3.35	49900	-21992
CO	22	20	140620	-4397

(1) Emissions attributable to the motorcycle vehicle fleet
(2) Calculated by stochiometry based on gasoline consumption

Table 10.4 and Figure 10.5 show the details of the economic analysis, with monetization of the environmental impacts. For reasons explained earlier, the banks are a net (financial) beneficiary.

Table 10.4: Distribution of costs and benefits (NPV, Rs million)

	Govt	*Motor cycle users*	*Banks*	*Total*	*Environment* *Local*	*Global*	*Total*
Fuel		949		949			949
Fuel taxes	-1278	1278		0			0
Import duties	611	-611		0			0
Consumer surplus		-80		-80			-80
Interest		-128	128	0			0
Motorcycle costs		-2305		-2305			-2305
Environment							
PM-10				0	4463		4463
NOx				0	-208		-208
Carbon				0		269	269
Total	-668	-897	128	-1436	4256	269	3089

Assumptions: discount rate 12 percent; world oil price $26/bbl; incremental cost of four-stroke motorcycle:US$85.

Figure 10.5: Distribution of costs and benefits

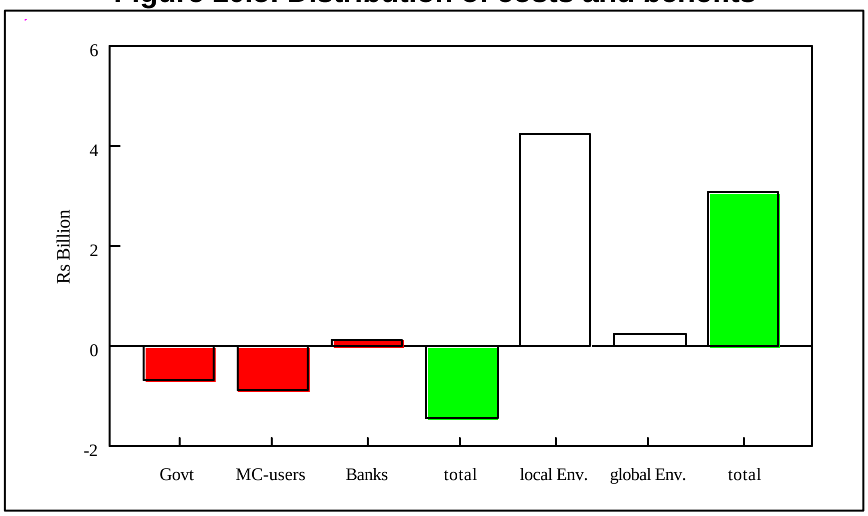


Table 10.5 shows the results of sensitivity analysis. Only under optimistic assumptions for both fuel economy improvement and incremental cost (case [3]) is the net impact on motorcycle users positive; in all cases the net result before environment is negative, and in all cases the net result *including* environmental externalities is *positive*. Moreover, it is evident that the environmental damage monetization values could be from 10 percent to 38 percent of the baseline values for the policy to remain economic. In short, the results are robust with respect to the main assumptions.

Table 10.5: Sensitivity analysis

		[1]	*[2]*	*[3]*	*[4]*	*[5]*
Incremental cost	[$US]	85	50	50	50	85
PM-10 emission factors		[consensus]	[consensus]	[consensus]	[Chandra siri]	[Chandra siri]
Two-stroke	[gms/km]	0.2	0.2	0.2	0.206	0.206
Four-stroke	[gms/km]	0.02	0.02	0.02	0.048	0.048
Fuel economy						
Two-stroke	[km/litre]	40	40	40	40	40
Four-stroke	[km/litre]	50	50	45	45	50
Results						
PM-10 reduction, 2010	[tons]	-328	-328	-328	-289	-289
Net benefits[NPV]						
Govt.	[RsMillion]	-668	-919	-410	-410	-668
Motorcycle-users	[RsMillion]	-897	390	-497	-497	-897
Total, before environment	[RsMillion]	-1436	-454	-832	-832	-1436
Local environment	[RsMillion]	4256	4256	4256	3727	3727
Global environment	[RsMillion]	269	269	153	153	269
Total	[RsMillion]	3089	4071	3577	3049	2560
E-multiplier (1)		***33 %***	***10 %***	***20 %***	***22 %***	***38 %***

(1) Switching value for environmental damage values, expressed as a multiplier of base values.

10.2 LPG Conversion[58]

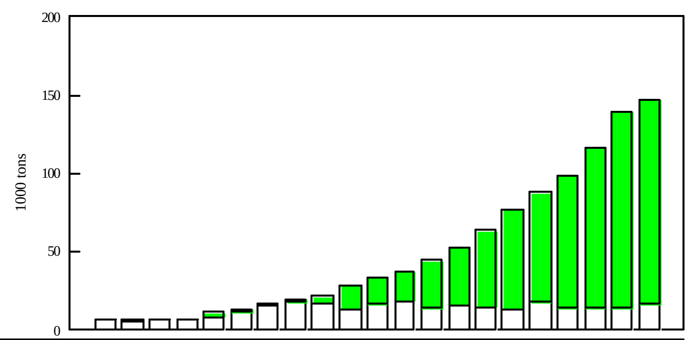
Over the past 20 years, LPG is the energy form that has by far the highest consumption growth rate in Sri Lanka, averaging some 16 percent per year, as opposed to 7 percent per year for diesel fuel, and about 7 percent for electricity. Since refinery production is quite limited, this has resulted in an exponential growth of LPG imports, as shown in Figure 10.5. Although the government has enacted legislation to legalize use of LPG as a motor fuel, so far no rules and regulations have been gazetted by the Commissioner of Motor Traffic.

Conversion of vehicles to LPG is attractive from an environmental point of view, since LPG is among the cleanest transportation fuels, comparable to ethanol and compressed natural gas (CNG). However, there are two disadvantages: LPG is relatively expensive and, for safe operation, vehicle conversion needs to be subject to strict regulation. As in the case of unleaded

58 This section was prepared with the assistance of R. Chandrasekera, Advisor to the Chairman, CPC.

gasoline and low sulphur diesel, the key is pricing policy. Conversion to LPG has in the past been driven by the subsidized price for bottles intended for domestic use, as compared to high taxation on gasoline. We estimate that by the end of 2000 some 15,500 gasoline cars and dual-purpose vehicles— about 10 percent of the fleet—had been converted.[59] However, following LPG price increases in 2000, the rate of growth of LPG consumption appears to have leveled off (as suggested by Figure 10.5).

Figure 10.5: Growth in LPG consumption (1,000 tons, by source)



	1980		1982		1984		1986		1988		1990		1992		1994		1996		1998		2000
refinery	7	6	7	7	9	12	16	18	18	13	17	19	14	17	15	14	18	14	14	14	17
imports	0	0	0	0	3	2	1	2	5	16	17	19	31	36	49	63	70	85	103	126	131

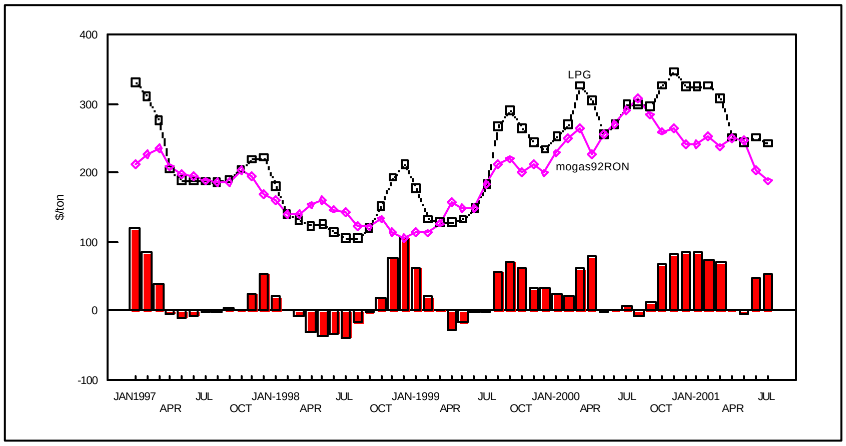
There is much anecdotal evidence—though few firm numbers—about the extent to which gasoline automobiles have been converted to LPG over the past few years. Some cars (and particularly taxis) are reported to have been converted to use LPG in domestic bottles, while others are equipped to make use of official LPG outlets, of which there are presently only 20, all in Colombo. Vehicle conversion costs also differ considerably: properly designed on-board storage tanks cost Rs 40,000-50,000 /vehicle, as compared to conversion costs of Rs 15,000-20,000 for using domestic bottles. Data on how many vehicles have been converted to use domestic bottles is particularly hard to estimate (since their owners are understandably reluctant to admit to this type of conversion).

59 ShellGasLanka estimates the demand (at official filling stations) at about 6,800 metric tons, equivalent to about 3 percent of the gasoline demand (of 220,000 tons in 2000). Much of the LPG conversion took place in 1998-1999, during which time LPG demand increased from 99,000 to 140,000 tons, as compared to the trend increase of 10-11,000 tons per year (which can be attributed to domestic demand). If we subtract 21,000 tons from the 41,000-ton increase in 1998 and 1999, it may be safe to assume that the remaining 20,000 tons of LPG increase is attributable to new automobile use, making total use in transportation equal to 27,800 tons.

Given 15,500 vehicles converted, the per-vehicle use would be 1.8 tons/year, or about 3,275 litres/year. If we take consumption at about 8 km/litre, this implies that these vehicles are driven 26,200 km/year, triple the distance we estimate for gasoline cars on average (8,275 km/year, see Table 2.2). That it is particularly the high-mileage vehicles that are converted to LPG is entirely logical, given the high conversion costs. Anecdotal evidence also supports these calculations, for until the LPG price rises in 2001, it was quite rare to encounter a fleet taxi running on gasoline.

Figure 10.6 shows the difference between fob prices for gasoline and LPG. The differential is strongly seasonal, with a maximum value in the winter months. Table 10.6 shows the annual averages.

Figure 10.6: FOB prices, gasoline and LPG ($/ton)



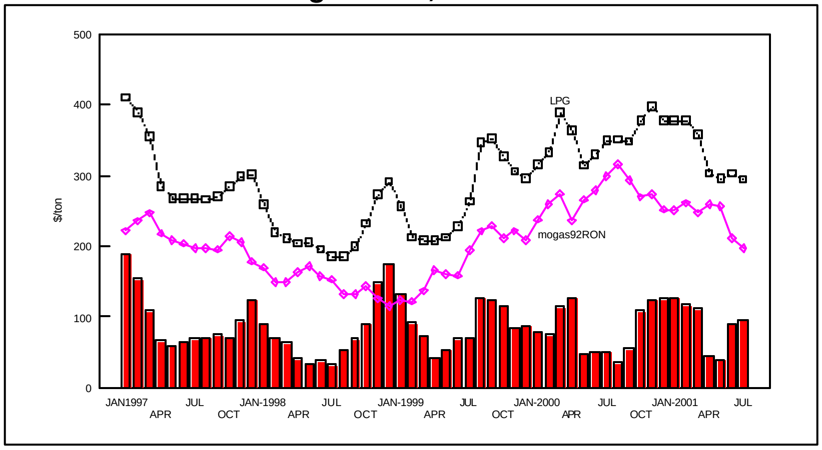
Source: LPG:Aramco posted price, ex-Gulf
gasoline: Mogas RON 92, Singapore spot, Platt's Oilgram.

Table 10.6: Annual average differentials

	Fob *$/ton*	*Cif* *$/ton*
1997	25.35	95.35
1998	5.25	75.25
1999	24.75	89.05
2000	35.9	82.60
2001 (to June)	46.9	89.10

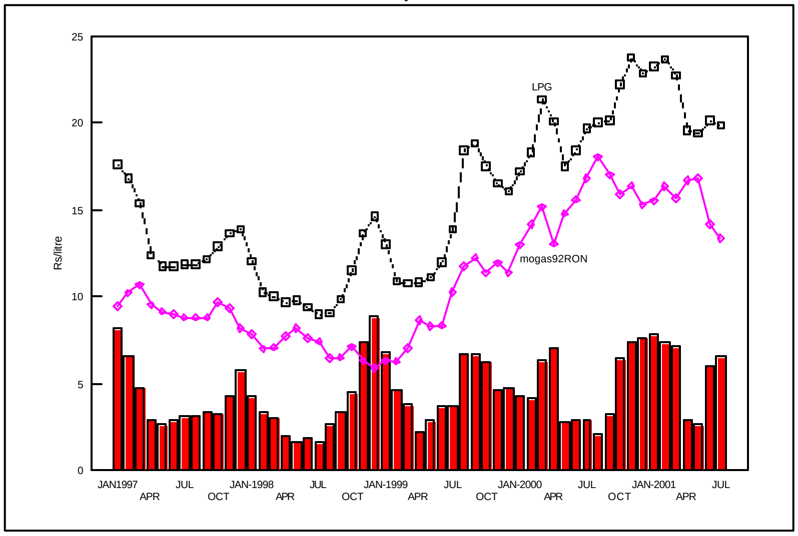
CIF prices are shown in Figure 10.7. Over the last three years, cif differential have been between $82 and $89 /ton, the increase in cif differentials having been offset by decreases in transportation cost (due mainly to larger parcel sizes).

Figure 10.7: CIF Colombo comparisons, LPG and gasoline, $/ton



Finally, Figure 10.8 shows a comparison of the delivered price at the pump (as Rs/litre). In these units the differential appears smaller than it actually is, because of the density of LPG (taken here as 1litre=0.55Kg); therefore fuel efficiency as km/litre is lower than it is for gasoline vehicles.

Figure 10.8: Filling station price comparisons for gasoline and LPG, Rs/litre



Cost of LPG

The delivered cost of LPG is strongly dependant upon transportation modality and cif cost. Table 10.7 shows the price structure under various transportation modes. The key assumptions are as follows:

?? *Tanker size*: The tanker size will help determine the actual freight charged. It is reported that the ARAMCO terminal would not normally handle pressurized storage vessels but only refrigerated vessels with a capacity greater than 13,000 metric tons. The freight for such vessels varies between US$35-45 per ton. The standard size pressurized storage vessels available are 1500 mt, 2500 mt, 4000 mt, and 5000 mt. For the smaller cargo vessels freight may be high as US$100 per ton. The freight paid by the local supplier is reported to have come down in the last two years from a high of US$80 per ton in early 1999 to US$52.25 in June 2000 possibly due to larger parcels imported. It is reported that LPG could be imported in tanktainers of capacity of 13.5 metric tons, for which the average freight may be around US$110/ton, but which would significantly reduce terminal costs from $100/ton to around $10/ton.[60]

60 These are pressurized containers that can be unloaded directly onto a suitable road vehicle and delivered without transhipment to the (bulk) consumer (such as a filling station). This is a new concept for LPG that is not yet widely practiced, but it has great potential to reduce delivered costs (and may well be used by other potential importers once ShellGasLanka loses its import monopoly). This is

?? *Terminal costs:* Most terminal operators inform us that they would plan for a margin of US$100 (between input and output prices). It is reported that present operators are compelled to work with a lower margin of around US$50 per ton at present.

?? *Local transportation*: The present local charges for bulk deliveries vary according to the parcel size. For parcel sizes up to 2000 kg, Rs 12/kg per km., parcel sizes 2,000 to 4,000 kg, Rs 0.10/kg per km and for parcel sizes above 4,000 kg, Rs 0.09/kg per km.

Table 10.7: Cost of LPG

	ARAMCO Fob, US$/ton	*Freight per ton, US$*	*National Security Levy*	*Termina cost US$/ton*	*Total ex-terminal Rs/kg*	*Delivered 50 Km Rs/kg*	*Delivered cost (city) Rs/litre*
Refrig. 13,000 mt.	250.00	40.00	23.56	100.00	33.91	38.91	18.65
Press. 1500 mt.	250.00	100.00	28.43	100.00	39.23	44.23	21.57
Press. 2500 mt.	250.00	80.00	26.81	100.00	37.45	42.45	20.59
Press. 5000 mt	250.00	52.25	24.57	100.00	34.99	39.99	19.24
Press. 1500 mt	250.00	100.00	28.43	60.00	35.95	40.95	19.77
Press. 1500 mt.	300.00	52.25	28.64	100.00	39.43	44.43	21.68

Present selling price of LPG at Auto Gas Outlet Rs 26.50 per litre in the city and Rs 29.50 in the outstations.
Present Delivered price of LPG to Auto Gas dealers Rs 34.00 per Kg.
US$ = Rs 82.00; Litre LPG = 0.55 Kg; National Security Levy = 6.5 percent; Transport Charges: Rs 0.10/kg/km

Table 10.8 compares the emission factors for gasoline vehicles using gasoline and LPG. There are no differences in the emissions that we have monetized (PM-10, SO_2 and NOx) except lead. The most significant differences (in favor of LPG) are for CO and VOC, for which LPG vehicles provide an 80 percent emission reduction.

Table 10.8: Emission factors (gms/km)

	Gasoline	*LPG*
NOx	2.19	2.16
CH_4	0.08	0.056
VOC	4.63	1.51
CO	49.97	7.17
N_2O	0.005	0.00
Lead	0.15[gms/litre]	0.00

Source: Chandrasiri, *Health effects, op.cit*, Annex 4.

Table 10.9 shows the benefits and costs of LPG conversion. We assume that LPG conversion continues at about 5 percent per year, maintaining the present 10 percent of the

particularly so at present retail prices, which will not allow a margin sufficient to attract new terminal investment.

petrol-engine vehicle fleet. Some arithmetic confirms that at present price levels, the terminal margins are around $50/ton (which is used below).

LPG conversion brings significant environmental benefits only if it displaces leaded gasoline; if leaded gasoline is phased out (as recommended in Section 9.2), the environmental benefits are marginal, and do not offset the economic costs of vehicle conversion and the higher cif costs of LPG imports. Clearly, road users obtain significant (financial) benefits, but these are a consequence of the distortions in taxation.

Table 10.9: Costs and benefits of LPG conversion (v. leaded gasoline)

Rs Million (NPV at 10 percent discount rate over 20 years)

	Road users	*Govt*	*Total*	*Env*	*Total*
Vehicle conversion costs (1)	-188		-188		-188
LPG, economic cost	-15457		-15457		-15457
Gasoline, economic savings	12431		12431		12431
Gasoline taxes	16687	-16687	0		0
LPG taxes (NSL)(2)	-1431	1431	0		0
Emissions reduction					
Lead			0	4077	4077
VOC,CO			0	x	0
Total	12042	-15256	-3213	4077	864

x=not monetized; (1) assuming conversion cost of Rs 20,000/vehicle (for bottled gas).[61]
(2) NSL= National security levy (this is the only tax levied on LPG prior to the currently proposed tax reforms)

The realization of the tanktainer concept could lower the economic costs, for terminal handling costs reduce from 100 to 10$/ton. However, the delivered *economic* cost at the pump would still be higher than that of gasoline, so the economic benefits before consideration of environment are still negative.

Conclusions

We draw several conclusions relevant for transport sector policy:

?? With 10 percent of gasoline vehicles presently converted to LPG there is a significant loss of gasoline tax revenue to the government. More importantly, with as many as 7 percent of gasoline vehicles likely using domestic bottles (i.e., some 11,000), any policy to now ban use of these in cars is not likely to be practical. Thus, initially, the emphasis should be on an inspection regime to ensure safe

[61] If one assumes the higher Rs 45,000/vehicle conversion cost for using filling-station-dispensed gas, the NPV for conversion costs increase to Rs 422million; the economic benefits before environment decrease to Rs 3448million, and after environmental benefits to Rs 629million (from Rs 864million shown in the table).

installation and operation.

?? The conversion of gasoline vehicles to LPG is driven entirely by distortions in tax policy, and the resulting price differential at the pump between highly taxed gasoline, and LPG (which is subject only to the National Security Levy). In effect, the present price structure provides a significant tax exemption to owners (and possibly users) of high-mileage vehicles, notably taxi fleets.

?? The effective tax exemption for domestic LPG also benefits the same middle and upper income groups who also own gasoline passenger cars and use the car-taxi service:[62] the overwhelming majority of the poor still use fuel wood for cooking, and would not be affected by petroleum tax reform.

At the time of writing (June 2002), the Government of Sri Lanka is considering changes in the tax structure that would replace the general sales tax (GST) and National Security Levy (NSL) by VAT, for which the proposed rate is 10 percent on domestic cylinders, and 20 percent on 15kg cylinders and above.

Whether these proposals will survive is unclear. While the differential between LPG and gasoline would narrow, the lower rate of VAT on domestic cylinders continues to provide incentives for use in converted vehicles.

---

62 Colombo is now served by a significant fleet of radio-controlled taxis, with a fare of about Rs 30/km, at which price the service is used mainly by the highest income groups (and tourists and businessmen). These taxis have almost all been converted to LPG (and a significant fraction use domestic bottles).

11

Investment Options

In this section we analyze options that involve project investments. In the first two options, the Colombo-Katunayake Expressway and suburban railway electrification, the principal rationale is the reduction of congestion in the Colombo road system, whereas in the third option, the Port Inland Clearance Depot, the rationale is reduction of congestion in the Port of Colombo as well as on the roads. But in all three cases there are significant environmental externalities, whose consideration reveals additional benefits not heretofore considered.

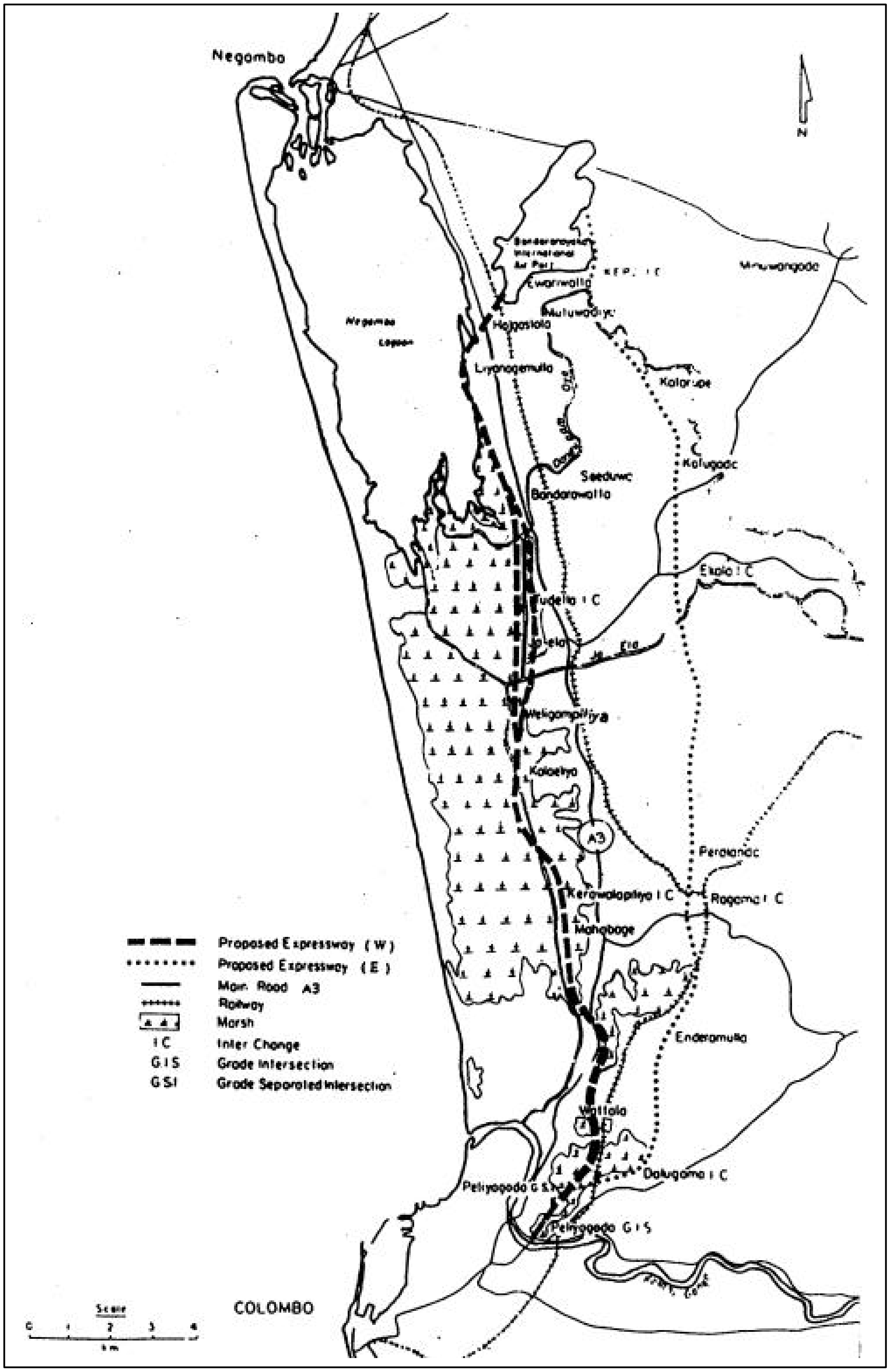
11.1 Colombo-Katunayake Expressway[63]

A four-lane, limited access expressway to link downtown Colombo to the Katunayake airport—a total distance of some 25 km—has been discussed for almost two decades.[64] Figure 11.1 shows the general location of the two main proposed alternatives (the so-called "eastern" and "western" traces, of which the western trace is the recommended one). The present A3 road in this section is the most heavily traveled in Sri Lanka (See Figure 11.2), with average daily traffic (ADT) in the sections closest to Colombo of 200,000. The A3 accounts for some 1 percent of all vehicle-km in the country.

63 We thank M. Ranjiva for his assistance in developing the spreadsheet used in this section.

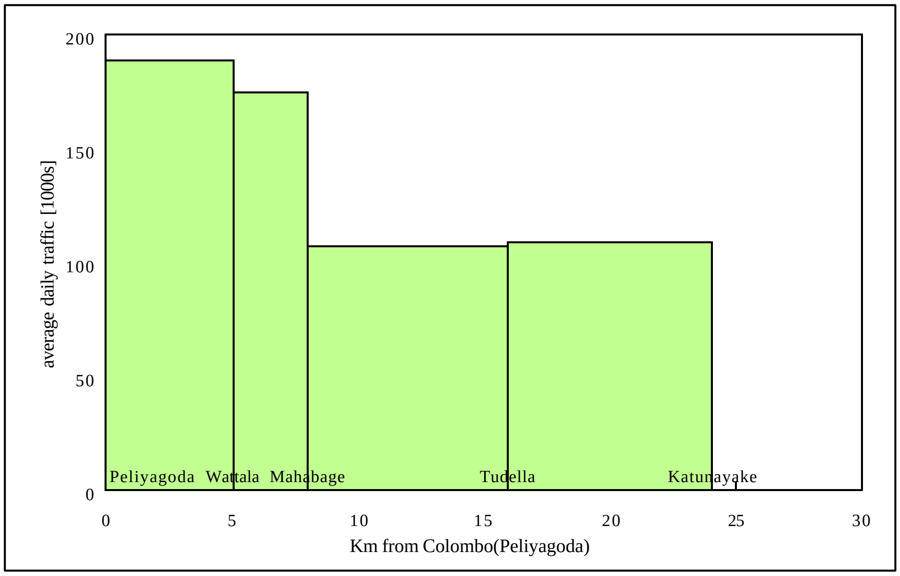
64 The first report appears to have been prepared in 1984 (Japan International Cooperation Agency (JICA), *Feasibility Study of the Colombo-Katunayake Expressway*, Colombo, 1984)

Figure 11.1: Project Location



The original feasibility and environmental impact studies provoked many objections,[65] and the project has been repeatedly delayed. Consequent to delays, construction costs have also increased, with the most recent estimate now standing at Rs 13.1 billion, up from the Rs 5 billion estimate of 1995. These cost increases have of course raised doubts about the economic analysis of the original proposal. However, construction finally began in 2000.[66]

Figure 11.2: 2015 Traffic volumes, A3 road without project



While opponents of the project have pointed to the environmental impacts associated with construction, the air pollution impacts of the present situation are becoming more serious as traffic congestion and travel times on the present A3 road have grown. Since emissions per km of both local air pollutants and carbon are inversely proportional to speed, in the absence of the expressway, emissions will increase due to yet further expected decreases in vehicle speeds.

Although the decision to proceed with construction of the expressway has now been taken by the government, there are a number of other proposals for projects of a similar type, notably the proposed Southern Highway (linking Colombo to Matara on the South Coast), and

---

65 For a scathing critique of the original environmental impact study, see e.g., V. Sivagnosothy and D. McCauley, "Environmental Considerations in the Environmental Impact Analysis of the Katunayake Expressway in Sri Lanka," in J. Rietbergen-McCracken and H. Abaza, eds., *Environmental Valuation: A Worldwide Compendium of Case Studies*, Earthscan Publications, London, 2000. However, it should be noted that this critique was based on a 1993 environmental impact analysis (Road Development Authority, Environmental Impact Analysis of the Colombo-Katunayake Expressway, Colombo, 1993). The subsequent report of June 1997 examined many of the issues previously omitted. Unlike the original analysis, it also included a monetization of the benefits of reduced congestion on the A3 and the reduced costs of accidents.

66 However, it is reported that some significant unforeseen geological conditions were encountered soon after work began, and that some significant further delays are now anticipated.

the Outer Circular Highway (Colombo orbital road, which would also connect to the Airport Expressway). Insights derived from the analysis of the expressway project may be taken to apply to these proposals as well.[67]

As with all the measures examined in this report, evaluation of the environmental consequences is integrated into the economic analysis, so that trade-offs between economic and environmental objectives can be examined in a consistent framework developed expressly for this study. The alternative of merely adding emissions calculations to expressway traffic forecasts developed by others—even if those forecasts were much more detailed and based on more sophisticated models—was judged inferior for two reasons. First, we wanted to ensure that all of the options studied in this report used a common analytical framework, so that comparisons among options would not encounter consistency problems. Second, the internal consistency and transparency of some of the more detailed models were not always evident (and since many of these studies go back several years, rerunning the models to our own assumptions and scenario designs was not practicable).[68]

Table 11.1 shows the traffic forecast for the A3 (in the absence of the project) for 2015. Note particularly the high proportion of motorcycles in the first and second segments which, as we shall see below, has important consequences for the impact of the expressway on local air emissions.

Table 11.1: Traffic forecasts, 2015, by vehicle type

	Peliyagoda-Wattala (Colombo)	*Wattala-Mahabage*	*Mahabage-Tudella*	*Tudella-Katunayake (Airport)*
	[1]	*[2]*	*[3]*	*[4]*
Cars	21521	31834	23033	25469
Vans	50667	53277	30404	33314
Trucks	27017	19534	16255	20315
Large trucks	4088	915	300	572
Large buses	9717	14634	10634	9151
Medium buses	9822	8877	5180	5487
Motorcycles	65679	46418	21436	14498
Total	188511	175489	107242	108805

67 Three major studies of the Southern Highway project have been conducted, the most recent of which is Wilbur Smith Associates, *Southern Transport Corridor Project*, December 1998. These studies have been reviewed by A. Kumarage, *Assessment of Public Investments in the Transport Sector*, Appendix A1, 1999. None of the three studies examined the impact on vehicle emissions.

68 A good example of this problem is the relationship between fuel prices and transportation demands. Econometric studies (reviewed in Section 5) reveal price elasticities of –0.136 for diesel and –0.078 for petrol. It does not appear that the engineering models that have been used to forecast expressway traffic take fuel price changes into account. Most of these earlier studies were done in the mid-1990s at which time the world oil price traded in the range $15-20/bbl, whereas the present trading range is $25-30$bbl. In some cases the impact of fuel prices has been accounted for in the estimate of vehicle operating costs, but whether price elasticity effects are consistently accounted for is unclear.

Frac motorcycles	34.8%	26.5%	20.0%	13.3%
Frac trucks	16.5%	11.7%	15.4%	19.2%

In this report we examine only the variant of the expressway recommended by the EIA (and selected by the government), namely that of the so-called "western trace." This was selected over the alternative "eastern trace" on grounds of both economic and environmental impacts: for example, the western trace requires the demolition of only 130 houses,[69] whereas the eastern trace requires demolition of 1,500 houses. Similarly the economic rate of return (ERR) of the western trace is estimated in the Colombo-Katunayake Expressway Environmental Impact Study (CKE-EIS) at 63 percent, compared to 38 percent for the eastern trace.[70]

Theory

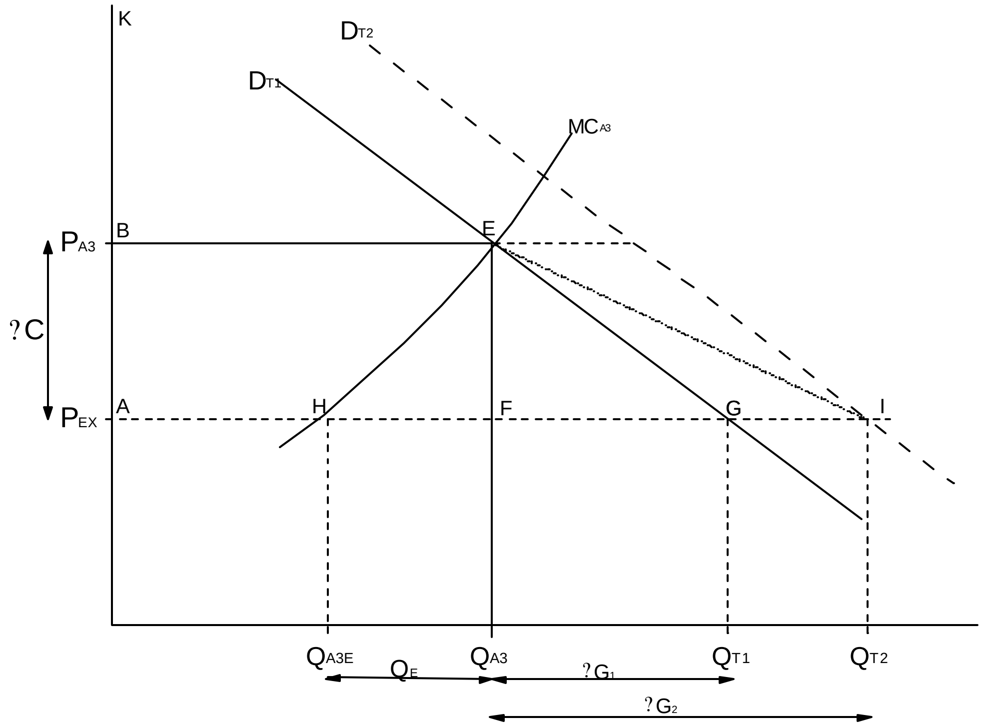
The economic benefits of a new road can be calculated as the change in consumer surplus enjoyed by its users.[71] Consider the demand curve $\boldsymbol{D_{T1}}$ depicted in Figure 11.3. Before the project, users on the A3 experience costs of $\boldsymbol{P_{A3}}$ at the traffic volume $\boldsymbol{Q_{A3}}$ (given by the intersection of the demand curve and the marginal cost curve, $\boldsymbol{MC_{A3}}$).

Figure 11.3: Estimating consumer surplus changes

69 Plus a further 60 to be acquired on the reservation. See CKE-EIS, Executive Summary, p. vi.

70 Railway electrification was also studied as an alternative, but found to be uneconomic. This is confirmed by our own analysis of Section 11.2.

71 It is not only those vehicles who elect to use the new expressway that derive benefits from reduced journey times, but, *ceteribus paribus*, users who continue to use the old A30 will also derive benefits because traffic volumes will be lower, and traffic speeds higher (since some fraction of the existing traffic will now be diverted to the expressway). These effects are captured in the model, though not illustrated in the figure.



Once the project is built, some vehicles (***Q_E***) will elect to use the expressway, leaving ***Q_{A3E}*** on the original road. Road users will experience lower costs, ***P_{EX}***, due to fuel and time savings $?\,\boldsymbol{C} = \boldsymbol{P_{A3}} - \boldsymbol{P_{EX}}$ **.** However**,** at the new lower cost ***P_{EX}***, the total travel demand increases from ***Q_{A3}*** to ***Q_{T1}***, the difference $?\,\boldsymbol{G}_1$ being the induced traffic (whose quantum is a function of the demand elasticity, i.e., of the slope of the line ***D_{T1}***).

The benefit is the change in consumer surplus, which increases from the original area ***KBE*** to ***KBAHFGE*.** Thus[72]

*? ?$_1$?? ?**KBAHFGE-KBE = ABEF + EFG**??????????????????????????????????* *Eq. [11.1]*

$= ?\,\boldsymbol{C}\,\boldsymbol{Q_{A3}} + \boldsymbol{0.5}\;?\,\boldsymbol{C}\;?\,\boldsymbol{G_1}$ *Eq.[11.2]*

There is also likely to be an outward shift in the demand curve, shown in the Figure as ***D_{T2}***. This intersects price ***P_{EX}*** at ***I***, from which follows an additional increase in traffic to ***Q_{T2}***. The result is a slightly larger increase in consumer surplus, namely from ***KBE*** to ***KBAHFGIE***, hence

*? ?$_2$?? ?**KBAHFGIE - KBE = ABEF + EFGI**?????????????????????????* *Eq. [11.3]?*

$= ?\,\boldsymbol{C}\,\boldsymbol{Q_{A3}} + \boldsymbol{0.5}\;?\,\boldsymbol{C}\;?\,\boldsymbol{G_2}$

The corresponding levels of traffic (at time ***t***) are shown in Figure 11.4. However, at the higher level of traffic *within* the corridor, there will inevitably arise increased congestion *outside*

---

72 The coefficient 0.5 in Eq. [11.2] presumes a linear demand curve (as drawn in Figure 11.3). Depending upon the elasticity, the area EFG may be much less than half the product $?\,\boldsymbol{C}\;?\,\boldsymbol{G_1}$

the corridor, particularly on the access roads to the expressway interchanges. This externality, say $?\,\boldsymbol{C}^*$, would reduce the level of benefits. In this study we make the assumption that this externality exactly offsets shifts in the demand curve induced by the expressway,[73] so that benefits are estimated as the amount $?\,?_1$ (in Eq.[11.1]).

[73] In other words, we assume that $?\,\boldsymbol{C}^* \sim ?\,?_2 - ?\,?_1$

Figure 11.4: Traffic forecasts

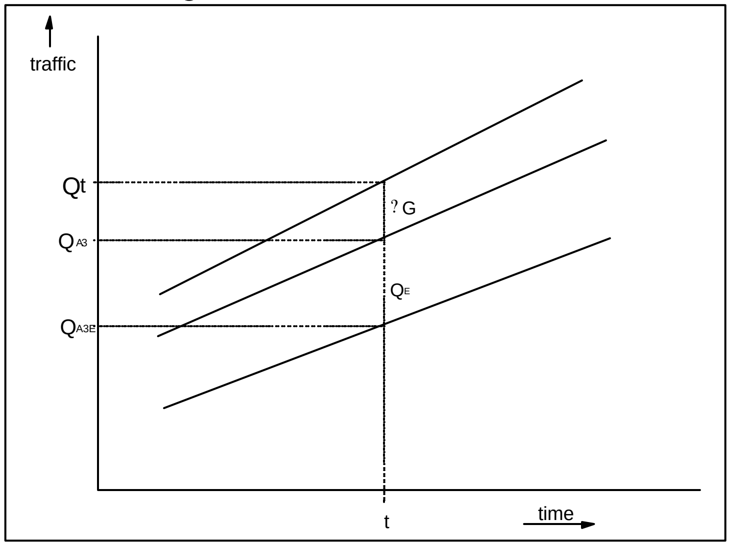
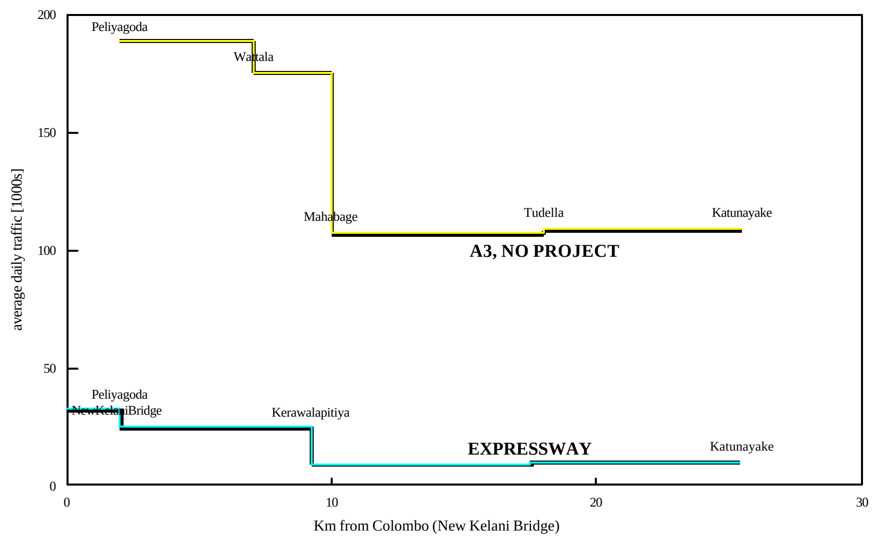


Figure 11.5: Expressway traffic volumes 2015 (compared to A3 with no project)



Assumptions: traffic forecasts

As one may expect for a project whose planning has extended for over a decade, many traffic forecasts have been made, and under all kinds of assumptions. The most recent forecast appears to be that prepared by the University of Moratuwa for the Board of Investment (BoI) in 2000,[74] which examined nine scenarios based upon different assumptions about GDP growth, automobile ownership, and level of toll (among others). Traffic forecasts were developed with

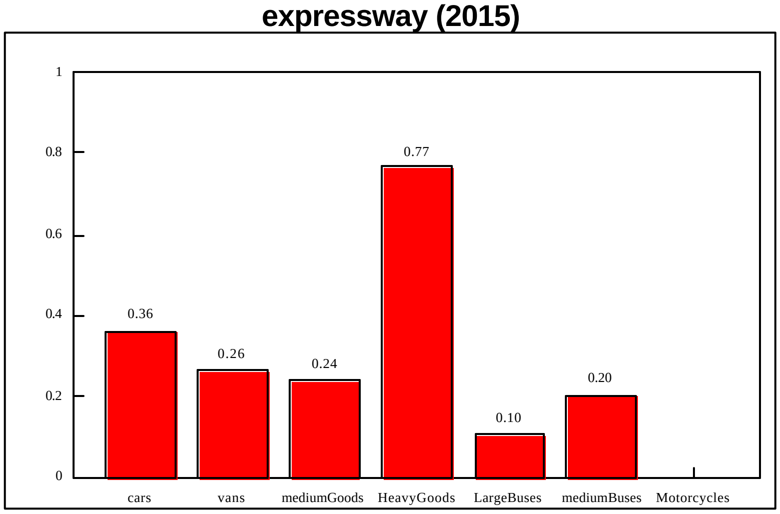
---

74 Department of Civil Engineering, University of Moratuwa, *Traffic Demand Estimation for Proposed Colombo-Katunayake Expressway*, Report to BoI, May 2000.

use of TransPlan, a sophisticated model developed by the University of Moratuwa.[75] Not surprisingly, the resulting traffic estimates span a very large range. For example, estimates of 2025 daily vehicle-km on the expressway range from 325,000 to 747,000, and on the A3 from 836,500 to 1,708,000; the corresponding toll revenue varies from Rs 1.7 to 4.1 million/day.[76] Figure 11.5 shows the 2015 average daily traffic in various segments of the expressway (compared to the A3 road without the project).

Figure 11.6 shows the fraction of total traffic that is expected to be diverted onto the expressway (in the baseline forecast with a flat Rs 50 toll). Although motorcycles would be banned from the expressway, increased speeds on the A3 for the remaining traffic would still benefit emissions from motorcycles. The large number of heavy goods vehicles diverted to the expressway, especially in the first segment from the New Kelani Bridge to Peliyagoda, close to heavily populated areas, can be expected to bring a significant reduction in diesel particulate emissions (see below).

Figure 11.6: Fraction of traffic diverted to expressway (2015)



Assumptions: tolls

The earlier expressway traffic forecasts appear to be based on a flat toll of Rs 50. The University of Moratuwa study is based upon the toll structure shown in Table 11.2.

We observe that these are very high rates of toll, particularly for trucks. In the case of cars, Rs 65 is 50 percent of the salary value of car passengers, and in line with potential time

75 This has been used in many recent transportation planning studies in Sri Lanka. For a description, see A. Kumarage et al., *TRANSPLAN V2: A Regional Traffic Estimation Model*, University of Moratuwa, 2000.

76 These are for Scenarios #1 and #8 (of the University of Moratuwa report), respectively, which span the range of GDP growth rate assumptions: Scenario #1 is based on a 3 percent GDP growth rate, Scenario #8 on 6 percent.

savings (of 30 minutes, or over 60 minutes at rush hour) for a trip to the airport. However, the toll is significantly higher than the value of time for goods vehicles. The model has been set up to investigate a variety of different tolls and toll structures. A toll price elasticity of –0.2 is used, based on the University of Moratuwa report.[77]

Table 11.2: Tolls proposed by BOI

Vehicle type	*Rs*
Car	65
Van	95
Bus	140
Large bus	180
Delivery van	195
Truck	390
Container truck	650

One-way toll (Rs) in 2000, Peliyagoda to Katunayake.

Assumptions: Vehicle speeds

The continued expected deterioration of vehicle speeds in the absence of the project plays a significant role in the increased rate of air emissions, since slower speeds mean higher fuel consumption and hence higher emissions per km traveled (Figure 11.7). Moreover, expected time savings will play a critical role in the choice made by road users to trade these off for the toll payment. Vehicle speeds will obviously be a function of the time of day: today the trip from Colombo to the airport can take as little as 30 minutes around midnight, to over 75 minutes around the 4 p.m. rush hour.[79]

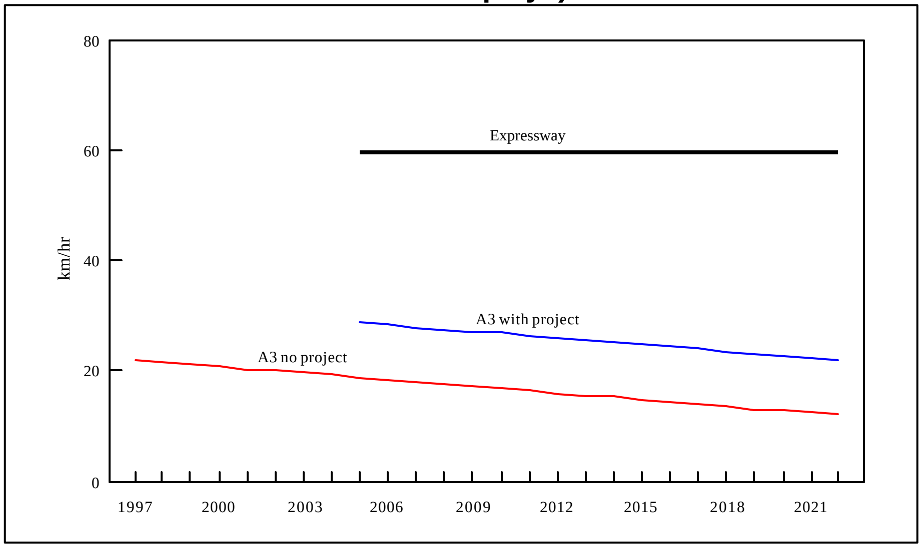
---

77 UM, *op. cit*., Section 5.5, notes: an increase of 50 percent [for the passenger vehicle toll] results in a decrease of 10 percent in traffic count. Therefore ***e=[dQ/Q]/[dP/P***]=-0.1/0.5=-0.2.

78 UM, *op. cit*., Section 5.5, notes: an increase of 50 percent [for the passenger vehicle toll] results in a decrease of 10 percent in traffic count. Therefore ***e=[dQ/Q]/[dP/P***]=-0.1/0.5=-0.2.

79 In fact, the rush hour trip into the city center can take even longer due to congestion at major junctions at the urban periphery. Problems of congestion at the exits may well continue even if the Expressway is built.

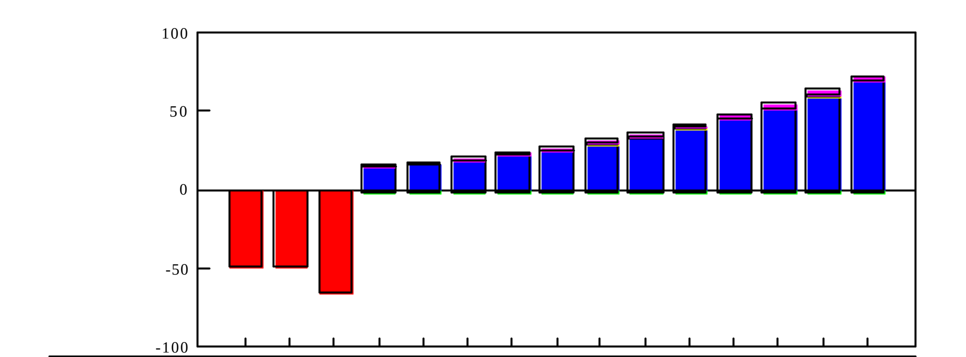
Figure 11.7: Estimated vehicle speeds (Peliyagoda-Tuwella/ Kerawalapitiya)



Economic impacts

Given these baseline assumptions, plus those already discussed in Section 2.3 for fuel consumption by vehicle category and speed, world oil prices and current levels of fuel taxes, the ERR computes to 19 percent. As is clear from Figure 11.8, construction costs and the value of time savings dominate the economic flows.[80]

Figure 11.8: Economic flows (US$ million at 2000 price levels)



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
construction	-49.1	-49.1	-65.5												
O&M				-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6	-2.6
time				14.0	16.2	18.8	21.7	25.2	29.1	33.5	38.6	44.5	51.4	59.4	68.8
petrol saved				0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7
diesel saved				1.3	1.4	1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.9	3.1	3.4

80 We have taken annual operating costs at 2 percent of the capital cost. It may be seen that even if this figure were doubled, it would have little impact on the overall picture.

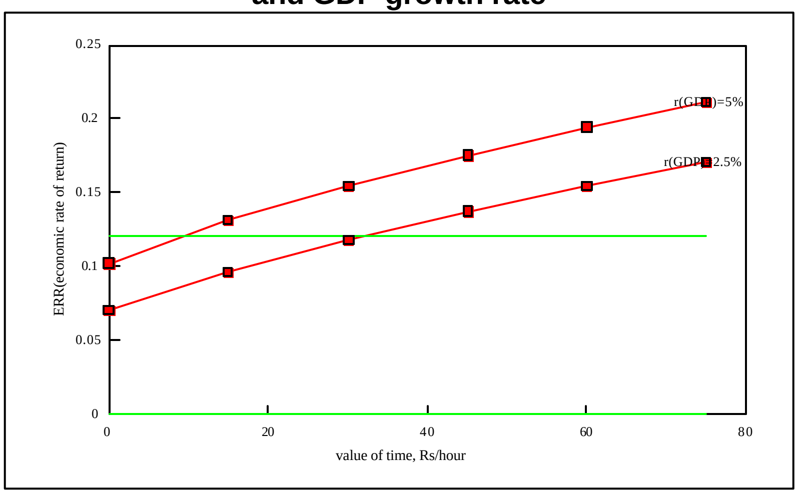
The three main input assumptions are capital cost, the assumed rate of GDP growth, and the average value of time, for which we have calculated the switching values as shown in Table 11.3).

Table 11.3: Switching values[81] for economic analysis

	Expected value	*Switching value*
Capital cost	Rs13.1 billion	Rs. 22.3 billion
Value of time	45Rs/hour	9 Rs/hour
GDP growth	5% p.a.	1.4% p.a.

Even under the most pessimistic circumstances, it is inconceivable that the GDP growth would fall to 1.4 percent as a long-term average, and Rs 9/hour is hardly conceivable as the value of time for car passengers. As shown in Figure 11.9, under the most reasonable low case for GDP growth of 2.5 percent p.a., the switching value for time is Rs 30/hour, which is comfortably below our already conservative assumption of Rs 45/hour. Capital costs would need to rise by 50 percent (in real terms), and are substantially higher than the government's worst-case figure (in current Rs) of $15 billion. In short, the ERR—before consideration of environmental externalities—may be regarded as robust, and very unlikely to fall below the opportunity cost of capital.

Figure 11.9: Sensitivity analysis: average value of time and GDP growth rate



Although these estimates of ERR are comfortably below the hurdle rate, we may note they are also significantly lower than those reported in the CKE-EIS, which reports a baseline

81 The switching value of an input assumption is defined as the value that makes the EER exactly equal to the opportunity cost of capital, which can be taken as the hurdle rate below which a project ought not to be undertaken.

ERR of 63 percent[82] (for the recommended western trace), compared to 38 percent for the eastern trace, and 18 percent for road widening. However, our estimate is comparable to the estimate of 18.9 percent (before consideration of environmental impacts) of Sivagnasothy and McCauley.[83]

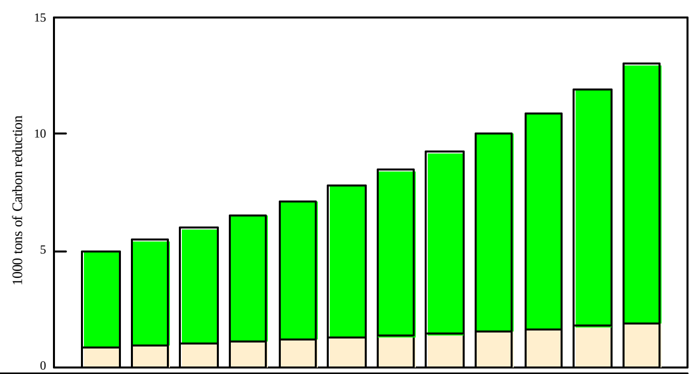
Environmental impacts

The calculation of avoided carbon follows directly from the fuel consumption, since emitted carbon may be taken as equal to the (known) carbon content of the fuel.[84] Calculated over the assumed 25-year life of the road, the undiscounted carbon savings amount to 319,000 tons, about 1.2 percent of the baseline carbon projection (see Section 7.4).

As shown in Figure 11.10, the reduction in carbon emissions derives mainly from diesel fuel savings: as noted in Section 2, the growth of gasoline vehicles is expected to lag behind diesel vehicles, and hence the number of gasoline vehicles diverted to the expressway will also be much smaller.

The impact on sulphur emissions will depend upon assumptions about the sulphur content of diesel fuel, discussed in Section 12.1, and in any event may be assumed to be linearly proportional to the reduction in fuel consumption. Here we assume that diesel fuel has a sulphur content of 0.5 percent.

Figure 11.10: Carbon savings



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
petrol	1	1	1	1	1	1	1	1	2	2	2	2
diesel	4	5	5	5	6	7	7	8	9	9	10	11

82 CKE-EIS,

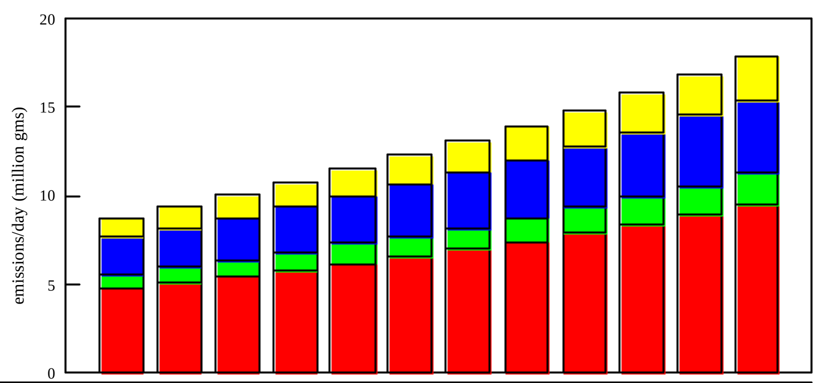
83 Sivagnas … own baseline estimate of 18 percent is purely coincidental. Indeed, some puzzling adjustments seem to have been made in Sivagnasothy and McCauley, although it is unclear whether these represent the authors' judgments, or those of the earlier environmental assessments undertaken by RDA in 1993. For example, with regard to the value of time, they note (p.106) ". . .*because of concern over the ability of passengers to capture the full benefits of such small amounts of time saved, the annual benefit figures adopted for use in the CBA were only 10 percent of the total estimated amount (i.e., Rs 230 million by 2010, 10 percent of the actual estimate of Rs 2.2 billion).*"

84 One of the questions that deserves further research is the impact of construction activity on the carbon balances, if only to demonstrate that the impact is relatively small when compared to lifetime carbon savings of road traffic. Clearly the energy input into cement, or the fuel consumption of heavy construction vehicles (and earth moving equipment), is not negligible.

One might expect that the most important local air emission benefit of the Expressway would be in the first two segments (New Kelani Bridge to Kerawalapitiya, see Figure 11.2), which carries the largest truck traffic, and where the diversion of more than 75 percent of truck trips onto the expressway will remove a major source of TSP emissions from the A3, which in this segment passes though densely populated commercial areas.

However, as shown in Figure 11.11, in fact the largest reduction in TSP emissions derives not from trucks, but from motorcycles (and 3-wheelers), which, even though they would be banned from the expressway itself, benefit from increased speeds on the A3. Two--stroke motorcycles in congested stop-and-go traffic are notorious polluters. While reductions in truck emissions are important, it must be remembered that in the first road segment, motorcycles account for over one-third of all traffic. It is the sheer volume of motorcycles that explains this result.[85]

Figure 11.11: TSP emission reductions by vehicle type



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
motorcycles	4.8	5.1	5.4	5.8	6.2	6.6	7.0	7.4	7.9	8.4	9.0	9.6
buses	0.8	0.9	0.9	1.0	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7
trucks	2.1	2.2	2.4	2.6	2.8	2.9	3.1	3.3	3.5	3.7	4.0	4.2
vans	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	2.2	2.3	2.5

Table 11.4 shows the annual changes in emissions (in year 2010).

Table 11.4: Physical air-emission impacts (reductions) of the expressway: in year 2010

		Change
Petrol	[1000 tons]	1572

85 Moreover, the model does not account for the changes in traffic mix in the course of the day. During night-time, when speeds on the existing A3 are relatively high, the proportion of motorcycles and three-wheelers is low. It is during rush-hours and midday when these vehicles are most evident, and when they make a disproportionate contribution to emissions (and to reduction in average speeds).

Diesel	[1000 tons]	8164
Emissions		
PM-10	[tons]	8
SOx	[tons]	82
NOx	[tons]	37

Table 11.5 shows a comparison of the various valuation estimates of environmental impacts for the CKE. For some categories of impacts (e.g., water pollution, noise,[86] road reduction in road accidents, and reduction in fishery productivity[87]), we have adopted the estimates of the CKE-EIS and Sivagnasothy and McCauley, as indicated; for local air emissions we use our own estimates.

Table 11.5: Valuations of local environmental impacts NPV, Rs Million

		Sigvagnasothy and McCauley (1991 prices)	*CKE-EIS (1995 prices)*	*Updated to 2000(5)*
1	Conversion of agricultural land (2)	-42		**-84**
2	Noise and air pollution (1)	-41		
3	Noise pollution (3)		-29	**-40**
4	Air pollution		1377	[x]
5	Reduced biodiversity and area of lagoon		-83	**-118**
6	Water pollution and reducing in fishery productivity	-8		**-16**
7	Reduction in road accidents (4)		112	**159**
8	Conversion of non-agricultural lands	-660		-1331
9	Loss of structures	-598		-1206
10	Increased flooding		-70	**-99**

Notes: Negative numbers=costs: positive numbers=benefits.

(1) This estimate is based on a simple hedonic pricing method, in which noise and air pollution impacts have been estimated on the basis of estimated changes in property values.
(2) Opportunity costs of lost agricultural production.
(3) Assuming a 10 percent loss of property value of the 416 properties expected to be affected by increased noise of the Expressway.
(4) The CKE-EIS reports the figures on an annual basis. These are converted to NPVs over 25 years at 12 percent discount rate.

86 The CKE-EIS made a detailed inventory of the number of properties likely to be affected, the land values involved (as much as Rs 100,000/perch in Peliyagoda and Katunayake), and then assumed a 10 percent decline in values. For reasons that are unclear (and almost certainly incorrect), it then assumed not a one-time loss in value, but a 10 percent loss in value each year over 21 years (with the property value itself escalating at 12 percent/year), resulting in an NPV of Rs 600million. This is an order of magnitude higher than the Sigvagnasothy and McCauley estimate (that uses the same hedonic pricing approach), and is obviously overstated. For this reason we use Sigvahnasothy and McCauley's estimate.

87 Interestingly, Sigvagnasothy and McCauley chose not to value this. " . .*the other potentially significant negative environmental impact identified but not valued was the loss of biologically diverse wetlands, but it did not appear that the route chosen for the Expressway would likely result in a major loss of such eco-systems*" (p.120).

(5) GDP deflator from Central Bank Annual report.
(6) These are included in the revised construction cost estimates and not itemized separately as an externality.
[x] CKE-EIS estimate not used; instead we use our own estimates (based on our emissions model). Estimates shown in **boldface** are adopted for this report. Non-air environmental impacts sum to Rs 357 million.

Items 8 and 9 in Table 11.5, concerning conversion of non-agricultural lands and structures, were inadequately treated by the earlier EIA; however, they appear to have been reflected in the new estimate of capital cost (which reflects more generous compensation packages than originally contemplated). We have already noted the error in the CKE-EIS valuation of local air pollution benefits, which is obviously overstated (and therefore has been replaced by our own calculations).

Table 11.6: Distribution of costs and benefits (NPVs in Rs Million at 2000 price levels)

	RDA	*Road users*				*Govt*	*CPC*	*Total*	*Environment*		*Total*
		Business	*Low-I (*)*	*Med-I*	*High-I*				*Local*	*Global*	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
Tolls	2922	-2922			-841			-841			-841
Construction	-10372							-10372			-10372
O & M costs	-1140							-1140			-1140
Time savings		14505	4065	1371	3051			22992			22992
Diesel fuel tax						-419	419	0			0
Petrol fuel tax						-359	359	0			0
Diesel savings		1681					-1681	0			0
Petrol savings		-0		88	536		-624	0			0
Fuel imports							1472	1472			1472
Port, dist. margins							55	55			55
Road accidents (from Table 11.4)			115					115			115
Environment											
Non-air impacts (from Table 11.4)									-357		-357
Air emissions											
PM-10								0	147		147
SOx								0	253		253
NOx								0	290		290
Carbon								0		574	574
Total	-8589	13264	4180	1460	2746	-778	0	12281	333	574	13188

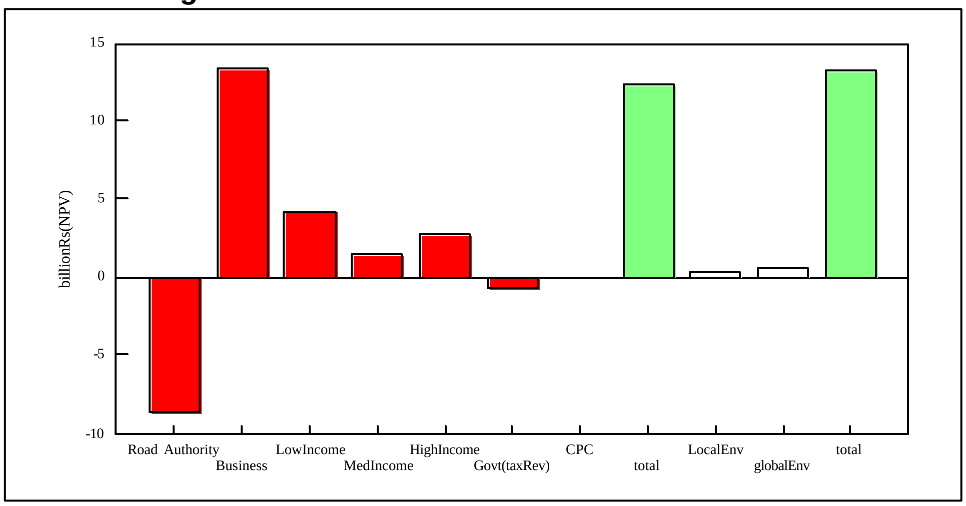
(*) Low I=low income=bus passengers and pedestrians.

88 Undoubtedly some effort would be made to charge higher fares for buses using the Expressway, though since the toll is far smaller than the time and fuel savings, the argument that the bus operators (Col.[3] of Table 11.15) would incur higher costs in total appears to have little merit.

Distributional impacts

The distribution of costs and benefits are shown in Table 11.6 and Figure 11.12. Bus passengers are assumed to benefit only from time savings (since fuel savings would accrue to bus owners): bus tolls would be paid by owners, and are assumed to be recovered from fuel savings rather than charged to passengers in the form of higher fares.[89] Even though motorcyclists are banned from the expressway (and therefore incur no tolls), they benefit from higher speeds on the A3 (deriving both time savings and fuel savings). It is assumed that any timesavings of bus, van, and truck drivers accrue to the owners of these vehicles (i.e., to "business").

Figure 11.12: Distribution of costs and benefits



It is evident that the air emission benefits outweigh the non-air costs (as computed by others), and that consideration of the environmental benefits makes a good project better.

As expected, business is the single largest beneficiary. Perhaps less expected is the result that low-income road users, as a group, derive greater benefit than do car passengers. The reduction in road accidents is shown under low income, for the majority of fatalities and serious injuries are suffered by pedestrians, who—at least in the case of the A3—may be assumed to fall into lower rather than higher income brackets. It may be seen that the toll income (even at a Rs 50 flat toll) would more than cover operations and maintenance (O&M) costs of the Expressway Authority, but still leaves a significant funding gap for debt service.

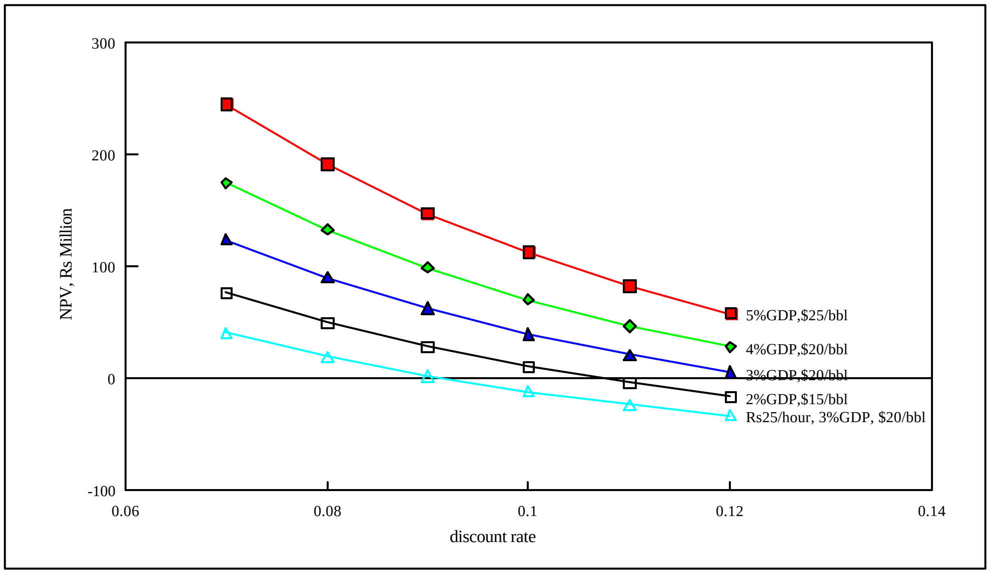
Sensitivity analysis: discount rates

Figure 11.12 shows a sensitivity analysis with respect to discount rate. Only under very

89 Undoubtedly some effort would be made to charge higher fares for buses using the Expressway, though since the toll is far smaller than the time and fuel savings, the argument that the bus operators (Col.[3] of Table 11.15) would incur higher costs in total appears to have little merit.

pessimistic assumptions (2.5 percent GDP growth rate, and 15$/bbl oil price, or a very low Rs 25/hour for the value of time) does the NPV become negative for high values of the discount rate. We conclude that the positive expressway investment decision is robust with respect to discount rate assumptions.

Figure 11.12: Sensitivity analysis: discount rates



Note: value of time Rs 45/hour except where stated

Railway electrification[90]

The Sri Lanka Railway has been studying the possibility of electrifying the suburban railways in Colombo for several decades. The objectives of this project have changed over time. These objectives have ranged from the reduction of fuel imports in the early years (particularly during the fuel crisis of the 1970s, when hydro power generation was in surplus during non-peak hours) to more recent concerns of attracting passengers from road to rail arising from the need to alleviate road traffic congestion.

A decision on railway electrification is presently under consideration by the Government of Sri Lanka, which is looking for private sector investments for electrification. One benefit of electrification would be the reduction of fuel and a reduction in air emissions. The reduction of fuel would arise from a number of different sources:

?? Fuel savings of road transport presently carrying passengers who would transfer to electrified railways

?? Fuel savings of other road traffic due to reduced road traffic and decongestion. However, this is offset by the emissions associated with increased electricity generation, given that incremental power generation will be from thermal rather than hydro sources.[91]

---

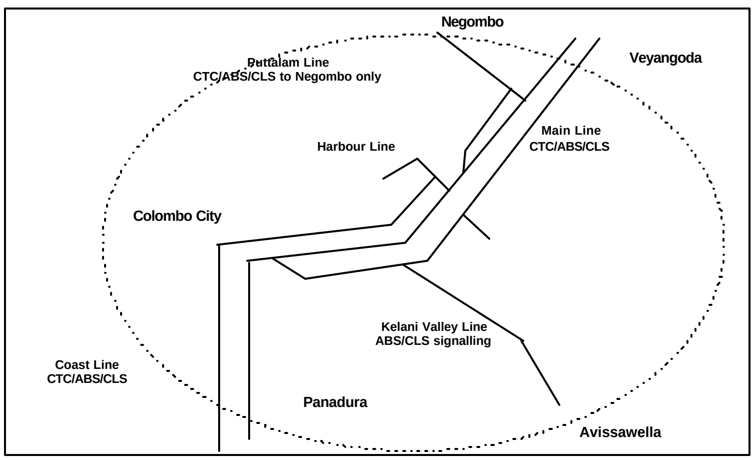
90 This section was prepared by A. Kumarage, University of Moratuwa.

91 There appear to be no detailed studies on the question of the incremental electricity consumption of the EMUs. The fuel consumption of a DMU has been estimated at 2.5 litres/km (Kumarage, *Assessment of Public Investments*, *op. cit.*, Appendix B4, p.4-4); we present below the calculations that convert the corresponding energy requirement to coal inputs at the (remote) coal-based power station. The

The section of railway line proposed for electrification between Colombo Fort and Veyangoda is part of the Main Line (see Figure 11.13). This particular line has three tracks going north-east of Maradana up to Orugodawatte where one line branches to the Port. The remaining two tracks continue over the Kelani River up to the Kelaniya station. A newly laid third track begins from this point up to Ragama. At Ragama, the Main Line branches with a single track going due north to Negombo and Puttalam with the Main Line continuing to Veyangoda and Polgahawela before it branches out further. The Project Impact Area (PIA) for the purpose of this case study is defined as the area that would form the passenger catchment for rail stations between Fort and Veyangoda, inclusive of both stations.

The present upgrading of the line is to provide speed capabilities of up to 100 km/h except at locations where permanent speed restrictions apply. The speeds on the third track between Kelaniya and Ragama are expected to be considerably lower than this. A centralized traffic control center located at Maradana has operational responsibility for the suburban railway operations. It extends up to Polgahawela on the Main Line.

Figure 11.13: Project area for rail electrification



Source: A.S.Kumarage, *Review of Household Income and Public Transport Services and Fares, op. cit.*, Figure 2.5.

The Colombo Urban Transport Study Stage 2[92] has calculated the existing rail line capacities. The Maximum Effective Capacity (MEC) is calculated as a percentage of the

assumption that coal would be the power generation source is conservative, since PM-10 emissions from an oil fired (steam cycle) power station would likely be lower. The use of LNG would of course be the most environmentally desirable form of power generation, but its costs (at the scale necessarily implied for Sri Lanka) are prohibitive (even assuming it were technically feasible, about which there are serious questions). See P. Meier, *Sri Lanka Electric Power Technology Assessment*, *op. cit.*, Section 6, for detailed discussion. Of course, given the prolonged paralysis regarding the decision about the coal plant, it may well be that the most likely source of thermal power would be short-gestation diesel plants, but this too is a very expensive way of providing electricity for railway electrification.

92 Colombo Urban Transport Study Stage 2, prepared by W.S. Atkins in association with the University of Moratuwa, Working Paper 7, June 1999.

theoretical capacity. The MEC on the Main Line is given as between 15 to 16 trains per hour per direction (tphpd) between Colombo Fort and Veyangoda. The present peak period (three hours in each direction) utilization of the MEC is calculated as varying between 27 to 51 percent. The peak hour utilization increases to 38 to 73 percent.

Present traffic patterns

The Sri Lanka Railways (SLR) origin destination matrix[93] for the Project Impact Area (PIA) is given as Tables 11.7 and 11.8 for ordinary and season tickets respectively. The section of line falling within the PIA is considered as between Colombo Fort and Veyangoda.

Table 11.7: Origin-destination matrix (balanced) by station for railway ordinary ticket trips/day (1998)

From/To	*Colombo sub*	*Kla/rgm*	*Wpa/gph*	*Drl/vgd*	*Total (PIA)*	*Total CMR*
Colombo area sub-total	1,223	4,575	3,142	1,170	10,111	19,277
Kelaniya-Ragama	4,575	1,800	1,892	499	8,766	10,515
Walpola-Gampaha	3,142	1,892	2,360	1,378	8,771	10,069
Daraluwa-Veyangoda	1,170	499	1,378	651	3,697	4,826
Total (PIA)	10,111	8,766	8,771	3,697	31,345	44,687
Total	19,277	10,515	10,069	4,826	44,687	72,531

Table 11.8: Origin-destination matrix (balanced) by station for railway season ticket trips/day (1998)

From /To	*Colombo subtotal*	*Kla/rgm*	*Wpa/gph*	*Drl/vgd*	*Total in PIA*	*Total (WP)*
Colombo area subtotal	298	6,698	11,611	5,199	23,806	53,019
Kelaniya-Ragama	6,698	982	1,850	559	10,089	11,550
Walpola-Gampaha	11,611	1,850	2,754	1,688	17,903	20,225
Daraluwa-Veyangoda	5,199	559	1,688	474	7,920	9,708
Total in PIA	23,806	10,089	17,903	7,920	59,718	94,502
Total	53,019	11,550	20,225	9,708	94,502	144,986

In order to use this data in the TransPlan V4 transport demand estimation model,[94] the station-to-station flow matrix given above has been converted to a matrix of travel among Secretariat Divisions (DSDs). A total of six such DSDs falls in whole or in part within the PIA. The conversion has been made on the basis of apportioning the SLR areas to different DSDs. In this process some approximations have occurred in the distribution of rail trips. The total rail trips have changed, as the boundaries are not identical. These are given as Table 11.9 and

93 Source: SLR Principal Costing Office, Railway Statistics, September 1998.

94 Source: University of Moratuwa, research in progress.

11.10 for ordinary and season tickets, respectively. Table 11.11 gives the total trip matrix, which indicates a total of 102,561 rail trips per day within the PIA.

Table 11.9: O-D matrix (balanced) by DSD for railway ordinary ticket trips/day (1998)

	Colombo	*Gampaha*	*Wattala*	*Ja-Ela*	*Kelaniya*	*Attanag.*	*Total (PIA)*	*Total (WP)*
Colombo	2,958	2,962	460	2,864	1,611	1,059	12,374	20,452
Gampaha	2,962	2,166	175	1,021	613	1,175	8,288	9,202
Wattala	460	175	18	137	63	45	916	1,019
Ja-Ela	2,864	1,021	137	1,036	479	327	6,000	6,914
Kelaniya	1,611	613	63	479	220	157	3,206	3,568
Attanagalla	1,059	1,175	45	327	157	527	3,334	4,053
Mahara	460	175	18	137	63	45	916	1,019
Total (PIA)	12,374	8,288	916	6,000	3,206	3,334	35,035	46,227
Total	20,452	9,202	1,019	6,914	3,568	4,053	46,227	65,827

Table 11.10: O-D matrix (balanced) by DSD for railway season ticket trips/day (1998)

	Colombo	*Kelaniya*	*Mahara*	*Wattala*	*Ja-Ela*	*Gampaha*	*Attanag.*	*Total (PIA)*	*Total (WP)*
Colombo	3,188	2,369	677	677	6,152	11,063	4,716	28,841	53,388
Kelaniya	2,369	120	34	34	283	602	176	3,619	3,965
Mahara	677	34	10	10	81	172	50	1,034	1,133
Wattala	677	34	10	10	81	172	50	1,034	1,133
Ja-Ela	6,152	283	81	81	707	1,057	387	8,749	9,663
Gampaha	11,063	602	172	172	1,057	2,539	1,410	17,016	18,646
Attanagalla	4,716	176	50	50	387	1,410	384	7,174	8,316
Total (PIA)	28,841	3,619	1,034	1,034	8,749	17,016	7,174	67,467	96,243
Total (WP)	53,388	3,965	1,133	1,133	9,663	18,646	8,316	96,243	135,121

Table 11.11: O-D matrix (balanced) by DSD for all rail trips/ day (1998)

	Colombo	*Kelaniya*	*Mahara*	*Wattala*	*Ja-Ela*	*Gampaha*	*Attanag.*	*Total (PIA)*	*Total (WP)*
Colombo	6,146	3,979	1,137	1,137	9,016	14,025	5,775	41,215	73,840
Kelaniya	3,979	341	97	97	762	1,216	333	6,825	7,533
Mahara	1,137	97	28	28	218	347	95	1,950	2,152
Wattala	1,137	97	28	28	218	347	95	1,950	2,152
Ja-Ela	9,016	762	218	218	1,743	2,079	714	14,749	16,577
Gampaha	14,025	1,216	347	347	2,079	4,705	2,585	25,304	27,848
Attanagalla	5,775	333	95	95	714	2,585	911	10,508	12,369
Total (PIA)	41,215	6,825	1,950	1,950	14,749	25,304	10,508	102,501	142,470
Total (WP)	73,840	7,533	2,152	2,152	16,577	27,848	12,369	142,470	200,948

The corresponding origin-destination bus flows are given in Table 11.12.[95] The comparison of the totals of rail and bus matrices shows that while the overall railway share of the public transport market is around 6.8 percent for the Western Province, its share in the PIA is higher at 15.8 percent.

Table 11.12: Origin-destination matrix (balanced) by DSD for bus passenger trips/day (1998)

	Colombo	*Gampaha*	*Wattala*	*Ja - Ela*	*Kelaniya*	*Attanag.*	*Mahara*	*Total (PIA)*	*Total (WP)*
Colombo	180,780	11,052	9,583	11,446	15,917	3,072	15,730	247,580	495,769
Gampaha	11,052	25,290	1,607	5,806	4,724	10,263	8,212	66,955	110,224
Wattal a	9,583	1,607	15,787	10,566	1,543	207	7,012	46,305	64,965
Ja – Ela	11,446	5,806	10,566	16,686	2,977	1,917	2,209	51,607	79,237
Kelaniya	15,917	4,724	1,543	2,977	8,285	1,112	7,069	41,627	69,317
Attanagalla	3,072	10,263	207	1,917	1,112	17,574	1,456	35,602	68,979
Mahara	15,730	8,212	7,012	2,209	7,069	1,456	14,011	55,697	69,394
Total (PIA)	47,580	66,955	46,305	51,607	41,627	35,602	55,697	545,373	957,886
Total (WP)	95,769	110,224	64,965	79,237	69,317	68,979	69,394	957,886	2,742,318

1.1 Assumptions

The passenger demand for electrification under each scenario, the demand with the diesel multiple unit (DMU) option, and the shift of bus passengers to electrification have been estimated. The following assumptions have been used in the estimation of the passenger demand changes for each of the scenarios:

- ?? Vehicle ownership has been incorporated into the model by using the appropriate vehicle ownership trends[96] as discussed before. Growth in employment has been considered as a percentage of population growth rates.
- ?? The present frequencies for DMUs have been considered as the base for the alternative to the project. In the case of the electric multiple unit (EMU) operations, a maximum frequency of 10 per hour (per direction) has been assumed as an appropriate level of service. The lower bound for maximum frequency has been considered as 6 trains per hour. Thus 144 EMU trips per day are made from an equal number of units as would be necessary for present DMU operations.
- ?? The level of access/egress to stations has also been incorporated into the cost estimates.
- ?? EMUs will cater only to passengers whose trip ends are entirely inside the PIA (i.e., between Fort and Veyangoda).

[95] Source: TransPlan Database, University of Moratuwa, 1999

[96] Kumarage, A.S., *Trends in Vehicle Ownership and Income*, research report under preparation,

?? Present long-distance trains operating through the PIA would continue in parallel with the EMUs, but would not carry passenger trips exclusively made within the PIA.

?? Any diversion of passengers from road transport would be entirely from buses.

?? Bus travel speeds would remain at present levels. This is made on the further assumption that highway and traffic improvements would take place anyway with or without the electrification project. However, traffic improvements due to diversion of bus trips to rail would be considered.

?? Bus fares that are presently approximately Rs 3/= for the first 2 kms and 40 cents for each additional km would remain constant in real terms.

?? Average operating speeds for EMUs may be assumed at 50 km/hr (with train stops).

?? DMU train speeds are assumed to be at the presently scheduled levels.

?? Fuel consumption of DMUs is taken as 2.5 litres per km[97]

?? The average per capita income for Western Province for 1998 may be assumed at US$1,113 per year.

?? The number of traffic days per year is taken as 365 days for ordinary travel and 260 days for season ticket travel. Thus average annual operating days would be considered as an equivalent of 320 days.

The travel demand model estimation for both scenarios was carried out using a combination of computer software developed for this purpose. The output is given in Table 11.13. This shows that with the electrification there would be a significant diversion from bus travel.

Table 11.13: Results (million units per year)

Policy	*Mode*	*Passenger trips*	*Passenger kms*	*Passenger hrs*
Present	DMU	31	629	19.26
Electrification	EMU	38	743	14.85
	Diversion from bus	7.3	113	-

Table 11.14 shows the total road traffic and the impact that the diversion of passenger trips from bus to rail as shown in Table 11.15 will have on the road traffic. Fuel consumption based on road speeds before and after electrification is shown in Table 11.16. The unit fuel consumption rates for each vehicle type are based on Table 2.2.

97 Sri Lanka Railways, *Annual Report*, 1999.

Table 11.14: Road traffic flows (before and after electrification)

	Km	*Time*	*Hours /day)*	*Flow/ day*	*Flow/hr*	*Fuel consumption per day (litres)*					
						MCs	*3Ws*	*Cars*	*Vans*	*Buses*	*Goods*
PRESENT STATUS											
Colombo-Kadawatha	4	peak	3	40,000	4000	800	600	600	1000	500	500
	4	off peak	10	40,000	2800	560	420	420	700	350	350
Kadawatha-Nittambuwa	36	peak	3	25,000	2500	500	375	375	625	313	313
	36	off peak	10	25,000	1750	350	263	263	438	219	219
AFTER ELECTRIFICATION											
Colombo - Kadawatha	4	peak	3	40,000	4000	800	600	600	1000	475	500
	4	off peak	10	40,000	2800	560	420	420	700	335	350
	36	peak	3	25,000	2500	500	375	375	625	288	313
	36	off peak	10	25,000	1750	350	263	263	438	204	219

Table 11.15: Fuel consumption of road traffic (before and after electrification)

Section of corridor	*PCUs/hr*	*Lanes/ direction*	*PCUs/ lane/hr*	*Speed km/hr*	*Fuel consumption per day (litres)*					
					MCs	*3Ws*	*Cars*	*Vans*	*Buses*	*Goods*
PRESENT STATUS										
Colombo-Kadawatha	4,950	1.75	1414	17.37	358	337	983	2,028	2,218	2,218
	3,465	1.75	990	24.16	740	696	2,031	4,228	4,708	4,708
Kadawatha-Nittambuwa	3,094	1	1547	15.25	2,131	2,007	5,845	12,025	13,084	13,084
	2,166	1	1083	22.68	4,252	4,001	11,670	24,247	26,890	26,890
AFTER ELECTRIFICATION										
Colombo – Kadawatha	4,888	1.75	1396	17.66	356	335	976	2,016	2,096	2,206
	3,428	1.75	979	24.33	738	694	2,027	4,219	4,499	4,701
	3,031	1	1516	15.75	2,101	1,979	5,762	11,864	11,891	12,925
	2,128	1	1064	22.98	4,232	3,982	11,618	24,148	24,964	26,802

Fuel consumption is summarized by fuel type in Table 11.16 and the savings are computed in Table 11.17. Accordingly, electrification will result in a savings of 80,000 litres of gasoline and 1.36 million litres of diesel from road use per year.

Table 11.16: Total fuel consumption for road traffic per year (before and after electrification)

Section	*Petrol*	*Buses (diesel)*	*Other (diesel)*	*Total road*
PRESENT STATUS				
Colombo-	537,171	709,856	1,358,903	2,068,758
Kadawatha	1,109,381	1,506,641	2,859,533	4,366,174
Kadawatha-	3,194,549	4,186,793	8,034,752	12,221,545
Nittambuwa	6,375,233	8,604,722	16,363,885	24,968,606
AFTER ELECTRIFICATION				
Colombo –	533,600	670,626	1,350,915	2,021,541
Kadawatha	1,106,805	1,439,764	2,854,293	4,294,057
	3,149,549	3,804,993	7,932,441	11,737,434
	6,346,522	7,988,479	16,303,915	24,292,395

Table 11.17: Fuel savings per year (before and after electrification)

	Total road (petrol)	*Total road (diesel)*	*Total*
Present status	11,216,334	43,625,084	59,449,418
After electrification	11,136,475	42,345,427	53,481,902
Savings	79,858	1,359,516	5,967,516
(%)	0.7	3.0	10.0

Economic analysis

The details of costs of railway electrification are shown in Table 11.18. We assume a three-year construction period, with operation commencing in 2005. Capital costs are estimated at Rs 5931 million (as NPV), and annual operating costs at Rs 183 million.

Table 11.18: Cost estimates for railway electrification

		Rs Million
Electrical engineering	Substation	236
	Overhead system	731
	Maintenance depot	61
Signals and telecommunications	Signaling modification	248
	Telecommunications upgrade	153
Civil works	DMU depot	287
	Substation	107
Maintenance depot	Plant & machinery	331
Rolling stock	12 EMUs	3427
Consultants, engineering & management		349
Contingencies		593
Total		6523

The benefits of railway electrification can be enumerated as follows:

- *Travel time savings to former DMU passengers:* By virtue of the higher travel speeds and greater operational frequency, the EMUs will save time for the former DMU passengers who will now use the EMUs. This savings in time is calculated by deducting the passenger hours by EMU travel from the corresponding value for DMU travel. The total time savings is then multiplied by the value of time taken as Rs 10.83 per hour.[98] This value is assumed to increase in real terms with the increase in per capita income assumed for each scenario.
- *Travel time savings to former bus passengers:* The savings in travel time for bus passengers is calculated by taking the difference in travel times for the those bus trips that have now been diverted to the EMUs. The same value of travel time has been applied for these passengers as well.
- *Vehicle operating cost savings from diversion of former bus passengers to EMUs:*[99] The reduced demand for bus passengers resulting from the transfer of former bus passengers to rail would then lead to fewer buses having to operate on

98 Value obtained from *Methods for Assessment of Capital Investments in Transport Sector Projects*, University of Moratuwa, 1999.

99 It might be argued that the DMUs that are presently in service on the main line to be replaced by EMUs would be available for use elsewhere, which would induce additional bus passengers to transfer to DMUs on these routes (e.g., the coastal line) in response to the better service that would be offered. If that were the case, however, then one would also have to add to the analysis: (i) the O&M costs of that additional DMU-based service; and (ii) the emissions associated with that service (which would be roughly equal to those of the present service, but which in turn would mean we would also need to add the emissions from electricity generation). This would have made the analysis much more complicated, and we therefore elected to simply consider a credit (salvage value) of the DMUs that would be replaced by EMUs.

the congested road network. The operational economic cost of these buses is taken as Rs 18.80 per km.[100] A further assumption is made that each of these buses will carry on average 50 passengers.[101]

?? *Reduction of air emission damages from reduced use of buses:* Reduced use of buses on congested roads will lead to less environmentally harmful air emissions. These are costed on the same basis as other options examined in this report (and shown in Table 11.19 as "E*nvironment: road traffic damages*").

?? *Reduction of air emissions due to electrification:* Under the assumption that the incremental electricity required for EMU operation is based on oil or coal, and that roughly the same amount of fossil fuel would need to be used for that electricity generation as is presently consumed by the DMUs, even if there is no change in emissions, there is a change in the *location* of emission.[102] DMU emissions occur at trackside, which for much of the suburban route passes through densely populated areas, whereas power generation—particularly if it occurs at a remote coal plant, results in emissions released from a tall stack— for which the health damage estimate is an order of magnitude less than for ground-level emissions in populated areas.[103] Typical health damages for high stack:ground level are in the ratio of 3114:42 for PM-10, 487:6 for SO2, and 123:2 for NOx. We apply these ratios to the emissions from former DMU operations (i.e., the 4.6 million litres of fuel estimated to be needed for the present DMU operations),[104] and show the results in Table 11.19 as "E*nvironment: DMU damages.*"

?? *Savings from accident costs from reduced bus travel:* Road transport accident costs have been estimated at Rs 0.08 [105]per passenger km. Although accident costs for rail transport have not been computed in Sri Lanka, an approximate computation using the same values for deaths and casualties as used in the road estimates gives a value of Rs 0.04 per passenger km. This is the cost for present

---

100 I*bid*.

101 Based on load factors given in Ministry of Transport and Highways, *Bus Transport Policy*, 1999.

102 DMU units would more accurately be described as "diesel-electric multiple units," because the diesel is used to generate electricity which in turn powers axle-mounted electric motors. Thermodynamically this is equivalent to the EMU, except that the electricity is not generated on board the unit, but at a remote location. While in theory one would need to account for transmission and voltage transformation losses in the EMU, the efficiency of large-scale generation would be better (even if generated by the same diesel technology), which offsets these losses.

103 Lvovsky et al., *Environmental Costs of Fossil Fuels, op. cit*., Table 6.3

104 4.6 million litres=3,840 tons of diesel. Ignoring EHV transmission losses, this is equal to 7,434 tons of coal (based on a calorific value of coal at 6,300 Kcal/kg and 10,180 Kcal/kg for diesel oil). Assuming carbon fractions of 0.875 for diesel and 0.6 for coal, it is clear that a shift from diesel fuel to coal would *increase* GHG emissions (from 3,365 tons/year to 4,460 tons/year).

105 A.S. Kumarage, *Assessment of Public Investments in Transport, op. cit*, Appendix B3.

railway operations. An increased level of safety will not be claimed for EMU operations, as costs for such have not been included in the project.

The physical environmental impacts are summarized in Table 11.19. Note in particular that PM-10 emissions for power generation from coal are lower than for diesel generation—a consequence of the assumption of state-of-the-art electrostatic precipitators (99.5 percent removal from fly ash) fitted to modern coal stations, as opposed to no controls on diesel-DMU engines. However, sulphur and carbon emissions are higher for coal-based generation (since we assume 0.6 percent sulphur coal without flue gas desulphurization (FGD)

Table 11.19: Physical environmental impacts of railway electrification: annual values

		Traffic	*Power generation*		
			DMU	*EMU (coal)*	*Net*
PM-10	[tons]	1.0	3.5	0.4	3.1
Sox	[tons]	11.4	385	892	-508
NOx	[tons]	48.6	156	74	81
Carbon	[tons]	1045.8	3365	4461	-1095
Fuel consumption	[tons]		3846 (diesel)	7434 (coal)	

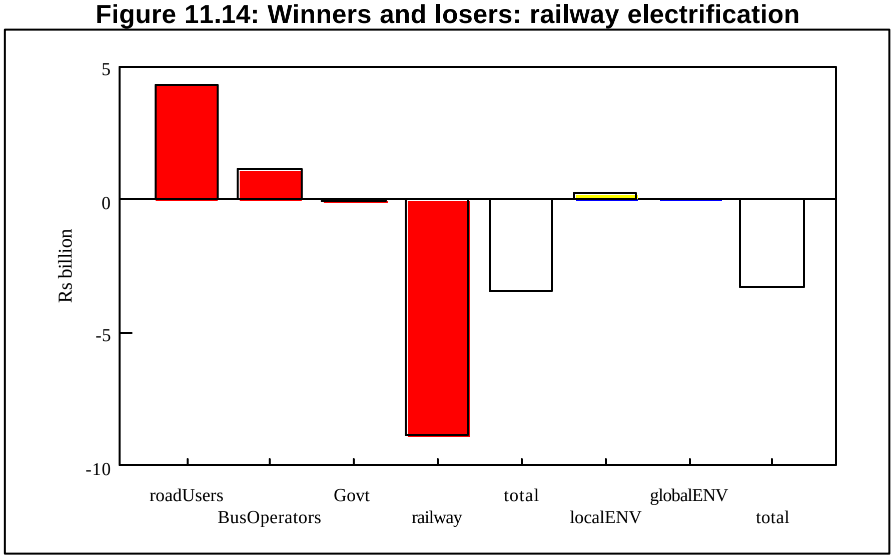
positive=savings (benefit), negative=increase (cost)

The distribution of costs and benefits is shown in Table 11.20. It is evident that this particular option for railway electrification is uneconomic. While there are clear benefits to road congestion and reduced vehicle operating costs (Figure 11.14), these are insufficient to warrant the high capital costs of electrification. Using a longer 30-year time horizon (that may be appropriate for electrification projects), the switching value of the discount rate is 4 percent (with environmental benefits), or 3.5 percent (without environmental benefits). These are much lower than the opportunity cost of capital (even if this is assessed at 7-9 percent rather than the 10 percent used for other options).

Table 11.20: Economic analysis of railway electrification

	Users	Bus operators	Govt	Railway	Total	Local	Global	Total
Time savings								
Existing rail passengers	2430				2430			2430
Former road passengers	1428				1428			1428
VOC reductions		1102			1102			1102
Fare differentials	-x			x	0			0
Road fuel taxes	48		-48					0
Accident reduction	401				401			401
Electrification costs				-11839	-11839			-11839
Salvage value of DMU				3000	3000			3000
Environment: road traffic damages								
PM-10					0	12		12
SOx					0	24		24
NOx					0	25		25
Carbon					0		27	38
Environment: DMU damages								
PM-10					0	40		40
SOx					0	80		80
NOx					0	1		1
Carbon							-10	-10
Total	4307	1102	-48	-8839	-3478	182	27	-3268

Figure 11.14: Winners and losers: railway electrification



Though positive, the environmental benefits are extremely small by comparison, and are clearly insufficient to offset the economic loss before consideration of environmental damage costs. The environmental benefits from electrification per se, even when based on coal-fired generation, are higher than the air emission benefits of reduced road congestion— except for carbon emissions, which are higher from coal-fired generation.106 Note that even though SOx emissions are greater from the coal power plant than from the DMU units, the health damage is lower because of the location of emissions.107

This analysis confirms the general view of previous studies that the case for electrification is doubtful:[108] our analysis shows that electrification of the northern commuter line is uneconomic. However, we also show that the environmental benefits are very small compared to the costs of electrification, even when we take into account the reduction in damage costs consequent to incremental EMU power generation at remote locations. Compared to other methods of reducing local air emissions, railway electrification is one of the most expensive options.

Port Inland Clearance Depot[109]

Colombo Port plays a key role in the economy of Sri Lanka. The handling of transhipment traffic is highly profitable, and the Port Authority has plans for further growth. However, there are significant harbor space constraints that prevent large-scale expansion, and therefore efficient operation of the port is of utmost importance. Colombo competes with several other ports in the region, each striving to become the regional hub for major container operators and consortia: most importantly, ports in South India endeavor to attract operators to use their ports directly without relays from others in the region. Nevertheless, Colombo, at the southernmost point of South Asia, has a unique geographical advantage, and consequently the government is desirous of exploiting that advantage for transhipment operations.

Several recent studies have examined port operations, all of which have drawn attention to the length of time that domestic containers spend in the port, thereby occupying space that might otherwise be given to the more profitable transhipment traffic—which will become

106 Clearly this is the expected finding: it does not matter where carbon emissions are produced since, unlike the local air emissions, they all have the same (worldwide) damage cost.

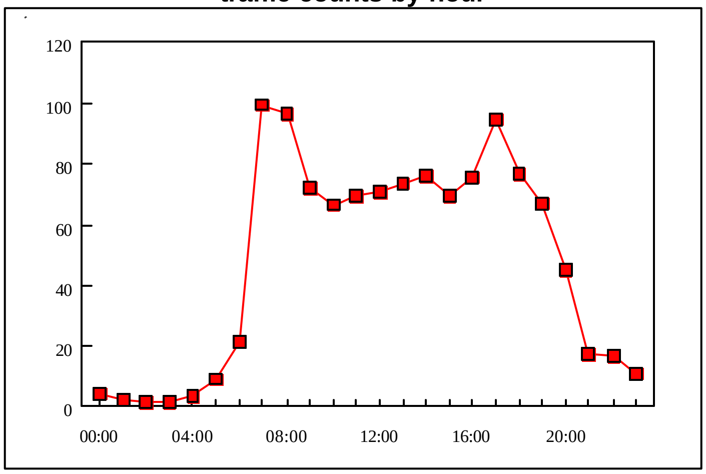
107 This is yet another argument as to why flue gas desulphurization (FGD) would be an uneconomic investment if the coal plant were built, but why state-of-the art electro-static precipitation (ESP) is economic.

108 E.g., Kumarage, *Review of Household Income and Public transport*, *op. cit*., notes ". . .Even though electrification had technical and environmental benefits, the Proposed Masterplan for transport development in the CMR, and working paper #25 of CUTS-2 suggest that the window of opportunity for electrification may have passed . . . many of the original technical advantages of electrification such as rapid acceleration and higher operating speeds that supported electrification are also now available for diesel units" (pp.4-7).

109 This section was prepared by D. Jayaweera, Transportation Planning Studies Centre, Colombo.

increasingly affected as the growth of the domestic economy requires increased domestic container traffic.[110] Even with improvements in productivity to reduce dwell time within the port, capacity will be reached by 2002.[111] To achieve further reductions in container dwell time, it has been proposed that all domestic containers be moved to an Port Inland Clearance Depot (PICD), which would ensure that the present capacity of the port was sufficient to 2006.

Figure 11.15: Heavy lorries: outbound A3 (2000): traffic counts by hour



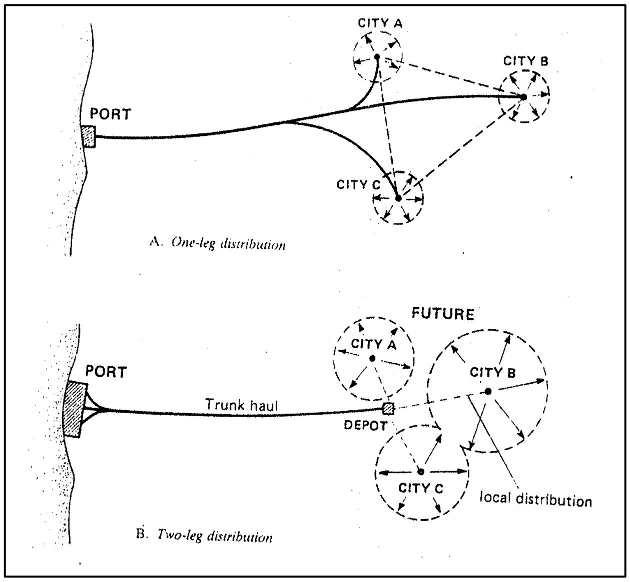
The problems of congestion inside the port are aggravated by congestion in the surrounding City of Colombo. As domestic container traffic has grown, increasing numbers of articulated container lorries move containers to their private inland container depots, many of which are located to the North of Colombo on the A3 radial road. This has significantly worsened congestion both on this key road and on the local roads leading to the A3 (see Figure 11.15). Heavy lorries, which are almost all container vehicles, account for about 5 percent of vehicles, but 8 percent of road capacity (when measured in PCUs).

---

110 Including a 1993 World Bank study of container traffic; Stage 1 of the Colombo Urban Transportation Study (CUTS, 1996), and the 1996 JICA study of the Development of a New Port for Colombo. These are reviewed in W.S. Atkins and University of Moratuwa, *Pre-feasibility Study of an Inland Container Depot*, Working Paper 12, Colombo Urban Transport Study, Stage 2 (CUTS2), June 1999.

111 *Ibid.*, p.2.21.

Figure 11.16: Container distribution concepts



Source: W.S.Atkins, *Pre-feasibility Study of an Inland Container Depot*, *op. cit*., Figure 3.1

The concept of the Port Inland Clearance Depot is to replace this so-called one-leg distribution system by a two-leg system, as depicted in Figure 11.16. The specific proposal of the prefeasibility study conducted as part of CUTS2 is to establish a trunk haul rail link to a PICD that would be located at Hunupitiya, close to the proposed Colombo-Katunayake Expressway (CKE).[112] All customs facilities for domestic traffic would be located at the PICD.

The prefeasibility study quantified the costs, but not the benefits, of such a scheme. The main elements of cost are shown in Table 11.21.[113] Figure 11.17 shows the geography of the project area with the proposed location of major facilities.

---

112 The pre-feasibility study also examined a site slightly further north at Ragama, but this was judged inferior because of low-lying ground, presence of a nearby ammunition dump, and being more distant from the proposed trace of the CKE.

113 It is reported that Indian locomotives may cost half of the value taken here (i.e., costing only Rs 100 million): the impact of this assumption is noted below.

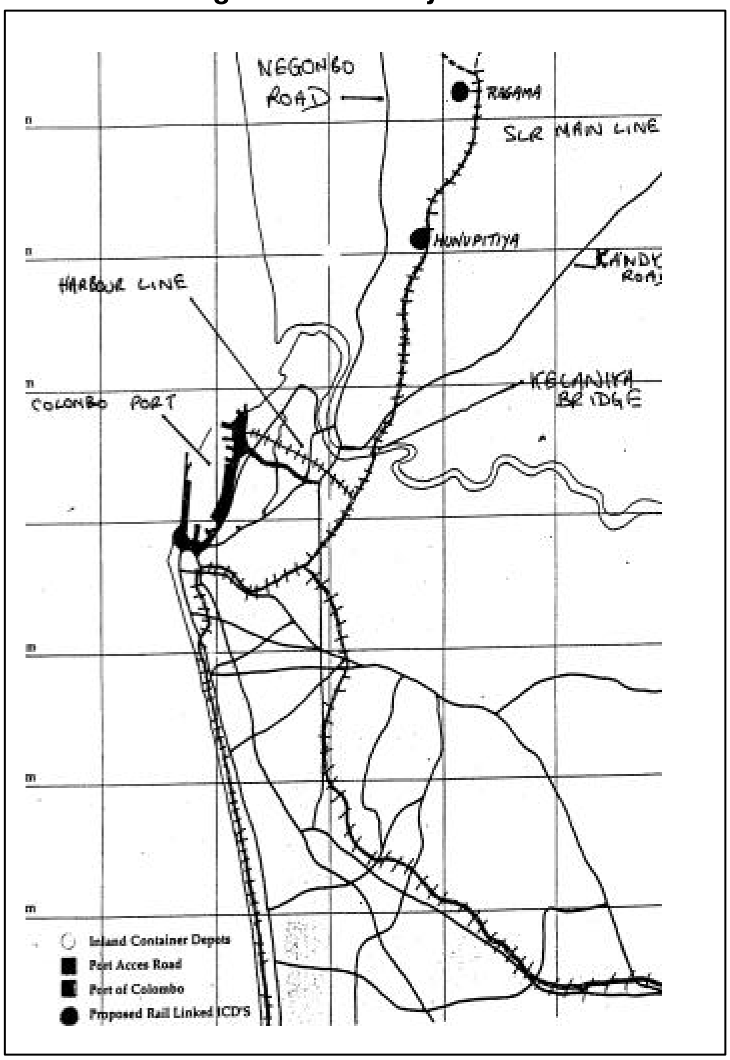
Table 11.21: Cost estimates (at 1999 prices)

	Rs Million
Railway infrastructure (1)	197
Rolling stock	
Locomotives, 4 @ Rs200m	800
Wagons, 120 @ Rs10m	1,200
Handling equipment at port and at PICD	745
Total	2,942

Source: W.S.Atkins and University of Moratuwa, *Pre-feasibility Study of an Inland Container Depot*, Working Paper 12, Colombo Urban Transport Study, Stage 2 (CUTS2), June 1999: Section 4 (Tables 4.1, 4.2, and 4.3).

Notes: Based on the option of construction of a new curve at Orugodawatte (rather than the slightly more expensive option of a new run-round loop and extra locomotive). Includes relocation and upgrading of Pettah marshalling yard, and cost of new sidings and civil works at the PICD.

Figure 11.17: Project area



Source: W.S. Atkins and University of Moratuwa, *Pre-feasibility Study of* *an Inland Container Depot*, Working Paper 12, Colombo Urban Transport Study, Stage 2 (CUTS2), June 1999: Figure 3.4, pp. 3-7.

A subsequent economic analysis of the proposal by the Transport Planning Studies Centre[114] made the following assumptions:

- ?? A 12.5 ha. site on low-lying marshland near Ragama Station adjacent to the main line railway.
- ?? Loading/unloading the train will be carried out by reach stackers.
- ?? The ICD sidings would connect to the third track of the mainline south of Ragama Station.
- ?? The railway line between Ragama and Urugodawatte, which is the junction of the port access line, consists of double tracks (1676 mm. gauge) known as the up and down lines. Urugodawatte is 2.8 km. north of Maradana Station and Ragama is 13.6 km. north of Maradana. Maximum axle loading is 16.5 tons. A third railway track is being constructed between Ragama and Kelaniya (5.0 km. north of Maradana). Some upgrading of the third track is required. There is a bottleneck in the track (by virtue of a 250-metre bridge) between Urugodawatta and Kelaniya, a distance of 2.1 km. where only two tracks are available.
- ?? The distance from Urugodawatte to the port is 2.0 km. This section of track needs complete rehabilitation.
- ?? The line inside the Port of Colombo is single track and is owned and maintained by the Sri Lanka Port Authority. The branch between the Port Gate and the Pettah Marshalling Yard—a distance of 1.9 km.—appears to be in reasonable condition.
- ?? Layout plans for the new Queen Elizabeth Quay (QEQ) terminal were not available at the time of carrying out this study. It should be possible to reactivate the QEQ branch, but this would require relaying of the track, including resleepering and replacement of rails. If container trains from the new ICD were to be handled at QEQ, a siding to accommodate a useful train length of 800 feet (244 m.) would be necessary.
- ?? Containers from the ICD can be loaded/unloaded at the Pettah Marshalling Yard (opposite JCT gate), which presently has six tracks. A new layout is suggested of one running line, with two sidings of 800 feet useful train length for container operation. An adjacent paved area plus an overhead gantry crane is suggested.
- ?? As passengers for container trains will not be available during peak commuter hours between 6:30 and -9:00 a.m. and 4:00 and 7:30 p.m., the maximum number of trips that can be made per day is nine if running-around, assuming availability of the third track between Kelaniya and Ragama.
- ?? The constraints on the length of train are seen to be at the ICD at Ragama, dictated by the length of site. This allows a maximum useful train of 800 feet. With local, total train length is 870 feet (265 m.). On the basis of new container flat wagons of 47

[114] D. S. Jayaweera, T. Gunaruwan, M. Bandusena and P. de Silva, *Economic Analysis of the Inland Container Depot at Ragama*, Transportation Planning Studies Centre, Colombo, July 2000.

feet, this gives 17 flat wagons. The 17 wagon consist allows transport of 34 TEUs per train. It is assumed those four sets of flat wagons will be used for the operation with one locomotive.

?? The maximum daily number of TEUs that can be transported (Port/Ragama) by one locomotive, therefore, is 408 per direction if running-around. Using two locomotives will increase but not double capacity because some trips would have to share the main line with passenger trains.

?? The SLR has indicated that the immediate requirements for Port/Ragama rail container traffic would be around 300 boxes. This is estimated to grow at around 10 percent per annum. On average mix, it is estimated that boxes translate into around 640 TEUs. Thus the 9 trains (17 wagons each) per day scenario, which offers 306 TEUs, can cater for demand right now. It is likely that the present train capacity will be exceeded by demand in three years. The report suggests other measures, which can be investigated to increase throughput.

?? There is need for a detailed check in the next study to confirm vertical clearances for containers on the Port to Ragama run. When planning a modern ICD, it is desirable to cater for containers in the 9'6 " and 10' size range. Clearances must be checked particularly at the two road over-bridges between Urugodawatte and the port entrance, with reported vertical clearances of 4.5 metres. If there is not clearance, then other options such as altering the obstructions or a mix of lower floor wagons may be considered.

It may be seen that these assumptions imply a more modest scale of operations than those assumed by the CUTS2 study—e.g., only one instead of four locomotives—which leads to a significantly lower capital cost estimate (Rs 1.48 billion v. Rs 2.9 billion).

Using these assumptions, the study estimated the NPV of the project as Rs 1.2 billion, with an ERR of 40 percent, based on a total cost estimate of Rs 1.4 billion, and benefits limited to estimates of time savings and avoided costs on the present A3 road: neither the improvements in port operations, nor the environmental benefits of reduced road traffic on the A3 were quantified.

Estimating the benefits on the operations of the Port of Colombo goes beyond the scope of this study, and will need to await the full feasibility study. Indeed, as noted, neither the prefeasibility study nor the TPSC economic analysis attempted such a quantification. Based on interviews with private operators conducted as part of the prefeasibility study, there is wide support among container operators for the idea, with preliminary indications that private sector involvement in financing the project would be likely. These benefits include:

?? Increased throughput of transshipment container traffic.

?? Deferral of the construction of a new port, or major new expansions to increase port capacity.

?? Cost savings to private operators attributable to a reduction in dwell time in the port.

However, the model presented earlier for evaluating congestion pricing can be used to identify the benefits from reduced road congestion on the A3 (as container traffic is diverted to the railway), and the concomitant environmental benefits (reduction of diesel emissions of container trucks, and reduction of emissions from other road vehicles consequent to increases in average speeds once the container lorries are removed from the local roads and the A3). Removal of this traffic from the A3 would improve average speeds by about 3-4 km/hour during peak hours (Figure 11.18).

Figure 11.18: Impact of ICD on speeds on the A3 (2001)

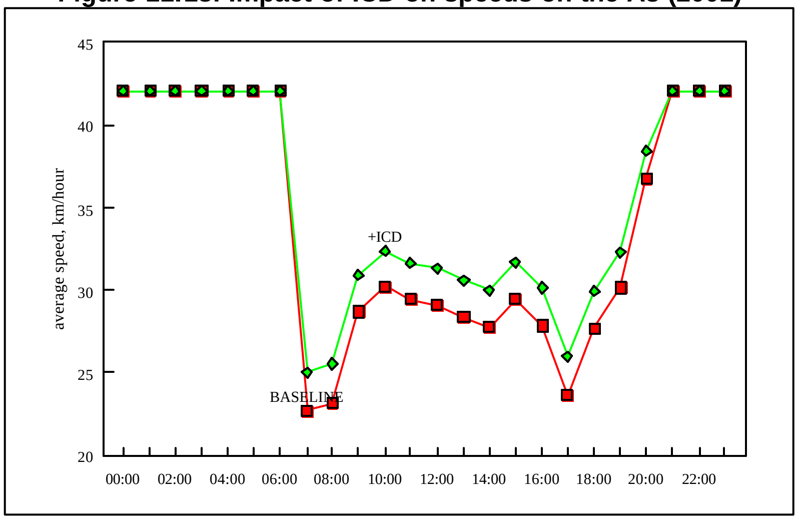


Table 11.22 and Figure 11.19 show the distribution of costs and benefits. The analysis considers both the A3 and Kandy roads (which are the two radial roads with the heaviest container lorry traffic): it is assumed that the ICD would reduce heavy lorry tariff on the A3 by 75 percent, and on the Kandy Road by 50 percent.[115] We make the further (conservative) assumption that the residence time of rail shipment is 50 percent of the corresponding value of road shipment.[116] It is assumed that the costs of the ICD incurred by the railways and the port are recovered in fees from the container operators, and the row "other savings" has been set so that the assumed ERR of the project equals the opportunity cost of capital: these are assumed to be the minimum level of additional benefits to the container operators (COs) to make the project viable; thus, the net economic benefits shown are really equal to just the externality reductions—to road users and to the environment. Clearly, the former benefits are very large, the latter very small: and the principal beneficiaries are bus passengers.[117]

---

115 For which we assume trip lengths of 12 km and 6 km, respectively.

116 Thus the value of freight delay given in Chapter 6 of Rs150 vehicle-hour is reduced to Rs 75/hour.

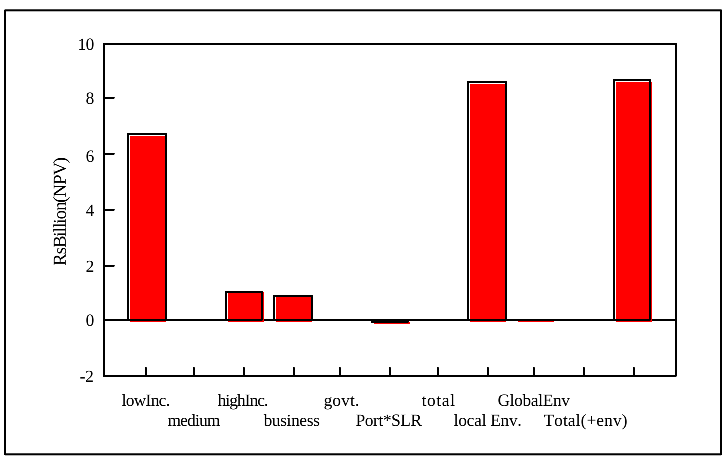
117 In the event that Indian locomotives were acquired, an additional (capital cost) savings of Rs 100million would be achieved, which would simply make an already good project that much better.

Table 11.22: Costs and benefits

	Road users								*Environment*		
	Low-I (bus)	*Med-I (MC)*	*High-I (cars)*	*Busin.*	*COs*	*Govt*	*SLR + port*	*Total*	*Local*	*Global*	*Total*
Time savings	5927	18	927	647	2639			10157			10157
Tolls	0	0	0	0		0		0			0
Gasoline fuel tax		1	26			-27		0			0
Diesel fuel tax	44		4			-48		0			0
Diesel savings	765			273	63			1101			1101
Petrol savings		1	85					86			86
Deadweight loss	0	0	0	0				0			0
VOC savings, CO					2957			2957			2957
Fees to SLR/ICD					-6579		6579	0			0
Other efficiency savings					919			919			919
Capital cost							-1712	-1712			-1712
O & M costs							-4866	-4866			-4866
Environment								0			0
PM10								0	7		7
SO2								0	11		11
NOx								0	13		13
GHG emissions								0		12	12
Total	6736	19	1042	920	0	-75	0	8642	31	12	8685

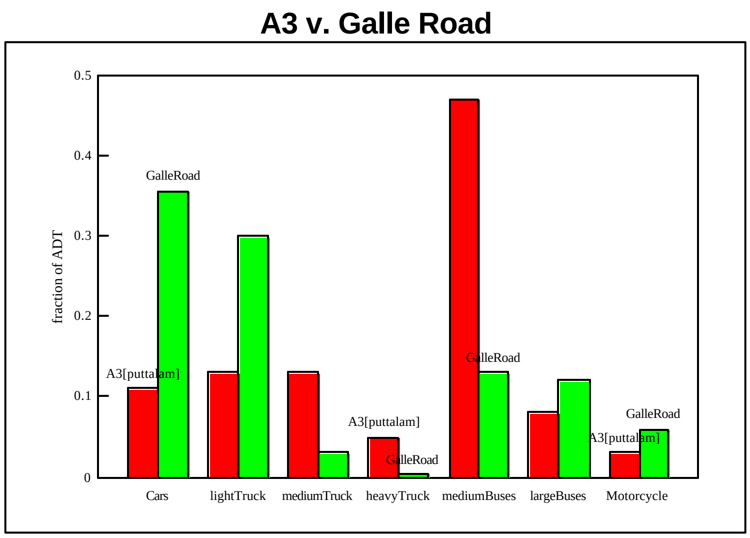
CO=container traffic operators.

Figure 11.19: Costs and benefits



This result is readily explained, because the A3 and Kandy roads have a significantly different traffic mix: the A3 has a much higher proportion of buses compared to other roads (such as the Galle Road), and a significantly lower proportion of cars and motorcycles (Figure 11.20).

Figure 11.20: Vehicle mix comparison:



Indeed, the physical environmental benefits are quite small, as indicated in Table 11.23.

Table 11.22: Air emission reductions (tons)

	2010	Lifetime
PM10	0.3	
SOx	3.3	
NOx	17.4	
GHG emissions	369	7774

12

Vehicle Emission and Fuel Quality Standards

12.1 Sulphur content of diesel fuel

Throughout the world, the sulphur content of diesel fuel is being lowered. Most European and North American countries are now introducing regulations to limit sulphur to 0.05 percent by weight (and some, like Finland and Sweden, to virtually sulphur-free fuel, 0.001-0.005 percent).[118] Faiz et al. (1999) describe the costs of reducing sulphur to 0.05 percent as "moderate"—less than 1 U.S. cent/litre. Yet a 1989 study concluded that the cost of reducing sulphur to 0.05 percent in Europe would be between 0.9 and 1.4 U.S. cents/litre, equivalent to $6,000-$9,000/ton of sulphur removed.[119] This is substantially higher than most valuations: as noted in Section 4, the highest plausible SO_2 damage estimate (from vehicle emissions) for Sri Lanka is around $2,900/ton.

The costs of sulphur removal from diesel can be gauged by price differentials on world markets. Figure 12.1 shows the differentials in Singapore spot prices: the lines shown represent the price for the sulphur content shown, relative to 1% S gasoil. Thus we see that for most of 1997-1999, the cost of 0.5% S was 20 U.S cents/bbl, falling in 2000 to 10 cents/bbl (though with some greater volatility). However these differentials pale in comparison with the volatility in overall price level.

118 Faiz, *op. cit*., p. 188.

119 CONCAWE (Conservation of Clean Air and Water in Europe) *Costs to Reduce the Sulphur Content of Diesel Fuel*, Report 10/89, The Hague, 1989.

Figure 12.1: Cost differentials over 1 %Sulphur gasoil, Singapore fob spot prices, in $/bbl

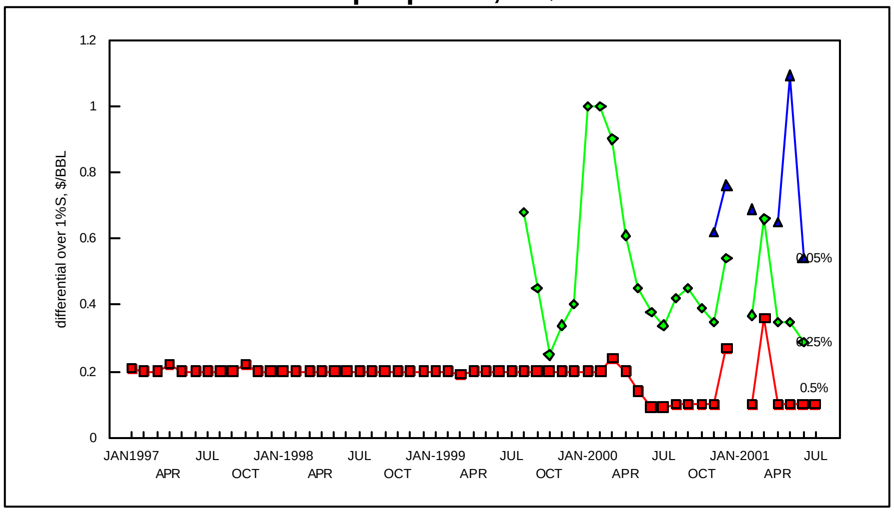
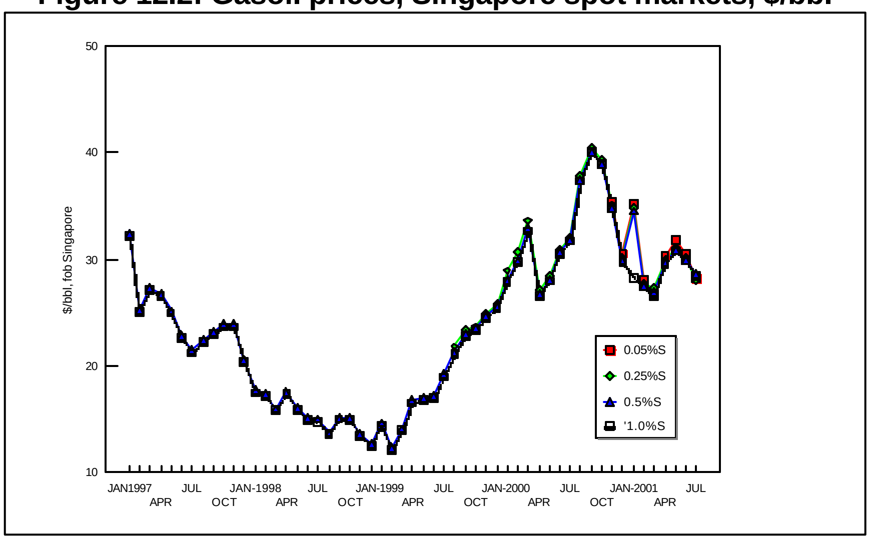


Figure 12.2: Gasoil prices, Singapore spot markets, $/bbl



Source: Platt's Oilgram

Table 12.1 shows December 2000 differentials:[120] 0.5% sulphur costs about 10 U.S. cents/bbl more than 1.0% S, equivalent to Rs 0.06/litre; reducing sulphur further to 0.05% commands U.S. cents 45/bbl, or Rs 0.30/litre. However, these small differentials reflect the high proportion of low-sulphur Indonesian and Malaysian crudes in Asia-Pacific refineries, whose distillate products also have correspondingly low sulphur contents. The differentials expressed as $/ton SO_2 that lie in the range of $75 to 564/ton (Table 12.1) are significantly lower than the

120 As reported by Platt's Oilgram.

health damage cost (for releases at street level) estimated for Colombo as based on the Six Cities study ($2,900/ton, see Table 4.12) [121]

Table 12.1: Sulphur differentials of Singapore quoted gasoils

Sulphur content	*1.00%*	*0.50%*	*0.25%*	*0.05%*
$/bbl	33.15	33.25	33.45	33.75
Differential (Figure 12.1)		0.1	0.3	0.6
bbls/ton	7.52	7.52	7.52	7.52
$/ton	249	250	251	253
d ($/ton)		0.752	1.504	2.255
S	0.01	0.005	0.0025	0.0005
Ton SO_2/ton	0.02	0.01	0.005	0.001
d (tonSO_2/ton)		0.01	0.005	0.004
d ($/ton$SO_2$)		75	301	564
Litres/ton	1196	1196	1196	1196
U.S. cents/litre	20.84	20.91	21.03	21.22
d (U.S. cents/litre)		0.063	0.126	0.189
D (Rs/litre)		0.060	0.120	0.180

This assumes that the relevant measure of environmental benefit is the one that applies to SO_2. However, because of secondary formation of sulphates from SO_2, sulphur content may also have bearing on particulate emissions.[122] However, the literature suggests that this phenomenon of secondary sulphate formation is largely one of long-range transport, as may apply to emissions from tall power plant stacks transported over long distances (and involving correspondingly long atmospheric residence times). There seems to be some question as to whether this would apply to vehicular emissions emitted at (or close to) ground level. Certainly to the extent that this *is* a concern, it could be argued that the exposure to secondary particulate matter from vehicular SO_2 emissions in Colombo would be felt inland (or offshore), necessarily involving lower (or zero) population exposure, and correspondingly lower health damages.

121 The SO_2 differentials of Table 12.1 are, in effect, the switching values for damage costs; if the damage costs are lower than the values indicated, then lowering the sulphur content of fuel is uneconomic.

122 One assessment of the sources of PM-10 suggested that only 70 percent of this total can be attributed to direct primary emissions of particulate matter, and that 30 percent is sulfates derived from SO_2 (and to a lesser extent to nitrates) (World Bank, *Comments on the Proposed Fuel Quality and Vehicle Emission Standards*, May 2000). Indeed, that analysis presents calculations of the benefits of reducing sulphur in fuel that are based entirely on the reduction of secondary sulfate particulate matter (and, not surprisingly, concludes that it is better to reduce diesel particulates directly through better inspection and maintenance programs than to try to reduce particulates indirectly by reducing sulphur content of diesel). We do not disagree with the conclusion; but it does seem that most studies in the literature do attribute some damage cost to SO_2 *per se*, and therefore in this section we use the SO_2 damage values as presented in Section 4.

Sri Lanka has been long been criticized for the relatively high sulphur content of its diesel fuel,[123] which most studies assume is at or near the specification value of 1.1% S by weight. Indeed, as suggested in Table 12.2, Sri Lanka has an unusually high sulphur specification for its diesel fuel.

Table 12.2: Comparison of specifications for sulphur in diesel fuel (% S by weight)

	1998	*1999*	*2000*	*2001*	*Future plans*
ASEAN(1)					
Brunei	0.25	0.25	0.25	0.25	
Cambodia					
Indonesia	0.5	0.5	0.5		
Laos					
Malaysia	0.5	0.5	0.3		
Myanmar	0.5	0.5	0.5		
Philippines	0.5	0.5	0.5	0.2	
Singapore	0.3	0.05	0.05	0.05	
Thailand	0.25	0.05	0.06	0.07	
Vietnam	0.5	0.5	0.5		
OTHER					
India					
Bangladesh					
China (3)				0.2-1.0	0.2 (in 2002)
Pakistan (2)		1		1	0.5 (in 2002)
Sri Lanka	1.1	1.1	1.1	1.1	0.5 (in 2003)

Source: ASEAN, Proceedings, Regional Workshop on Fuel Quality and Alternative Fuels, Delhi, May 2001: (1) G. Balce, Overview of Regional Fuel Market and Fuel Quality Standards; (2) S. M. Zaidi, Country experience of Pakistan in improving fuel quality; (3) Z. Yangsheng, Improving Fuel quality in China.

However, the actual average sulphur content of diesel produced at Sapugaskanda is typically in the range of 0.65 - 0.8% S, depending upon the sulphur content of the crude refined (Table 12.3).

When low-sulphur Meri crude is refined, the diesel fuel sulphur content may be as low as 0.05%; however the predominant Middle Eastern crudes produce diesel with a sulphur content in excess of 1% (Table 12.4). Historically, CPC has opposed a tighter sulphur specification largely because of fears that it would lose flexibility in crude purchases.

[123] Again, for example, the World Bank TSS states (para 5.12)

. . . the diesel fuel permitted for use in Sri Lanka contains up to 1.1 percent sulphur, contributing to the high levels of SO_2 emissions.

Table 12.3: Estimated sulphur in auto-diesel produced by the refinery

Year	*S percent*
1989	0.94
1990	0.72
1991	0.72
1992	0.75
1993	0.66
1994	0.61
1995	0.56
1996	0.79
1997	0.81
1998	0.69
1999	0.79
2000	0.80
2001	0.73

Source: CPC

Table 12.4: Sulphur in diesel fuel v. crude type

	% S
Arabian light	1.2
Basrah light	1.15
Upper zakum	1.15
Arabian medium	1.7
Mirri Light	0.05
Tapis	0.05

Source: CPC

There are, therefore, three options for Sri Lanka to reduce the sulphur content of its diesel fuel:

?? Increasing the proportion of sweet crudes.
?? Hydrotreating at the refinery
?? Blending by import of low-sulphur diesel.

These three options have been analyzed using the CPC's linear programming optimization model of the Sapugaskanda refinery:[124] in each case we ask what would have been the least-cost way of meeting the 2000 product demands for 0.5% S.

[124] The details of the LP model results are provided in Annex 12.1.

Analysis of the first option (Box 12.1) shows an incremental cost of Rs 0.34/litre (2.5 cents/bbl).[125] This is significantly less than the 10 cents/bbl noted above.

Box 12.1: Case I: Adjust crude mix

CRUDE OIL	PRICE US $/MT	PRODUCTS	PRICE US $/MT
Iranian Light	204.5	LPG	353.4
Arabian Light	195.7	Naphtha (Export)	273.8
Upper Zakum	212.1	JetA-I/Kero	285.0
Miri Light	239.8	Gasoil 1.0%S	250.7
Airli	242.0	Gasoil 0.5%S	251.8
		FO 180cst	170.0
		FO 380cst	162.0

1. Base case to produce 1.0 % S

	Processed MT	MODE	Crude Oil Sulphur %	Gasoil Yield % wt	Gasoil Sulphur %	Gasoil MT	Sulphur MT	Sulphur % wt.
Iranian Light	564280	Kero	1.45	22.5	1.00	126963	1269.6	
Iranian Light	585360	Jet A-1		23.1	1.00	135218	1352.2	
Arabian Light	300000	Kero	1.80	20.5	1.20	61500	738.0	
Arabian Light	0	Jet A-1		24.0	1.20	0	0.0	
Upper Zakum	180000	Kero	2.00	23.4	1.15	42120	484.4	
Upper Zakum	0	Jet A-1		24.8	1.15	0	0.0	
Miri Light	420000	Kero	0.12	48.6	0.06	204120	122.5	
Miri Light	0	Jet A-1		47.8	0.06	0	0.0	
Airli	0	Kero	0.12	37.5	0.06	0	0.0	
Airli	0	Jet A-1		45.5	0.06	0	0.0	
Crack GO from Visbreaker					1.50	55951	839.3	
Total Refinery	2049640					625872	4806	0.77
less Gas Oil for Blending						44500		
Imported Gas oil						1149100		
Total Gas oil for Local demand						1730472 MT		

	Million US $
Cost Of Crude Oil	432.7
Cost Of Imported Products	389.5
Less Bunker Revenue	124.6
Less Value of Exports	31.8
Net Imports	665.8

2. With Gasoil 0.5 % S Constrain

	Processed MT	MODE OF OP.	Crude Oil Sulphur %	Gasoil Yield % wt	Gasoil Sulphur %	Gasoil MT	Sulphur MT	Sulphur % wt.
Iranian Light	0	Kero	1.45	22.5	1.00	0	0.0	
Iranian Light	0	Jet A-1		23.1	1.00	0	0.0	
Arabian Light	916110	Kero	1.80	20.5	1.20	187803	2253.6	
Arabian Light	187720	Jet A-1		24.0	1.20	45053	540.6	
Upper Zakum	0	Kero	2.00	23.4	1.15	0	0.0	
Upper Zakum	0	Jet A-1		24.8	1.15	0	0.0	
Miri Light	420000	Kero	0.12	48.6	0.06	204120	122.5	
Miri Light	0	Jet A-1		47.8	0.06	0	0.0	
Airli	0	Kero	0.12	37.5	0.06	0	0.0	
Airli	548550	Jet A-1		45.5	0.06	249590	149.8	
Crack GO from Visbreaker					1.50	36505	547.6	
Total Refinery	2072380					723071	3614	0.50
less Gas Oil for Blending						33300		
Imported Gas oil						1040700		
Total Gas oil for Local demand						1730471		

	Million US $
Cost Of Crude Oil	449.5
Cost Of Imported Products	366.0
Less Bunker Revenue	110.1
Less Value of Exports	31.8
Net Imports	673.6

Aditional cost of reducing Gasoil Sulphur to 0.5 % S level.	7.8	Million US $
Total quantity of Gas oil	1730400	MT
Additional cost per litre	0.34	Rs

125 We assume Airlie rather than Tapis as the low sulphur crude. The pour point of atmospheric residue from Tapis crude is 108°F, which is high compared to the residue from the Iranian light design crude, which is only 75°F. Waxy residue from Tapis crude clogs pipelines and creates operational problems in the fuel oil system as well as in some heat exchangers. Even though it gives a higher yield of gas oil, mainly because of its waxy residue problem, Tapis crude is no longer used at Sapugaskanda.

Box 12.2: Case II: Unifiner gasoil hydro-treating unit

Capacity	Feed	1000	MTPSD	1.1 % S		
	Crack Gasoil	25%	of Feed	1.5 % S		
	Input Sulphur			1.2 % S		
	Out Put			0.124 % S		
Revamp Capital Cost			250	Million Rs		
Catalyst Costs(18340 Kg*9.3 $.Kg)			170562	US $		
Assuming 350 days/year	% Of Feed					
H2 Requirement	1.7	6000	MT			
Fuel Requirement		15	SRF Kg/MT			
Assuming 350 days/year						
Cost of S.R Gasoil (1.0 % S)			33.34	US $/bbl		
Refinery Production of S.R Gasoil (0.8% S)		736422	MT			
07 Yields						
		MT	US $/MT	Cost US $	Density	
Feed S.R Gasoil		350000	247.87	*************	0.846	
H2		6000	184.36	1106179		
Fuel Gas Production		10690	184.36	1970842		
Treated Gasoil	98.66	345310			0.846	
Fuel Consumption						
Fuel Gas (MT)		4005.0	184.36	738374		
Fuel Oil		1336.0	152.30	203321		
Total Cost of Tr. GO (o.124% S)				86833150		
		Quantity MT	Sulphur % wt.	Price US $/MT	COST US $	
07 Treated Gasoil		345310	0.124	251.46	86833150	
Balance S.R Gasoil		386422	0.80	247.87	95784208	
Total 0.5% S Gasoil Production		731732	0.48	249.57	182617358	
Production Cost of Refinery 0.5% S GO		5440245.7844	bbl	33.92	US $/bbl	
Operating Cost of reducing GO S to 0.5% S				0.33	Rs/Litre	
Assuming economic life of 15 years						
		US $				
Revamp cost		2777778				
Catalyst Cost		170562				
Total		2948340				
Capital Cost per MT		0.27		0.04	US $/bbl	
		Quantity MT	Sulphur % wt.	Price US $/bbl	COST US $	
Annual Demand of GO		1730435				
Balance Import(.5%S)		998703.0	0.5	33.49	*************	
Refinery Production		731732	0.48	33.96	184756652	
TOTAL GAS OIL		1730435		33.83	435199741	US $
Total Additional cost Of Reducing GO S to 0.5%				0.28	Rs/litre	

In Box 12.2 we summarize the results of the unifiner conversion option.[126] With the

[126] The original unit was designed to process 7,200 BPSD of kerosene for desulphurization and smoke point improvements. Following the installation of kerosene Merox unit this was no longer needed, and has been revamped to hydrotreat gasoil. The feed stock rate is 1,000 TPSD to maximize processing of visbroken cracked

completion of the project to convert the (previously mothballed) kerosene hydro-treater to desulphurize gasoil, expected in late 2001, the Sapugaskanda refinery will have the ability to produce 1,000 tons/day of 0.1% diesel, which can be blended with other stocks to meet the new specification of 0.5% sulphur diesel, required to be met by January 2003.[127] This is seen to have slightly lower costs (Rs 0.28/litre). However, this includes the $2.7 million revamp cost – which is sunk.

Finally, in Box 12.3 we show the cost of blending with low-cost gasoil imported from Singapore. This is seen to lower costs further, to around Rs 0.18/litre.

Box 12.3: Blending

OPTION 1- BLEND WITH IMPORTED LOW SULPHUR GO

Based on 2000 actual demand and production

IMPORTS	Quantity BBL	SULPHUR %	PRICE * US $/bbl	Total Cost US $
GO 1.0% S	398,291	1.00	33.34	13279036
GO 0.5% S	981,346	0.50	33.49	32865266
GO 0.25% S	4,647,368	0.25	33.91	157592244
GO 0.05% S	1,510,751	0.05	34.16	51607271
				255343817
REFINERY PRODUCTION				
GO 1.0 % S	5475115	0.8	33.34	182540326
FINAL GASOIL POOL				
GO 0.5 % S (BBL)	13012871.2	0.50	33.65	437884144
REQUIREMENT	13012871.2	0.5		
GO BBL/ 1 MT	7.52			
Rs/US $	90			
Additional cost Rs/Litre			0.18	Rs/litre

Given the recent volatility of the gasoil differentials, whether product imports would always be cheaper than crude adjustments or the unifiner operation may be open to question. However, these analyses confirm that imposing a 0.5% sulphur specification will have minimal cost implications on CPC, and is trivial compared to the impact on CPC's finances caused by volatility in the overall world oil price level.

The presumption of some past assessments is that further reductions in the sulphur specification for diesel—i.e., to below 0.5%—would require further modifications at the

---

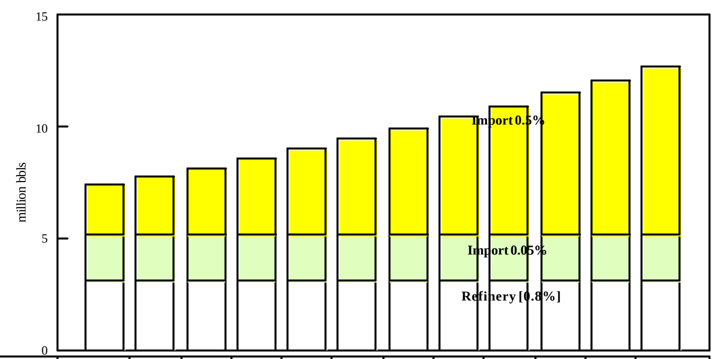
gasoil up to a maximum of 25 percent of feed. The target desulphurization of 90 percent has been set with a product flashpoint of 150 ^{o}F.

127 The source of hydrogen for this unit is the platformer (which is produced as a by-product of the process to produce gasoline by increasing the octane number of straight-run naphtha).

It should be noted that the sulphur that is captured by hydro-desulphurization is in the form of hydrogen sulphide gas—and injected into the refinery fuel-gas stream. If this were burnt in the refinery furnace the sulphur would again be released into the atmosphere, and therefore it is necessary to convert the H_2S to elemental sulphur in a sulphur recovery unit. However, it is unclear whether such a unit is being planned by CPC.

Sapugaskanda refinery,[128] which would indeed be very expensive.[129] However, it is unclear why such modifications would in fact be necessary, since one could simply import lower sulphur (say 0.005% S) gasoil to make up the difference. Given the 300,000 tons per year of 0.1% sulphur diesel that can now be produced locally (using the unifiner), the blend stocks (and incremental costs) required to meet any given sulphur specification are readily calculated.[130] Figure 12.3 shows the optimal blending to meet a 0.5% sulphur gasoil requirement.[131]

Figure 12.3: Optimal blending to meet 0.5% sulphur gasoil



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Refinery [0.8%]	3086	3086	3086	3086	3086	3086	3086	3086	3086	3086	3086	3086
Import 0.05%	2057	2057	2057	2057	2057	2057	2057	2057	2057	2057	2057	2057
Import 0.25%	0	0	0	0	0	0	0	0	0	0	0	0
Import 0.5%	2248	2618	3006	3414	3842	4291	4762	5258	5778	6324	6897	7499
Import 1%	0	0	0	0	0	0	0	0	0	0	0	0

In NPV terms over the next two decades, the impact of the 0.5% diesel-sulphur specification is as shown in our usual format of Table 12.5.132 For the purposes of this calculation we assume that the cost of producing the 0.1% S blend stock at the Sapugaskanda

128 For example, a May 2000 report by the World Bank noted, *" . . . given the configuration of the CPC refinery, it would be very expensive to meet the sulphur limit of 0.05 percent. This would require installing a diesel hydrotreater and possibly a hydrogen unit, both expensive options and not economic for a refinery as small as the one in Sri Lanka"* (World Bank, *Comments on the Proposed Fuel Quality and Emission Standards*).

129 The World Bank estimated the costs of such modifications at \$50-\$100 million, based upon experience with a refinery of similar size in Pakistan. These are 20-30 times greater than the \$2.7 million cost of the Unifiner revamp at Sapugaskanda.

130 In other words, the yardstick for any judgment about costs of meeting a tighter specification is not the cost of modification of the local refinery (which may or may not be economic), but by using the relevant differentials on world markets; in any event, the economic returns on any local refinery modification should be based upon a comparison to these differentials.

131 These were calculated using a simple linear programming blending model.

132 This table assumes that the only environmental benefit of lower sulphur diesel fuel is the reduction of SO_2. However, the lower sulphur content of the fuel results in generally improved engine performance, which may in turn reduce emissions of other pollutants. This effect is ignored in our calculations.

refinery is equal to the differential observed on world markets.[133] The deadweight losses are (essentially) zero.[134] Because we assume that all diesel sold meets the 0.5 percent specification, the distinction between super and ordinary diesel is eliminated, requiring no further costs at outlets for installation of an additional set of tanks and pumps.

Table 12.5: Benefits of 0.5% S diesel fuel; NPV, Rs Million

	Road users	Govt	Total	Local	Total
Diesel costs	-467		-467		-467
Diesel taxes	0	0	0		0
Distribution cost		0	0		
Outlet cost	0	0	0		
Deadweight losses	0	0	0		0
Environmental benefits			0	3360	3360
Total	-467	0	-467	3360	2893

Based on incremental benefits over actual recent sulphur content of 0.8% S (rather than 1% as assumed in the calculations of Table 12.1). Environmental benefits based on avoided damages of 290$/ton SO2.

Even a further reduction to 0.3% S is economic (with costs of Rs 1,290 million, and environmental benefits of Rs 3,360). This should not surprise, given the externality values implied by the Singapore gasoil sulphur differentials. If the higher damage values of the Six Cities study were correct,[135] even a move to 0.005% sulphur would be justified, and even under most unfavorable sulphur differentials.

Lubricating oil for three-wheelers

Cleaning up Colombo's three-wheeler fleet ranks as one of the higher priorities. While exact figures are not available, of the total national fleet of 85,000 three-wheelers in 2000 (see

133 However, this not merely raises the question of whether this is in fact true (which assumes that the cost of desulphurization at Sapugaskanda is equal to the corresponding costs at a world scale refinery in Singapore), but the further question of the wisdom of the basic strategy employed, i.e., to modify the refinery to produce 0.1 percent sulphur gasoil, and then blend with *higher* sulphur imports to make up the balance (as shown in Figure 12.1); or whether one should have left the refinery to continue to produce the higher sulphur gasoil (i.e., in the range of 0.7-1 percent sulphur), and import *lower* sulphur gasoil to meet the 0.5 percent specification. However, since the decision (on the strategy to meet a 0.5 percent standard) has already been taken, the question is moot, and we leave it unanalyzed and unanswered.

134 The increase in price is Rs 0.05/litre on a retail price of Rs 18/litre, i.e., 0.27 percent which, given a high value of price elasticity, produces a negligible impact on consumption.

135 Indeed, even the figure of \$2,900/ton SO_2 is at the low end of the range observed in the Six Cities study: in some cities the value is much higher (e.g., Bangkok, for which the estimate is \$5,087/ton, and Santiago, at \$16,864/ton). See Lvovsky, et al., *op. cit*., Table 1.5.

Table 2.2), 60 percent—some 50,000—are likely to be in Colombo area. The fleet of these vehicles has grown rapidly: just three years ago, the national 1997 fleet was estimated at 59,000.[136] The Colombo health impact study reviewed earlier[137] identifies the drivers of this fleet as being at high risk, and even cursory observation shows that many are in dilapidated condition, and subjecting both drivers and passengers to amounts of acrid smoke suggested that the drivers were highly aware of the health risks they faced, and expressed a significant willingness to pay for a device that would "reduce fumes."

The reasons why two-stroke engines used in three-wheelers have significantly higher emissions than four-stroke engines are discussed in a recent World Bank study, [138] whose main findings may be summarized as follows:

- Inappropriate type and amounts of lubricating oil.
- Adulteration of gasoline: the widespread price differential between gasoline and kerosene throughout South Asia results in the adulteration of gasoline by kerosene. But kerosene has as a higher boiling point than gasoline and is therefore more difficult to burn; thus, more deposits build up in the engine, and more hydrocarbons enter the exhaust gas. Limited sampling and testing of gasoline by the World Bank in Dhaka in 1998 indicated that a significant fraction of gasoline used in three-wheelers was adulterated. However, in Sri Lanka, it appears that adulteration of diesel is more common than adulteration of gasoline, notwithstanding that the price differential between gasoline and kerosene is greater than the price differential between diesel and kerosene.[139]
- Poor maintenance of vehicles.

Based on the successful experience in India and the recommendations of the Kojima study, it seems reasonable to examine three specific measures targeted at three-wheelers. That report notes the high level of uncertainty regarding PM-10 emissions from two-stroke engines, but nonetheless presents the results of a number of studies (from India and Bangladesh) that suggest emission factors considerably higher than previously assumed, as shown in Table 12.6.

Table 12.6: Comparison of emission factors for three-wheelers (two-stroke)

	Emission factors, gms/km

[136] However, the most recent new vehicle licensing data shows that the rate of growth in the three-wheeler fleet has slowed somewhat since the peak in 1998.

[137] Chandrasiri and Jayasinghe, *Health Impacts, op. cit*

[138] M. Kojima, C. Brandon and J. Shah, *Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles*, World Bank South Asia Environmental Unit, Dec. 2000.

[139] This is evident from the characteristic kerosene odor that emanates from the exhaust of some private diesel buses. Indeed, it should be noted that adding kerosene to diesel makes for a "better" diesel, while adding kerosene to gasoline makes for a worse gasoline (i.e., more difficult to combust in an engine designed for gasoline).

	Vehicle age, yrs.	*Lube oil type*	*Percentage lubri.*	*Hydro-carbons*	*CO*	*NOx*	*PM*
Typical past assumption (1)				15.9	21.9	0.08	0.08
Bangladesh (2)	7	straight	8 percent	23	25	0.03	2.7
	7	2T	3 percent	16	17	0.09	0.9
	4	straight	8 percent	9	8	0.08	0.6
	4	2T	3 percent	9	10	0.09	0.2

(1) As in Chandrasiri, *op. cit*., or Faiz et al., *op. cit*. (from Table 2.2).
(2) Kojima et al., *op. cit*., Table 3 (p.10).

Table 12.7 shows the result of the application of these factors to Sri Lanka (for the year 2000): 20 percent of total PM-10 emissions are attributable to three-wheelers (if we assume four-year old vehicles, on average, emissions of 0.6 gms/km for three-wheelers using standard mineral oil for lubrication).[140]

Table 12.7: Emissions of PM-10 (2000)

	[tons]	
Two-stroke Motorcycles	396	8%
Three-wheelers	923	19%
Total two-stroke	1319	27%
Four-stroke Motorcycles	94	2%
Cars + D/P	1130	23%
Buses	913	18%
Lorries	1391	28%
Land vehicles	102	2%
Total other	3630	73%
Total	4949	100%

Assumptions: vehicle-km from Table 2.2.
Emission factors from Table 3.7.
Two-stroke emission factors from Kojima, *Emissions from two-stroke engines*, op.cit.
The World Bank report did not study Sri Lanka in detail, but noted that 141
In some countries, such as Sri Lanka, 2T oil is not readily available at filling stations.

Caltex is the major supplier of lube oils in Sri Lanka, accounting for some 97 percent of total. A Caltex manager reported that 2000 sales of 2T oil amounted to 2.6 million litres.[142] Our

[140] Even given the rapid growth of three-wheelers over the past decade, four years as an average age is conservative: while there is no good data, observation suggests that there are significant numbers of three-wheelers in service in Colombo that are 10 and more years old.

[141] *Ibid*., p.11.

[142] Personal communication to D. Chandrasekera.

estimate of petrol consumption in 2000 in 2-stroke engines is 24 million litres in 2-stroke motorcycles, and 59 million litres in three-wheelers, totaling 83 million litres—which suggests a rate of addition of 2T oil of some 3.1 percent. Indeed, the present retail price of 2T oil is Rs 130/litre, compared to Rs 138/litre for standard SAE-30 or SAE-40 oil—so, unlike Bangladesh, where 2T oil is 80 percent more expensive[143]—there is no incentive to use oil other than 2T, if available.

Box 12.4: Electric three-wheelers

In Nepal, diesel-powered "TEMPOS"—three-wheelers that carry up to 10 passengers—were banned by the government in 1999 for air pollution reasons. As early as 1994-1996, a USAID-funded program demonstrated the feasibility of conversion to lead-acid battery operation, and as of 2000, some 500 of these vehicles were operating in Kathmandu.[144] Public acceptance of these vehicles is high.

The economics of electric three-wheelers are highly dependent upon the availability of surplus power. In Nepal, the opportunity cost of off-peak hydropower (for night-time recharging of batteries) is zero for about six to eight months in the year, due to the large number of pure-run-of river hydro projects in Nepal (i.e., projects that do not have daily peaking capacity). Indian studies show that an electric three-wheeler costs about $1,000 more than the standard model, effectively doubling the capital cost.[145]

The situation in Sri Lanka is quite different, because unlike Nepal, Sri Lanka already has a significant number of oil-fired independent power producers (IPPs) , whose number can only grow over the next few years. Although the power system is also largely hydro, there is very little prospect of spilled energy in the foreseeable future. Even in a wet year, IPP thermal plants would be backed down during off-peak hours to avoid fuel charges, so the availability of surplus off-peak hydro in Sri Lanka is small.

Although these data suggest that 2T-oil is being used in two-stroke engines in about the correct proportion, there are significant uncertainties that can only be resolved by a data collection effort that goes beyond the scope of this study:

?? 2T-oil may well be available in most filling stations in Colombo: however, whether this is true of rural stations needs confirmation.

?? Even if the average rate of addition is close to the generally recommended ratio, since 2T oil is *cheaper* than standard mineral oil, some 2T-oil may well be used by other

143 Kojima et al., *op. cit* reports a 2T oil price of 90 takas per litre in Dakka, as opposed to 50 takas for mineral oil.

144 For further description of this Nepalese program, see, e.g., Kojima et al., *op. cit*, pg23-24.

145 Kojima et al., *op. cit*. pg 23.

vehicles. Absent actual filling station survey data, it is difficult to come to any definite conclusions.

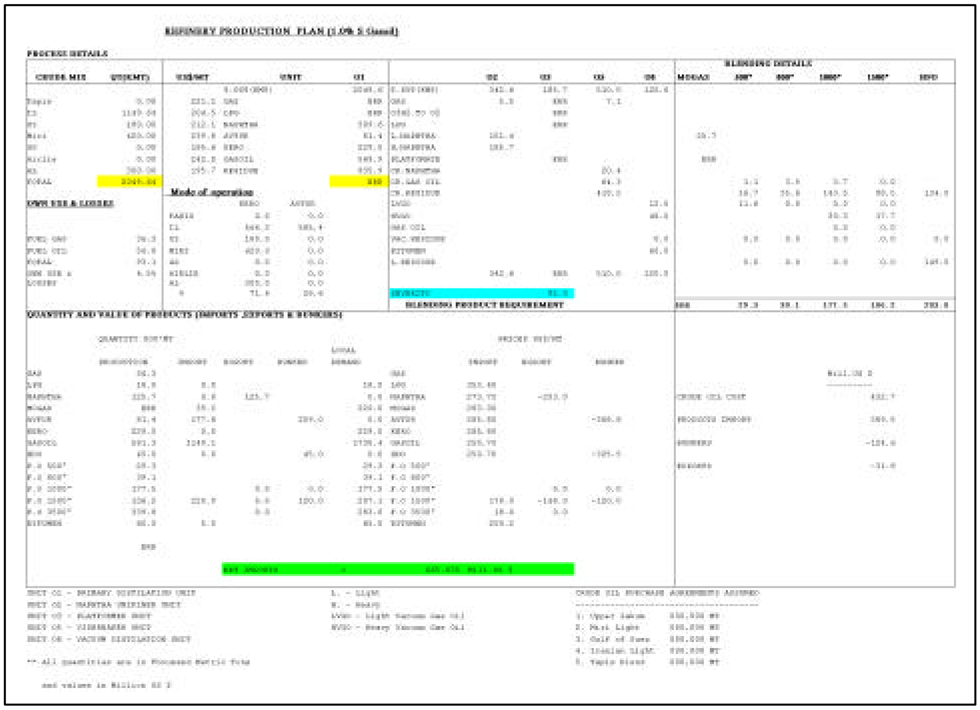
?? Anecdotal evidence suggests that other aspects of poor engine maintenance for three-wheelers may be more important than lube oil use per se.

Consequently, we have not identified any specific policy option for benefit-cost analysis.

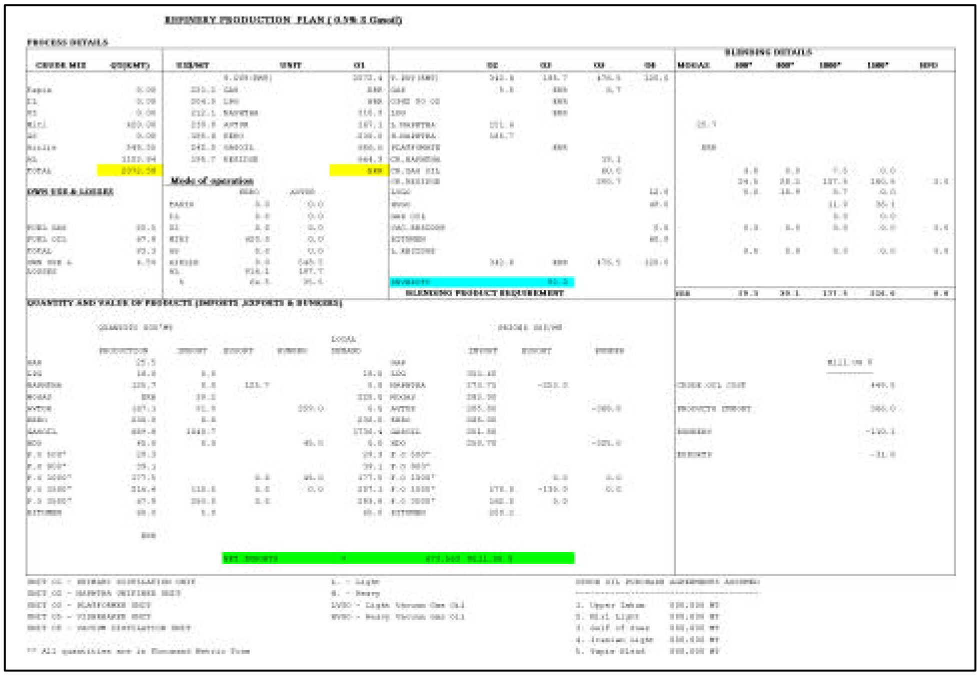
Annex 12.1

Details of Refinery Optimization

Box 12.5: Refinery production plan, 1% S gasoil



Box 12.6: Refinery production plan, 0.5 %S gasoil



REFINERY PRODUCTION PLAN (0.5% S Gasoil)

PROCESS DETAILS

OWN USE & LOSSES

Mode of operation

BLENDING DETAILS

BLENDING PRODUCT REQUIREMENT

QUANTITY AND VALUE OF PRODUCTS (IMPORTS, EXPORTS & BUNKERS)

Reference

Abeygunawardena, P. et al., 1999 "Yunnan Dachaoshan Power Transmission Project," in *Environment and Economics in Project Preparation: Ten Asian Cases*, Asian Development Bank.

Academie des Sciences, 1996 *Pollution atmospherique due au transport*, Rapport Stage I, Paris, France.

ASEAN, 2001 Proceedings of the Regional Workshop on Fuel Quality and Alternative Fuels, Delhi, India.

Atkins W. S. and University of Moratuwa, 1999 *A Masterplan for the Development of Transport in the Colombo Metropolitan Region*, Colombo Urban Transport Study, Stage 2: Working Paper 25, Moratuwa, Sri Lanka.

Atkins W.S. and University of Moratuwa, 1999 *Pre-feasibility Study of an Inland Container Depot*, Working Paper 12, Colombo Urban Transport Study, Stage 2 (CUTS2), Moratuwa, Sri Lanka.

Atkins W.S., 1999 Colombo Urban Transport Study Stage 2, in association with the University of Moratuwa, Working Paper 7, Moratuwa, Sri Lanka.

Balce, G., 2001 Overview of Regional Fuel Market and Fuel Quality Standards in Proceedings, ASEAN Regional Workshop on Fuel Quality and Alternative fuels, Delhi, India.

Banaszak S., Chakravorty U., and P. S. Leung, "Demand for Ground Transportation Fuel and Pricing Policy in Asian Tigers: A Comparative Study of Korea and Taiwan," *Energy Journal*, 20:2, 145.

BCHydro, 1995 *1995 Electricity Plan*, Volume C of this Plan presents the economic and trade-off analysis, Vancouver, BC.

Bose R. K. and V. Srinivasachary, "Policies to Reduce Energy Use and Environmental Emissions in Delhi," *Energy Policy*, 23:3, pp. 1137-1150, 1997.

Central Bank, 2000 Annual Report, Colombo, Sri Lanka.

Chandrasiri S. and S. Jayasinghe, 1998 *Health Effects of Vehicular Emissions in Colombo*, UC-ISS Project Working Paper Series, 9805, Colombo, Sri Lanka.

Chandrasiri S., 1999 *Controlling Automotive Air Pollution: the Case of Colombo City*, Economy and Environment Programme for Southeast Asia, Research Report Series, Colombo, Sri Lanka.

CONCAWE (Conservation of Clean Air and Water in Europe) 1989 *Costs to Reduce the Sulphur Content of Diesel Fuel*, Report 10/89, The Hague, Netherlands.

CPC, 1992 *Environmental Concerns as a Result of Increase in Use of Petroleum Fuels,* Colombo, Sri Lanka.

CPC, 1994 Report of the Subcommittee on Fuel Reformulation, Colombo Sri Lanka.

Dahl C. and J. Sterner, 1991 "Analysing Gasoline Demand Elasticities: A Survey," *Energy Policy*, July, pp. 203-210.

Department of Health, 1998 *Quantification of the Effects of Air Pollution on Health in the U.K,*. Committee on the Medical Effects of Air Pollution, UK.

Dheerasinghe, K. G. D. D. and D. S. Jayaweera, 1997 *Economic, Social and Environmental Demands on Transport: Past Performance and Emerging Challenges*, in Sri Lanka, Transport Sector Study, Volume II, South Asia I Infrastructure Division, World Bank Report 16269-CE, Washington, D.C.

Diandas J., "Bus Managers and Users vis-à-vis Ownership, Regulation, Competition and Systems*," Proceedings*, European Transport and Planning,

Diandas J., 1988 "Notes for Benefit Comparison of Government Sector and Private Sector Supplied Bus Services," in *Aspects of Privatisation in Sri Lanka,* Friedrich Ebert Stiftung, Colombo, Sri Lanka.

Faiz, A., C. Weaver and M. Walsh, 1996 Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions, World Bank, Washington DC.

Freeman M., 2000 *Valuation of Environmental Health Damages in Developing Countries: Some Observations*, EEPSEA Special Paper, Biannual Workshop of the Economy and Environment Programme of Southeast Asia, Bangkok

Garbacz C., 1989 "Gasoline, Diesel and Motorfuel Demand in Taiwan," *Energy Journal*, 10:2, 153.

Glaister et al*., Transport and Health in London, A* Report for the NHS Executive, London.

Gomez-Ibanez, J. A., 1996 Bus Industry Issues and options, in TSSS, op.cit., p.126.

Greene D., 1992 "Vehicle Use and Fuel Economy: How Big is the Rebound Effect?" *Energy Journal*, 13:1, pp. 117-143.

Halcrow Fox Associates, 1995 *Colombo Urban Transport Study,* Working Paper 8: Transport Costs.

Harvey G. and E. Deakin, 1992 *Transportation and Air Quality,* U.S. Department of Transportation, Federal Highway Administration, Policy Discussion Series #5.

Indraratna A.D.V. de S., 1994 *Economic and Environmental Implications of Petrol/Diesel Pricing*, University of Colombo, Colombo, Sri Lanka.

Jayaweera D. S., T. Gunaruwan, M. Bandusena and P. de Silva, 2000 *Economic Analysis of the Inland Container Depot at Ragama*, Transportation Planning Studies Centre, Colombo, Sri Lanka.

Jayaweera D., 1999 *Effective Steps Towards Traffic Calming in Developing Countries: A Case Study for the Metropolitan Region of Colombo in Sri Lanka*, Ph.D. Thesis, MIT.

Jayaweera D., 1997 *Is There Significant Travel Congestion in Colombo?* paper presented at the Annual Meeting of the Chartered Institute of Transport, Colombo, Sri Lanka.

Jayaweera D., 1999 Project Completion Report, CUTS, Colombo, Sri Lanka.

Jayaweera, D., 2000 Transport Pricing and Charges in Sri Lanka, Transport Studies and Planning Centre, Colombo, Sri Lanka.

Kojima M., Brandon C. and J. Shah, 2000 *Improving Urban Air Quality in South Asia by Reducing Emissions from Two-Stroke Engine Vehicles*, World Bank South Asia Environmental Unit.

Kumarage A. S. and W. Wijertane, 1999 *Estimates of Operational Vehicle Fleet in Sri Lanka 1998 Update*, University of Moratuwa, Moratuwa, Sri Lanka.

Kumarage A. S., 1999 "Managing the Demand for Cars in Cities," *Proceedings*, National Conference, "Cities for All," World Habitat Day 1999, Sri Lanka.

Kumarage A., 1999 *Assessment of Public Investments in the Transport Sector*, University of Moratuwa, Moratuwa, Sri Lanka.

Kumarage A.S., 1993 "Estimates of Passenger Car Units," *Proceedings Annual Sessions*, Institute of Engineers Sri Lanka.

Kumarage A.S., 1996 "Traffic Engineering and Traffic Management," *Journal of the Sri Lanka Energy Managers Association*, 7:1, pp. 15-18.

Kumarage A.S., *et al*., 2000 TRANSPLAN V2: A regional traffic estimation model, University of Moratuwa, Moratuwa, Sri Lanka.

Kumarage, *Review of Household Income and Public Transport*. Sri Lanka.

Lovei M., 1998 *Phasing out Lead from Gasoline*, World Bank Technical Paper 397, Washington, D.C.

Lutkepohl H., 1991 *Introduction to Multiple Time Series Analysis*, Springer-Verlag, New York.

Lvovsky K., Hughes G., Maddison D., Ostrp B. and D. Pearce, 2000 *Environmental Costs of Fossil Fuels, A Rapid Assessment Method with Application to Six Cities*, World Bank, Environment Department, Paper 78.

Meier P., 1997 *Economic Analysis of the Haryana Power Sector Restructuring and Reform Program*, World Bank, New Delhi. India.

Meier, P., 1999 *Economic Analysis of the Andhra Pradesh Power Sector Restructuring Program*, World Bank, New Delhi, India.

Meier P., 1999 *India: Environmental Issues in the Power Sector: A Case Study of Haryana*, World Bank.

Meier, P., and M. Munasinghe, 1999 *GHG mitigation options in the Sri Lanka Power Sector*, World Bank, Washington, DC.

Meier P. and M. Munasinghe, 2002 *Sri Lanka Electric Power Technology Assessment*, World Bank, Washington DC.

Meier P. and M. Munasinghe, 2002 *Environmentally Sustainable Energy Development in Sri Lanka: Impacts, Issues and Policy Options*, World Bank, Washington DC.

Meier, P., M. Munasinghe, and T. Siyambalapitiya, 1997 Energy Sector Policy and the Envrionment: A Case Study of Sri Lanka, in W. Cruz et al., Eds., "Greening of Economic Policy Reform", Vol II: Case Studies, World Bank.

Metropolitan Environmental Improvement Program (MEIP), 1993 *Air Quality Management in Sri Lanka*, Colombo, Sri Lanka.

Ministry of Transport and Highways, 1999 *Bus Transport Policy*, Colombo, Sri Lanka.

Munasinghe, M., 1992 *Environmental Economics and Sustainable Development*, Paper presented at the UN Earth Summit, Rio de Janeiro, and reprinted by the World Bank, Wash. D.C.

Munasinghe M., et al., 1998 *Linkages between Economic Policies and the Environment in Sri Lanka*, Lanka International Forum on Environment and Sustainable Development, Working Paper Series, No.1, Colombo, Sri Lanka.

Newberry D., 1990 “Pricing and Congestion: Economic Principles Relevant to Pricing Roads,” *Oxford Review of Economic Policy,* 6:2.

Newman and Kenworthy, 1990 *Cities and their Traffic*, Gower Publications.

Pace University, 1990 *Environmental Costs of Electricity,* Centre for Environmental Legal Studies, Oceana Publications, New York.

Pigou A., 1924 *The Economics of Welfare*, MacMillan, London.

Ranasinghe, A. P., 1989 Impact of fuel price changes on Transport, in E. N. Wijeratne, ed., "Energy pricing options in Sri Lanka", ILO.

Ratnasiri J., ed., 1998 *Final Report of the Sri Lanka Climate Change Country Study*, Ministry of Forest and Environment, Environment Division, Colombo, Sri Lanka.

Road Development Authority, 1997 *Colombo Katunayake Expressway, Environmental Impact Assessment Report*, Colombo, Sri Lanka.

Rowe R. D., et al., 1995 *The New York Electricity Externality Study*, Oceana Publications, Dobbs Ferry, N.Y.

Samarakoddy R. P., 1999 "Air Quality Monitoring in Sri Lanka," Asian Aerosol Data Synthesis Workshop, New Delhi, India.

Samaraweera, C. P., 1989 Determinants of petroleum demand in Sri Lanka, in E. N. Wijeratne, ed., "Energy pricing options in Sri Lanka", ILO.

Schafer A. and D. Victor, 1999 "Global Passenger Travel: Implications for Carbon Dioxide," *Energy,* 24, pp. 657-679.

Schipper L., 1999 *Flexing the Link: Transport Sector Policy and GHG Emissions*, World Bank, Washington, D.C.

Schwartz J., 1994 "Societal Benefits of Reducing Lead Exposure," *Environmental Research,* 66, pp. 105-124.

Senanayake M. P., Samarakoddy R. P., Jayasinghe R. P., Hettiarachchi A.P., Sumanasena A. P. and J. Kudalugodaarachchi, 2000 *Is Colombo Choking its Children: A Case-Control Analysis of Hospital Attendance and Air Pollution*, NBRO and Faculty of Medicine, University of Colombo, Colombo, Sri Lanka.

Shoup, D., and S.Stark, 2000. The Parking of Nations, Access Almanac # 17, University of California, Berkley.

Sivagnosothy V. and D. McCauley, 2000 "Environmental Considerations in the Environmental Impact Analysis of the Katunayake Expressway in Sri Lanka," in J. Rietbergen-McCracken and H. Abaza, eds., *Environmental Valuation: A Worldwide Compendium of Case Studies*, Earthscan Publications, London.

Smith, K. R., 1993. Fuel combustion, air pollution exposure and health: the situation in Developing countries, Annual Review of Energy and Environment, 18: 529-566.

Sri Lanka Railways, 1999 *Annual Report*, Colombo, Sri Lanka.

Thomas V. M., 1995 "Elimination of Lead in Gasoline," *Annual Review of Energy and Environment*, 20: 301-324.

Toh R. S., 1996 "Experimental Measures to Curb Road Congestion in Singapore: Pricing and Quotas," *Logistics and Transportation Review,* 28:3, pp.289-317.

Transport Studies and Planning Center, 1996 Study of Transportation Services Provided by School and Office Vans, Colombo, Sri Lanka.

Univ. of Sussex, 1989 *17th Summer Annual Meeting on Transport in Developing Countries*, University of Sussex, UK.

University of Moratuwa, Department of Civil Engineering, 2000 Assessment of Capital Investment in Transport Sector Projects', Moratuwa, Sri Lanka.

University of Moratuwa, Department of Civil Engineering, 2000 Traffic demand estimation for proposed Colombo-Katunayake expressway, Report to BoI. Moratuwa, Sri Lanka

University of Moratuwa, Department of Civil Enmgineering, 1999 Assessment of Public Investment in Transport Sector, Final Report, Moratuwa, Sri Lanka.

University of Moratuwa, 1999 Methods for Assessment of Capital Investments in Transport Sector Projects, Moratuwa, Sri Lanka.

USAID, 1995 *Integrated Resource Plan for Andhra Pradesh*, Report to APSEB, Hyderabad.

USEPA, 1985. *Costs and Benefits of Reducing Lead in Gasoline; Final Regulatory Impact Estimate,* Office of Policy Analysis, Washington, D.C. EPA-230-05-85-006.

Vivekaphirat P., 2001 "Experience of Thailand in Improving Fuel Quality," *Proceedings*, Regional Workshop: Fuel Quality and Alternative Fuels, Delhi, India.

Walsh M., 1992 *Motor Vehicle Pollution Control in Sri Lanka, A Preliminary Strategy for Progress in Colombo*, Report to the Natural Resource and Environmental Policy Project (NAREPP), Colombo, Sri Lanka.

Wilbur Smith Associates, 1999 *Southern Transport Corridor Project*, December 1998. These studies have been reviewed by A. Kumarage, *Assessment of Public Investments in the Transport Sector*, Appendix A1.

World Bank, 1996 *Petroleum Sector Study* Energy and Project Finance Division, Country Department I, South Asia Region.

World Bank, 2000 *Comments on the Proposed Fuel Quality and Vehicle Emission Standards.*

World Bank, 2001 Promoting Renewable Energy in China: An Economic Analysis of a Mandated Market Share Policy.

World Bank, 1994 *Thailand: Mitigating Pollution and Congestion Impacts in a High-Growth Economy,* Report 11770-TH, East Asia and Pacific Region.

World Bank, 1996 Sri Lanka, Transport Sector Study, South Asia I Infrastructure Division, Report 16269-CE, Washington, D.C.

Yangsheng, Z., 2001 Improving Fuel quality in China; in Proceedings, ASEAN Regional Workshop on Fuel Quality and Alternative fuels, Delhi, India.

Zaidi, S. M., 2001 Country experience of Pakistan in improving fuel quality, in Proceedings, ASEAN Regional Workshop on Fuel Quality and Alternative fuels, Delhi, India.