

DISS. ETH NO. 17669

# Efficiency, Demand, and Pricing of Public Bus Transport in India

A dissertation submitted to

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for the degree of

Doctor of Sciences

presented by

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2008



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# Abstract

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Public bus transport is of great import in India. Not just is an efficient public bus system important for meeting the mobility needs in this rapidly growing economy, a higher share of bus transport would also have a positive impact on pollution, both local and global, and energy demand. That apart, an extensive public transport system is critical for ensuring access to basic services such as education and health, and integrating rural communities in the economic mainstream. To increase the share of public transport, ensure financial viability, and ensure economic efficiency in service delivery, public bus transport companies in India have to be restructured.

To identify the relevant policy directions and reform strategies, this research addresses the following issues in the public bus transport industry in India:

- Structure of the market in terms of the number of firms and the distribution of production across firms and space.
- Management of the firms and the implications of alternative organizational structures on the cost of service delivery.
- Factors influencing public bus transport demand and the role of monetary and non-monetary policy variables.
- Impact of alternative pricing strategies of the public bus transit firms on demand, consumer surplus, and profits.

This research is analytically rooted in neo-classical microeconomics and uses econometric panel data models for carrying out the empirical estimations. The research elements include the estimation of a cost function for public bus transport firms, and an aggregate demand function at the state level. Then using the cost and demand functions estimated, alternative pricing regimes are developed.

The estimation of a Translog cost function using an unbalanced panel comprising a cross section of 70 firms over 15 years reveals significant Economies of Scale in all firms though the degree of Economies of Scale falls as output increases. A large proportion of firms report significant Economies of Density and Scale even when network length is included as an output characteristic in the model. The potential for cost savings from spatial reorganization is also revealed in the cost advantage reported by bus companies that have mixed rural and urban operations compared to those with only urban operations. As expected, the impact of the management structure of a bus company is ambiguous and depends on the specification

and estimation technique used, and not always significant. Since all organizational forms of public bus transport have the same legislative oversight that enforces uniform regulatory policies, differences in management structure do not seem to manifest themselves in terms of variation in costs.

Significant inelastic price effects are obtained from the estimation of a log linear aggregate public bus transit demand function for 22 states in India similar to the results reported elsewhere in the literature. The low price elasticity reflects the importance of public bus transit in the economy. Income effects, on the other hand, are not significant and are estimated to be negative. This is despite using a specification that separates income effects from those of vehicle ownership, which are negative as expected. The most important factor influencing transit demand, however, is access to the bus network that has been defined as network length per unit area. Clearly, access to the service, and hence infrastructure for service delivery, is of greater interest than only pricing if transit demand is to be influenced significantly. Demographic variables indicate how complex social and economic issues affect transit demand. A larger workforce results in a higher public bus transit demand, while a higher literacy rate implies a lower transit demand.

The pricing regimes based on the cost and demand functions estimated are assessed not just in terms of the gains in economic efficiency, but also in changes in travel demand and consumer surplus when compared to the current prices. Three different pricing strategies that are feasible for the sector are developed in a partial equilibrium framework with the objective of improving economic efficiency and ensuring revenue adequacy, namely, average cost pricing, marginal cost pricing, and two-part tariffs. In all three pricing schemes, a change in prices from the current level implies an increase in prices, a fall in losses, and an overall gain in economic efficiency. However, this gain comes about at the expense of a fall in demand and consumer surplus. To the extent that this fall in public bus transit demand could lead to an increase in the use of personal vehicles, social costs would rise due to higher emissions and congestion. In this context, a more comprehensive analysis including all modes of transport and addressing all social costs including external and user costs is necessary to estimate price and tax changes required to achieve social optimum. In general, however, given the mobility needs and the developmental concerns of a growing economy such as India, the challenge for policy makers would be to balance the gains in economic efficiency in the public bus transit sector against other social, political, and developmental goals.

# Zusammenfassung

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Busse als öffentliche Verkehrsmittel sind in Indien von grosser Bedeutung. Ein effizientes öffentliches Bus-System ist nicht nur wichtig, um den Mobilitäts-Ansprühen einer schnell wachsenden Volkswirtschaft gerecht zu werden, ein grösserer Anteil öffentlicher Busse würde auch einen positiven Einfluss auf die lokalen und globalen Schadstoffemissionen, sowie die Energienachfrage haben. Darüber hinaus ist ein ausgedehntes öffentliches Verkehrssystem entscheidend, um den Zugang zu Grunddienstleistungen wie Bildung und Gesundheit zu gewährleisten sowie um ländliche Gemeinden in die Volkswirtschaft zu integrieren. Um den Anteil öffentlicher Verkehrsmittel zu erhöhen und deren Wirtschaftlichkeit sicher zu stellen, müssen die öffentlichen Verkehrsbetriebe in Indien restrukturiert werden, um eine ökonomische Effizienz des Dienstleistungsangebots zu gewährleisten.

Um wirkungsvolle Politik- und Reformstrategien zu identifizieren, behandelt diese Untersuchung die folgenden Themen im Bereich öffentlicher Busunternehmen in Indien:

- Die Analyse der Marktstruktur hinsichtlich der Anzahl von Firmen sowie der räumlichen Produktionsaufteilung.
- Das Management der Firmen und die Auswirkungen alternativer Organisationsstrukturen auf die Kosten des Angebots.
- Einflussfaktoren auf die Bustransportnachfrage und die Rolle der monetären und nicht-monetären Politikvariablen.
- Der Einfluss alternativer Preisstrategien auf die Nachfrage nach Bustransporten, auf die resultierende Konsumentenrente sowie auf die Unternehmungsgewinne.

Die Forschungsarbeit folgt einem neo-klassischen mikroökonomischen Ansatz, um diese Fragestellungen zu untersuchen. Die empirischen Schätzungen basieren auf ökonomischen Modellen mit einer Panelstruktur. Die Arbeit beinhaltet die Schätzung einer Kostenfunktion und einer aggregierten Nachfragefunktion auf Staatsebene. Basierend auf diesen Kosten- und Nachfragefunktionen wird ein alternatives Preissystem entwickelt.

Die Schätzung einer Translog-Funktion, basierend auf einem unausgewogenen Panel, das aus einem Querschnitt von 72 Firmen über einen Zeitraum von 15 Jahren besteht, zeigt signifikante Skaleneffekte in der Mehrzahl der Firmen. Die Skaleneffekte verringern sich jedoch mit steigender Produktionsmenge. Die meisten Firmen weisen sowohl "Economies of Density" und als auch Skaleneffekte auf, sogar wenn die Netzwerklänge im Modell berücksichtigt wird. Das Kosteneinsparungspotential räumlicher Neuorganisation zeigt sich auch in den Kostenvorteilen von Busfirmen, die sowohl in städtischen als auch ländlichen Gebieten tätig sind,



dies im Vergleich zu Firmen, die nur in städtischen Gebieten tätig sind. Der Einfluss der Management-Struktur ist abhängig von der Modell-Spezifikation und der Schätzmethode und ist wie erwartet nicht immer signifikant, vermutlich weil alle Busunternehmen der selben gesetzlichen Aufsicht unterstehen, welche die Regulierung einheitlich umsetzt.

Die Schätzung einer aggregierten log-linearen Nachfragefunktion für den öffentlichen Busverkehr in 22 indischen Staaten zeigt signifikante inelastische Preiseffekte. Dieses Ergebnis ist in Übereinstimmung mit Ergebnissen ähnlicher Studien. Die geringe Preiselastizität reflektiert die hohe Bedeutung des öffentlichen Busverkehrssystems. Auf der anderen Seite sind Einkommenseffekte nicht signifikant. Dies obwohl eine Spezifikation verwendet wurde, welche Einkommenseffekte von den Fahrzeugeigentums-Effekten separiert. Letztere sind, wie erwartet, negativ. Der wichtigste Einflussfaktor auf die Busverkehrsnachfrage ist jedoch der Zugang zum Busnetz, hier definiert als dessen Länge pro Flächeneinheit. Es wird deutlich, dass der Zugang zur Verkehrsdienstleistung, d.h. das Infrastrukturangebot, eine höhere Bedeutung hat im Vergleich zu reinen Preisstrategien, wenn die Nachfrage nach öffentlichen Verkehr entscheidend beeinflusst werden soll. Die Ergebnisse bzgl. demographischer Variablen zeigen, wie komplex soziale und wirtschaftliche Faktoren die Verkehrsnachfrage beeinflussen. Eine grössere berufstätige Bevölkerung führt zu einer vergrößerten Nachfrage nach öffentlichem Verkehr, wohingegen eine Erhöhung der Bildungsrate zu einer geringeren Nachfrage führt.

Die verschiedenen Preissysteme werden, basierend auf Kosten- und Nachfrage-Funktionen, nicht nur hinsichtlich verbesserter ökonomischer Effizienz, sondern auch bezüglich Veränderungen in der Verkehrsnachfrage und der Konsumentenrente bewertet. Drei verschiedene durchführbare Preisstrategien werden mit dem Ziel, die ökonomische Effizienz zu steigern und angemessene Einnahmen sicher zu stellen, entwickelt: eine Durchschnittskosten-, eine Grenzkostenpreissetzung sowie zweiteilige Tarife. In allen drei Preissystemen führt eine Preiserhöhung zu geringeren Verlusten und zu einer allgemeinen Erhöhung der ökonomischen Effizienz. Diese Verbesserung geht jedoch auf Kosten eines Nachfragerückgangs sowie einer verringerten Konsumentenrente. Für den Anteil der reduzierten Nachfrage, die durch die Benutzung privater Fahrzeuge kompensiert wird, steigen die sozialen Kosten aufgrund von höheren Emissionen und Staus. In diesem Kontext ist eine umfassendere Analyse, welche alle Verkehrsarten und alle sozialen Kosten, externe und Nutzerkosten eingeschlossen, notwendig, um festzustellen, welche Änderungen im Preis- und Steuersystem zu einem sozialen Optimum führen. Im Kontext der Mobilitäts- und Entwicklungsbedürfnisse einer wachsenden Volkswirtschaft wie Indien liegt die wahre Herausforderung für politische Entscheidungsträger darin, die Steigerung der ökonomischen Effizienz im öffentlichen Busverkehr gegen andere soziale, politische und Entwicklungsziele abzuwägen.

# 1. Introduction

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Rapid economic development exerts pressure on all infrastructure services vital for economic efficiency and social sustainability, particularly transport infrastructure. Sustaining this increase in economic productivity is contingent on meeting the mobility demand that such economic growth creates, and hence on optimally utilizing existing infrastructure (Gowda (1999); Justus (1998)). In addition, transport accounts for a substantial and growing proportion of air pollution in cities, contributes significantly to greenhouse gas emissions, and is a major consumer of energy (Ramanathan et al. (1999)). Transport is also the largest contributor to noise pollution, and has substantial safety and waste management concerns (Singh (2000)). Finally, access to transport services is considered critical for addressing equity concerns by facilitating access to primary education and employment generation facilities. Transport infrastructure is also important for integrating rural communities in the socioeconomic structure of the nation.

Passenger transport in India is dominated by two modes, rail and road. Over time, there has been a shift in traffic from rail to road with road meeting 80% of passenger traffic. Within the road transport sector, liberalization of the automobile industry in parallel to a rapid increase in per capita incomes has led to a shift towards personal vehicles. The share of public transport, on the other hand, has declined over time. The economy is now being constrained by the increasing number of vehicles causing congestion, and thus slower speeds on roads. Transport infrastructure is recognized as being the critical constraint here (Ramanathan et al. (1999)). Efficient and optimal utilization of the available transport infrastructure would require meeting mobility needs through a greater share of public transport (Planning Commission (2002)). For the railways, this would imply an increase in the rolling stock for passenger transport, a greater emphasis on passenger comfort, and providing services that reflect consumer preferences. More importantly, since most passenger transport in India is road based, the share of public bus transport should be increased (Ramanathan et al. (1999)).

Public bus transport in India is overwhelmingly provided by government owned bus companies. Even though the private sector owns more buses than the government, privately owned buses are rarely allowed to operate as public transport and are generally put to use in servicing schools and other educational institutions, tourists, etc. Thus, to increase the share of public transport, an increase in the capacity of the government owned public bus companies in India is required (Singh (2005b)). In addition to an increase in the capacity of public transport, improvements in service quality are also needed. These could come about through a greater sensitivity to consumer's needs in terms of network design, route planning,

scheduling, and with an emphasis on comfort, travel time, and scientific traffic planning. In addition, given that access to public transport is not universal in India, an improvement in access to public transport is the most significant attribute of service quality. All these improvements call for significant investments, which in turn depend on the financial viability of the services provided, the fare box collections compared with the cost of service in this case. Besides, a reorganization of the market and production structure could lead to cost savings from potential Scale Economies and improved management, and hence improve sector viability.

This research addresses the issues of the optimal structure of the sector to obtain cost savings, the tariff reforms necessary to achieve cost recovery, and the impact of efficient pricing and other policy variables on travel demand. Issues related to the structure of the industry are addressed by estimating the degree of Scale Economies to assess if sector reorganization would lead to lower costs per unit output. In addition, alternative management structures of the firm are also evaluated based on their impact on costs. Tariff reforms are designed such that full cost recovery is ensured for the firms. The impact of these reforms is then assessed in terms of the impact on demand, consumer surplus, and profits of the firms.

The following section describes the transport sector in India, and provides the context and motivation for this research. The role and position of road based public transport is detailed at some length, along with trends in the sector. The section concludes by highlighting the concerns arising from trends and policy developments, and the need for reforms in public bus transport. The study problem arising from the description of the sector and the issues for concern are formalized in section 1.2. Section 1.2 also lists the research issues and the objectives of this research. Sections 1.3 and 1.4 then briefly indicate the approach and the structure of this thesis, respectively.

## **1.1. Overview of the transport sector in India**

The transport sector in India can also be divided into passenger and freight. Both passenger and freight services can be provided through several modes, the most important ones being road and rail. Among other commonly used transport modes, air is used mostly for passenger transport. Pipelines, and shipping and waterways are common freight modes.

The Indian road network with 3.32 million kilometers is the largest in the world. Long distance traffic is served by national highways and state highways. Regional and district traffic is served by major district roads. Village and urban roads meet local traffic needs. National highways account for only about 2% of the total road length, but carry about 40% of the total traffic. Out of the total length of National Highways, only 12% is four lane standard

or more (Government of India (2006)). The Indian Railways are the second largest in the world under single management and consist of an extensive network of routes spread over 63,500 km. Freight accounts for roughly 67% of revenues of the railways, and hence is financially more important (Planning Commission (2002)). Civil aviation is gradually gaining importance in passenger movement with increased private participation in the operation of airlines and gradual improvements in airport infrastructure (Planning Commission (2002)). However, it still is a very small proportion of the total passenger traffic and comprises less than 1% of the travel demand (Sundar et al. (2004)).

Other transport modes in India are significant primarily for freight movement. With an extensive coastline of 7,517 km, India has 12 major ports and 187 minor ports out of which only about 30 handle cargo traffic. The total traffic carried by both the major and minor ports during 2004/05 was estimated to be well over 500 million tonnes. However, in terms of the domestic freight movement, coastal shipping and inland waterways meet only about 1% of the total freight traffic demand (Sundar et al. (2004)). Pipeline as a mode of transport is relevant only for energy and energy products, and currently accounts for about 40% of the total petroleum traffic (Deb (2001)).

### *1.1.1. Passenger transport in India*

Transport in India has shown a substantial modal shift away from the railways in favour of roads, both in passenger and freight transport. Within passenger transport, rail dominates long haul passenger movement whereas road transport accounts for most of the short haul movement. At present, 80% of the total passenger movement in the country is met by road transport (Government of India (2006)).

Personal vehicles dominate road passenger transport in India as indicated by a rapid growth in the number of vehicles registered. There were more than 72 million vehicles registered in India on 31 March 2004 (Table 1.1.1). The gradual liberalization of the Indian automobile industry since the mid 1980s and faster growth in per capita incomes in this period has meant that personal vehicles have become more affordable. Before 1983, the automobile sector in India was governed by regulations where imports, collaborations, and equity ventures were severely restricted by the government. Technology transfer from foreign companies was subject to government approvals. The partial liberalization of the sector in 1983 was followed by extensive liberalization in the 1990s. This has led to the entry of new small and fuel-efficient cars and a proliferation of two-wheelers, with an increase in the domestic as well as foreign investment. The consequence has been a phenomenal growth in the vehicle population. However, the growth has not been even across all categories of motor

vehicles, with personal modes of transport (scooters, motorcycles, and cars/jeeps) dominating sales (Table 1.1.1).

**Table 1.1.1. Growth of vehicles in India**

Year	All Vehicles (in thousands)	Share in total vehicle fleet					
		2 Wheelers	Cars, etc	Buses	SRTU* buses	Goods vehicles	Others
1981	5,391	48.56%	21.52%	3.01%	1.37%	10.28%	16.64%
1986	10,577	59.04%	16.83%	2.15%	0.79%	8.16%	13.82%
1991	21,374	66.44%	13.82%	1.55%	0.48%	6.34%	11.85%
1996	33,786	68.82%	12.44%	1.33%	0.31%	6.01%	11.40%
1997	37,332	68.92%	12.51%	1.30%	0.29%	6.28%	10.99%
1998	41,368	69.24%	12.42%	1.30%	0.27%	6.13%	10.91%
1999	44,875	69.81%	12.38%	1.20%	0.25%	5.69%	10.91%
2000	48,857	69.83%	12.57%	1.15%	0.23%	5.56%	10.89%
2001	54,991	70.11%	12.83%	1.15%	0.20%	5.36%	10.54%
2002	58,924	70.57%	12.92%	1.08%	0.19%	5.05%	10.39%
2003	67,007	70.92%	12.83%	1.08%	0.17%	5.21%	9.96%
2004	72,718	71.40%	13.00%	1.06%	0.16%	5.16%	9.39%

Source. MTS (Various Issues)

\*SRTU (State Road Transport Undertaking) buses are the buses that belong to the government owned bus companies, the State Road Transport Undertakings.

The share of buses in the number of vehicles has steadily fallen over this period. Planning Commission (2002) reports that personal and privately owned vehicles currently account for 90% of passenger road traffic in the country. The remaining 10% is then provided by government owned public transport bus companies. While the private sector owns a larger number of buses compared to the government (about 85% of the total number of buses), most private bus operations are based on the 'Contract Carriage permit' that allows these buses to be hired and leased out for private use, and prohibits their use as a means of public transit (Maunder et al. (1987)). In some cities with a large commuting population such as Delhi and Kolkata, though, public transit operations by private buses are prevalent. These are exceptions, and in general, public transit is usually a government owned legal monopoly in most parts of India (Gowda (1999)).

These public bus companies have been plagued by severe financial constraints and are hard pressed to even meet their fleet replenishment needs, let alone augment the fleet to cater to the growing demand (Kadam (1999)). Simultaneously, per capita incomes have increased rapidly and personal vehicles have become more affordable since the 1990s. A result of these two concurrent trends has been a declining share of public transit in meeting transport demand in the country.

### *1.1.2. Institutional and regulatory structure of public road transport in India*

In India, the regulation of road based public transport operators is essentially the responsibility of the state government. The two main laws that regulate the functioning of public bus transport services are the Motor Vehicles Act (1988), and the Road Transport Corporations Act (1950) (Deb (2003)). This regulatory framework is independent of the management structure of the bus company and is identical for all bus based public transport operators in India. For instance, even if the bus operator is established as a municipal undertaking under a municipal legislation such as the Bombay Provincial Municipal Corporations Act (1949), regulatory and operational control is seceded to the Road Transport Corporations Act (1950) and the Motor Vehicles Act (1988). Similarly, even if the bus company is set up as a company under the Companies Act (1956), legislative oversight continues to be provided by the Road Transport Corporations Act (1950) and the Motor Vehicles Act (1988).

The Motor Vehicles Act (1988) provides for two types of bus services, namely, Stage Carriages and Contract Carriages. Stage Carriage buses are normal public transport buses. On the other hand, Contract Carriage buses are buses licensed for use by either individuals or companies for their own use, or for leasing. Contract Carriages are not allowed to pick up or set down passengers en route as Stage Carriage buses do. Permits for both these services are obtained from a Regional Transport Authority or a State Transport Authority of the state governments. In most states, Stage Carriage permits are only given to state owned bus companies.

The Road Transport Corporations Act (1950) provides for the establishment of Road Transport Corporations by each state government. The Act lays down the procedures for the management of the corporation. Section 18 of the Act states that the duty of the corporation shall be to provide, secure, or promote the provision of an efficient, adequate, economical, and properly coordinated system of road transport services in the state.

## **1.2. Study problem and goals**

The major reasons for the decline in the share of public transport are the inability of public transport operators to keep pace with the increasing demand and the deteriorating quality of service arising out of continued losses and thus inadequate capital generation for capacity augmentation (Gowda (1999)). Such a situation has arisen because of continuing inefficiency in operations and uneconomical operations to meet the universal service obligation (Maunder (1984)). This has also resulted in a continuous drain on scarce budgetary resources and been compounded by the growing inability of the government to provide grants. Funding of bus transport in India by internal resources, market borrowings, and equity capital provided by the Union and state governments is proving to be inadequate. Simultaneously,

the gradual liberalization of the automobile industry since the mid 1980s has increased the number of personal vehicles and hence has resulted in a shift away from public transport. This has presented another concern – any increase in tariffs can lead to further erosion of the ridership in public transport. In addition, being public sector initiatives, public bus transport companies in effect operate as monopolies without a regulatory regime that incentivizes productive efficiency or quality in terms of access to the service (Maunder (1984)). Moreover, the current pricing regime does not ensure economic efficiency. Finally, efficiency also depends on the organization of the sector in terms of the structure of the market and the size of each firm.

Thus, the sector is faced with a unique challenge. Though fare increases are considered necessary to ensure financial viability, they are constrained by two factors: meeting the universal service obligation and the threat of reduced ridership due to the shift away from public transport. The sector has to increase capacity while improving service quality in terms of access to transport, comfort, frequency, and reducing travel time. This calls for a two-pronged strategy, namely, efficiency in service provision in terms of the organization of the sector, and cost recovery based on efficient pricing.

In assessing the efficiency of the current market and production structure, the first issue is the structure of the market in terms of the number of firms and the distribution of production between firms and over space. This relates to the degree of Economies of Density and Scale at the current level of production in each of the firms. By merging smaller companies into larger ones and companies that ply in neighbouring areas, it might be possible to reduce average costs.

The other issue is of the management structure of the bus companies themselves. The organizational form for public sector bus transportation in India varies from state to state, the most common being that of a Corporation. Other management forms include companies formed under the Indian Companies Act (1956), municipal departments, and state government departments (CIRT (Various years)). Bhattacharyya et al. (1995) and Kumbhakar et al. (1996) find that the management form is a significant variable while estimating costs of service delivery in public bus transit in India and report that the organizational form significantly affects efficiency of public bus transit. However, it is not clear how the management structure affects the efficiency of service delivery. All management forms of public transport in India are regulated by the Road Transport Corporations Act (1950) and the Motor Vehicles Act (1988). Thus, it is important to assess the suitability of alternative management forms of government owned bus corporations to identify the differences in costs due to different management structures.

Finally, optimal pricing of public transport services to ensure economic efficiency and cost recovery is critical. In the post-liberalization era, it would be difficult for governments to continue to provide financial support to loss making ventures such as the government owned bus companies, especially with the growing emphasis on fiscal discipline. The result of this policy has been the withdrawal of capital contribution to the public bus companies (Planning Commission (1992)). Nevertheless, as mentioned earlier, increasing the share of public transport is critical to ensuring the sustainability of the sector. Agashe (1999) estimates that nearly 200 billion rupees were required during the period 1998–2004 to meet just the fleet replacement needs of all bus companies in India. Thus, it is necessary to review the functioning of these firms in India with a view to improving revenue collection and hence the tariff regime (Cervero (1990); Planning Commission (2002)).

In summary, apart from efficiently meeting mobility needs in a growing economy, public transport is less polluting and causes less congestion than personal vehicles, for each passenger trip. Hence, increasing the share of public transport is the most effective strategy for meeting economic, environmental, and energy goals (Sundar et al. (2004)). Ramanathan et al. (1999) show that a modal share promoted in favour of public transport would lead to a 46% reduction in energy consumption and hence greenhouse gas emissions. In particular, bus based public transport is the cheapest and most cost effective way of meeting mobility needs (Mohan et al. (1999); Planning Commission (2002)). Encouraging bus based mass transit systems along with improved quality of service is the key strategy here (Singh (2005b)).

Thus, this research is an empirical analysis of the following aspects of public bus transport in India:

- Structure of the market in terms of the number of firms and the distribution of production across firms and organized in space.
- Management of the firms and the implications of alternative organizational structures on the cost of service delivery.
- Factors influencing public bus transport demand and the role of monetary and non-monetary policy variables.
- Impact of alternative pricing strategies of the public bus transit firms on demand, consumer surplus, and profits.

In all the literature that is available for review, this is the only study that provides a thorough analysis of bus based public transit in India focusing on sector organization, productive and economic efficiency, factors influencing public bus transit demand, and efficient pricing. A comprehensive analysis has been attempted by estimating a cost function from data



including all public transit firms in the country and estimating of an aggregate demand function with data from almost all states in India. This study also uses a much richer specification compared to the existing literature, including not just environmental and operating characteristics, but also assessing the impact management structure has on costs. The current research is possibly one of the very few studies that use panel data for such a thorough analysis. In terms of methodology, this research compares the results from several econometric models, that have not all been applied in this context.

### 1.3. Approach and methodology

The approach here derives from neo-classical microeconomics, applied to data from a developing country to estimate the cost and demand structure of the industry at the state level, and the market equilibrium. By analyzing the production technology of firms operating in the public transit market, in conjunction with the behaviour of commuters, efficient price and quantity outcomes are calculated. The analytical structure of the study is thus rooted in neo-classical cost theory and consumer behaviour, and the interaction of economic agents in a market.

The study uses panel datasets for the estimation of the cost and demand functions. Single equations using panel datasets can be estimated as either Fixed Effects or Random Effects depending on assumptions made about intercept and error terms. A Seemingly Unrelated Regression model along with the share equations has also been estimated to assess the stability of the single equation panel models in the case of the cost function. In addition, with panel datasets, it is possible to distinguish between the short run and long run characteristics, and address heterogeneity issues in parallel. This allows the quantification of effects that are not identified in time series and cross sectional analysis separately (Hsiao (2003)). In estimating aggregate demand, comparing static panel data estimates with dynamic panel data estimates reveals the importance of persistence variables such as habit formation. In terms of static models, the first type of models are the conventional static one way panel data models, namely, Fixed Effects and Random Effects. The second type, the Panel Corrected Standard Error method as proposed by Beck et al. (1995) is an alternative to the conventional panel data models. In terms of the dynamic specification, two Generalized Method of Moments based models, Arellano–Bond and Blundell–Bond, have been estimated. The two models are distinguished by the way instruments are constructed for each system. The Corrected Least Squares Dummy Variable estimations provide an alternative estimate to the Generalized Method of Moments models for the dynamic specification.

## 1.4. Structure of the thesis

The following three chapters form the substantive part of the research. Chapter 2 presents the estimation of the cost function. The dataset used for the cost analysis in chapter 2 includes observations on almost all bus corporations that have operated, or are currently operating, in India, hence allowing for a comprehensive national analysis. The specification chosen builds on previous cost estimations from India using environmental and operating characteristics, and management structure as explanatory variables assessing the key policy variables affecting transit costs in India. The industry structure in terms of the number of firms and the output level of each firm, and the management structure of the firms, is also assessed. The industry structure is analyzed from estimated Economies of Scale, hence revealing the potential for reducing costs by redistribution production between the firms. Cost characteristics are reported in terms of the Economies of Density and Scale, and marginal costs.

Chapter 3 presents the estimation of an aggregate demand function for public bus transport in India. Unlike other studies that estimate demand functions for Indian transit firms using datasets comprising of only a few cities, this study uses panel data from almost all states in India and hence provides a comprehensive analysis of public transit demand in India. The specification used also attempts to capture actual market transactions to relate these with firm behaviour, using passenger kilometers as a measure of demand. It also accounts for quality issues by using density of coverage as an indicator of service quality in terms of access to the transit network. Unfortunately, user costs and external costs are not available for this study and hence only public bus transit fares are included. Hence, the price elasticities obtained are only for public bus transit fares and not generalized transportation costs for the public bus users as in Mohring (1970). Finally, the use of demographic and social characteristics is expected to reveal the import of non-monetary variables in the context of a developing country. The results are presented in terms of price, income, and service quality elasticities for public bus transport. As a result, important policy variables influencing public bus transit demand in India can be identified from the analysis. In particular, the significance and magnitude of non-price variables such as the quality of service and demographic characteristics is highlighted in this analysis.

Chapter 4 then uses the cost estimates from chapter 2 and the aggregate public bus transit demand estimated in chapter 3 to present alternative pricing regimes. The proposed pricing regimes reflect several constraints in achieving socially optimal prices. These include the presence of Economies of Scale, the need for revenue adequacy, and the need to meet maximum possible demand. The pricing strategies that are assessed focus on both economic efficiency as well as revenue adequacy. Finally, the welfare impacts of the current and the

efficient pricing schemes have been estimated. The results are presented in terms of the equilibrium prices and quantities, and the change in demand and consumer surplus arising from the change in price from the existing market price to the estimated equilibrium price. It is noted, however, that data for estimating user costs and external costs is not available for this study and hence only the production costs of firms are included while estimating the various pricing regimes. In addition, as the demand analysis reveals, non-price variables such as quality of service and demographic changes are also significant variables that would influence the level of public bus transit demand and hence the sustainability of the transport sector as a whole.

Chapter 5 then provides a synthesis of the research in this thesis and the policy regulatory implications therein.

## 2. Cost characteristics of public bus transit in India

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Empirical analysis of cost functions in the transport sector originated with rail cost analysis in the United States where railroads were regulated and much of the data was publicly available (Pels et al. (2000)). Since then, estimating cost functions has been the most common approach for analyzing the production and cost behaviour of transit firms. Most such studies have attempted to assess the efficiency of the existing industry structures and the economic justification for regulation. These are usually defined in terms of Scale Economies and monopoly power. In addition, analyzing transport cost structures provides information on optimal firm size and opportunities for joint production for multi-product firms such as railways providing both freight and passenger services. Other studies have estimated cost functions to assess the demand for inputs, the potential for factor substitution, and the impact of policy and environmental variables on the cost of providing mass transit services. Estimation of cost functions also reveals the structure of average and marginal costs, which then can be used to determine the level of monopoly power and efficient tariffs. Cost estimations are useful even when the estimation of a production function is not possible which is the case if the firm is not a price taker in the output market, for example, a firm with monopoly power (Diewert (1992)).

This chapter presents the results of a Translog cost function estimated using an unbalanced panel of 70 public bus companies in India between 1989/90 and 2003/04 to analyze output characteristics and cost behaviour. The dataset includes observations on almost all bus companies that have operated, or are currently operating in India, hence allowing for a comprehensive national analysis. Given the availability of a reasonably long panel, and with a large cross section of firms, several panel data models are estimated and compared. Cost characteristics are reported in terms of the Economies of Density and Scale, and marginal costs.

The following section briefly describes the properties of the neoclassical cost function. It then goes on to define concepts for characterizing cost impacts of outputs, and discusses issues in specifying cost functions in the transport sector. A brief description of the trends in cost and operational performance in the public bus transport sector in India is presented in section 2.2. Section 2.3 discusses the relevant literature on estimating cost functions for bus companies and summarizes the issues in selecting the appropriate functional form and variables for analysis. The specification used in this research is given in section 2.4. The estimation process and the econometric models used are given in section 2.5. Section 2.6

describes the data used in the analysis. Section 2.7 presents the results of the analysis and discusses the implications therein. Finally, section 2.8 provides some concluding comments.

## 2.1. Neoclassical cost theory

A neoclassical cost function is defined as the relationship ( $C(\cdot)$ ) that gives the minimum cost of producing a fixed level output of an output vector ( $\mathbf{y}$ ), given a production technology  $f(\mathbf{z})$  as described by the way a vector of inputs ( $\mathbf{z}$ ) are combined to produce the vector of outputs, and input prices ( $\mathbf{w}$ )<sup>1</sup>. This assumes that the firm takes input prices as given and the production technology does not change for the duration of production. The cost function can be represented as follows:

$$C = C(\mathbf{w}, \mathbf{y}) = \min \{ \mathbf{z}'\mathbf{w} : \mathbf{y} = f(\mathbf{z}) \} \quad 2.1$$

where  $C$  is the total cost,  $\mathbf{z}$  is a vector of  $j$  inputs,  $\mathbf{w}$  is a vector of  $j$  input prices, and  $\mathbf{y}$  is a vector of outputs.

### 2.1.1. Duality

Uzawa (1964), extending the duality between production and cost functions established by Shephard (1953), derives the following conditions under which given cost functions uniquely determine production characteristics.

- The cost function is defined, continuous, and non-negative for all positive input prices and output levels.
- The cost function is non-decreasing in outputs.
- The cost function is non-decreasing and concave in input prices.

In addition, the cost function is homogeneous of degree one in input prices.

Given these conditions, the production technology satisfies the following conditions, thereby establishing a unique dual relationship between each production technology and its cost function.

- The production function is non-empty, closed, and consists of non-negative vectors  $\mathbf{z}$ .
- The production function is concave in outputs.
- Disposal activities are costless, that is,

$$\text{if } \mathbf{y}_1 = f(\mathbf{z}_1) \geq \mathbf{y}_2 = f(\mathbf{z}_2) \text{ then } f(\mathbf{z}_1) \subseteq f(\mathbf{z}_2) \text{ and } \mathbf{z}_1 \leq \mathbf{z}_2 \quad 2.2$$

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<sup>1</sup> For a comprehensive review of production and cost theory, refer to Chambers (1988)

Due to this duality, production technology can be described ‘solely in terms of the cost function’ and ‘the specification of a well behaved cost function is equivalent to specification of a well behaved production function’ (Chambers (1988)). This duality property can be used to specify a system of equations for estimating costs. Using Shephard’s Lemma (Shephard (1953)),  $\partial_{\mathbf{w}} C(\mathbf{w}, \mathbf{y}) = \mathbf{z}(\mathbf{w}, \mathbf{y})$ , well behaved input demand functions corresponding to the dual production technology can be obtained. These can then be used, along with the cost function, for specifying a system of equations for estimating a cost function more efficiently, as demonstrated by Nerlove (1963).

### 2.1.2. Returns to scale, and average and marginal costs

A large part of the cost estimation literature focuses on the impact of production technology on industry structure, particularly the *Elasticity of Scale*. Chambers (1988) defines this as the proportional change in output as an input bundle is changed by a scalar  $\lambda$ , evaluated at  $\lambda = 1$ . For the single output case:

$$ES = \left. \frac{\partial \text{Ln}f(\lambda z)}{\partial \text{Ln}\lambda} \right|_{\lambda=1} = \sum_j e_{yz_j} \tag{2.3}$$

where  $e_{yz_j} = \frac{\partial \text{Ln}f(z)}{\partial \text{Ln}z_j}$  is the output elasticity with respect to input  $z_j$ . The elasticity is always

evaluated at given combinations of inputs, that is, where the ratio between any two inputs,  $z_i/z_j$ , remains constant. If  $ES = 1$ , the production function is said to demonstrate constant returns to scale, that is, a proportional increase in all inputs results in an increase in output in the same proportion.  $ES < 1$  ( $ES > 1$ ) can then be interpreted as decreasing (increasing) returns to scale.

Whether a production technology exhibits constant, decreasing, or increasing returns to scale, has implications for the most efficient structure of the industry. In particular, if an industry were characterized by a production technology with increasing returns to scale for a given output range, the efficient industry structure is a monopoly within that range.

In terms of input productivity, the elasticity of scale can be defined as the sum of the ratios of marginal to average productivity of all inputs. That is,

$$ES = \sum_j \frac{\partial \text{Ln}f(z)}{\partial \text{Ln}z_j} = \sum_j \left( \frac{\partial f(z)}{\partial z_j} / \frac{f(z)}{z_j} \right) \tag{2.4}$$

To translate the definition of returns to scale in terms of the cost function, consider *Cost Flexibility*, which is defined by Chambers (1988) as the ratio of marginal cost to average cost, or the following:

$$e_{cy}(\mathbf{w}, \mathbf{y}) = \sum_k \frac{\partial \text{Ln}C}{\partial \text{Ln}y_k} = \sum_k \left( \frac{\partial C}{\partial y_k} / \frac{C}{y_k} \right) \quad 2.5$$

with  $k$  different outputs,  $y$ .

The reciprocal of *Cost Flexibility* is then defined as the elasticity of size or scale if and only if the production technology is homothetic, given cost minimization (Chambers (1988)). Hence, *Economies of Scale* can be defined in terms of the cost function as follows (Panzar (1989)):

$$ES(\mathbf{w}, \mathbf{y}) = \frac{1}{e_{cy}(\mathbf{w}, \mathbf{y})} \quad 2.6$$

Analogous to returns to scale, if the elasticity of scale is greater than, equal to, or less than unity, the cost function is said to demonstrate increasing, constant, or decreasing Economies of Scale. Following Farsi et al. (2004), we do not impose the homotheticity requirement here and instead adopt the definition of Economies of Scale in Panzar (1989).

### 2.1.3. Aggregating output and Hedonic cost functions

In neoclassical cost theory, all output units are homogeneous. Hence, the production of one unit of output is indistinguishable from the next, and can be interchanged without any impact on costs. In transport economics, however, an industry is characterized not only by the total output produced but also the structure of the network served (Caves et al. (1984))<sup>2</sup>. The motivation for this complex characterization arises from the fact that costs in network industries are influenced not only by the total output produced but also by the network structure. For instance, a 33.33% increase in output of a transit firm serving three nodes with traffic volumes 3, 6, and 9 units of transport can be achieved with an increase in output at each point to 4, 8, and 12 units respectively, or by adding another node with output of 6 units. Clearly, costs would not be influenced in the same way in both cases (example adapted from Braeutigam (1999)).

Hence, transit output is not homogeneous. From a demand perspective, the output of a transit firm is the aggregate of services provided, that is, a set of routes with varying service characteristics such as area covered, frequency of service, travel speed, etc. From a cost perspective, the cost of operating 10 buses with 50 passengers over a distance of 100 km each

<sup>2</sup> For a detailed discussion on Hedonic and general specifications of transport cost functions, refer to Oum et al. (1989) and Panzar (1989).

will be substantially higher than the cost of 1 bus with 100 passengers over 500 km, even though the passenger kilometers output would be identical.

Empirically, heterogeneity can be addressed by estimating a cost function for each output, such as for each origin–destination combination for each freight commodity (Oum (1979a)). However, the critical constraint in such an exercise is data availability and the large number of parameters that have to be estimated even for a small cross section of firms due to an output vector of huge dimensions. A measure of output that approximates output characteristics and allows aggregation for the entire system is therefore required.

The common strategy in applied research is the use of multiple aggregate outputs, mostly in combination with attribute and quality variables describing output (Oum et al. (1989)). Early studies defined homogeneous output categories by aggregating production within specified quality or attribute ranges, such as average haul or average lead (Harmatuck (1981)), or using different types of output (Colburn et al. (1992)), and then estimating a multiproduct cost function. However, even while using a multiproduct cost function in bus transport with output differentiated across quality attributes, unless each passenger trip on each route is treated as a separate output, there still might be some unobserved heterogeneity. Given the infeasibility of carrying out such estimations, quality and other output attributes are included in the cost function besides output to control for differences in outputs between firms or over time. For instance, Caves et al. (1985) use firm dummies to account for unobservable output heterogeneity between firms.

Most recent studies, though, use specifications that allow such heterogeneity to vary. The *Hedonic Cost Function* (Spady et al. (1978)) specifies aggregate output functions within the cost function as  $C = f(\mathbf{w}, \varphi(\mathbf{y}, \mathbf{N}))$  where  $\varphi(\mathbf{y}, \mathbf{N}) = \mathbf{y}\phi(\mathbf{N})$  and  $\mathbf{N}$  is a vector of  $n$  output characteristics. Berechman (1993) characterizes  $\mathbf{N}$  as network characteristics in bus transport. From duality, inputs are combined in a cost minimizing manner to produce  $\varphi(\cdot)$  which can then be obtained from any combination of  $\mathbf{y}$  and  $\mathbf{N}$  such that  $\varphi(\mathbf{y}, \mathbf{N})$  is satisfied. In our earlier example, this would imply the network adjusted output of 24 units of transport output can be produced using either three nodes of 4, 8, and 12 units of output respectively, or four nodes of output 3, 6, 6, and 9, if the network structure is explicitly accounted for in the cost function, perhaps by using the number of transport nodes as an output attribute. Hence,  $\varphi(\mathbf{y}, \mathbf{N})$  can then be interpreted as the attribute adjusted output measure, or the *effective output*. Feigenbaum et al. (1983), Friedlaender et al. (1983), and Kaserman et al. (1991) estimate Hedonic cost functions comparing the impact of several hedonic measures of output on costs.



In Hedonic Cost Functions, the effect of output attributes on the output measure is independent of input prices, and is *quality separable*. That is,

$$\frac{\partial}{\partial \mathbf{w}} \left( \frac{\partial C(\mathbf{w}, \varphi(\mathbf{y}, \mathbf{N}))}{\partial \varphi(\mathbf{y}, \mathbf{N})} \bigg/ \frac{\partial C(\mathbf{w}, \varphi(\mathbf{y}, \mathbf{N}))}{\partial \mathbf{N}} \right) = \frac{\partial^2 C(\mathbf{w}, \varphi(\mathbf{y}, \mathbf{N}))}{\partial \mathbf{w} \partial \mathbf{N}} = 0 \quad 2.7$$

Friedlaender et al. (1981) impose further separability within output attributes,

$$\frac{\partial^2 C(\mathbf{w}, \varphi(\mathbf{y}, \mathbf{N}))}{\partial N_n \partial N_m} = 0 \quad 2.8$$

This separability is clearly a restriction on the cost function and needs to be tested for empirically in each estimation (Oum et al. (1989))<sup>3</sup>. Berndt et al. (1973) provide the parameter tests for separability in the Translog functional form. More general specifications of the cost function do not impose separability of hedonic variables. The cost function is then described as  $C = f(\mathbf{w}, \mathbf{y}, \mathbf{N})$ . Hence, the Hedonic Cost Function is nested in the more general specification, with fewer parameters to be estimated.

Thus, the choice between the Hedonic Cost Function and the more general specification, that is richer and more flexible due to less arbitrary restrictions, depends on the size of the dataset available and any ex-ante knowledge about the structure of the cost function. With a large enough dataset, and without prior knowledge of the production technology, it is more appropriate to estimate a more general specification. Hence, this study uses the more general specification  $C = f(\mathbf{w}, \mathbf{y}, \mathbf{N})$ .

#### 2.1.4. Economies of Scale and Density

As discussed above, bus transport is characterized by both the total output produced and the network size and structure<sup>4</sup>. Hence, in the definition of Economies of Scale, a proportional increase in inputs would impact both output and the network structure (Caves et al. (1985)).

<sup>3</sup> Blackorby et al. (1977) and Denny et al. (1977) show that separability in output attributes implies that either the production function is a Cobb–Douglas function of Translog output aggregates or a Translog function of Cobb–Douglas output aggregates. In particular, ‘once separability is imposed ..., the Translog specification of the function is no longer capable of providing a second order approximation to any unknown arbitrary separable cost function...and thus must be interpreted as an exact functional form’ (Oum et al. (1989)). The Translog and Cobb–Douglas functions are described in Section 2.3.1.

<sup>4</sup> For a general description of Economies of Scale and Density, refer to Panzar (1989). For a detailed exposition in bus transport, refer to Berechman (1993).

In this case, the cost elasticity of output ( $e_{cy}$ ) can be distinguished from the cost elasticity of network ( $e_{cN}$ ). Formally,

$$e_{cy}(\mathbf{w}, \mathbf{y}, \mathbf{N}) = \sum_k \frac{\partial \text{Ln}C}{\partial \text{Ln}y_k} \quad 2.9$$

$$e_{cN}(\mathbf{w}, \mathbf{y}, \mathbf{N}) = \sum_n \frac{\partial \text{Ln}C}{\partial \text{Ln}N_n} \quad 2.10$$

$e_{cy}$  is then the change in cost as the density of output increases per unit of network. Hence, *Economies of Density* are defined as the inverse of the elasticity of cost with respect to output, that is, the relative increase in total cost resulting from an increase in output, holding all input prices and output attributes fixed, and ignoring the homotheticity requirement (Caves et al. (1981)):

$$ED(\mathbf{w}, \mathbf{y}, \mathbf{N}) = \frac{1}{e_{cy}(\mathbf{w}, \mathbf{y}, \mathbf{N})} \quad 2.11$$

Economies of Density are said to exist when  $ED(\mathbf{w}, \mathbf{y}, \mathbf{N}) > 1$  (or  $e_{cy}(\mathbf{w}, \mathbf{y}, \mathbf{N}) < 1$ ) and arise from higher capacity utilization or larger equipment. *Economies of Scale*, on the other hand, describe how costs change for a proportional change in both output and the network, given input prices. These are defined as the following:

$$ES(\mathbf{w}, \mathbf{y}, \mathbf{N}) = \frac{1}{e_{cy}(\mathbf{w}, \mathbf{y}, \mathbf{N}) + e_{cN}(\mathbf{w}, \mathbf{y}, \mathbf{N})} \quad 2.12$$

Economies of Scale exist when  $ES(\mathbf{w}, \mathbf{y}, \mathbf{N}) > 1$  (or  $e_{cy}(\mathbf{w}, \mathbf{y}, \mathbf{N}) + e_{cN}(\mathbf{w}, \mathbf{y}, \mathbf{N}) < 1$ ). Since  $e_{cN}(\mathbf{w}, \mathbf{y}, \mathbf{N}) \geq 0$ ,  $ED(\mathbf{w}, \mathbf{y}, \mathbf{N}) > ES(\mathbf{w}, \mathbf{y}, \mathbf{N})$ . Thus, if an industry is characterized by Economies of Scale, it also implies the existence of Economies of Density.

While including  $\mathbf{N}$ , Gagne (1990) uses the definition of output attributes to obtain an explicit relationship,  $\mathbf{N}(\mathbf{y})$ , in calculating the Economies of Scale. Recognizing this exact relationship between some output characteristics, Jara-Diaz et al. (1996) argue that when including output characteristics in the cost function as above, that hedonic measures,  $\mathbf{N}$ , should not be treated similar to output.  $C = f(\mathbf{w}, \mathbf{y}, \mathbf{N})$  is only an implicit representation of  $C = f(\mathbf{w}, \mathbf{y})$ , 'the best econometric effort'. In other words,

$$C = f(\mathbf{w}, \mathbf{y}) = f(\mathbf{w}, \mathbf{y}, \mathbf{N}(\mathbf{y})) = f(\mathbf{w}, \mathbf{y}, \mathbf{N})$$

In this case, the definition of Economies of Scale needs to reflect this implicit nature of the cost function. The cost elasticity for each output,  $y_k$ , and Economies of Scale are then defined as follows:

$$e_{cy}^k(\mathbf{w}, \mathbf{y}, \mathbf{N}) = \sum_m \frac{\partial \text{Ln}C}{\partial \text{Ln}y_m} \frac{\partial \text{Ln}y_m}{\partial \text{Ln}y_k} + \sum_n \frac{\partial \text{Ln}C}{\partial \text{Ln}N_n} \frac{\partial \text{Ln}N_n}{\partial \text{Ln}y_k} \quad 2.13$$

$$ES(\mathbf{w}, \mathbf{y}, \mathbf{N}) = \frac{1}{\sum_k e_{cy}^k(\mathbf{w}, \mathbf{y}, \mathbf{N})} \quad 2.14$$

Jara–Diaz et al. (1996) show that this definition equals 2.12 only when

$\partial \text{Ln}y_m / \partial \text{Ln}y_k = \partial \text{Ln}N_n / \partial \text{Ln}y_k = 1$ , which is when aggregate output is the unweighted sum of individual outputs. For instance, using the example of average length of haul, Jara–Diaz et al. (1996) show that the elasticity of cost with respect to average length of haul should never be included in the definition of *ES*. In particular, while using average load, capacity utilization, or vehicle kilometers, the influence of changes in these parameters on output needs to be explicitly accounted for in the analysis.

Ying (1990) and Xu et al. (1994) demonstrate that the impact of output attributes is significant by statistically estimating  $\mathbf{N}(\mathbf{y})$  and explicitly including it in calculating the Economies of Scale. While Ying (1990) estimates this relationship by including policy variables such as deregulation as regressors, Xu et al. (1994) use input prices and other output characteristics as regressors. In both cases, the theoretical basis of these regressions is not clear. Interestingly, Fraquelli et al. (2004) define output as the product of total seats offered and vehicle kilometers, so as to take into account output characteristics such as network length, frequency of service, and fleet size, and hence eliminate the need for distinguishing between Economies of Density and Scale.

Nevertheless, while comparing Economies of Scale estimates from studies using an aggregate measure of output with those from studies using hedonic measures of output in the cost function, the definition of cost elasticity of output needs to be carefully considered. In particular, Scale Economies estimated without using hedonic output measures would correspond to Scale Economies estimated using hedonic output measures only if output characteristics are independent of the output level.

## 2.2. Public bus transport in India

The participation of the government in road transport commenced in 1950 and since then government owned bus companies have been formed in every state (Gandhi (1999)). These firms are called State Road Transport Undertakings. At present, there are 52 government

owned bus companies in the country. They operated a fleet of over 118 thousand buses, and employed more than 700 hundred thousand people as on 31 March 2004. Out of the 52 firms, 14 operate exclusively in the urban areas, 8 only in rural areas, and the remaining 30 provide services in both urban and rural areas (Table 2.2.1). Just over 15% of the total buses service urban areas. About 20 bus companies have more than 1000 buses with the largest being Andhra Pradesh State Road Transport Corporation with nearly 19 thousand buses.

**Table 2.2.1. Rural and urban public bus transit operations in India in 2004**

Number	Urban	Rural	Rural and urban
SRTUs	14	8	30
Buses	18,114	96,268	

Source. CIRT (Various years)

The organizational form for public sector bus transportation in India varies from state to state, the most common being that of a Corporation constituted under the provisions of the Road Transport Corporation Act (1950). There are 24 such corporations in operation today. While nine firms have been formed under the Indian Companies Act (1956), public transport is also operated by 10 Municipal Corporations under various municipal legislations. The remaining eight function as part of government departments<sup>5</sup> (CIRT (Various years)).

**Table 2.2.2. Management of public bus companies in 2004**

Management Structure	Number of firms
Corporation	24
Government Department	8
Company	9
Municipal Department	10

Source. CIRT (Various years)

### 2.2.1.1. Operational performance

The total strength of the public bus companies in India grew from less than 74 thousand in 1981 to over 118 thousand in 2004, an increase of more than 50%. However, while the total vehicle fleet strength grew at almost 10% per annum in the 1990s, the public bus fleet grew by less than 3% per annum (Table 2.2.3). Given that the increase in the bus fleet over this period has been less than personal vehicles, the size and spread of public transport has declined in the last five years.

<sup>5</sup> The number of firms under each management structure reported to be in operation today is different from the numbers reported in Table 2.6.2 since some firms have merged, shut down, or been unbundled over time. Table 2.6.2 includes all public transport bus companies that were and have been in existence since 1989/90 in India.

**Table 2.2.3. Annual growth rates of vehicle population in India**

Year	SRTU buses	Total buses	Personal vehicles
1986	3.25%	6.98%	16.26%
1991	1.96%	7.84%	16.41%
1996	-0.36%	6.29%	9.86%
1997	2.07%	7.80%	10.73%
1998	1.59%	11.16%	11.11%
1999	0.69%	0.37%	9.19%
2000	1.72%	4.07%	9.16%
2001	-2.54%	12.81%	13.30%
2002	-0.26%	0.16%	7.85%
2003	0.17%	13.54%	14.07%
2004	-3.05%	6.52%	9.36%

Source. CIRT (Various years)

The operational characteristics of public bus companies however do not show any distinct trend (Table 2.2.4). While the proportion of the total fleet on road represented by fleet utilization had been gradually increasing over time, it has stagnated since 2000. Similarly, the density of coverage, defined as the ratio of vehicle kilometers to the total area of the country, has increased over time though the changes have been less perceptible in the last few years. Clearly, a lower growth in public transport productivity compared to the increase in demand, combined with a slow growth in the vehicle fleet, implies a lower share of public transport in meeting road transport demand.

**Table 2.2.4. Operational performance of public bus companies in India**

Year	Fleet Utilization	Density of Coverage (vehicle km per km <sup>2</sup> )
1986	85.00%	2,055.39
1991	85.30%	2,680.04
1996	87.70%	3,261.07
1997	88.00%	3,267.16
1998	90.20%	3,434.47
1999	89.90%	3,577.44
2000	89.40%	3,708.25
2001	90.80%	3,641.33
2002	88.80%	3,653.50
2003	92.10%	3,562.23
2004	92.00%	3,772.14

Source. CIRT (Various years)

### 2.2.1.2. Financial performance

Public passenger road transport in India is funded by internal resources, market borrowings, and equity capital provided by the central and state governments. The overall financial performance of public bus companies in India appears to be gloomy and they are heading for a severe financial crisis. These corporations had incurred an accumulated loss of nearly 130 billion rupees as of March 2004. Only two of the 52 bus companies in India make profits. The

accumulated loss is nearly 23% more than the aggregate amount of equity of both the Union Government and the state governments and reserves (104.64 billion rupees). Further, this loss is significantly larger than the total assets of the companies (CIRT (Various years)). However, given the important social and economic role of public transport in the country, even such poor financial performance would not lead to these bus companies being closed down and the government would have to continue to finance public transport operations (Agashe (1999)). Maunder (1986) notes that the present policy is to finance such losses through non-repayable loans.

This dismal capital structure can be traced to continuous and increasing losses from bus operations. As the earnings per kilometer have grown slower than the costs per kilometer, losses per kilometer have grown by nearly 12.5% per annum since 1996 (Table 2.2.5). Krishna (1998) reports that the rate of increase in revenue per passenger kilometer has been much lower than the change in the consumer price index, indicating a fall in revenue per passenger kilometers in real terms.

**Table 2.2.5. Financial performance of public bus companies in India**

Year	Total revenue (Rs 10 <sup>7</sup> )	Total costs (Rs 10 <sup>7</sup> )	Profit (loss) per vehicle km
1991	5,169.16	7,532.71	-2.68
1996	9,499.01	10,558.95	-0.99
1997	10,088.48	11,502.52	-1.32
1998	11,556.08	12,838.44	-1.14
1999	12,367.00	14,284.88	-1.63
2000	14,113.47	16,310.81	-1.80
2001	15,323.56	17,272.02	-1.63
2002	16,040.50	18,233.16	-1.83
2003	15,287.82	18,143.09	-2.44
2004	16,440.12	19,581.76	-2.53

Source. CIRT (Various years)

A result of the continuing losses has been the inability to generate adequate funds for capital expenditure and replacement of rolling stock. There exists a vicious circle of continuous losses leading into inadequate funds for capital expenditure and poor management of the fleet, which in turn leads to poor operational performance, causing even higher losses (Cervero (1990); Singh (2005b)). Continued losses also affect the debt–equity ratio adversely and hence the ability of the firms to leverage funds from the market, thus accentuating this vicious circle. Krishna (1999) demonstrates, using a sample of five bus companies in India over an 11 year period, that poor farebox collections have a negative impact on the debt–equity ratio of transit firms. Hence, current operations must be reviewed to identify areas for reform.

## 2.3.Literature review

There is a large variation in cost estimates reported in the literature that Berechman (1993) attributes to differences in functional forms, definition of outputs, inputs considered, and other variables taken into account. Much of the variation arises from different motivations for research – whether the objective is to assess impact of demand patterns (Dalen et al. (2003)), regulatory constraints (Dalen et al. (2003)), geographical features (Cubukcu (2006)), or ownership and management structure (Filippini et al. (2003)). The focus of the literature review here is to assess the impact that different specifications, functional forms, and estimation approaches have on cost characteristics of output. In particular, the literature review, in combination with the data available, would allow the identification of variables to be included in the estimation of an appropriate specification to obtain Density and Scale Economies.

A summary of some recent studies estimating cost functions and frontiers is presented in Table 2.3.1. The selected studies include two studies that use Indian datasets, and four other studies that reflect current trends in research, particularly in terms of regressors used and functional forms. Bhattacharyya et al. (1995) use a short five year panel for 32 Indian bus corporations to estimate a Translog variable cost frontier with passenger kilometers as output, and labour and fuel as inputs. Obeng et al. (2000) estimate a Translog total cost function using a pooled dataset of 23 United States transit systems over 10 years, with vehicle miles as the output and fuel, labour, and capital as inputs. Filippini et al. (2003) also estimate a Translog total cost model with bus kilometers but add an output attribute, network length to the analysis. They also estimate the same model with seat kilometers as the output measure. Farsi et al. (2006) have a similar specification though using a more complex estimation process, namely, stochastic frontiers. Fraquelli et al. (2004) have a richer specification with a more complex characterization of output, in addition to using average commercial speed as an output attribute. In the Indian context, Singh (2005a) is a simple variable cost estimation using an 11 year panel of seven urban Indian bus companies.

This is possibly one of the very few studies estimating transit cost functions for developing countries. Unlike other studies that estimate cost functions for Indian transit firms using datasets comprising only a few firms, this study uses data from almost all firms in India and hence provides a more comprehensive assessment of the public bus transit industry in India. This is an important distinction in comparison to the datasets used by Kumbhakar et al. (1996) and Singh (2001); (2002); (2005a). Importantly, the impact of network variables on costs is not just included in the regression as in Singh (2005a), but also in the definition of Economies of Density and Scale to reflect the current state of research.

**Table 2.3.1. Recent studies estimating cost functions**

Paper	Cost Definition	Dependent Variables	Functional Form	Data
Windle (1988)	Total cost	Output = passenger miles. Inputs: fuel, labour, capital and materials. Output characteristics: load factor, speed, average trip length, and route miles.	Translog SUR.	Cross section of 91 United States transit firms in 1978/79.
Bhattacharyya et al. (1995)	Total variable cost = labour + fuel	Output = passenger kilometers. Inputs: Labour compensation for traffic and administration, divided by number of people. Fuel = total fuel bill divided by quantity of diesel. Fixed input: Capital = number of vehicles on road per day. Network characteristics: fleet utilization, load factor.	Translog Stochastic Cost Frontier.	Unbalanced panel dataset of 32 publicly owned Indian bus corporations over 1983–1987.
Obeng et al. (2000)	Total cost	Output = vehicle miles. Inputs: Labour compensation divided by total labour hours. Fuel price = total residual cost divided by fuel. Capital price = capital cost	Translog SUR.	Panel dataset of 23 United States transit systems during 1983–1992.
Karlaftis et al. (2002)	Total variable cost	Output = total vehicle miles. Inputs: labour, fuel, materials. Fixed factor: number of buses. Market variables: network size. Time dummy for each year.	Translog.	Balanced panel of 256 United States bus companies during 1986–1994.
Filippini et al. (2003)	Total cost	2 models. Model 1: Output = bus kilometers, Network characteristic = network length. Model 2: Output = seat kilometers, Network characteristic = number of stops. Factors of production: labour, capital, energy.	Translog SUR.	Balanced panel of 34 Swiss bus companies during 1991–1995.
Fraquelli et al. (2004)	Total variable cost	Output = total vehicle kilometers $\times$ average number of seats per bus $\times$ fleet size, prices of variable factors (labour, fuel, materials and services), quasi-fixed input (capital), network characteristics (average commercial speed).	Translog SUR.	Pooled data for 45 Italian municipal transit companies.
Singh (2005a)	Total operating cost = Labour cost + diesel costs + bus costs	Output = revenue passenger kilometers, labour price, diesel price, bus cost.	Translog SUR.	Unbalanced panel of 7 Indian urban bus companies from 1990/91 to 2001/02.
Farsi et al. (2006)	Total cost	Output = seat kilometers provided. Factors of production: labour, capital. Time. Network length.	Translog cost frontier.	Unbalanced panel of 94 Swiss rural bus companies from 1986 to 1997.

### 2.3.1. Functional specification

The early literature employed the linear (Koshal (1970); Miller (1970); Pickrell (1985); Wabe et al. (1975)), log-linear (Lee et al. (1970)), or the Cobb–Douglas functional forms (Keeler (1974)). Krishna et al. (1998) estimate separate log linear specifications for five bus companies in the state of Tamil Nadu in India using a 12 year time series for each of the firms. Most of these studies do not take into account regularity conditions for cost function as derived from neoclassical microeconomic theory (Berechman et al. (1985)). Even estimations where functional forms satisfy neoclassical cost function conditions, the assumed functional



forms (mostly Cobb–Douglas) are highly restrictive on elasticities of substitution (Button et al. (1986)). For instance, the Cobb–Douglas cost function can be described as follows:

$$\text{Ln}C_i = \alpha_0 + \sum_k \alpha_k \text{Ln}y_k + \sum_j \alpha_j \text{Ln}w_j + \varepsilon_i \quad 2.15$$

where  $C_i$  is the total cost,  $\mathbf{w}$  is a vector of  $j$  input prices, and  $\mathbf{y}$  is a vector of outputs. The following restriction is imposed ex-ante:  $\sum_j \alpha_j = 1$ .

Marginal costs, elasticities of cost with respect to the arguments, and elasticities of factor substitution are constant using such specifications. In addition, a number of studies have rejected the Cobb–Douglas form (Berechman et al. (1984); Button et al. (1986); de Borger (1984); Obeng (1984); Williams et al. (1981a); Williams et al. (1981b)). Hence, using the Cobb–Douglas specification is unlikely to be statistically reliable for most mass transit systems. Therefore, flexible forms have been developed with the desirable property that ex-ante restrictions on the technology are not necessary and that these restrictions can be tested for ex-post.

Flexible functional forms have been defined as functions that allows any set of elasticities at any data point with an appropriate choice of parameter values (Caves et al. (1980a)). Examples of flexible functional forms are the Translog, the Generalized Leontief, the Quadratic and the Generalized McFadden. These functions are second order Taylor approximations of an unknown function around a point, usually the mean or the median. For instance, the Translog specification is a second–order approximation of an unknown cost function (or technology) around a specified point. Most studies of bus transit have estimated the Transcendental or Trans Logarithmic (Translog) cost function first introduced by Christensen et al. (1973). This is defined as follows:

$$\begin{aligned} \text{Ln}C_i = & \alpha_0 + \sum_k \alpha_k \text{Ln}y_k + \sum_j \alpha_j \text{Ln}w_j + \sum_k \sum_j \alpha_{kj} \ln w_j \text{Ln}y_k \\ & + \frac{1}{2} \sum_l \sum_j \alpha_{jl} \text{Ln}w_j \text{Ln}w_l + \frac{1}{2} \sum_m \sum_k \alpha_{mk} \text{Ln}y_m \text{Ln}y_k + \varepsilon_i \end{aligned} \quad 2.16$$

Homogeneity in input prices implies the following conditions:

$$\sum_j \alpha_j = 1 \quad \sum_k \sum_j \alpha_{kj} = 0 \quad \sum_l \sum_j \alpha_{jl} = 0$$

Symmetry in input prices implies the following condition:

$$\alpha_{kj} = \alpha_{jk}$$

The limitation of the Translog form is that it does not allow zero output firms to be included in the sample since the natural logarithm is not defined for zero (Caves et al. (1980b)). In such cases, the other flexible functional form, though rarely used for estimating costs in bus

transit (Farsi et al. (2007); Viton (1992); (1993)) following Friedlaender et al. (1983), is a Quadratic function first introduced by Lau (1974). This is defined as follows:

$$C_i = \alpha_0 + \sum_k \alpha_k y_k + \sum_j \alpha_j w_j + \sum_k \sum_j \alpha_{kj} w_j y_k + \frac{1}{2} \sum_l \sum_j \alpha_{jl} w_j w_l + \frac{1}{2} \sum_m \sum_k \alpha_{mk} y_m y_k + \varepsilon_i \quad 2.17$$

The Quadratic form, while allowing for zero output levels, does not always satisfy the neoclassical condition of homogeneity of degree zero in input prices unless imposed exogenously by normalizing all the cost and price variable by one of the input prices (Farsi et al. (2007); Trujillo et al. (2003)). This is referred to as the Normalized Quadratic Cost Function by Martinez-Budria et al. (2003). The symmetry condition remains the same as for Translog.

Both these functional forms allow for a U-shaped average cost function characterized by a regime of decreasing average cost followed by increasing average costs. In addition, concavity in input prices cannot be exogenously imposed and has to be tested for ex ante. In several cases, this condition is not satisfied (Berndt et al. (1979)). In particular, Caves et al. (1980a) highlight the tradeoff between flexibility and the regularity conditions from neoclassical economics. Once parameter estimates for the Translog or any other flexible form are set, then price and income elasticities are determined for all observations. However, there may exist data points, sometimes within the dataset, for which the cost function would not satisfy monotonicity and concavity conditions. Despite these limitations, flexible forms are a significant improvement over more simple specifications such as the Cobb–Douglas.

The above functional forms are typically estimated together with the input cost share equations or factor demand equations derived using Shephard’s Lemma. For the Translog form, the input cost share equation for each of the  $j$  inputs is the following:

$$S_j = \frac{\partial \text{Ln}C}{\partial \text{Ln}w_j} = \alpha_j + \sum_k \alpha_{kj} \text{Ln}y_k + \sum_l \alpha_{jl} \text{Ln}w_l \quad 2.18$$

Using the share equations with the cost function increases the degrees of freedom without adding any additional parameters and hence makes the parameter estimates more efficient. The system of equations is then estimated as a Seemingly Unrelated Regression proposed by Zellner (1962).

Zero output cases usually arise in the estimation of multi-product cost functions, where it may not be ex-ante possible to separate costs between the various outputs produced by the same firm. This is not a concern in our dataset since all firms produce only one output and zero output implies zero expenditure. Hence, only the Translog function is estimated.

### *2.3.2. Defining the dependent variable: Total or variable costs*

A long run cost function assumes all input factors to be variable and hence total costs are minimized. However, in the short run, the level of a fixed input such as capital may be predetermined. Hence, at any point in time, the firm may not minimize cost with respect to all inputs but only with respect to subsets of inputs, conditional on given quantities of the remaining (fixed) inputs. At any given output, the short run cost will be at least as high as the long run cost (Oum et al. (1991)). Hence, it is important to determine if the firm operates with any fixed inputs and estimate costs accordingly. Caves et al. (1981) estimate a variable cost function rather than estimating a total cost function, and then use this variable cost function to estimate the corresponding elasticities for analysis. However, Oum et al. (1991) argue that for non-homothetic production functions, the optimal level of the quasi-fixed (or fixed) inputs, rather than the actual level, should be used to calculate the total costs and the corresponding elasticities. In other words, the long run cost function should be derived by minimizing the short run total cost with respect to the quasi-fixed factors or enveloping the short run cost functions (Pels et al. (2000); Schankerman et al. (1986)).

Most recent studies in the sector have estimated variable or operating cost functions (Fraquelli et al. (2001); (2004); Gagnepain et al. (2002); Jha et al. (2001); Karlaftis et al. (2002)). All these studies use the number of buses as a measure of capital (Oum et al. (1996)). Surprisingly, most such studies report positive variable cost elasticity with respect to the capital stock, contrary to expectations from the neoclassical cost theory which states that variable costs are non-increasing in the fixed variable (capital in this case). This is either ascribed to multicollinearity (Filippini (1996)), excess capital even in the long run because firms are not minimizing costs (Caves et al. (1985); Windle (1988)), or a discontinuous change in the user cost of capital (Oum et al. (1991)).

In our dataset, there is substantial Within Variation in capital expenditure (Standard Deviation = 2266.9) and the number of buses (Standard Deviation = 711.5). Hence, following Obeng (2000), Filippini et al. (2003), and Farsi et al. (2006), a total cost function is estimated. This also avoids the possibility of positive variable cost elasticity with respect to capital. Hence, implicit in our analysis is that all firms are minimizing total costs.

### *2.3.3. Output characteristics*

From the review of the neoclassical cost theory, and its application to network industries, the issues in defining output involve not just defining the output measure, but also output attributes and the implications for Density and Scale Economies.

### 2.3.3.1. Defining output

Transit output is usually defined in the literature in terms of a measure that reflects transit demand (passengers carried), or one that reflects supply (bus–kilometers or bus–hours operated), or a hybrid of the two (passenger kilometers).

Data on bus–kilometers is easily available and this measure is highly correlated with cost items. Importantly, by ignoring demand while defining output, a major source of heterogeneity in a cross section or a panel dataset is avoided. However, supply measures do not reflect the motivation for providing bus services, namely carrying passengers. In addition, unless explicitly accounted for, measures of capital utilization such as the proportion of the fleet being used or the number of seats occupied are not reflected in an aggregate measure such as bus–kilometers.

Demand related measures such as passenger–trips or passenger kilometers are based on actual market transactions and allow more comprehensive economic analyses (Costa (1998)). However, input costs may not systematically vary with demand–related output measures. Secondly, heterogeneity in demand characteristics would need to be addressed by either including additional parameters that reduce degrees of freedom, or using a more complex econometric technique such as stochastic frontier analysis. On the other hand, there is usually strong correlation between demand characteristics, and the spatial and quality attributes of supply, which would in any case require additional parameters to be included in the specification. Finally, whether the market is regulated in terms of bus–kilometers to be delivered or not, a cost function based on cost minimization of total passenger kilometers can still be estimated (Berechman (1993)).

In this research, one of the objectives is to estimate efficient price levels, and hence the definition of output needs to reflect actual market transactions while characterizing the firms' technology. Hence, passenger kilometers are taken as the output measure. As is later reported, the two measures of output, passenger kilometers and bus–kilometers, show a very high level of correlation in our dataset (Table 2.7.2).

### 2.3.3.2. Operating and network characteristics

Output of a transit firm is the aggregate of services provided, that is, a set of routes with varying service characteristics such as area covered, frequency of service, travel speed, etc. In addition, as discussed earlier, the size of an industry is characterized not only by the total output produced but also by the structure of the network served. Such heterogeneity is key to explaining variations in estimates of cost functions in public transit firms (Matas et al. (1998)), particularly related to size (Berechman (1993)). Unless firms are stratified by varying operating characteristics, the results are likely to be skewed towards the more 'influential'

firms (Berechman (1983); (1993); Berechman et al. (1984)). In particular, Berechman et al. (1985) note that it is erroneous to compare cost measures such as elasticities and returns to scale for firms across a cross section, or even over time unless heterogeneity is explicitly taken into account.

To minimize the heterogeneity bias, various operating (or output) characteristics are used as control variables in the specification of the cost function. These include network length (Caves et al. (1984)), number of points served (Filippini et al. (2003)), average network speed (Fraquelli et al. (2001)), average length of each trip (Windle (1988)), average load factor (Levaggi (1994)), various indices of network complexity, etc. Karlaftis et al. (1999) suggest introducing size specific output coefficients for different system sizes. Friedlaender et al. (1980), among others, proposed measures such as average shipment size to further control for aggregation bias. Other factors such as quality and composition of services (Colburn et al. (1992)), ownership pattern (Filippini et al. (2003)), and regulatory regime (Filippini et al. (1994)) could result in significant variation in operating environment and hence influence costs (Berechman (1983)). Moreover, in many cases, operating costs are affected by factors that are not observable or recorded in datasets (Dalen et al. (2003)).

Filippini et al. (1992) reported that costs rise as the number of stops increase for a given network size. Fazioli et al. (1993) and Levaggi (1994) observed that a larger network led to higher costs for a sample of Italian transit firms. Sakano et al. (1997), however, came to an opposite conclusion. Levaggi (1994), Viton (1992), Viton (1993), and Gathon (1989) show that costs decline with higher operational speed, a factor that could explain the substitutability between labour and fuel. However, Fazioli et al. (1993) reject average commercial speed as a network characteristic due to correlation problems despite its extensive use in other studies on bus transit in Italy (Fraquelli et al. (2001)). Matas et al. (1998) reported that efficiency decreases with average fleet age while Viton (1986) found no significant capital–vintage effects. Fraquelli et al. (2004) include a dummy variable for firms offering intercity services. A common demand characteristic is the average load factor. While Kumbhakar et al. (1996) obtain a positive coefficient on this variable while estimating a variable Translog cost function for 32 Indian bus companies over the period 1983–1987, Singh (2001); (2002) report that load factor has a negative effect on total costs using a smaller cross section of nine firms in India over a longer period of 1983–1996. Karlaftis et al. (2002) use dummy variables for each year in the sample as opposed to using a time trend, thus allowing for varying and non–linear technology impacts.

### 2.3.3.3. Economies of Density and Scale

Most studies that distinguish between Economies of Density and Scale in the transport sector report that output can be increased without a proportional increase in costs, though these

gains usually decline over time and output size (Table 2.3.2). The gains due to a proportional increase in output and network size are smaller or even non-existent in some cases (Levaggi (1994)). The output or network characteristic most commonly used is the network length. Other characteristics used include route length, number of stops, and average speed.

**Table 2.3.2. Economies of Scale and Density in bus transport**

Paper	Output attributes	Economies of Scale	Economies of Density
Windle (1988)	Route miles	1.30 for the total cost model, 1.02 for the variable cost model	1.25 for the total cost model, 1.19 for the variable cost model
Fazioli et al. (1993)	Route length	2.61 for the median bus operator	1.70 for the median bus operator
Filippini et al. (1994)	Number of stops	1.37 for the median bus operator	1.11 for the median bus operator
Levaggi (1994)	Network length, Average speed of buses	Short run Economies of Scale = 1.43, long run Economies of Scale = 0.92. Evaluated at mean.	Short run Economies of Density = 1.38, long run Economies of Density = 0.89. Evaluated at mean.
Karlaftis et al. (2002)	Network length	Economies of Scale exist	Short run Economies of Density.
Filippini et al. (2003)	Network length, Number of stops	1.97 for the median operator	1.17 for the median operator
Farsi et al. (2006)	Network length	1.71 for the median operator	2.12 for the median operator

Interestingly, studies that do not distinguish between Economies of Scale and Density do not necessarily report larger values for Economies of Scale than studies that differentiate the two. For instance, Obeng et al. (2000) and Piacenza (2002) report values for Economies of Scale that are comparable with those reported in Filippini et al. (1994) and Levaggi (1994) hence indicating that these definitions seem to be independent of whether output characteristics have been accounted for in the estimation of the cost function. However, recalling that Fraquelli et al. (2004) define output in a manner to account for network characteristics within the elasticity of cost with respect to output, the reported values are higher than most studies. For studies that use datasets from India, Bhattacharyya et al. (1995), do not include network variables in their definition of Economies of Density and Scale despite including them in their regression and report returns to scale of 0.9. Singh (2001); (2002) report Diseconomies of Scale for medium and large firms while using a pooled dataset of nine of the largest firms over a period of 12 years. It is noted that if Economies of Scale decline as output increases, there would be very few firms that would exhibit Economies of Scale in the sample used by Singh (2001); (2002) since they include only very large firms. Singh (2005a) does not include network variables in the regression and hence only reports Economies of Scale.

There is some variation in the estimates according to the definition of output. Demand based outputs measures mostly lead to the conclusion of Scale Economies (Berechman (1983); (1987); Berechman et al. (1984); Button et al. (1986); Hensher (1987)). Supply based

measures on the other hand, give conflicting cost elasticity results. Williams et al. (1981a) found Scale Economies for the larger operators in Illinois but Diseconomies of Scale for smaller ones while Berechman et al. (1984) found Scale Diseconomies for their United States sample. Windle (1988), using data on 91 United States bus firms for the years 1977–1979, concluded constant Scale Economies. The contradicting results between demand and supply based output measures can be explained by recognizing that even with Diseconomies of Scale, while using supply based output measures, it may be possible to increase the number of passengers served without a proportional increase in infrastructure and costs (Vickrey (1980)). de Rus (1990) estimated decreasing or constant returns to scale, when vehicle kilometers was used as the measure of output, and small Scale Economies when passenger trips was the output measure for a cross section of 160 Spanish urban transit systems.

### *2.3.4. Other independent variables*

Apart from output, the neoclassical cost function is specified in terms of input prices, and other variables describing the operating environment and production technology. The definition of these variables and their use in transit literature is discussed in this section.

#### **2.3.4.1. Input prices**

Traditionally, the input set used in transport studies included capital and labour (Viton (1992) and Jha et al. (2001) have labour as the only input). Some studies also include maintenance and energy costs in the analysis. For instance, Fraquelli et al. (2001) pool data from 1996, 1997, and 1998 for 45 municipal local transit companies to estimate a Translog variable cost function with capital as the fixed factor and labour, fuel, and materials and services as the variable factors.

The price variables are either taken as reported by the transit firms or estimated from the total expenditure for an input, per unit of input quantity consumed, as reported by the transit firms (Braeutigam (1984)). For example, total wage bill divided by the total work force or labour hours paid for is often used as a proxy for labour price. Similarly, fuel price is taken either from the market prices reported or as the ratio of total fuel bill divided by the quantity of fuel consumed. Capital costs are generally considered as residual costs after taking into account all other cost items such as fuel and labour.

#### **2.3.4.2. Ownership and management**

Early surveys suggest that ownership and management systems are not correlated with performance and efficiency, even though public operators generally offer higher service levels (Perry et al. (1986)). Recent empirical results are mixed regarding the more efficient form of ownership with some studies finding private ownership not being a significant variable

(Fazioli et al. (1993); Filippini et al. (2003); Jorgensen et al. (1995)) while others find private ownership leading to higher efficiency (Cowie et al. (1999); Kerstens (1996); Perry et al. (1986)).

The dataset at hand does not include private bus operators in India. However, apart from ownership, the management structure may prove important as well. The management structure of public transport companies in India includes corporations, private limited companies, municipal operations, and government departments. The regulatory and legislative framework governing the sector, however, is embodied in the Road Transport Corporations Act (1950) and the Motor Vehicles Act (1988) irrespective of the management structure (Deb (2003)).

Bhattacharyya et al. (1995), analyzing several bus companies in India, assessed different management structures by including dummy variables for each type. They concluded that the form of public ownership and management structure affect efficiency levels. Nationalized firms experience the highest degree of inefficiency, while autonomous public transport corporations are less efficient than operations organized directly by the government. In contrast, using a similar database, Kumbhakar et al. (1996) calculate the change in Total Factor Productivity for each company in the sample. They report that the nationalized firms grow fastest while firms run directly by government transport departments perform worst over time.

Both Bhattacharyya et al. (1995) and Kumbhakar et al. (1996) do not explain how the difference in management structure manifests itself in the cost structure. This is particularly perplexing since the regulatory, financing, and operational oversight is uniform for all bus corporations in India, independent of the management structure. Hence, this research will assess the suitability of alternative management forms of government owned bus corporations in India as in Bhattacharyya et al. (1995) and Kumbhakar et al. (1996). To build on the current literature, however, a longer and wider panel dataset will be used to identify the differences in costs due to different management structures using dummy variables for each type of management structure, namely, Corporation, Government Department, Company, or Municipal Corporation.

## 2.4. Model Specification

The following model specification is proposed based on the literature review presented above and the dataset available. Passenger kilometers have been taken as the output measure since this reflects actual market transactions ( $pkm$ ). Three inputs prices have been taken into account in the model, namely, labour, fuel, and capital ( $P_l, P_f, P_k$ ). Based on the above



described studies, the following network and demand characteristics are included in the analysis to control for heterogeneity: network length ( $NL$ ), average load factor ( $LF$ ), and dummy variables for the area of operation – urban, rural, mixed, or hilly ( $AR_i$ ), and for types of management structure ( $MG_i$ ). The model that has been estimated is the following:

$$C = f(pkm, P_l, P_f, P_k, t, LF, NL, AR_i, MG_i) \quad 2.19$$

In particular, using network length as the hedonic variable to distinguish Economies of Density from Economies of Scale avoids the implicit relationship between output and network characteristics since there is no direct correlation between network length and passenger kilometers unlike that between capacity utilization and output (Jara-Diaz et al. (1996)). A linear time trend has been included to account for pure technical change ( $t$ ). This of course does not account for non-neutral technical change (interaction term between  $t$  and  $P_i$ ) and scale augmenting technical change (interaction between  $t$  and  $pkm$ ).

The second order terms for these technical changes have not been included in the specification since this study does not focus on productivity and technology changes in public transit and additional parameters would need to be estimated that would imply a reduction in the degrees of freedom. The Translog function has been estimated after normalizing at median values for each variable. Linear homogeneity was imposed with capital price as the numeraire.

The complete specification is given below:

$$\begin{aligned} \text{Ln}C = & \alpha_0 + \alpha_y \text{Ln}pkm + \alpha_l \text{Ln} \frac{P_l}{P_k} + \alpha_f \text{Ln} \frac{P_f}{P_k} + \frac{1}{2} \alpha_{yy} \text{Ln}pkm^2 + \frac{1}{2} \alpha_{ll} \text{Ln} \frac{P_l^2}{P_k^2} + \frac{1}{2} \alpha_{ff} \text{Ln} \frac{P_f^2}{P_k^2} \\ & + \alpha_{yl} \text{Ln}pkm \cdot \text{Ln} \frac{P_l}{P_k} + \alpha_{yf} \text{Ln}pkm \cdot \text{Ln} \frac{P_f}{P_k} + \alpha_{lf} \text{Ln} \frac{P_l}{P_k} \cdot \text{Ln} \frac{P_f}{P_k} + \alpha_t t \\ & + \alpha_{LF} \text{Ln}LF + \frac{1}{2} \alpha_{LFLF} \text{Ln}LF^2 + \alpha_{yLF} \text{Ln}pkm \cdot \text{Ln}LF + \alpha_{LF_l} \text{Ln}LF \cdot \text{Ln} \frac{P_l}{P_k} + \alpha_{LF_f} \text{Ln}LF \cdot \text{Ln} \frac{P_f}{P_k} \\ & + \alpha_{NL} \text{Ln}NL + \frac{1}{2} \alpha_{NLNL} \text{Ln}NL^2 + \alpha_{yNL} \text{Ln}pkm \cdot \text{Ln}NL + \alpha_{NL_l} \text{Ln}NL \cdot \text{Ln} \frac{P_l}{P_k} + \alpha_{NL_f} \text{Ln}NL \cdot \text{Ln} \frac{P_f}{P_k} + \alpha_{NLLF} \text{Ln}NL \cdot \text{Ln}LF \\ & + \alpha_{AR1} \text{Ln}AR1 + \alpha_{AR2} \text{Ln}AR2 + \alpha_{AR3} \text{Ln}AR3 + \alpha_{AR4} \text{Ln}AR4 + \alpha_{MG1} \text{Ln}MG1 + \alpha_{MG2} \text{Ln}MG2 + \alpha_{MG3} \text{Ln}MG3 \end{aligned}$$

2.20

In comparison to the literature reviewed above, particularly studies estimating transit costs for India, this study uses a much richer specification including not just environmental and operating characteristics, but also assessing the impact management structure has on costs. In the absence of information on private bus operations in India, and with the continued

government monopoly in most areas, the role of management structure is an important policy variable in India.

## 2.5. Estimation

A panel dataset includes repeated observations of the same units and hence can be used to study time effects and firm effects separately<sup>6</sup>. Estimations using panel datasets could either estimate a single equation, such as a cost function, or a system of equations, such as a Seemingly Unrelated Regression consisting of a cost function and input share equations obtained using Shephard's Lemma. Both single equation regressions and systems of equations can also be estimated as either Fixed Effects or Random Effects depending on assumptions made about intercept and error terms.

### 2.5.1. Fixed Effects

The Fixed Effects model has varying intercepts ( $\alpha_0 + \nu_i$ ) over cross section units or time periods while slope coefficients ( $\alpha_1$ ) remain constant. For  $i = 1, 2, \dots, I$  firms, over  $t = 1, 2, \dots, T$  time periods, the Fixed Effects model can be represented as follows:

$$C_{it} = \alpha_0 + \mathbf{X}_{it} \alpha_1 + \nu_i + \varepsilon_{it} \quad 2.21$$

No distributional or orthogonality assumptions on the Fixed Effects,  $\nu_i$ , are required.

However, a large cross section implies a loss of degrees of freedom in the Fixed Effects estimation and may lead to multicollinearity between regressors, and hence high standard errors, arising from the incidental parameters problem (Neyman et al. (1948)). In addition, Fixed Effects that are constant over one dimension such as the operational area of a firm are not identified in the model and that leads to an overestimation of the Fixed Effect (Cameron et al. (2005); Kumbhakar (2000)). This is a critical factor in selecting an appropriate model for this research given the time invariant dummy variables characterizing operational area and management structure being used in this analysis. Finally, using results from Fixed Effects for prediction purposes, as is required identifying policy implications, is possible only for firms within the sample since the regression estimates are conditional on the Fixed Effects,  $\nu_i$  (Cameron et al. (2005)).

### 2.5.2. Random Effects

The Random Effect model avoids the incidental variables problem by including individual effects in the likelihood function, rather than the likelihood function being conditional on the

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<sup>6</sup> Refer to Baltagi (2002) and Wooldridge (2002) for a detailed description on panel data models.

individual effects (Lancaster (2000)). This is, in effect, a regression with a random constant term (Greene (2003)). The model works on the assumption of orthogonality between the idiosyncratic error term,  $\varepsilon_{it}$ , the explanatory variables,  $\mathbf{X}_{it}$ , and the Random Effect,  $\nu_i$ . In addition, both  $\nu_i$  and  $\varepsilon_{it}$  are assumed to be serially uncorrelated and have constant variance. In other words,

$$\sigma_{\nu_i + \varepsilon_{it}}^2 = \sigma_\nu^2 + \sigma_\varepsilon^2 \text{ and } Cov(\nu_i + \varepsilon_{it}, \nu_j + \varepsilon_{js}) = \begin{cases} \sigma_\nu^2 + \sigma_\varepsilon^2 & \text{if } i = j \text{ and } s = t \\ \sigma_\varepsilon^2 & \text{if } i \neq j \text{ or } s \neq t \end{cases} \quad 2.22$$

where  $\sigma_\nu^2$  and  $\sigma_\varepsilon^2$  are the variances of the individual effect and the idiosyncratic error term respectively.

In addition, Random Effects better identifies firm specific heterogeneity by explicitly controlling for time invariant variables. Out of sample predictions are also possible with Random Effects estimates since ‘individual effects are integrated out as independent random variables’ (Cameron et al. (2005)).

A Random Effect model is estimated by Generalized Least Squares when the variance structure is known and Feasible Generalized Least Squares when the variance is unknown (Schmidt et al. (1984)). If the distribution of  $\nu_i$  is posited to be Gaussian, then the Maximum Likelihood Estimates can be obtained (Pitt et al. (1981)). Other distributional assumptions have been suggested in the literature such as the exponential distribution (Battese et al. (1992)). Following Farsi et al. (2005), only Generalized Least Squares estimates are presented in this paper given the distributional assumptions necessary in using Maximum Likelihood Estimation.

### 2.5.3. Systems of Equations

A Seemingly Unrelated Regression (SUR) improves the efficiency of ordinary least squares estimates by taking into account correlation in the disturbance terms between the cost and the various input cost share equations (Zellner (1962)). Avery (1977) recognized that single equation panel data models could be extended by accounting for error correlations between systems of equations as in a SUR by including additional cross equation variance terms in the covariance matrix of the error terms between equations. Unlike using Zellner (1962) on a time series or cross section dataset, Generalized Least Squares estimates for the system do not equal single equation Generalized Least Squares estimates even with the same set of independent explanatory variables in the presence of cross equation correlated errors (Avery (1977)). Verbon (1980) reports SUR estimates for industry specific labour demand with Random Effects that vary across industries and extends Avery (1977) to allow for

heteroscedasticity. Wan et al. (1992) further extend this to two-way Random Effects with heteroscedasticity while estimating demand for rice, maize, and wheat production functions in China. Beierlein et al. (1981) demonstrate the improvement in estimates from using SUR Random Effects model when compared to simple Ordinary Least Squares and single equation Random Effects to estimate the demand for electricity and natural gas in north eastern United States. Sickles (1985) estimate a Translog cost function along with the input cost shares using Shephard's lemma with random errors for the United States airline industry.

Given the complexity of programming a Fixed Effects or Random Effects SUR model and the focus only on output characteristics in this research, only single equation panel data models have been estimated. A SUR model without individual effects along with the share equations has been estimated to assess the stability of the single equation panel model estimates.

#### *2.5.4. Comparing models*

The Hausman specification test, a comparison of the covariance matrix of the regressors between the two models, is the classical test of whether the Fixed or Random Effects model should be used (Hausman (1978)). This test compares the coefficients on regressors between the consistent Fixed Effects model and the Random Effects model under the null hypothesis that the individual effects are uncorrelated with the other regressors. In most applications, the following principle is used: if there is such a correlation, the Random Effects regressor coefficients are inconsistent. If there is no such correlation, then the Random Effects model is more parsimonious, and hence more efficient. However, Hsiao et al. (2000) note that as in most hypothesis testing, while the null is well specified, consistent coefficients in Fixed Effects in this case, the alternative hypothesis is composite. Hence, the results of testing are indirect, choosing the Random Effects due to less number of parameters to be estimated in this case. They recommend treating Fixed Effects and Random Effects as different models for comparison.

In addition, the Hausman test relies on a common set of coefficient estimates between the two models. In our specification, there exist time invariant firm characteristics that are not identified in the Fixed Effects model but are retained in a Random Effects model. In particular, correlation in the Fixed Effects model may be caused by omitted time invariant variables, and hence Random Effects may provide an improved specification with the addition of such time invariant variables (Cameron et al. (2005)). Hence, the coefficient set is different between the two models estimated. As a result, the Hausman specification test is not useful for such comparison.

In summary, there is no direct comparison between the models being considered in the study, and only a general assessment based on the overall goodness of fit for each model and specification, and the significance level of the key variables being considered is possible.

## 2.6.Data

Data on a total of 70 public bus operators in India over a period of 1989/90 to 2003/04 was collected for this analysis (CIRT (Various years)). This is not a balanced dataset as data for all firms is not available for all years due to mergers, unbundling, and closures. In addition, data for all operators is not available for any year in the dataset. In all, 686 observations were available, ranging from 53 cross sectional units in 2000 to 38 in 2004.

**Table 2.6.1. Area of operation: Number of firms**

Operational Area	Frequency
Rural	3
Urban	14
Mixed	45
Hilly	8

For some years, financial and physical performance data disaggregated by urban and rural operations is available for three firms, namely, Karnataka State Road Transport Corporation, Andhra Pradesh State Road Transport Corporation, and Gujarat State Road Transport Corporation. In these cases, the rural and urban operations have been included as individual firms. However, most observations include information on both rural and urban operations and are classified as mixed (Table 2.6.1).

**Table 2.6.2. Management structure: Number of firms**

Management Structure	Frequency
Corporation	28
Government Department	6
Company	24
Municipal Department	12

In addition, for the nine firms operating in the state of Tamil Nadu, data disaggregated by different geographical divisions is available for most years giving 24 cross sectional units with the management structure of a company. Again, these geographical divisions have been treated as separate firms (Table 2.6.2). In general, though, most firms in the country are structured as Corporations. Operations as municipal departments are currently prevalent in only two states, Gujarat and Maharashtra. In the past, Municipal Corporations in Punjab also

ran public bus transit services. Public bus transit operators as state government departments are present only in small states.

Three inputs have been considered in the analysis, namely labour, energy, and capital. Labour costs include all expenditures related to personnel costs for all categories of staff. Energy costs include only expenditures on diesel. Expenditures on Compressed Natural Gas have been excluded from the analysis as they are present in only four observations. Capital costs are obtained as a residual from total costs after excluding personnel and energy expenditures. This category includes interest, depreciation, taxes, expenditure on tires, lubricants, batteries etc., payment for private operations, and other undefined expenditures. All cost variables have been deflated to take into account inflation. The deflators were calculated from the appropriate inflation indices reported by Government of India (2005):

- Labour costs have been deflated by the Consumer Price Index for Industrial Workers.
- Energy costs have been deflated using the Wholesale Price Index for Fuel, Power, Light, and Lubricants.
- Capital costs were deflated using the Wholesale Price Index for Machinery and Machine Tools.
- Total costs were deflated using the Wholesale Price Index for All Commodities.

Input quantities have been defined as follows:

- Labour: Total staff strength.
- Energy: Kilolitres of diesel consumed.
- Capital: Number of buses on an average during a year.

The price variables are estimated from the total expenditure for each input divided by the input quantity consumed (Braeutigam (1984)). For instance, energy price is the total expenditure on diesel divided by the total diesel consumed. Following Obeng (2000), Filippini et al. (2003), and Farsi et al. (2006), capital price is defined as the residual cost divided by average number of buses in use in a year.

Average load factor, and dummy variables for the area of operation and management structure have been included as network and demand characteristics. In addition, network length has been estimated as a product of the average route length and the number of routes. However, data on the number of routes and the average route length is available from 1997 onwards. Hence, only a shorter panel of eight years can be estimated while including network length as an output characteristic.

**Table 2.6.3. Variables considered in the analysis\***

Definition	Units		Mean	Standard Deviation	Minimum	Maximum
Total Cost	10 <sup>5</sup> Rupees# per annum	overall	14,571.33	22,484.98	76.16	117,758.50
		between		20,363.89		
		within		4,256.39		
Passenger km (pkm)	10 <sup>5</sup> km	overall	101,811.20	149,807.60	94.00	765,269.00
		between		137,439.30		
		within		21,244.03		
Labour price (Pl) = Labour cost / Total staff	10 <sup>5</sup> Rupees per annum	overall	0.31	0.09	0.03	0.66
		between		0.07		
		within		0.06		
Energy price (Pf) = Diesel cost / Diesel consumed	10 <sup>5</sup> Rupees per annum	overall	0.04	0.02	0.00	0.26
		between		0.02		
		within		0.01		
Capital price (Pk) = Residual cost / Average buses held	10 <sup>5</sup> Rupees per annum	overall	2.32	0.92	0.17	6.60
		between		0.79		
		within		0.53		
Labour (L) = Total staff	Number	overall	18,202.15	27,367.73	429.00	131,540.00
		between		24,701.36		
		within		4,079.94		
Energy (F) = Diesel consumed	Kiloliter	overall	56,800.32	83,266.56	110.06	410,448.00
		between		76,040.72		
		within		13,091.37		
Capital (K) = Average buses held	Number	overall	2,576.26	3,904.85	27.00	19,249.00
		between		3,494.00		
		within		711.42		
Load Factor (LF) = Passenger km / Seat km	%	overall	68.62	12.61	16.55	128.57
		between		10.11		
		within		8.17		
Network Length (NL) = Total routes × Average route length	Kilometers	overall	179,727.00	363,351.70	100.08	2,719,122.00
		between		277,775.50		
		within		166,662.60		
Labour cost share	%	overall	41.35%	0.10	4.79%	81.29%
		between		0.08		
		within		0.05		
Energy cost share	%	overall	17.47%	0.05	0.00%	28.37%
		between		0.04		
		within		0.02		
Capital cost share	%	overall	41.19%	0.08	13.43%	93.71%
		between		0.06		
		within		0.06		

\* Area of operation (AR<sub>i</sub>) from Table 2.6.1 and Management type (MG<sub>i</sub>) from Table 2.6.2 are included as dummy variables

#1 Swiss Franc equaled approximately 36 Indian Rupees in February 2008.

## 2.7. Analyses and Results

The data has been analyzed and the estimations carried out in STATA Intercooled Version 10.0. Two different single equation panel data models were estimated, namely, Fixed Effects

and Random Effects. The Random Effects model has been estimated using Generalized Least Squares. In addition, a Seemingly Unrelated Regression (SUR) model has also been estimated along with the share equations to assess the stability of the panel model estimates.

Various specifications have been estimated. The first specification includes the load factor, and dummy variables for area of operation and the management structure for the entire length of the panel (Model 1). A shorter panel of eight years has also been estimated by including the network length as an additional network variable (Model 2). This variable is available only for the last eight years of the panel. The specification with network length is compared with estimates from a specification without network length, but using the shorter panel of eight years (Model 3). This allows us to compare the values of Economies of Scale under the two specifications, that is, while using network length and without using network length. The number of observations and the cross sectional spread for each specification is given in Table 2.7.1.

**Table 2.7.1. Number of observations for each specification**

	Model 1	Model 2	Model 3
Number of observations	680.00	211.00	211.00
Number of years	15.00	8.00	8.00
Number of groups	70.00	51.00	51.00
Min. observations per group	1.00	1.00	1.00
Observations per group: average	9.70	4.10	4.10
Max. observations per group	15.00	8.00	8.00

The correlation matrix given in Table 2.7.2 describes the relationship between the various variables considered in the analysis. As mentioned earlier, the two measures of output, passenger kilometers and bus kilometers, are almost perfectly collinear. As expected, the size variable network length is correlated with the two output measures, and the other heterogeneity characteristic, load factor.

**Table 2.7.2. Correlation matrix**

	pkm	vkm*	P <sub>f</sub>	P <sub>i</sub>	P <sub>k</sub>	LF	NL
pkm	1.000						
vkm	0.989**	1.000					
P <sub>f</sub>	-0.019	-0.016	1.000				
P <sub>i</sub>	0.132	0.090	0.133	1.000			
P <sub>k</sub>	0.127	0.115	0.229**	0.123	1.000		
LF	-0.120	-0.181	-0.101	0.251**	0.336**	1.000	
NL	0.745**	0.771**	-0.038	-0.076	0.120	-0.204**	1.000

\* bus kilometers \*\* Correlation is significant at the 0.01 level.



### 2.7.1. Regression results

The first order coefficients of the regressions are presented below. Dummy variables for operations only in urban areas ( $AR_1$ ) and management structure within a government department ( $MG_1$ ) are omitted to avoid singularity, and hence the coefficients for area of operation and management structure dummies are interpreted relative to these excluded values. The detailed coefficient estimates are presented in section 2.9.

The cost function has to satisfy some regularity conditions. These are that the cost function should be non-decreasing in input prices and output, and linearly homogeneous and concave in input prices. All models satisfy linear homogeneity by construction. In addition, the coefficients on input prices and outputs are positive and significant in all cases. From the detailed results reported in section 2.9, a positive and significant  $\alpha_{yy}$  at median factor prices and output attributes indicates a U-shaped cost curve in all the models (Spady et al. (1978)).

While using the longer dataset in Model 1, the coefficient on time trend is not significant and very close to zero. Hence, there appears to be no pure technical change over the period considered in the regression. It is noted that Singh (2001) finds evidence of significant technological progress, both neutral and embodied, for bus companies in India. However, he estimates a Fixed Effects model using a panel dataset comprising only the nine largest firms in the country, in comparison to a much more comprehensive dataset in this case.

As expected, the load factor is negatively correlated with costs, that is, costs fall as the load factor rises. While Bhattacharyya et al. (1995) and Kumbhakar et al. (1996) report the contrary, the results in Table 2.7.3 are similar to those reported by Singh (2001); (2002). Recalling that the load factor in the dataset is defined as the ratio of the passenger kilometers to the total seat kilometers, the negative coefficient on load factor probably captures the reciprocal relationship of seat kilometers with total costs.

The time invariant variables, that is, the dummy variables for area of operation and management structure, are dropped in the Fixed Effects model. Hence, only the SUR and Random Effects models report coefficients for these variables. In the SUR and Random effects models, urban operations are more expensive than operations with mixed or hilly routes. Cost differences between urban and rural operations however do not appear to be significant. That urban operations are more expensive could in part be explained by lower average speeds in urban areas, a factor that is reported to have a negative influence on costs (Fraquelli et al. (2004); Piacenza (2002); Viton (1992); (1993)).

The least cost effective organizational structure is that of a Corporation, though the cost difference other management forms is not always significant. The most efficient management structure is that of a company.

**Table 2.7.3. Regression results for Model 1**

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
$\alpha_0$	3.925	3.100	12.569**	4.778	6.989*	3.312
$\alpha_y$	0.476***	0.027	0.802***	0.009	0.646***	0.020
$\alpha_f$	0.194***	0.033	0.178***	0.002	0.198***	0.036
$\alpha_l$	0.492***	0.030	0.442***	0.002	0.483***	0.033
$\alpha_t$	-0.001	0.002	-0.006*	0.002	-0.003	0.002
$\alpha_{LF}$	-0.360***	0.058	-0.559***	0.069	-0.513***	0.059
Mixed			-0.204***	0.034	-0.124	0.101
Hilly			-0.060	0.056	-0.692***	0.145
Rural			-0.266***	0.081	0.021	0.196
Company			-0.430***	0.040	-0.344**	0.128
Municipal Undertaking			-0.302***	0.048	-0.300*	0.149
Corporation			0.030	0.037	0.161	0.123
R <sup>2</sup> Overall	0.911		0.953			
F statistic	145.270***					
Wald $\chi^2$					3333.970***	

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level, \*\*\* Variables significant at 99.9% confidence level

The addition of network length to the specification reduces the length of the panel to eight years and removes the rural observations from the dataset (Table 2.7.4). The coefficient on network length has the expected sign; as the network length increases, so does cost. However, the impact of an additional kilometer in network length is modest, only 6.4% in the Fixed Effects model and 13.21% in the Random Effects model.

Except for the Fixed Effects model, the addition of network length as an output attribute marginally reduces the cost elasticity of output at the median value of factor prices and output attributes. This could be because the output attribute being considered here, network length, captures some of the scale effects as suggested by Panzar (1989) and Jara-Diaz et al. (1996). In particular, the coefficients on output,  $\alpha_y$ , in Model 1 and Model 3 are similar to the sum of the coefficients on output and network length,  $\alpha_y$  and  $\alpha_{NL}$ , in Model 2. Hence, Economies of Scale in the three models probably reflects that the output and network effects in Model 2 are being captured by only the output in Model 1 and Model 3. In addition,

including network length reduces the elasticity of total cost with load factor. In fact, in the SUR model, load factor becomes an insignificant.

The loss of observations over seven years also makes the organizational structure less significant. The impact of the other management structures on total costs is ambiguous and depends on the specification adopted. Though Bhattacharyya et al. (1995) and Kumbhakar et al. (1996) report this as a significant factor, the result in Table 2.7.4 is not surprising as all these organizational structures put bus operations directly under the control of the state or municipal government with similar access to financing options, procurement rules, personnel policies, etc.

**Table 2.7.4. Regression results for Model 2**

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
$\alpha_0$	1.738	8.024	-5.711	14.217	-0.832	9.997
$\alpha_y$	0.521***	0.046	0.723***	0.022	0.650***	0.030
$\alpha_f$	0.155	0.060	0.170***	0.003	0.182**	0.071
$\alpha_l$	0.602***	0.057	0.437***	0.004	0.574***	0.067
$\alpha_t$	0.000	0.004	0.004	0.007	0.001	0.005
$\alpha_{LF}$	-0.329**	0.100	-0.148	0.148	-0.365**	0.005
$\alpha_{NL}$	0.064*	0.030	0.086***	0.021	0.132***	0.030
Mixed			-0.793***	0.082	-0.599***	0.145
Hilly			-1.127***	0.125	-1.324***	0.216
Company			-0.355*	0.146	0.612*	0.252
Municipal Undertaking			-0.379*	0.170	0.626*	0.286
Corporation			0.122	0.134	0.881***	0.245
R <sup>2</sup> Overall	0.782		0.970			
F statistic	80.800***					
Wald $\chi^2$					2366.850***	

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level, \*\*\* Variables significant at 99.9% confidence level

The coefficient estimates of Model 2 reported in Table 2.7.4, using the shorter panel while including network length as an output attribute, are not very different from the estimates of Model 3 in Table 2.7.4 that uses the shorter panel but excludes network length as a regressor. As expected, load factor becomes significant if network length is dropped as a regressor, and in the SUR and Random Effects models, the coefficient on output also increases.

**Table 2.7.5. Regression results for Model 3**

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
$\alpha_0$	-0.375	7.984	0.449	16.687	0.396	11.037
$\alpha_y$	0.506***	0.045	0.757***	0.019	0.677***	0.027
$\alpha_f$	0.182**	0.060	0.170***	0.003	0.165	0.078
$\alpha_l$	0.574***	0.053	0.438***	0.004	0.565***	0.070
$\alpha_t$	0.001	0.004	0.001	0.008	0.000	0.006
$\alpha_{LF}$	-0.297**	0.100	-0.348*	0.168	-0.378**	0.133
Mixed			-0.737***	0.078	-0.382**	0.143
Hilly			-0.961***	0.137	-1.462***	0.236
Company			-0.701***	0.155	0.304	0.268
Municipal Undertaking Corporation			-0.848***	0.168	0.215	0.298
R <sup>2</sup> Overall	0.726		0.958			
F statistic	103.200***					
Wald $\chi^2$					1843.520***	

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level, \*\*\* Variables significant at 99.9% confidence level

As described in section 2.5.4, a direct comparison of the three models being used is not possible. Only general comments on the suitability of the various models are feasible, based on their performance, the significance of key variables, and the appropriateness to the research question being studied.

The Random Effects model captures the variation for each firm over time, and between firms. In general, the model performance improves with additional explanatory variables. Even in the smaller panel, including network length (Model 2) leads to an improved fit compared to the specification without network length (Model 3). In addition, the time invariant output characteristics, that is, area of operation ( $AR_i$ ) and management structure ( $MG_i$ ), are significant in most cases in the SUR, and to a lesser extent, the Random Effects model. Hence, the time invariant variables turn out to be important for improving the performance of the models. Thus, the Random Effects and SUR models are preferred to the Fixed Effects model because the Fixed Effects model ignores time invariant firm and output characteristics.

The Hausman Test to compare the Fixed Effects and Random Effects model is not useful in our specifications as a large number of time invariant variables which are not identified in the Fixed Effects model. This results in a dissimilar set of regressors in the Random Effects and the Fixed Effects models since time invariant variables are not identified in the latter. Hence,

a comparison of the coefficients between the two is not possible (Baltagi (2002); Cameron et al. (2005)). Given the improvement in the goodness of fit in the SUR and Random Effects models due to the addition of firm and output characteristics, including the time invariant variables, using the Fixed Effects model would result in a loss of information on the role of these variables in determining costs (Cameron et al. (2005); Kumbhakar (2000)). The low Within Variation for several of the regressors (Table 2.6.3 ) would also result in imprecise standard error estimates of the coefficients in the Fixed Effects model since it relies on within variation to carry out the estimation (Cameron et al. (2005)). In addition, with a larger number of firms than sample length, the Random Effects model is preferred (Kumbhakar (2000)). Random Effects estimates can also be used to make out of sample prediction. Since one objective of this study is to estimate optimal public transit fares based on the costs being estimated in this chapter, the following discussion of the regression results and output characteristics is limited to the Random Effects model.

### *2.7.2. Economies of Density and Scale*

All firms in the sample have been divided into four groups using output quartiles for estimating the Economies of Scale and Density. The first group includes all firms with output less than 2,822.54 million passenger kilometers per annum. The second group includes all firms with output greater than the first quartile of 2,822.54 million passenger kilometers per annum to the median of 6,074.88 million passenger kilometers per annum. The third group has an output range between of 6,074.88 million to 12,295.18 million passenger kilometers per annum. The final group contains all the firms with output greater than 12,295.18 million passenger kilometers per annum. Table 2.7.6 reports the median values for each group estimated at the median values of all other variables.

Almost all firms demonstrate significant Economies of Scale though these reduce as output increases (Table 2.7.6). There is not a large variation in estimates of Economies of Scale between the models with similar length. All firms in the longer sample display Economies of Scale, as is expected since we use a demand based definition of output (Vickrey (1980)). This reduces to about 70% when the sample is reduced to eight years with the largest 30% of the firms showing marginal Diseconomies of Scale. Hence, the inclusion of an explicit size variable such as network length does reduce the impact of output size. In addition, over 70% of the firms can exploit Economies of Density. The Economies of Density and Scale are also quite similar reflecting the low elasticity of cost with respect to network length. Finally, recall that Scale Economies without output characteristics (Model 1 and Model 3) are comparable with Scale Economies estimated with output characteristics (Model 2). This is observed only for firms in Group II and III, that is, with output between 2,822.54 and 12,295.18 million passenger kilometers per annum.

**Table 2.7.6. Median values of output characteristics from the Random Effects Model**

Output quartiles	Output Range in million passenger kilometers per annum	Model 1		Model 2		Model 3	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Economies of Scale							
Group I	<2,822.54	1.976	0.106	2.087	0.486	3.307	0.758
Group II	2,822.54 – 6,074.88	1.674	0.082	1.450	0.199	1.836	0.255
Group III	6,074.88 – 12,295.18	1.465	0.042	1.155	0.119	1.299	0.085
Group IV	12,295.18>	1.238	0.104	0.953	0.094	0.923	0.145
Economies of Density							
Group I	<2,822.54			9.583	8.292		
Group II	2,822.54–6,074.88			2.150	0.468		
Group III	6,074.88–12,295.18			1.293	0.114		
Group IV	12,295.18>			0.842	0.160		
Marginal Costs							
Group I	<2,822.54	0.135	0.037	0.038	0.023	0.070	0.023
Group II	2,822.54–6,074.88	0.099	0.024	0.073	0.023	0.073	0.023
Group III	6,074.88–12,295.18	0.077	0.017	0.089	0.020	0.079	0.017
Group IV	12,295.18>	0.098	0.029	0.185	0.067	0.154	0.076

The latter results are similar to Jha et al. (2001) who also use a smaller sample of nine Indian bus companies over thirteen years with a Translog specification of a variable cost function. Singh (2002), though, reports significant Diseconomies of Scale for medium and large firms in India. However, the sample in the case of Singh (2002) comprises only the nine largest bus companies in India. The sample used in this study includes all the bus companies in India, including small companies. In addition, it is noted that Economies of Scale decline with increase in output as reported both by Singh (2002) and in Table 2.7.6. Hence, the results from the two estimations indicate similar trends. The marginal costs are very similar across the three models. In addition, as output increases, marginal costs first fall and then rise, resulting in the familiar U-shaped curve.

## 2.8. Conclusion

A Translog cost function has been estimated for 70 bus corporations in India using an unbalanced panel between 1989/90 and 1993/94 to evaluate Economies of Density and Scale, and marginal costs. This research builds on previous cost estimations from India using environmental and operating characteristics and management structure as explanatory variables assessing the key policy and non-policy factors affecting transit costs in India.

The results indicate very little technical change in public transit operations in India over the fifteen years considered in the regression. Even though urban operations appear to be more expensive, the difference is not significant, indicating some economies in mixed routes arising from joint rural and urban operations. In terms of organization structure, the least

cost effective organizational structure is that of a Corporation, though the cost difference between other management forms is not always significant. As expected, the impact of the other management structures on total costs is ambiguous and depends on the specification adopted since all organizational structures operate under a similar regulatory and management structure.

Economies of Scale are present in a majority of the firms though the degree of Scale Economies decreases with output. The distinction between Economies of Density and Scale with the introduction of network length as an output characteristic further reduces the gains possible from increase in output. Economies of Density and Scale are quite similar reflecting the low elasticity of cost with respect to network length. The marginal costs are very similar across the three models and reveal a U-shaped curve. The robust estimates of Economies of Density and Scale, and marginal costs indicate how well the regressors selected for the model represent the cost structure of public transit in India.

## 2.9. Appendix. Estimation results

### Model 1

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
$\alpha_0$	3.925	3.100	12.569**	4.778	6.989*	3.312
$\alpha_y$	0.476***	0.027	0.802***	0.009	0.646***	0.020
$\alpha_f$	0.194***	0.033	0.178***	0.002	0.198***	0.036
$\alpha_l$	0.492***	0.030	0.442***	0.002	0.483***	0.033
$\alpha_{yy}$	0.060***	0.012	0.068***	0.006	0.103***	0.010
$\alpha_{ff}$	0.027***	0.004	0.019***	0.001	0.028***	0.004
$\alpha_{ll}$	0.226***	0.028	0.152***	0.005	0.229***	0.030
$\alpha_{yl}$	-0.031**	0.010	-0.014***	0.001	-0.031**	0.011
$\alpha_{yf}$	0.031***	0.007	0.010***	0.001	0.032***	0.008
$\alpha_{lf}$	-0.044***	0.013	-0.009***	0.002	-0.047***	0.014
$\alpha_t$	-0.001	0.002	-0.006*	0.002	-0.003	0.002
$\alpha_{LF}$	-0.360***	0.058	-0.559***	0.069	-0.513***	0.059
$\alpha_{LFLF}$	0.138	0.158	1.058***	0.260	0.269	0.169
$\alpha_{yLF}$	-0.072**	0.026	-0.012	0.033	-0.120***	0.027
$\alpha_{LFl}$	-0.032	0.070	0.040***	0.011	-0.038	0.083
$\alpha_{LFf}$	-0.200**	0.077	0.011	0.010	-0.207**	0.075
Mixed			-0.204***	0.034	-0.124	0.101
Hilly			-0.060	0.056	-0.692***	0.145
Rural			-0.266***	0.081	0.021	0.196
Company			-0.430***	0.040	-0.344**	0.128
Municipal Undertaking			-0.302***	0.048	-0.300*	0.149
Corporation			0.030	0.037	0.161	0.123



	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Labour share						
$\alpha_0$			0.442***	0.002		
$\alpha_y$			-0.014***	0.001		
$\alpha_f$			-0.009***	0.002		
$\alpha_l$			0.152***	0.005		
$\alpha_{LF}$			0.040***	0.011		
Energy share						
$\alpha_0$			0.178***	0.002		
$\alpha_y$			0.010***	0.001		
$\alpha_f$			0.019***	0.001		
$\alpha_l$			-0.009***	0.002		
$\alpha_{LF}$			0.011	0.010		

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level,

\*\*\* Variables significant at 99.9% confidence level

Model 2

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Total cost						
$\alpha_0$	1.738	8.024	-5.711	14.217	-0.832	9.997
$\alpha_y$	0.521***	0.046	0.723***	0.022	0.650***	0.030
$\alpha_f$	0.155	0.060	0.170***	0.003	0.182**	0.071
$\alpha_l$	0.602***	0.057	0.437***	0.004	0.574***	0.067
$\alpha_{yy}$	0.300***	0.032	0.228***	0.024	0.359***	0.029
$\alpha_{ff}$	-0.194	0.115	0.032**	0.011	-0.175	0.137
$\alpha_{ll}$	0.201*	0.091	0.164***	0.010	0.200	0.108
$\alpha_{yl}$	-0.133**	0.044	-0.011**	0.003	-0.118*	0.048
$\alpha_{yf}$	0.168**	0.053	0.008**	0.003	0.164	0.058
$\alpha_{lf}$	0.056	0.095	-0.039***	0.009	0.069	0.113
$\alpha_t$	0.000	0.004	0.004	0.007	0.001	0.005
$\alpha_{LF}$	-0.329**	0.100	-0.148	0.148	-0.365**	0.121
$\alpha_{LFLF}$	-0.239	0.502	2.780***	0.704	0.300	0.629
$\alpha_{yLF}$	-0.345***	0.063	-0.642***	0.082	-0.558***	0.066
$\alpha_{LFI}$	0.314	0.195	-0.027	0.019	0.200	0.293
$\alpha_{Lff}$	-0.398	0.236	0.020	0.016	-0.338	0.244
$\alpha_{NL}$	0.064*	0.030	0.086***	0.021	0.132***	0.030
$\alpha_{NLNL}$	0.026*	0.012	0.028	0.017	0.037	0.013
$\alpha_{yNL}$	-0.062**	0.021	-0.085***	0.018	-0.106***	0.021
$\alpha_{NLI}$	0.094*	0.041	-0.009***	0.003	0.112*	0.060
$\alpha_{Nlf}$	-0.105	0.056	-0.001	0.002	-0.101	0.044
$\alpha_{NLLF}$	0.180***	0.053	0.319***	0.069	0.293***	0.060
Mixed			-0.793***	0.082	-0.599***	0.145
Hilly			-1.127***	0.125	-1.324***	0.216
Company			-0.355*	0.146	0.612*	0.252
Municipal Undertaking Corporation			-0.379*	0.170	0.626*	0.286
			0.122	0.134	0.881***	0.245

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Labour share						
$\alpha_0$			0.437***	0.004		
$\alpha_y$			-0.011**	0.003		
$\alpha_f$			-0.039***	0.009		
$\alpha_l$			0.164***	0.010		
$\alpha_{LF}$			-0.027	0.019		
$\alpha_{NL}$			-0.009***	0.003		
Energy share						
$\alpha_0$			0.170***	0.003		
$\alpha_y$			0.008**	0.003		
$\alpha_f$			0.032**	0.011		
$\alpha_l$			-0.039***	0.009		
$\alpha_{LF}$			0.020	0.016		
$\alpha_{NL}$			-0.001	0.002		

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level, \*\*\* Variables significant at 99.9% confidence level .

## Model 3

	Fixed Effects		SUR		Random Effects	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Total cost						
$\alpha_0$	-0.375	7.984	0.449	16.687	0.396	11.037
$\alpha_y$	0.506***	0.045	0.757***	0.019	0.677***	0.027
$\alpha_f$	0.182**	0.060	0.170***	0.003	0.165	0.078
$\alpha_l$	0.574***	0.053	0.438***	0.004	0.565***	0.070
$\alpha_{yy}$	0.243***	0.026	0.098***	0.015	0.268***	0.018
$\alpha_{ff}$	-0.284*	0.116	0.033**	0.011	-0.237	0.153
$\alpha_{ll}$	0.141	0.087	0.166***	0.010	0.134	0.115
$\alpha_{yl}$	-0.077*	0.031	-0.019***	0.003	-0.100*	0.040
$\alpha_{yf}$	0.107	0.036	0.008***	0.002	0.156***	0.047
$\alpha_{lf}$	0.129	0.093	-0.038***	0.009	0.124	0.123
$\alpha_l$	0.001	0.004	0.001	0.008	0.000	0.006
$\alpha_{LF}$	-0.297**	0.100	-0.348*	0.168	-0.378**	0.133
$\alpha_{LFLF}$	-0.528	0.507	1.905*	0.806	0.082	0.697
$\alpha_{yLF}$	-0.180***	0.041	-0.342***	0.066	-0.311***	0.048
$\alpha_{LFl}$	0.313	0.200	-0.026	0.022	0.059	0.274
$\alpha_{LFf}$	-0.468	0.238	0.022	0.017	-0.358	0.324
Mixed			-0.737***	0.078	-0.382**	0.143
Hilly			-0.961***	0.137	-1.462***	0.236
Company			-0.701***	0.155	0.304	0.268
Municipal Undertaking			-0.848***	0.168	0.215	0.298
Corporation			-0.220	0.145	0.587*	0.260

	Fixed Effects	SUR	Random Effects			
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
$\alpha_y$			-0.019***	0.003		
$\alpha_f$			-0.038***	0.009		
$\alpha_l$			0.166***	0.010		
$\alpha_{LF}$			-0.026	0.022		
Energy share						
$\alpha_0$			0.170***	0.003		
$\alpha_y$			0.008***	0.002		
$\alpha_f$			0.033**	0.011		
$\alpha_l$			-0.038***	0.009		
$\alpha_{LF}$			0.022	0.017		

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level, \*\*\* Variables significant at 99.9% confidence level.

### 3. Estimating public transport demand elasticities in India

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Transport demand modeling developed in the United States in the 1950s with the initial focus on infrastructure planning and management. Much of the research has since focused on the impact of price changes on ridership using price elasticity estimates (Cervero (1990)). In recent years, the focus has shifted to the influence of policy parameters on travel demand, and their use as a means to ensure the sustainability of the sector (European Commission (1995); (2000)).

There are two major types of empirical transit demand studies, namely, those derived from the Random Utility Theory that analyze the choice of a transport mode (Oum (1989); Winston (1983)), and those derived from conventional analysis of consumer utility maximization that analyze continuous consumption patterns. In the former, the transport good is considered to be discrete, and demand is analyzed as a choice problem between competing modes such as bus and personal vehicles given a fixed level of aggregate travel (Oum et al. (1992)). In the latter, quantity changes in demand are analyzed using demand models that take quantity as a continuous variable (McCarthy (2001)). Importantly, elasticities estimated from discrete choice models do not correspond to direct price elasticities in the neoclassical sense (Oum (1979b)). Changes in the economic environment in the case of continuous goods, however, result in changes in quantity consumed. Moreover, for the estimation of these demand functions, aggregate as well disaggregate data can be used.

Demand analysis in the case of a continuous variable, in turn, follows either of two approaches. The first approach estimates a system of equations simultaneously for several commodities or commodity groups. The second focuses only on one commodity, or a commodity group, and hence essentially estimates the demand in a single market. In either case, with a complete systems approach that is theoretically more consistent, a more comprehensive dataset is required that includes demand for, or expenditures on, all commodity groups. In the absence of such an extensive dataset, equations are specified in a more ad hoc manner including cross-commodity influences from only close substitutes and complements (Thomas (1987)).

The empirical approach used for any estimation thus is dependent on the research objectives, and is constrained by the data available. This research uses an unbalanced aggregate panel dataset between 1990/91 and 2000/01 for 22 large states in India to assess the price and income effects on public bus transport demand. Here, direct price elasticities can be obtained

after estimating an aggregate demand model and hence the choice based approach is not used in this study. In terms of estimating an aggregate demand system, a comprehensive dataset that includes information on all household expenditures on all commodities is required. Consequently, estimation of a system of equations is not possible using information only on one commodity, as is the case with the dataset available for this study.

Only states with government run public transit services are included in the analysis since this is the only data available. Different static and dynamic panel data models are estimated to compare the short run and long run effects of price, income, and other changes. Demand characteristics are then reported in terms of price, income, and service quality elasticities.

The following two sections briefly describe elements of neoclassical consumer theory, and discuss issues in specifying aggregate demand functions arising from the theory. Section 3.3 discusses the relevant literature on number, timing, and spatial distribution of trips by mode in estimating travel demand, all of which are infinitely faceted and hence can result in a large variety of alternatives for each consumer, making travel demand modeling complex (Jovicic et al. (2003)). The estimation process and the econometric models used are given in section 3.4. The specification used in this research is given in section 3.5. Section 3.6 describes the data used in the analysis. Section 3.7 presents the results of the analysis and discusses the implications therein. Finally, section 3.8 concludes.

### 3.1. Review of consumer theory

A consumer's market demand correspondence<sup>7</sup>  $\mathbf{x}(\mathbf{p}, w_i)$  assigns a set of chosen consumption bundles, comprising quantities of selected goods and services,  $k$ , for each pair of individual wealth ( $w$ ) and the vector of prices of all commodities ( $\mathbf{p}$ ). Formally, each consumer  $i$ 's demand correspondence can be represented as follows (Mas-Colell et al. (1995)):

$$\mathbf{x}^i(\mathbf{p}, w_i) = \begin{bmatrix} x_1^i(\mathbf{p}, w_i) \\ x_2^i(\mathbf{p}, w_i) \\ \dots \\ x_K^i(\mathbf{p}, w_i) \end{bmatrix} \in \mathfrak{R}^K \quad 3.1$$

In classical consumer demand theory, this correspondence arises from utility maximization<sup>8</sup>. Thus,  $\mathbf{x}^i(\mathbf{p}, w_i)$  is defined as the following (Mas-Colell et al. (1995)):

<sup>7</sup> A single value assignment leads to a demand function.

<sup>8</sup> The dual in this case, expenditure minimization, results in compensated or Hicksian demand. The key difference between the ordinary and the compensated demand is that price effects in the latter comprise only substitution effects, and hence exclude income effects.

$$\mathbf{x}^i(\mathbf{p}, w_i) = \left\{ \mathbf{x}^i, \mathbf{y}^i \in \mathfrak{R}^K : U(\mathbf{x}^i) \geq U(\mathbf{y}^i) \quad \forall \mathbf{p} \cdot \mathbf{y}^i \leq w_i \right\} \quad 3.2$$

where  $\mathbf{p} \cdot \mathbf{y}^i \leq w_i$  includes all commodity bundles,  $\mathbf{y}^i$ , that the consumer can afford for a given wealth level,  $w_i$  and  $U(\mathbf{y}^i)$  is the utility achieved by consuming a given commodity bundle,  $\mathbf{y}^i$ .

Such demand functions are said to be integrable (Jorgenson (1997)). Under the assumptions of rationality and convexity of the preference structure that gives the utility function, and local non-satiation, the demand function will satisfy the following properties (Deaton et al. (1980)):

- The demand correspondence is homogeneous of degree zero in  $(\mathbf{p}, w_i)$ , that is,
 
$$\mathbf{x}^i(\mathbf{p}, w_i) = \mathbf{x}^i(\alpha\mathbf{p}, \alpha w_i).$$
- Walrus' law:  $\mathbf{p} \cdot \mathbf{x}^i = w_i$ .
- Convex preferences result in demand correspondences that are convex. Strictly convex preferences result in single valued demand correspondences, that is, demand functions.

### 3.1.1. Changes in demand

The demand for any commodity depends on its price and the prices of all other commodities, individual wealth levels, and tastes.

#### 3.1.1.1. Price effects

From the demand correspondence, price effects,  $\partial_{\mathbf{p}} \mathbf{x}^i(\mathbf{p}, w_i)$ , can be defined as following (Mas-Colell et al. (1995)):

$$\partial_{\mathbf{p}} \mathbf{x}^i(\mathbf{p}, w_i) = \begin{bmatrix} \frac{\partial x_1^i(\mathbf{p}, w_i)}{\partial p_1} & \dots & \frac{\partial x_1^i(\mathbf{p}, w_i)}{\partial w_K} \\ \dots & \dots & \dots \\ \frac{\partial x_K^i(\mathbf{p}, w_i)}{\partial w_1} & \dots & \frac{\partial x_K^i(\mathbf{p}, w_i)}{\partial w_K} \end{bmatrix} \in \mathfrak{R}^K \quad 3.3$$

In particular,  $\partial x_k^i(\mathbf{p}, w_i) / \partial p_l$  is the price effect of the price of good  $l$  on the demand for good  $k$ .

This includes both the *substitution effect*, that is the effect of a change in relative prices between the goods for a fixed real wealth level, and the *income or wealth effect*, which measures the change in demand due to the change in real wealth arising from a change in the price. While  $\partial x_k^i(\mathbf{p}, w_i) / \partial p_k \leq 0$  for most commodities, if the demand curve is upward sloping, then  $\partial x_k^i(\mathbf{p}, w_i) / \partial p_k > 0$  and the commodity is called a *Giffen good* (Deaton et al. (1980)).



The two measures of *price elasticity of demand* can then be defined using the price effects (Mas-Colell et al. (1995)).

$$\text{Own price elasticity: } e_k^p(\mathbf{p}, w_i) = \frac{\partial \text{Ln}x_k^i(\mathbf{p}, w_i)}{\partial \text{Ln}p_k} \quad 3.4$$

$$\text{Cross price elasticity: } e_{kl}^p(\mathbf{p}, w_i) = \frac{\partial \text{Ln}x_k^i(\mathbf{p}, w_i)}{\partial \text{Ln}p_l} \quad 3.5$$

These describe the percentage change in demand as price changes.

### 3.1.1.2. Wealth effects

The Engel curve, or the *wealth expansion path*, describes the relationship between individual wealth and demand, for a given level of prices, say  $\bar{\mathbf{p}}$  (Deaton et al. (1980)). Formally,

$$W^i = \{ \mathbf{x}^i(\bar{\mathbf{p}}, w_i) : w_i > 0 \} \in \mathfrak{R}_+^K \quad 3.6$$

Wealth effects,  $\partial_w \mathbf{x}^i(\mathbf{p}, w_i)$ , can then be defined as the following:

$$\partial_w \mathbf{x}^i(\mathbf{p}, w_i) = \begin{bmatrix} \frac{\partial x_1^i(\mathbf{p}, w_i)}{\partial w_i} \\ \frac{\partial x_2^i(\mathbf{p}, w_i)}{\partial w_i} \\ \dots \\ \frac{\partial x_K^i(\mathbf{p}, w_i)}{\partial w_i} \end{bmatrix} \in \mathfrak{R}^K \quad 3.7$$

A commodity is said to be *normal* if  $\partial_w x_k^i(\mathbf{p}, w_i) \geq 0$ . Conversely,  $\partial_w x_k^i(\mathbf{p}, w_i) < 0$  implies that commodity  $k$  is an *inferior* good.

In most empirical studies, the estimated demand function would include income, instead of wealth, as an argument. In such studies, the *income elasticity of demand* is often estimated as an indicator of the wealth effects. For each commodity,  $k$ , this is defined as the following:

$$e_k^w(\mathbf{p}, w_i) = \frac{\partial \text{Ln}x_k^i(\mathbf{p}, w_i)}{\partial \text{Ln}w_i} \quad 3.8$$

### 3.1.2. Differentiating preferences

An estimated demand function characterizes a representative consumer. That is, it predicts the vector of all commodities demanded for each pair of wealth ( $w$ ) and the vector of prices

of all commodities ( $\mathbf{p}$ ). Any deviation from the observed demands is then only due to random measurement errors. However, such an approach implicitly assumes that all consumers are identical in their preferences, and all variation in demand can be explained using only the variation in individual wealth and the price vector between individuals. This is a restrictive assumption given the large differences in socioeconomic and demographic characteristics observed between consumers. Such differences can be used as indicators of variation in preferences and empirical studies include such variables in demand estimation (McCarthy (2001)). The estimated aggregate demand function can then be represented as  $\mathbf{x}(\mathbf{p}, w, \mathbf{s})$  where  $\mathbf{s}$  is a vector of socioeconomic and demographic characteristics.

### 3.2. Individual demand and the Aggregation Problem

Consumer theory reveals that the demand of an individual consumer can be expressed in terms of a price vector comprising all commodities in the market, and the consumer's income<sup>9</sup>. Given individual demands,  $\mathbf{x}^i(\mathbf{p}, w_i)$ , the aggregate market demand can be written as the sum of individual market demands:

$$\mathbf{x}(\mathbf{p}, w_1, w_2, \dots, w_I) = \sum_i \mathbf{x}^i(\mathbf{p}, w_i) \quad 3.9$$

while the average market demand would be the following:

$$\bar{\mathbf{x}}(\mathbf{p}, w_1, w_2, \dots, w_I) = \frac{1}{I} \sum_i \mathbf{x}^i(\mathbf{p}, w_i) \quad 3.10$$

That is, the aggregate market demand depends not only on the price vector,  $\mathbf{p}$ , but also on the wealth levels of each individual,  $w_i$ .

Hence, aggregate market demand is a function of the distribution of wealth. This is clearly a limitation for empirical analysis, as often only data on aggregate wealth (or income) or average income,  $\bar{w}$ , is available and not its distribution (Thomas (1987)). While consumer theory postulates a relationship between the quantity demanded, and prices and income for an individual, it is not necessary that the relationship be replicated for aggregate demand, and prices and aggregate income. The conditions under which the individual relationships can be aggregated to an economy wide macro relationship such as those of a 'representative individual' are referred to as the *Aggregation Problem* (Deaton et al. (1980)). In particular, *Exact Aggregation* is possible if:

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<sup>9</sup> Refer to Deaton et al. (1980), Thomas (1987), and Filippini (1997) for a more detailed exposition on the Aggregation Problem

$$\bar{\mathbf{x}}(\mathbf{p}, w_1, w_2, \dots, w_I) = \bar{\mathbf{x}}(\mathbf{p}, \bar{w}) \quad 3.11$$

where  $\bar{w} = \left( \frac{w^i}{I} \right)$  is the average income. In other words, Exact Aggregation implies that aggregate or average demand does not depend on the distribution of income across consumers.

To see the Aggregation Problem in the case of a linear demand function<sup>10</sup>, consider individual demand that is described as follows:

$$x_k^i = \alpha_o^i + \mathbf{p}' \alpha_p^i + \alpha_w^i w^i \quad 3.12$$

where  $x_k^i$  is the demand for commodity  $k$ , of household  $i$ , for each pair of individual wealth ( $w^i$ ) and the vector of prices of all commodities ( $\mathbf{p}$ ).  $\alpha_o^i, \alpha_p^i, \alpha_w^i$  are parameters that can then be estimated empirically.

Then aggregate demand equals the following:

$$x_k = \sum_i x_k^i = \sum_i \alpha_o^i + \mathbf{p}' \sum_i \alpha_p^i + \sum_i \alpha_w^i w^i \quad 3.13$$

In terms of average demand,

$$\begin{aligned} \bar{x}_k &= \frac{1}{I} \sum_i x_k^i = \frac{1}{I} \sum_i \alpha_o^i + \mathbf{p}' \frac{1}{I} \sum_i \alpha_p^i + \left( \sum_i \frac{\alpha_w^i w^i}{w^i} \right) \frac{1}{I} \left( \sum_i w^i \right) \\ &= \bar{\alpha}_o + \bar{\alpha}_p \mathbf{p}' + \left( \sum_i \frac{\alpha_w^i w^i}{w^i} \right) \bar{w} \end{aligned} \quad 3.14$$

where  $\bar{w} = \frac{1}{I} \sum_i w^i$  is the average income. Hence, all parameters can now be expressed as the arithmetic mean of the parameters from the individual demand equation, except for the coefficient on average income. This latter term is the weighted mean of individual  $\alpha_w^i$ s with weights being equal to the proportion of aggregate income attributed to each individual.

In principle, though, average wealth can be used to represent average demand if its assumed that the marginal effects of income changes are constant across all consumers, and across all levels of consumption (Deaton et al. (1980); Filippini (1997)). Formally,

$$\partial_w x_k^i(\mathbf{p}, w_i) = \partial_w x_k^j(\mathbf{p}, w_i) \quad 3.15$$

for any two consumers,  $i$  and  $j$ , and for each commodity  $k$ . In that case,

<sup>10</sup> Example adapted from Thomas (1987) and Stoker (1993).

$$\mathbf{x}(\mathbf{p}, w_1, w_2, \dots, w_I) = \sum_i \mathbf{x}^i(\mathbf{p}, w_i) = \mathbf{x}(\mathbf{p}, w) \quad 3.16$$

where  $w = \sum_i w^i$ . This is possible only if individual preferences are homothetic or quasi-linear such as the linear case described above (Gorman (1953)). This implies that  $\alpha_w^i = \alpha_w \vee i$ , and hence,  $\sum_i \alpha_w^i w^i / w^i = \alpha_w$ . The expenditure function that arises from such quasi-linear specification is referred to as the Gorman form (Gorman (1953)) and can be written as follows:

$$E^i(\mathbf{p}, u^i) = \beta_o^i(\mathbf{p}) + \beta_u(\mathbf{p})u^i \quad 3.17$$

where  $E^i(\cdot)$  is the total expenditure of consumer  $i$ , and  $\beta_o^i(\mathbf{p})$  and  $\beta_u(\mathbf{p})$  are concave functions in prices. Interestingly, the linear relationship between demand and total expenditure would also extend to other consumer attributes such as demographic or socioeconomic variables.

Aggregation issues become more significant with increasing complexity of the functional form. For instance, if the functional form assumed were log linear, then instead of defining the aggregate variables as the arithmetic means of individual demand variables, these would have to be defined as the geometric means.

A weaker condition than the equal marginal propensity to consume described above is given by the *Convergence Approach* (Thomas (1987)). According to this, if  $\alpha_w^i$  and  $w^i$  are independently distributed, then in a large sample, the weighted mean approximates the arithmetic mean. That is,

$$\sum_i \alpha_w^i w^i / w^i = \alpha_w \quad 3.18$$

Hence, aggregation as defined above is a reasonable approximation.

Muellbauer (1975); (1976) generalized Gorman's concept of a representative consumer to allow for non-homothetic preferences and nonlinear demand defining the representative consumer in terms of budget shares and not quantities consumed. Here aggregate expenditure shares depend on prices and a function of individual expenditures that is not restricted to aggregate or per capita expenditure. In further work, Lau (1982) provides a general framework where aggregate demand functions depend on symmetric functions of individual expenditures and household attributes. Generalized linearity allows significant heterogeneity in consumer preferences (Stoker (1993)). Here, Gorman (1953) is a special case with only one statistic describing the population of consumers, namely, aggregate

expenditure, and Muellbauer's model involves two statistics, one of which must be aggregate expenditure.

In summary, homothetic or quasi-linear individual preferences allow aggregation. However, exact linear aggregation is clearly a restrictive assumption and restricts the relationship between demand for individual goods and income (Deaton et al. (1980); Jorgenson (1997)), and has been empirically discredited (Houthakker (1957)). Nevertheless, in the absence of disaggregated wealth (or income) data, it is one that is often implicitly assumed.

As described in detail in section 3.6, there is a reasonably large panel dataset comprising 206 observations that is available for this study. Hence, appealing to the independence assumption between  $\alpha_w^i$  and  $w^i$  in the convergence approach, linear exact aggregation is assumed to be approximated here.

### 3.3. Literature review

Transport demand models need to account for the peculiar characteristics of transport markets (Small et al. (1999)). Since transport is a derived demand, it encompasses several interrelated decisions of mode, destination, vehicle ownership, and location. In addition, every trip is unique in terms of temporal, origin-destination, and purpose characteristics. Finally, demand is sensitive to service quality attributes. The effect on transit demand of these factors is generally expressed in terms of elasticities. Statistically, isolating the impact of these different factors is often the key issue most research focuses on (Cervero (1990)).

Recognizing this, Berechman (1993) defines a three-phase methodological framework as a common approach to identifying factors influencing transit travel demand. First, a theoretical model of household travel decision making is defined. This is followed by an analytical specification of a travel demand function including explanatory variables. The exact specification here would depend on the preceding theoretical model. The third phase is an empirical estimation of this demand function. The results from this estimation indicate the statistical significance of the various demand determinants and their relative contribution to travel decisions. This three-phase framework reflects the complexity of modeling travel demand comprising activity location, and demographic and socioeconomic changes.

The literature has been reviewed in the context of the framework suggested by Berechman (1993) assessing the impact that different specifications and estimation approaches have on demand elasticities. In combination with the data available, the literature review allows identification of variables to be included and estimation of an appropriate specification to obtain the price elasticities of demand. The focus in this review is only on aggregate demand estimations, ignoring the extensive literature estimating discrete modal choices. A summary

of some recent studies using either panel data or those estimating aggregate demand functions is presented in Table 3.3.1. Following that, a review of some issues in estimating travel demand using aggregate data, and how they have been addressed in the relevant literature, are outlined.

Dargay et al. (1999) present a comprehensive review of the literature followed by demand estimations at the national, regional, and county levels in the United Kingdom, using annual time series data between 1970 and 1996. They use a dynamic specification of aggregate demand relating journeys per capita to real bus fares defined as revenue per journey, real per capita income, and service level defined as bus kilometers. By estimating a dynamic relationship, they distinguish between short run and long run elasticities, with the short run defined by the periodicity of the data, one year in this case. The estimated short run price elasticity for the entire country is  $-0.4$  increasing to  $-0.9$  in the long run. The regional price elasticities vary between  $-0.2$  and  $-2.0$  in the short run and  $-0.4$  and  $-1.7$  in the long run. Service quality elasticities at the national level are estimated to be  $0.4$  in the short run and  $0.9$  in the long run. The wealth effects are measured using the income elasticities and vary between  $-0.3$  and  $-0.4$  in the short run and  $-0.5$  and  $-1.0$  in the long run, making public transport an inferior good.

Romilly (2001) uses annual time series between 1953 and 1997 for the United Kingdom excluding London, to estimate a dynamic log linear demand function as a single equation Auto Regressive Distributed Lag model, after correcting for cointegrating relationships. Demand is defined as passenger journeys per person, with the regressors being bus fares and motoring costs, real personal disposable income, and service frequency proxied by vehicle kilometers per person. The fare elasticity is estimated to be  $-0.38$  in the short run and  $-1.03$  in the long run, the income elasticities are  $0.23$  in the short run and  $0.61$  in the long run, and finally, service elasticities are  $0.11$  in the short run and  $0.30$  in the long run.

Dargay et al. (2002) estimate a partial adjustment model relating per capita bus patronage to bus fares, income, and service level, using a panel dataset of 46 counties in England for the period 1987–1996. Two specifications are estimated, namely, log linear and semi log, with only the transit fare in levels in the latter. The models estimated include Fixed Effects, Random Effects, and Random Coefficients, where again only the coefficients on transit fare vary between counties. Interestingly, demographic variables are not found to be significant in the estimation. The results are similar to Dargay et al. (1999).

Bresson et al. (2003) estimate demand as a function of fares, service supply, and income using separate panels of 46 counties in England over 1987 and 1996, and 62 French urban areas over 1986 and 1995, with a partial adjustment specification. They estimate Fixed and Random Effect models and compare the results with a Random Coefficients approach,

suggesting that the latter provide improved elasticity estimates. The English dataset is the same used by Dargay et al. (2002) while the French panel consists of 62 urban areas between 1987 and 1995. The fare elasticities for the two countries lie in the interval of  $-0.2$  to  $-0.5$  in the short run and  $-0.5$  to  $-0.8$  in the long run.

Only a few studies have used panel data that combine cross sectional and time series data. The current research is possibly one of the very few studies estimating travel demand using aggregate data for developing countries. Unlike other studies that estimate demand functions for India using datasets comprising only a few firms or cities, this study uses panel data from almost all states in India and hence provides a comprehensive analysis of public transit demand in India. It also complements the cost analysis of chapter 2 and hence could be used for the developing alternative pricing regimes for public bus transit. In terms of methodology, this research compares the results from several econometric models detailed in section 3.4, that have not all been applied in this context.

**Table 3.3.1. Recent studies estimating demand functions**

Paper	Variables	Functional Form & Estimation Method	Data	Price elasticity		Income elasticity		Service elasticity	
				Short run	Long run	Short run	Long run	Short run	Long run
Dargay et al. (1999) <sup>11</sup>	Two models: Bus passenger kilometers per capita and bus trips per capita bus fares, disposable income, car ownership and motoring costs used only in the structural models.	Two types of models: Error Correction Models and Structural Models.	Time series of annual observations between 1970 and 1996 for the United Kingdom.	From -0.33 to -0.40 for trips. -0.18 to -0.19 for passenger kilometers	From -0.62 to -0.95 for trips. -0.43 to -0.92 for passenger kilometers	From 0.18 to 0.41 for trips. 0.05 to 0.16 for passenger kilometers	From -0.45 to -0.80 for trips. -0.15 to -0.63 for passenger kilometers		
Romilly (2001)	Bus journeys per capita. Personal disposable income, index of bus fares, index of motoring cost, service frequency measured by vehicle kilometers per person.	Log linear model, estimated as a single equation Auto Regressive Distributed Lag model after corrections for cointegrating relationships.	Time series of annual observations between 1953 and 1997 for United Kingdom excluding London.	-0.38	-1.03	0.23	0.61	0.11	0.30

<sup>11</sup> Only national level results reported.



Paper	Variables	Functional Form & Estimation Method	Data	Price elasticity		Income elasticity		Service elasticity	
Dargay et al. (2002)	Bus journeys per capita fare, service level, per capital disposable income, pensioners in population, motoring costs.	Partial adjustment Fixed Effects, Random Effects, and Random Coefficient models. Two specifications: log linear, semi log where only fares are in levels and not logs.	Panel data between 1987 and 1996 for 46 counties in United Kingdom.	From -0.33 to -0.44	From -0.68 to -0.75	From -0.39 to -0.60	From -0.81 to -1.02	0.42 to 0.49	0.79 to 1.03
Bresson et al. (2003) <sup>12</sup>	Journeys per capita. Mean fare defined as revenue per trip, service measured by vehicle kilometers per capita, disposable income per capita	Two specifications: Semi log with only fares being in levels, and log linear. Estimated as Arellano and Bond fixed coefficients and random coefficient models	Panel data of 46 county annual observations in United Kingdom and 62 urban areas in France during 1987 and 1996.	-0.53 for England and -0.40 for France	-0.73 for England and -0.70 for France	-0.48 for England and -0.01 for France	-0.66 for England and -0.02 for France	-0.71 for England. -0.19 for France	-0.97 for England. -0.33 for France

<sup>12</sup> Only fixed coefficients' results reported.

### *3.3.1. Defining demand*

Most travel demand models use the number of trips or passengers as the dependent variable (Dargay et al. (2002); Hanly et al. (1999); Romilly (2001)). A trip, comprising a combination of an origin with a destination, can be definitely defined as a commodity, and hence can be priced. Dargay et al. (1999) is the only study in the literature review undertaken that uses passenger kilometers as the measure of demand for their aggregate national analysis of travel demand. However, using only the number of trips or passengers as a measure of travel demand ignores an important characteristic of demand, the length of each trip. This is clearly an important parameter that also reflects the motivation for the supply and pricing of public transit services.

The other issue in the definition of the dependent variable is that demand is often normalized by a size measure such as population, as is reflected in Table 3.3.1. However, as FitzRoy et al. (1999) point out, if travel demand is not completely localized, then such normalization would not reflect the complete magnitude of operations. Data on travel demand used in this research has been obtained from all the government owned public transit firms operating in India. Several firms have a few routes that terminate outside their primary area or state of operation. However, the share of the traffic of these routes is relatively small.

In this research, the objective is to identify factors that influence public bus transit demand from the perspective of the bus transport industry. Hence, the definition of demand needs to reflect actual market transactions. Using passenger kilometers as an output measure allows transit demand to be related to a supply measure and hence can be used to analyze public transit markets, as is the objective of this research. It is also noted that passenger kilometers has been used as the output measure in the estimation of the cost function in chapter 2. The two measures of transit demand, the number of passengers and passenger kilometers, are very highly correlated in the dataset used in this analysis, with a correlation of over 90%. Hence, passenger kilometers are taken as the output measure. Moreover, a measure of the extent of operation, proxied by the population of the state that the firm is based in, could be suitably used as an indicator of market size.

### *3.3.2. Independent variables*

The studies listed in Table 3.3.1 show that the empirical estimation of a demand function is determined by monetary and non-monetary variables. Monetary variables include the price of the product, prices of available alternatives, and wealth or income levels. Non-monetary variables include non-price product attributes such as quality and other characteristics, and consumer tastes. In estimating transit demand, the non-monetary attributes include product characteristics such as access to the network, travel time, and quality of service. Consumer

tastes are represented by non-income characteristics of households such as demographic or cultural attributes (Goodwin et al. (1985)). Hence, transit demand can then be described as follows (Berechman (1993)):

$$x = x(p, w, \mathbf{y}, \mathbf{s}, \mathbf{q}, \mathbf{p}_v, \mathbf{L})$$

where  $x$  is transit demand in units of trips or passenger trips,  $p$  is public transit fare,  $w$  is the aggregate wealth or income level,  $\mathbf{y}$  is a vector of outputs (such as vehicle kilometers),  $\mathbf{s}$  is a vector of passenger characteristics (including income, car ownership and other socioeconomic factors),  $\mathbf{q}$  is a vector of service attributes (frequency of service, reliability, speed of travel, period of operation and route design),  $\mathbf{p}_v$  is a vector of prices of alternative modes,  $\mathbf{L}$  is a vector of land use characteristics (rural or urban (Meurs et al. (1990)), population density). Since data on actual fares for each trip is not always available, the public transit fare is usually approximated by the revenue per trip or revenue per passenger kilometer adjusted for an inflation measure (Balcombe et al. (2004)).

The two significant and long run influences on travel demand are land use and urban structure changes, and socioeconomic characteristics (Berechman (1993)). Socioeconomic characteristics include demographic factors (population density, age distribution, sex ratio), economic factors (per capita income, share of services in employment and output), and social factors (private car ownership, female participation in the labour force, proportion of school going children) (Goodwin et al. (1985)).

Income is the most important socioeconomic characteristic that affects transit demand (Berechman (1993)). A higher income is associated with lower demand for public transit. This inverse relationship is due to two factors, namely, car ownership and value of time. A rise in income is correlated with a higher rate of car ownership and the value of time that trip makers perceive, hence leading to a lower demand for transit (Dargay et al. (1999)). This effect is different from the direct income effect where a rise in income is associated with greater demand for travel. Empirical analysis can help distinguish between these two effects in terms of income and car ownership elasticities.

Other socioeconomic and demographic characteristics such as occupation, lifestyle, age, and gender are also known to affect the demand for transit (Kemp (1973); Wabe (1969)). Matas (2004) uses the level of suburbanization and employment levels to explain demand changes in Madrid during 1979–2001. The empirical estimation of the effect of these variables on transit demand is not always straightforward since many of them are highly correlated with income or with other socioeconomic variables.

A public transit demand model should include some variables representing the quality of the service. Some studies use output measures such as vehicle kilometers as service quality

measures (Balcombe et al. (2004); Fitzroy et al. (1993); Goodwin et al. (1985)). Such measures, however, result in an identification problem between the variable defining demand, and the variable defining service quality. In addition, service quality changes due to changes in capacity, such as larger buses resulting in more seat kilometers, would be ignored in such a measure (Balcombe et al. (2004)). Other aggregate service quality measures use the ratio of network length to area size or population as a proxy of access to transit services to avoid such identification issues (Dargay et al. (2002); Romilly (2001)). Bresson et al. (2003) estimate a log linear specification with income, price, and network density as variables for quality. FitzRoy et al. (1997) argue that journey time is an important quality parameter and use average frequency and route density as proxies.

### 3.3.3. Dynamic demand models

Elasticities can be differentiated as short run and long run, particularly when recognizing the importance of habit formation (Cowie et al. (1993)). McCarthy (2001) argues that optimization errors arising from incomplete information also gives rise to persistence in travel demand. Such decompositions, however, require quite large databases and estimation of dynamic demand models as described in Table 3.3.1. One common approach to capture the long run effects of price changes is to use a distributed lag model where the direct price impact yields only the short run elasticity (Oum (1979a)). For instance, Dargay et al. (2002) described in Table 3.3.1 use the following partial adjustment model of constant elasticity demand function with lags:

$$\text{Ln}x_k^t = \alpha_0 + \sum_l \alpha_l \text{Ln}p_l^t + \sum_s \alpha_s \text{Ln}s_s^t + \alpha_w \text{Ln}w^t + \delta \text{Ln}x_k^{t-1} + \varepsilon_i \quad 3.19$$

The short run and long run elasticities can be defined as follows (Balcombe et al. (2004))

$$\text{Short run: } e_{kl}^{SR}(\mathbf{p}, w_i) = \alpha_l \quad 3.20$$

$$\text{Long run: } e_{kl}^{LR}(\mathbf{p}, w_i) = \frac{\alpha_l}{1-\delta} \text{ since } x_k^t = x_k^{t-1} = x_k^* \text{ in equilibrium} \quad 3.21$$

As with any time series model, the partial adjustment models could also suffer from non-stationary variables and spurious regressions (Cowie et al. (1993); Romilly (2001)). While cointegration and error correction models address such problems, these are more data intensive. In addition, elasticity estimates from simple partial adjustment models and from error correction models have been reported to be similar (Balcombe et al. (2004); Romilly (2001)). Cowie et al. (1993) estimate a model in first differences and compare the results with a model in levels to assess how robust the estimates are. Dargay et al. (2002) estimate demand elasticities for 46 counties in the United Kingdom, an approach similar to that that

would be adopted in this study, to estimate firm specific demand elasticities to estimate the optimal pricing regime.

Since the objective of this study is to estimate direct price elasticities for public transit demand, following Dargay et al. (1999), Romilly (2001), Dargay et al. (2002) and Bresson et al. (2003), a partial adjustment specification is also estimated in addition to a static model to distinguish between short run and long run elasticities.

### *3.3.4. Functional forms*

It is not possible to infer the functional form from consumer theory, and the choice here depends on whatever a priori assumptions are made about consumer preferences (Thomas (1987)). The only information from consumer theory that can be inferred in defining an appropriate specification of demand is that the domain of the function should include prices of all commodities and income. This is clearly not possible since sample sizes are not unlimited and the number of parameters is limited by the number of available degrees of freedom. Translating consumer theory into an empirically estimated demand function often requires some ad hoc assumptions that simplify the specification and functional form which can then be estimated using the datasets available (Thomas (1987)).

There are various functional forms that have been used in the literature to estimate aggregate transit demand, namely, linear functions, semi-log or log linear, and generalized non-linear models (de Rus (1990); Appelbaum et al. (1991)). The most common functional form used is the log linear (Romilly (2001)). Only a handful studies have estimated a semi-log functional form where only transit price is included in levels and all other explanatory variables are in logs (Bresson et al. (2003); Dargay et al. (2002)). Statistically, a log linear specification significantly reduces the number of coefficients to be estimated. In terms of the estimates, the coefficients can be readily interpreted as elasticities. Finally, the log linear form also allows for non-linear interactions between demand and the various parameters, hence capturing more complex relationships than just simple linear effects (Clements et al. (1994); Oum (1989)). Since the focus of this study is to estimate direct price elasticities for transit demand, a log linear specification is estimated.

### *3.3.5. Elasticities reported in literature*

The studies presented in Table 3.3.1 are representative of the elasticity estimates reported in the literature. However, it is important to recognize some limitations in comparing elasticity estimates from different studies (Berechman (1993)). Most elasticity measures are reported at the sample mean and are point elasticities. Hence, unless the demand function is a constant elasticity type such as a Cobb-Douglas, elasticity estimates will vary with the level of

demand. As in the case of cost functions in Chapter 2, there is no a priori reason for demand elasticities to be constant (Goodwin et al. (1985)). In addition, elasticities reported in the literature are regarded as long run equilibrium elasticities. As mentioned above, persistence could be an important influence on aggregate demand. Finally, depending on the functional form selected, and appropriate for the market under consideration, the observed demand changes may be influenced not just by prices and income, but also other factors. Hence, a numerical representation of elasticity may not reflect the complexity of transit demand determination.

Nijkamp et al. (1998) highlight several factors that may explain the differences in elasticity estimates and may limit the application of elasticity estimates from a particular study to every context. Even after controlling for the differences in the definition of elasticity, definition of variables, and time horizon of the study, variation in the type of data, estimation methods, modes included, and heterogeneity in local conditions are important in explaining the differences in literature.

### 3.3.5.1. Transit price elasticities

Fare elasticities vary with temporal, socioeconomic, and demographic factors. Goodwin et al. (1985) report that most transit operators in the United Kingdom use an elasticity measure of  $-0.3$  for operational purposes. This value was also commonly used in the United States, though Kemp (1973) reports the elasticity estimates in the range of  $-0.1$  and  $-0.7$ . Oum et al. (1992) provide a detailed survey of own price elasticities of transport demand and methodological issues therein, covering both freight and passenger transport over all modes. Goodwin (1992) provides a similarly detailed survey focusing on public transport and automobile demand. The range of demand elasticity estimates for urban transit in the former is  $-0.01$  to  $-0.78$ . The ranges are smaller in pooled data and cross section studies though still significant. Goodwin (1992) reports an average bus fare elasticity of  $-0.41$ , with a range between  $-0.21$  to  $-0.65$ , the higher end corresponding to long run elasticities. This is also similar to the elasticity estimated for 52 transit systems in the United States (Pham et al. (1991)). A meta analysis of European transit systems estimates price elasticities in the range of  $-0.4$  and  $-0.6$  (Nijkamp et al. (1998)). Estimates for the United Kingdom are  $-0.4$  for the short run and  $-0.7$  for the long run in the case of rising fares (Hanly et al. (1999)). Hanly et al. (1999) report that income and price elasticities decrease with as the network size increases. The review by Litman (2004) suggests short run price elasticities are in the range between  $-0.2$  to  $-0.5$ , and long run elasticities are in the range  $-0.6$  and  $-0.9$ . Balcombe et al. (2004) report an average short run value of  $-0.41$  from a survey of 44 studies (same as Goodwin (1992) and Paulley et al. (2006)) and a long run estimate close to unity. In a review of dynamic direct aggregate demand models, Meurs et al. (1990) report elasticity estimates

between  $-0.21$  and  $-0.28$  for the short term, and  $-0.55$  and  $-0.65$  for the long term. These estimates also reflect the range of elasticities reported from the literature listed in Table 3.3.1.

### 3.3.5.2. Income, private vehicle fleet, and service

The influence of private vehicles on demand for transit depends on the level of vehicle ownership and its usage. While the former would rise with income levels (vehicles being normal goods) and have a negative effect on transit demand, personal vehicles usage would fall with rising operating prices, particularly fuel price. Hence, a higher fuel price should lead to a higher transit demand through its influence on private vehicle usage (Berechman (1993)).

In general, the literature reports negative elasticities for bus and rail transit travel with respect to income and car ownership. Early reviews reported a range of  $-0.2$  to  $-0.8$  for income, and  $-0.1$  to  $-0.8$  for vehicle ownership (Webster et al. (1981)). Hence, public transport is reported to be an inferior good (Fitzroy et al. (1993)). More recent studies report that a 10% rise in income will reduce the demand for transit by 3–7% (Balcombe et al. (2004); Bresson et al. (2003)), whereas a 10% increase in car ownership will reduce transit demand by 5–7%. Dargay et al. (1999) conclude a unitary elasticity of transit demand with respect to car ownership. The negative elasticity with respect to income is thought to reflect the positive effect of income on car ownership and usage, and the resultant negative effect on bus patronage (Dargay et al. (1999)). Maunder (1984) reports for India that income effects are significant only for very low income levels. Once per capita income rises above a threshold, changes in income have negligible impact on public transit demand.

As mentioned earlier, including vehicle ownership in the analysis can help establish if public transit is a normal or inferior good based on true income effects. Previous research in India, however, has been ambiguous about the impact of vehicle ownership and demand for transit services (Maunder (1984)). Hence, it would be interesting to assess if definitive income effects are obtained in this research, and the impact of vehicle ownership on travel demand.

Estimates for service quality elasticities range from 0.2 to 1.2 with a median of about 0.7 in research studies (Dargay et al. (2002); Webster et al. (1981)) and 0.5 in actual operations (Goodwin et al. (1985)). Service quality measures here are defined in terms of network density or other measures for access to the service. de Rus (1990) reports positive service elasticity estimates between 0.39 and 1.88 in a study of 11 Spanish cities. Massot (1994) reports per capita vehicle kilometers as the most robust explanatory variable for public transit demand. Only one transit operator with a negative elasticity is reported in the literature (Goodwin et al. (1985)). In their review of 20 studies reporting service elasticities, Lago et al. (1981) report a higher elasticity between 0.75 and 0.85 if the starting level of

service was low, and 0.30 with a higher starting point. They conclude that transit demand is relatively inelastic to service levels. Again, off-peak service elasticities are reported to be twice as high as peak hour elasticities. Using route kilometers per square kilometer, FitzRoy et al. (1995) report a service elasticity of 0.73 for rail passenger transit in a sample of European countries. Fouracre et al. (1987) estimate service quality and access to be the most significant variable influencing demand in their study of three Indian cities using survey data collected between 1983 and 1985.

### 3.4. Estimation methods

Early estimations using cross section datasets are usually considered to reflect long term relationships with the implicit assumption that all variables are at their long term equilibrium levels and consumers have adjusted to these values completely (Kmenta (1978)). While cross sectional analysis can clearly identify the importance of inherent individual variation between different observations and hence isolate the impact of the variables under consideration from general heterogeneity, they are unable to identify the dynamics of adjustment. Estimations that use time series datasets, on the other hand, generally focus on transitions in variables over time. Hence, the values obtained from time series estimations are considered to reflect short run values, with variable not being at their long term equilibrium values. However, heterogeneity impacts often cannot be separated from other variables in time series datasets as can be done with cross section datasets (Hsiao (2003)).

With panel datasets, it is possible to distinguish between the short run and long run characteristics and address heterogeneity issues in parallel, hence combining the advantages of both cross section and time series analysis. This allows the quantification of effects that are not identified in time series and cross section analysis independently (Hsiao (2003)). In addition, comparing static panel data estimates with dynamic panel data estimates reveals the importance of persistence variables such as habit formation in the model. Hence, if it is expected that dynamic effects are important, these should be tested for explicitly.

Statistically, it is possible to construct and test more complicated panel data models than is possible only with time series and cross section datasets (Baltagi (2002)).

The static and dynamic panel data econometric models relevant for the research issues at hand and used in the study are presented below.



### 3.4.1. Static Fixed and Random Effects models with Autoregressive Errors

A description of static panel data models is presented in chapter 2. Here only salient points of the models are highlighted. The focus here is on the specification and estimation of the models with first order Autoregressive Errors (Baltagi et al. (1999))<sup>13</sup>.

There are two static panel data models in the standard literature, namely, Fixed Effects and Random Effects. The Random Effects model is estimated using Generalized Least Squares in the absence of distributional assumptions. The Fixed Effects model has varying intercepts over cross section units while slope coefficients remain constant. The most common type of the Fixed Effects model allows for variation in the intercepts only between cross sectional units and not over time. In terms of the first order Autoregressive process, the Fixed and the Random Effects models can be specified as follows:

$$y_{it} = \alpha_0 + \mathbf{X}_{it}\boldsymbol{\alpha}_1 + v_i + \varepsilon_{it} \quad 3.22$$

Here,  $\varepsilon_{it}$  is specified as follows:

$$\varepsilon_{it} = \rho\varepsilon_{i,t-1} + \eta_{it} \quad 3.23$$

$\eta_{it}$  is independently and identically distributed around mean zero, with a variance  $\sigma_\eta^2$ , and  $|\rho| < 1$ . If  $v_i$  are assumed to be fixed parameters, the estimates are from the Fixed Effects model. If they are assumed to be randomly distributed, the estimation yields Random Effects estimates.

Baltagi et al. (1999) propose a transformation of the data that removes this first order Autoregressive component. The error sequence obtained from this transformation can then be used to estimate the variance components and the Fixed or Random Effects parameters.

### 3.4.2. Panel Corrected Standard Errors

The Kmenta approach, a precursor to the standard error correction models, recognizes that key issues in using panel datasets are autocorrelation arising from the time series nature of the dataset, and heteroscedasticity between cross sectional units<sup>14</sup>. Also known as the Cross Sectionally Heteroskedastic and Time-Wise Autoregressive model (Baltagi (2002); Kmenta (1997)), or the Parks method (Parks (1967)), this method allows for autocorrelation and

<sup>13</sup> The discussion here is based on only one-way error components. Hence, only individual effects are discussed and time effects are ignored.

<sup>14</sup> Refer to Beck et al. (1995); Kmenta (1997) for a description, and Farsi et al. (2007) for an application in the public transit sector.

heteroscedasticity. Hence, it allows for an autoregressive error structure,  $\varepsilon_{it} = \rho_i \varepsilon_{i,t-1} + \mu_{it}$ , and cross sectional heteroskedasticity to account for unobserved heterogeneity across states,  $E[\mu_{it}^2] = \sigma_i^2$ . It consists of two sequential Feasible Generalized Least Squares transformations to remove autocorrelation and cross sectional heteroscedasticity respectively (Baltagi (2002); Kmenta (1997)).

This method is recommended if the number of cross section units is lower than the number of periods, or when the Within Variation of many explanatory variables is very low. Baltagi (1986) suggests first testing for autocorrelation and heteroscedasticity before using the Kmenta method, stating that the loss in efficiency is much greater if this method is used instead of the standard error components model, and the disturbances have an error components structure.

Beck et al. (1995) recognize that the Kmenta method depends on knowing the true error process and in the absence of this knowledge, leads to a downward bias in the estimates of the standard errors and recommend using PCSE (Panel Corrected Standard Errors). PCSE uses Ordinary Least Squares parameter estimates but replaces Ordinary Least Squares standard errors with panel corrected standard errors. In general, the Random Effects and Fixed Effects models provide more parsimonious estimates with a much lower number of parameters to be estimated, while incorporating individual heterogeneity explicitly (Baltagi (2002); Baltagi et al. (1986)). In addition, as noted by Baltagi (1986), if the addition of variables reduces or removes heteroscedasticity in the model, then a Fixed Effects or Random Effects model provide more efficient parameter estimates.

### 3.4.3. *Dynamic Error Component models*

In the dynamic specification reviewed in section 3.3.3, there is autocorrelation between subsequent periods leading to persistence over time. Here the within estimator for Fixed Effects is biased and inconsistent, especially if the number of periods is not large (Kiviet (1995); Nickell (1981)). Similarly, the Random Effects estimator is also biased and not efficient (Baltagi (2002); Sevestre et al. (1985)). Often the individual effects are assumed to be Fixed and not Random to address the non-orthogonality issues (Bun et al. (2001)). Using Monte Carlo simulations, Doel van den et al. (1995) report that static panel models usually underestimate long run effects if the true specification is dynamic. The commonly used technique to estimate panel data models with unobserved heterogeneity is to transform the model into first differences and then use sequential moment conditions to estimate parameters using Generalized Method of Moments.

### 3.4.3.1. Generalized Method of Moments based approaches

Arellano–Bond (Arellano et al. (1991)) present a Generalized Method of Moments estimator for panels with a dynamic specification that removes individual effects by carrying out estimation in differences. This is estimation with the instruments in levels while the regressors are in differences. While the lagged variable is still endogenous, deeper lags are assumed orthogonal to the error term and hence are used as instruments. The prerequisite for this model is that the number of periods should be larger than the number of regressors in the model, and the number of instruments should be less than the number of cross sectional units. Dargay et al. (2002) and Bresson et al. (2003) estimate the Arellano–Bond model using panel data from counties in England only in the case of the former, and counties both in England and France, in the latter, to distinguish between the short run and long run elasticities.

However, with highly persistent data, the first differenced Generalized Method of Moments estimators may suffer a small sample bias due to weak instruments. Here Arellano–Bover (Arellano et al. (1995)) suggest an alternative transformation to the Arellano–Bond differencing of the dependent variable and the regressors. By carrying out estimations in first differences, the Arellano–Bond approach drops more observations in unbalanced panels. The Arellano–Bover approach uses differences from the mean of all future observations to reduce the loss of observations arising from unbalanced panels. Blundell–Bond (Blundell et al. (1998)), using the Arellano–Bover approach, present a Generalized Method of Moments estimator that uses differences of instruments to obtain orthogonality instead of differencing the regressors in the Arellano–Bond estimator. The principle used here is that even if the regressors used are endogenous to the model, as long as they are independent of the individual effects, the first differences of the regressors can be used as valid instruments and hence improve the efficiency of the estimates. Blundell–Bond use extra moment conditions that rely on stationarity of the initial observations. Abrate et al. (2007) is possibly the only application of the Blundell–Bond approach to estimating public transit demand yet.

The choice of the number of instruments here is an issue that needs to be addressed. On one hand, enough instruments are required so that the finite sample properties in such estimations are satisfactory. On the other hand, each additional instrument over and above the number of explanatory variables bias the estimates (Kennedy (2003)). Arellano et al. (1991) suggest the Sargan test which tests the joint hypothesis that the model is correctly specified and that the instruments used are valid. Hence, the Sargan test can be used to evaluate the performance of the Generalized Method of Moments based dynamic panel data models by assessing the use of instruments in obtaining consistent estimates.

Bun et al. (2007) argue that with a highly persistent series, with a small sample of cross section and time series observations, the Blundell–Bond approach may lead to weak instruments. This is in part due to the high variance in the individual effects due to variance in transitory shocks.

#### 3.4.3.2. Corrected LSDV based estimations

Kiviet (1995) proposes a Bias Corrected LSDV (Least Squares Dummy Variables) estimate, or a Fixed Effects estimate, by estimating the sample bias from an uncorrected LSDV estimate and using this to remove the inconsistency in the parameter estimates. This has been refined and simplified in Bun et al. (2003). The approximation depends on not just the conditioning variables but also on the unknown true parameter values. However, Monte Carlo experiments have shown that approximations arising from such a bias correction are ‘very accurate for a wide range of parameterizations’ (Bun et al. (2003)). Due to the small variance of the LSDV estimator, much smaller than the Generalized Method of Moments estimators, the parameter estimates are also very efficient. Again Abrate et al. (2007) is one application of this approach to public transit demand.

### 3.5. Model specification

The model specification presented in this section is based on the review of the literature presented above and the issues discussed therein. Since the study assesses public bus transit price elasticities in the context of actual market transactions, passenger kilometers have been taken as the output measure ( $pkm$ ). Public bus transit fares ( $p$ ) and per capita income ( $w$ ) are the monetary variables. Service quality is characterized by the density of coverage ( $q$ ). The total population ( $pop$ ) of the state is included to isolate the effect of size of the market. The demographic and socioeconomic variables in the model are the proportion of population in the labour force ( $work$ ) and literacy rate ( $lit$ )<sup>15</sup>.

Unfortunately, data on the prices of substitutes and complements is not available in this study. The only transport service that is of import here is personal vehicle usage. The impact of changes in personal vehicle usage can be approximated using another socioeconomic variable, per capita private vehicle ownership ( $s$ ).

The model specification used is the following:

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<sup>15</sup> The proportion of population living in urban areas and the sex ratio were also included in early specifications on the model. However, these variables did not significantly improve the goodness of fit. In addition, in terms of the elasticities obtained for the key variables of interest, these were not found to have any significant influence.

$$pkm = f(p, w, q, s, pop, work, lit) \quad 3.24$$

As described in section 3.3.4 and from the studies reviewed in Table 3.3.1, the functional forms most commonly used in the literature are log linear and semi-log. Since the log linear form is easily interpretable, and simple for computing elasticities, the log linear function has been estimated<sup>16</sup>. The demographic variables are already in percentages. These have not been converted into logs and are included as reported. In this case, the coefficients can be readily interpreted as elasticities. Thus, the static model is the following,

$$\begin{aligned} \text{Ln}pkm = & \alpha_o + \alpha_p \text{Ln}p + \alpha_w \text{Ln}w + \alpha_q \text{Ln}q + \alpha_s \text{Ln}s + \alpha_{pop} \text{Ln}pop \\ & + \alpha_{work} work + \alpha_{lit} lit + \varepsilon_t \end{aligned} \quad 3.25$$

The dynamic structure of demand has been captured using a partial adjustment model. This implies that given an optimum, but unobservable, level of transit demand,  $pkm^*$ , demand only gradually converges towards the optimum level between any two time periods. Hence,

$$\text{Ln}pkm_t - \text{Ln}pkm_{t-1} = \delta(\text{Ln}pkm^* - \text{Ln}pkm_{t-1}) + \eta_t \quad 3.26$$

where  $(1 - \delta)$  is the adjustment coefficient indicating the rate of adjustment of  $pkm$  to  $pkm^*$  and  $\varepsilon_t$  is random disturbance (Kmenta (1978)). Substituting  $pkm^*$  in the dynamic adjustment equation gives:

$$\begin{aligned} \text{Ln}pkm_t = & \alpha_o \delta + \alpha_p \delta \text{Ln}p + \alpha_w \delta \text{Ln}w + \alpha_q \delta \text{Ln}q + \alpha_s \delta \text{Ln}s + \alpha_{pop} \delta \text{Ln}pop \\ & + \alpha_{work} \delta work + \alpha_{lit} \delta lit + (1 - \delta) \text{Ln}pkm_{t-1} + \delta \varepsilon_t + \eta_t \end{aligned} \quad 3.27$$

or

$$\begin{aligned} \text{Ln}pkm_t = & \alpha'_o + \alpha'_p \text{Ln}p + \alpha'_w \text{Ln}w + \alpha'_q \text{Ln}q + \alpha'_s \text{Ln}s + \alpha'_{pop} \text{Ln}pop \\ & + \alpha'_{work} work + \alpha'_{lit} lit + (1 - \delta) \text{Ln}pkm_{t-1} + \varepsilon'_t \end{aligned} \quad 3.28$$

where  $\alpha'_i = \alpha_i \delta$  and  $\varepsilon'_t = \delta \varepsilon_t + \eta_t$ . This dynamic specification is estimated.

This is possibly one of the very few studies estimating public bus transit demand in developing countries. The specification being used also attempts to capture actual market transactions to relate these with firm behaviour using passenger kilometers as a measure of demand. In addition, using density of coverage provides a clear indicator of service quality in terms of access to the transit network, and hence avoids simultaneity with the measure of

<sup>16</sup> The coefficient estimates obtained from using the log linear and the semi-log functional forms were compared and found to be similar.

demand and output. Finally, the use of demographic and social characteristics is expected to reveal the import of such non-monetary variables in the context of a developing country.

### 3.6.Data

An unbalanced panel of 22 states in India between 1990/91 and 2000/01 has been used in the analysis with 206 observations. The panel ranges from 21 states in 1993/94 to 16 in 1997/98. Data on public bus transit demand is the same used to estimate costs in chapter 2 and has been taken from CIRT (Various years)<sup>17</sup>. Public bus transit fares have been estimated as the ratio between traffic revenue and total demand, with the information obtained from CIRT (Various years). Thus, non-traffic revenue such as advertising revenue or interest accrued, has been excluded from the definition of public transit fares. Unfortunately, user costs and external costs are not available for this study and hence only public bus transit fares are included. Hence, the price elasticities obtained are only for public bus transit fares and not generalized transportation costs for the public bus users as in Mohring (1970).

Density of coverage has been estimated as the ratio between vehicle kilometers reported in CIRT (Various years) and the area of each state. Demographic and social variables have been obtained from Census of India 2001 (2001). The per capita income series is based on total State Domestic Product reported in EPWRF (2003) and population totals from Census of India 2001 (2001). Private vehicles in the analysis have been defined as cars, two-wheelers, and jeeps with the data from MTS (Various Issues). This has been divided by the population of each state to obtain the per capita private vehicle ownership. The two monetary variables, namely public bus transit fares and per capita incomes, have both been deflated to 1989/91 prices using the Wholesale Price Index for All Commodities reported by the Government of India (2005) to carry out the estimations in terms of real values. Table 3.6.1 describes the dataset and the variables used in the analysis. Each observation of each variable,  $x_{it}$ , has also

been decomposed into two separate series of between observations  $\left(\bar{x}_i = \sum_t x_{it}/T\right)$  and within

observations  $\left(x_{it} - \bar{x}_i + \sum_i \bar{x}_i/I\right)$  to examine the cross section and time series behaviour in

terms of the Between and Within standard deviations (STATA (2005)). The Between estimates reflect the cross section variation in the dataset, while temporal changes can be observed through the Within Variation. The key Between and Within parameters of interest are the standard deviations since the Fixed Effects regression is in effect regression with the

<sup>17</sup> For the six states with more than one operator, data has been summed across all the operators to obtain state level aggregates.

variables modified to their Within values. Random Effects estimates, on the other hand, are based on a weighted average of the Between and Within Variations.

For most variables, the overall variation in the dataset comes from the Between Variation. For instance, the variation in per capita income, density of coverage, and private vehicle ownership is almost completely due to the Between Variation. In addition, there is a large variation in the dataset for most variables as can be observed from the minimum and maximum values. This high variation is similar to the variation noted in the panel dataset used to estimate cost characteristics in chapter 2. Hence, as was the case in estimating costs, it is important to include a variable that reflects the size differences between states. This size effect is captured by using the total population of each state.

**Table 3.6.1. Descriptive statistics of the variables included in the analysis**

Variable		Mean	Std. Dev.	Min	Max
Passenger kilometers (10 <sup>5</sup> km)	Overall	230,194.300	324,248.600	112.570	2,236,124.000
	Between		292,371.900		
	Within		127,504.700		
Public transit fare (Rupees <sup>#</sup> per passenger kilometer)	Overall	0.089	0.046	0.031	0.384
	Between		0.038		
	Within		0.033		
Per capita income (Rupees per person)	Overall	6,073.593	3,430.798	164.383	19,191.890
	Between		3,398.596		
	Within		1,470.881		
Density of coverage (10 <sup>5</sup> vehicle km per km <sup>2</sup> )	Overall	0.257	0.778	0.0001	4.089
	Between		0.868		
	Within		0.123		
Per capita private vehicle ownership (Vehicles per person)	Overall	0.047	0.079	0.005	0.493
	Between		0.089		
	Within		0.017		
Population (number)	Overall	43,700,000.000	38,300,000.000	719,601.000	166,000,000.000
	Between		38,300,000.000		
	Within		3,029,920.000		
Population in the labour force (%)	Overall	38.87%	0.048	30.87%	49.24%
	Between		0.047		
	Within		0.009		
Literacy rate (%)	Overall	53.55%	0.109	30.57%	80.04%
	Between		0.106		
	Within		0.035		

<sup>#</sup>1 Swiss Franc equaled approximately 36 Indian Rupees in February 2008.

The correlation matrix for the variables used in the analysis is presented in Table 3.6.2. In general, the variables seem to be independent. As reported in Table 3.7.1, the coefficient signs and significance levels that are obtained are satisfactory. Hence, multicollinearity does not appear to be a problem.

**Table 3.6.2 Correlation matrix**

	pkm	p	w	q	s	pop	work	lit
pkm	1.000							
p	-0.264*	1.000						
w	0.139	-0.379*	1.000					
q	-0.078	-0.232*	0.724*	1.000				
s	-0.026	-0.239*	0.706*	0.896*	1.000			
pop	0.378*	-0.134	-0.274*	-0.271*	-0.236*	1.000		
work	0.402*	0.101	-0.054	-0.211*	-0.073	-0.093	1.000	
lit	0.135	-0.342*	0.605*	0.405*	0.379*	-0.396*	-0.109	1.000

\* Correlation is significant at the 0.01 level.

### 3.7. Analysis and results

The data has been analyzed and the estimations carried out in STATA Intercooled Version 10.0. Three models each for both the static and dynamic specifications have been estimated. Dynamic models allow a distinction between long run and short run effects. A comparison with the static models demonstrates the importance of persistence in demand, and the difference between the short run and long run equilibrium behaviour. In the static specification, the first type of models are the conventional static one way panel data models, namely, Fixed Effects and Random Effects. Both these models have been estimated with a first order Autoregressive specification of their error structure. The second type, the PCSE method as proposed by Beck et al. (1995), is an alternative to the conventional panel data models. The PSCE is appropriate for pooled datasets with low within variation as is the case with our dataset (Table 3.6.1), and in the presence of heteroscedasticity and autocorrelation. In terms of the dynamic specification, the two Generalized Method of Moments based models, Arellano–Bond and Blundell–Bond, have been estimated. The two models are distinguished by the way instruments are constructed for each system. The Corrected LSDV estimations provide an alternative estimate to the Generalized Method of Moments models for the dynamic specification.

#### 3.7.1. Comparing the models

As mentioned earlier, three static models and three dynamic models have been estimated. The static and dynamic specifications cannot be directly compared in terms of statistical performance except in terms of general goodness of fit and significance of key variables. Overall, only general remarks comparing the models are possible.

The Fixed and Random Effects models can be directly compared. The Hausman test comparing the coefficients on the regressors in the Fixed Effects and Random Effects rejects the null hypothesis that the Random Effects Coefficients are consistent ( $\chi^2_{(7)} = 152.27$ ).

However, as pointed out by Cameron et al. (2005), the low Within Variation for several of the



regressors could result in imprecise coefficients in the Fixed Effects model since it relies on Within Variation to carry out the estimation. Moreover, Random Effects estimates can be applied outside the sample for predictions, which is not appropriate for estimates obtained from the Fixed Effects models (Cameron et al. (2005)). This is important in the context of the current research since the objective is to identify general policy directions.

The results reported for the PCSE are similar to those of the Random Effects model as discussed earlier. The hypothesis of independently and identically distributed errors, homoskedasticity, cannot be rejected ( $\chi^2 = 0.8769$  for the Breusch–Pagan test). Hence, following Baltagi (1986), the Random Effects model provides more efficient estimates.

Within the dynamic models, the null hypothesis in the Sargan test that the over-identifying restrictions are valid is not rejected in the Arellano–Bond model (Table 3.7.1). The model cannot reject the null hypothesis of no first order autocorrelation. In addition, the model also rejects the null hypothesis of second order autocorrelation. Hence, the estimates in the Arellano–Bond model are consistent.

Estimates were also obtained using the Blundell–Bond model for the dynamic specification. However, the Sargan test for over-identifying restrictions is not satisfied even if only the last lag of only one variable is used as an instrument. This problem probably arises from the small dataset that is available (Bun et al. (2007)).

The Corrected LSDV has been estimated with coefficients from the Arellano–Bond estimation as the starting values since these were the only consistent and statistically significant dynamic estimates available. The estimates are not very sensitive to the initial values assumed. Initial values from the Blundell–Bond estimates result in coefficient values comparable to the Arellano–Bond initial values. The bootstrapped errors have been estimated based on 300 replications. In this case, the estimates are robust to the number of replications. Since this model cannot be directly compared with any of the other estimations, the results are reported only for interest.

In comparing the static and the dynamic specifications, the parameter of interest is the coefficient on the persistence variable,  $(1 - \delta)$ , since this denotes the importance of the dynamic component in the model. Observing the estimated value in Table 3.7.1, the coefficient of adjustment is significant in the Blundell–Bond and Corrected LSDV models, though it is not significant in the Arellano–Bond model. Hence, the benefits from using a dynamic specification are not evident.

### 3.7.2. Regression results

The regression results from all the models are presented in Table 3.7.1. Transit price has the correct sign and is significant in all the models. The confidence interval is smaller in the dynamic models indicating a change in transit price is mostly reflected in travel demand immediately and only to a much smaller degree over time through lagged values of transit demand.

Income is negative but not significant in any of the models. As reported in some of the literature, the negative sign indicates that income is an inferior good. Even with the distinction between the direct income effect on demand and the indirect effect through higher vehicle ownership, a negative income effect is obtained. However, since the coefficient is not significant in any of the models, a negative income effect is not definite.

Related to wealth, private vehicle ownership is negatively correlated with demand. The coefficient is significant in the models where the individual effects are random but is insignificant in the Fixed Effects and the Corrected LSDV models. This is probably due to the low within variation observed for this variable (Table 3.6.1).

Service quality has the highest elasticity values. Clearly, this is the most significant policy variable and has the largest impact on travel demand as expected from the literature (Cervero (1990)). Following Lago et al. (1981), this probably reflects the low coverage of public transit services in India.

As expected, population has a positive and significant impact on demand in all the static models and the Blundell–Bond model. Surprisingly, there is a negative correlation between population and passenger transit demand in the Arellano–Bond and the Corrected LSDV models. This could probably be due to the coefficient of adjustment in the models already capturing some population increase effects.

Literacy rate is negatively correlated with demand. The negative correlation with literacy rate indicates the low social acceptance of public transit. The impact of a large working population is positive and significant. Thus, with a larger proportion of population in the workforce, travel demand is higher and resulting in a larger demand for public transit. In general, the significance of social variables such as the proportion of working population and literacy rates indicated the importance of non–monetary factors in determining travel demand.

Table 3.7.1. Regression results

	Fixed Effects		Random Effects		PCSE		Arellano–Bond		Blundell–Bond		Corrected–LSDV	
	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
$\alpha'_p$	-0.460***	0.041	-0.354***	0.050	-0.359***	0.076	-0.420***	0.035	-0.262***	0.051	-0.374***	0.043
$\alpha'_w$	-0.020	0.034	-0.065	0.038	-0.061	0.040	-0.016	0.026	-0.058	0.038	-0.027	0.025
$\alpha'_q$	0.834***	0.031	0.818***	0.027	0.754***	0.029	0.691***	0.048	0.160***	0.043	0.676***	0.052
$\alpha'_s$	-0.028	0.048	-0.106***	0.052	-0.212***	0.064	-0.003***	0.052	-0.118*	0.047	0.037	0.054
$\alpha'_{pop}$	0.662***	0.038	0.938***	0.043	1.026***	0.032	-1.662***	0.291	0.099*	0.049	-0.500*	0.248
$\alpha'_{work}$	6.770***	0.618	6.798***	0.481	11.797***	0.564	3.711***	0.788	2.674**	0.370	2.450*	1.085
$\alpha'_{lit}$	-4.089***	0.138	-3.665***	0.887	-1.099***	0.862	-4.140***	0.035	-0.787*	0.051	-1.974***	0.506
$(1 - \delta)$							0.119	0.070	0.886	0.049	0.294***	0.056
$\alpha'_o$	1.273***	0.041	-3.350***	0.050	-8.829***	0.076	0.042***	0.012	-1.060	0.579		
F statistic	366.57***											
R <sup>2</sup>	0.8939				0.9874							
Wald $\chi^2$			1635.03***		3784.45***		662.94***		69,650.56***			
Sargan $\chi^2$							47.40		77.01***			
AR (1)							-1.72		-5.73***			
AR (2)							0.16		0.88			

\*Variables significant at 95% confidence level, \*\*Variables significant at 99% confidence level, \*\*\*Variables significant at 99.9% confidence level

### 3.7.3. Price and Income Elasticities

Given the model specification as log linear in transit price, income, and service quality, the coefficients on these variables can be interpreted as elasticities. However, arising from the log linear specification, elasticity values do not vary with the level of demand. The long run elasticities have been approximated around their mean values using the Delta method (Oehlert (1992)) to obtain significance levels as well. Since the Blundell–Bond does not satisfy the Sargan test, elasticities are not estimated for this specification. In addition, since the dynamic component in the Arellano–Bond model is not significant, elasticity estimates are not presented for this model as well.

The reported price elasticity is significant in all models and less than unity. The estimates lie between  $-0.354$  and  $-0.523$  in equilibrium or the long run. In all cases, transit demand is inelastic to fare changes. Also, as predicted by Doel van den et al. (1995), the static panel models report lower price elasticity values than the long run estimates using dynamic models, though the difference is not large. The price elasticity values are very much in consonance with the literature reported in section 3.3.5.1. The lower long run values compared to the literature could be perhaps explained by the fact that, most demand elasticity estimates in the literature have been obtained using datasets from developed countries, while this study is based in India. The low elasticity values, therefore, may represent the state of economic development in India vis-à-vis estimates in other studies. The inelastic demand may also arise from the fact that only public transit fares are included in this analysis since estimates for user costs and external costs are not available for this study. As a result, these estimates do not reflect the elasticity of demand with respect to the generalized transportation costs for the public bus users.

The literature reports negative income elasticities and characterizes public transit as an inferior good. Even though the estimates presented about report a negative income elasticity, since the coefficients are not significant, public transit cannot be characterized as an inferior good in India. These results are similar to Maunder (1984) where again income effects are insignificant above a minimum threshold of income. Dargay et al. (1999) report that the negative income elasticity during the period of analysis in their study of the United Kingdom between 1970 and 1998 coincided with a rapid increase in personal vehicle ownership. This may be the case in this study as well, given the rapid increase in personal vehicle population in India during the period under consideration and the significant negative coefficient obtained for personal vehicle ownership in most models.

Service quality remains the most significant policy variable for influencing transit demand. Again, this is as expected since the constraining factor for most infrastructure services in

India, including public bus transit, is availability (Lago et al. (1981)). Fouracre et al. (1987) also report in their limited analysis of three Indian cities that a higher level of service results in a higher demand for public transit. They also report this to be a more significant policy variable for influencing demand. As a result, transit demand can be increased by making more services available. If the policy objective is to raise public transit ridership to meet environmental or energy goals, service quality is clearly a much more important policy tool compared to transit prices. However, it is noted that service quality also depends on revenues to finance quality improvements, which in turn would lead to higher costs and hence fares (Cervero (1990)).

**Table 3.7.2. Price and Income Elasticity estimates**

	Fixed Effects	Random Effects	PCSE	Corrected LSDV	
				Short run	Long run
Price	-0.460***	-0.354***	-0.359***	-0.374***	-0.523***
Income	-0.020	-0.065	0.061	-0.027	-0.038
Service quality	0.834***	0.818***	0.754***	0.676***	0.957***

\*\*\* Significant at 99.9% confidence level

### 3.8. Conclusions

This chapter estimates transit price, income, and service quality elasticities for a direct aggregate demand function for public transport in India using an unbalanced panel between 1990/91 and 2000/01 for 22 states to assess the price, income, and service quality effects on bus transport demand using both static and dynamic specifications of a log linear model. Demand has been defined as total passenger kilometers to capture actual market transactions, while the regressors include public transit fare, per capita income, service quality, and other demographic and social variables. The measure of service quality used in the study is density of coverage, hence ensuring independence from demand and output measures.

The estimated price elasticity is significant in all models. In all cases, transit demand is inelastic to the fare level and comparable to those reported in the literature. The long run estimates, however, are lower compared to other studies. This is ascribed to the state of economic development in India since most studies emanate from the developed countries. In particular, the low elasticity values indicate that public transit remains a necessity in India. In addition, all models report negative but insignificant income elasticity. This can be attributed to the transition in the Indian transport industry, with a rapid increase in the number of personal vehicles, which masks some of the direct wealth effects. Service quality is the most significant policy variable for influencing transit demand given the low availability of transit services. Finally, social and demographic variables highlight the complex nature of public bus transit demand in India.

## 4. Optimal pricing of public bus transit in India

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As the cost analysis in chapter 2 shows, a majority of public bus transit firms in India demonstrate significant Economies of Scale and falling average costs over a large range of output. That is, public bus transport firms are usually considered a natural monopoly given the production technology and operating environment in India. As a result, the most efficient production structure is to have only one firm operating in each public bus transport market. This does not preclude competition from other passenger transport modes such as personal vehicles. Nevertheless, with the sector demonstrating natural monopoly characteristics, an efficient pricing policy is necessary to ensure optimal allocation of resources across sectors in the economy, as well as within the sector. Such pricing regimes can in turn be implemented either through the government directly fixing public bus fares at their optimal levels, or indirectly using other regulatory strategies, such as incentive based regulation or rate of return regulation.

Public transit pricing is also considered to be an important policy instrument in promoting an appropriate share allocation across public and private transport modes (Cervero (1990)), so as to meet energy or environmental goals, or even reduce congestion (Mekoth et al. (2005); Obeng (1983)). In particular, in a developing country, public transit pricing is often used as a policy instrument to address equity and other sociopolitical objectives (Vickrey (1980)). For instance, public transit services, and hence public transit pricing, are considered to be critical in facilitating access to primary education and employment generation facilities, to address equity concerns (Gómez-Ibáñez (1999); Mekoth et al. (2005)). In addition, policy objectives may also include guaranteed access to a minimum level of transit services at affordable prices (Maunder (1986)). This could result in some consumers being subsidized by paying fares less than average costs. Moreover, bus based public transport is the cheapest and the most cost effective way of meeting mobility needs in a developing country (Mohan et al. (1999); Planning Commission (2002)). Thus, while prices motivated by economic efficiency and financial viability are a useful indicator for reforms and the potential for economic and financial gains, it is important to assess the role of optimal pricing in the overall context of other developmental priorities in a country with unmet mobility needs.

With respect to tariff setting in India, public bus fares largely follow the multi stage fare system, wherein the tariff is based on the distance traveled. Fares are defined in terms of rupees per passenger kilometers. For instance, the Delhi Transport Corporation has a four-stage system. Tariff setting is vested with the state governments under Section 67(1) of the Motor Vehicles Act (1988). Within the state government, tariff setting has been motivated by

social and political considerations and, as a result, fares are not based on the cost of service delivery (Kadam (1999); Mekoth et al. (2005)). In addition, tariffs have generally been set such that public bus companies have faced increasing losses over time. It is of consequence then, to assess the impact that tariff reforms would have on the finances of public bus companies in India and the gains in economic efficiency that are possible on one hand, and changes in demand and consumer surplus on the other.

This chapter, in the tradition of most research on public transit pricing, focuses only on the analysis of economic efficiency of bus fares. Hence, social, environmental, and political considerations, which may be equally important, are ignored in this analysis. In addition, other modes of transport, such as personal vehicles, are not included and the focus is on the prices charged by public transport bus companies. While it is recognized that a study of entire transport sector including all modes would be of great value, data to carry out such a detailed analysis is not available. The limited scope of the analysis clearly has implications of the policy directions that emerge from this study. Nevertheless, this study provides a thorough analysis of public bus transit pricing in India focusing on economic efficiency, and its impact on transit demand and consumer surplus. The pricing strategies that are assessed focus on both economic efficiency and revenue adequacy. To sum up, this chapter estimates several pricing regimes for public bus transit firms in a partial equilibrium framework, and assesses these in terms of their impact on demand, consumer surplus, and profits.

The following section briefly presents the need for regulation and the issues involved in tariff regulation in the transit sector. Section 4.2 describes various pricing strategies focusing on network industries, and highlights their key features and issues in estimation and implementation. Section 4.3 presents studies that estimate efficient prices in the transit sector and other network industries, using analysis similar to those in this study. Following that, in section 4.4, the three tariff regimes for single product monopolies feasible given the industry in India, are estimated. These are average cost pricing, marginal cost pricing, and a second best two-part tariff. While average cost pricing and the two-part tariff ensure complete cost recovery, marginal cost pricing could lead to losses in the presence of Economies of Scale. Finally, section 4.5 concludes.

## 4.1. Need for price regulation

The traditional case for economic regulation arises from the existence of natural monopolies (Braeutigam (1989)). An industry is characterized as a natural monopoly if one firm can produce a given output quantity at a lower cost compared to two or more firms, that is costs are sub-additive. In a single output firm, the sufficient condition for the existence of a natural monopoly is declining average costs at a given level of output. In public transit, this

key characteristic is revealed by Economies of Scale arising from large fixed costs leading to marginal costs being lower than average costs. As demonstrated in chapter 2, the majority of public bus transport firms in India show significant Economies of Scale, and hence natural monopoly characteristics. In particular, defining the representative firm by the median values of all variables included in the specification of the cost function, the public bus transport industry in India can be characterized as a natural monopoly. As Kahn (1970) describes, in the presence of Economies of Scale, economic efficiency necessitates a natural monopoly to minimize total costs for a single output monopoly. This is often also a motivation for governments to nationalize these industries (Sundar et al. (2000)) or directly regulate their operation (Train (1991)).

However, Braeutigam (1989) argues that presence of a natural monopoly may not necessarily imply that the firm can exploit its monopoly power. In particular, if the monopoly power depends on franchising from the government, then franchise bidding would imply that all monopoly profits are bid away. In this case, competition for the market would lead to average cost pricing (Demsetz (1968)). A similar outcome is obtained if markets are 'contestable' (Baumol et al. (1982)). According to this approach, in the absence of sunk costs, and with free entry and exit, even an industry characterized by Economies of Scale would lead to average cost pricing. Pricing higher than average costs by an incumbent would result in the incumbent's monopoly position challenged by an entrant. The entrant could now charge a price marginally higher than the average cost but lower than the incumbent has and hence corner the entire market. However, a deregulated contestable market would still need to be complimented with regulations detailing quality and other technical parameters. In addition, in the absence of free entry and exit to the market, constant monitoring to ensure compliance with such technical standards is necessary. Changes in technology, demand patterns, and other environmental factors would also necessitate periodic reviews of the regulatory strategy or the franchise.

The evidence on the contestability of public bus transport markets is not definitive. For instance, in the United Kingdom, the Department of Transport (1984) had argued for deregulation of the public bus transport sector, arguing that the sector is contestable since the large fixed costs in terms of buses do not constitute sunk costs. However, subsequent reviews have argued that the outcome of deregulation does not reveal that the sector is actually contestable (Evans (1991); Langridge et al. (2000); Mackie et al. (1995)). Mackie et al. (1995) argue that economic barriers do exist in terms of economies of experience and human capital which lead to sunk costs, and the regulatory structure that is in place. Langridge et al. (2000) report that entry and exit are not costless and that this could explain the market behaviour in the United Kingdom. While there is no consensus on what entry or exit barriers are the cause, it is generally accepted that the hypothesis of contestability in the



United Kingdom market is not true. In any case, the industry structure in India is such that bus public transport is a legal monopoly where only government owned firms are permitted to operate. Hence, it is not expected that contestability could achieve an efficient outcome. Thus, the need for price regulation in the industry, given the natural monopoly characteristics, remains.

## 4.2.Pricing transit services

Revenue streams for bus operators often comprise of both farebox collections and some form of subsidy from the government. Given the existence of natural monopoly characteristics in the public bus transit firms in India, in the absence of any form of price regulation, and with the firms operating on the basis of the profit motive, the price would be fixed such that the marginal cost equals the marginal revenue. However, public bus transit in India is overwhelmingly provided by the government, and prices are directly regulated by it.

Optimal or first best pricing of public bus transit services implies that fares should be fixed such that they equate the marginal social costs. Marginal cost pricing, however, would lead to losses given the significant Scale Economies that exist in the public bus transit in India. To address concerns arising from losses in public transport, pricing regimes need to ensure revenue adequacy. Pricing regimes that systematically diverge from uniform marginal cost pricing to ensure revenue adequacy are classified as second best pricing regimes. These include simple linear tariffs as in the case of average cost pricing, and more complex non-linear pricing regimes including two-part tariffs, Ramsey Pricing, and Peak Load pricing. Ramsey Pricing and Peak Load pricing are examples of price discrimination regimes where different customers are charged different prices to obtain revenues larger than those obtained from a single price for all consumers. These are relevant to public bus transit where demand varies temporally. Thus, demand in the peak period is often significantly higher than that in the off-peak period. Demand patterns could also vary across different consumer categories. For instance, demand elasticities for educational trips by students would be different from work related trips. In principle, if it were possible to distinguish between demand elasticities of different consumer groups and over time, differential pricing regimes could be applied.

Unfortunately, given the analysis in chapter 3, data is not available for different consumer categories to be able to estimate aggregate demand functions differentiated temporally or by for each consumer category. Hence, differential pricing rules are not applied in this chapter. In addition, there may be legal issues that prevent charging different prices to different consumers or consumer groups (Braeutigam (1979)).

### 4.2.1. First best pricing

First best pricing is derived from maximizing net social benefits, that is, the difference between the willingness of consumers to pay for the services and the cost of producing them (Gómez-Ibáñez (1999)) or the sum of consumer and producer surplus' (Braeutigam (1989)). Formally, the net social benefits,  $NSB$ , are defined as follows (Berg et al. (1988)):

$$NSB = CS(\cdot) - \pi \quad 4.1$$

where  $CS(\cdot) = \int_0^x p(x)dx - p(x)x$  is a measure of consumer surplus,  $\pi = pX - C(X)$  are the profits from producing  $X$  quantity of output,  $C(X)$  is the total cost of providing  $X$ .

The optimal price can then be obtained from maximizing  $NSB$  with respect to  $x$ . Following Gómez-Ibáñez (1999),

$$\begin{aligned} p^*(x) &= AC(x) + x \frac{dAC(x)}{dx} \\ &= MC(x) \end{aligned} \quad 4.2$$

where  $AC(x) = \frac{C(x)}{x}$  is the average cost and  $MC(x) = \frac{dC(x)}{dx}$  is the marginal cost of producing  $x$ . The second order sufficiency conditions require the slope of the marginal cost curve be larger than the slope of the demand curve.

Hence, optimal prices equal the marginal costs of providing transit services. The optimal fare can be split into two parts, the first being the average cost of serving each passenger, and the second being the change in the cost from serving each additional passenger (Gómez-Ibáñez (1999)). Charging consumers a price equal to the marginal costs would ensure that consumers demand an extra unit of the product only if the value of the additional unit is larger than the additional cost of producing it.

This regime is premised on several crucial assumptions, which make its effectiveness uncertain (Gómez-Ibáñez (1999)). In particular, marginal cost pricing assumes that there are no externalities in production and consumption. In the presence of such externalities not addressed explicitly through taxes or subsidies, the social costs of production would diverge from the firms' costs and hence lead to inefficient outcomes. For example, the price of using a personal vehicle usually comprises the actual cost of using a vehicle without accounting for external costs such as those from pollution or congestion. Hence, unless the use of personal vehicles is taxed such that the tax rate equals the marginal external costs from using personal vehicles, fixing bus fares equal to marginal cost of providing public transit services will not

maximize the net social benefit. Of course, the external costs need to be accounted for in the fixing of bus fares also.

With marginal cost pricing, concerns also arise in network industries since these are usually characterized by Economies of Scale. In particular, for a single output firm, the presence of Economies of Scale imply that marginal costs are lower than average costs and average costs are falling<sup>18</sup> (Kahn (1970)). That is,

$$\frac{dAC(x)}{dx} < 0 \quad 4.3$$

In that case, equating the fare to marginal costs means that average costs exceed the price. In terms of the formulation above,

$$p^*(x) < AC(x) \quad 4.4$$

$$\text{or } \pi = [p^*(x) - AC(x)]x < 0 \quad 4.5$$

Hence, providing transit services with marginal cost pricing will imply a loss in the presence of Economies of Scale (Braeutigam (1989); Gómez-Ibáñez (1999)).

In addition, Lipsey et al. (1956) point out that marginal cost pricing is a first best, if and only if, all other prices in the economy are also at their marginal cost levels. As Baumol et al. (1970) show, in the absence of all prices being at their optimal level, marginal cost pricing in just one market may lead to significant sub-optimality. In effect, if the price of even one close complement or substitute is not equal to its marginal cost, marginal cost pricing of transit services will not be optimal.

#### *4.2.2. Second best pricing rules*

As described above, marginal cost pricing in the presence of Economies of Scale implies losses for a transit firm. Sustaining operations, especially over the long term, implies that subsidies or financial support is necessary, usually from the government. A lump sum transfer, to cover the difference between costs and revenues with marginal cost pricing in an industry characterized by increasing returns to scale, clearly Pareto-dominates a scenario with prices higher than marginal costs (Kahn (1970); Willig (1978)).

However, governments are generally averse to providing direct subsidies to cover the difference between total costs and fare box collections (Kahn (1970)). This reluctance can be, at least in part, traced to the political economy of deficit budgeting. In particular, with

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<sup>18</sup> Economies of Scale are defined in terms of the cost function as the ratio of average cost to marginal cost if and only if the production technology is homothetic, given cost minimization. Refer to chapter 2 for details.

increasing focus on fiscal responsibility and financial viability, direct transfers to public transit firms are unlikely. Such arguments are strengthened by arguing that the lack of a budget constraint implies that firms do not have incentives for minimizing costs (Garcia et al. (2004)). Importantly, such revenue transfers have to be lump sum so that there are no new distortions created in the economy. This is because such transfers might end up being financed using new tax measures, which in turn may be distortional.

In addition, for regulated industries, the regulatory agencies may not have access to fiscal resources to provide for subsidies. Hence, regulatory strategies are constrained by the revenue adequacy of the firms. If prices are above the marginal costs, this would necessarily imply a reduction in demand from the socially optimal level, resulting from a reduction in the consumer surplus (Braeutigam (1989)). This loss of efficiency is referred to as the deadweight loss.

#### 4.2.2.1. Average cost pricing

The simplest pricing strategy followed by most utilities for ensuring that all costs are met is setting the price equal to the average cost. As a result, this strategy is also called the revenue–recovery principle (Garcia et al. (2004)). Following White (1981),

$$p(x) = \frac{C(x)}{x} \quad 4.6$$

where  $C(x)$  is total cost of providing  $x$ .

In the transit sector, this translates into dividing the total costs by the number of passengers to obtain the average cost per passenger and setting the fare equal to that. This is the simplest case of charging a flat fare to cover all costs of operation. In this case, the output  $x$  is defined in terms of the number of passengers. Hence, the average cost price obtained is a flat fare per trip.

However, often transit services are priced according to the distance covered. To incorporate a distance dimension to average cost pricing, the total cost is divided by the passenger kilometers. The result here is a fare per kilometer that is charged to each passenger. Other characteristics of average cost pricing could include temporally differentiated prices, by different types of services provided, etc.

The most significant criticism of this scheme is that such prices do not signal scarcity as they would in neoclassical economics (Garcia et al. (2004)) and therefore create a deadweight loss. As a result, there is a loss in economic efficiency that comes about from prices that do not reflect marginal costs and demand, and hence a loss in net social benefit.

#### 4.2.2.2. Budget constrained two-part tariff

Most early analysis of costs and benefits did not explicitly recognize deficit between revenues and costs in the social objective function, instead focusing on only the consumer surplus and cost of production (Obeng (1983)). However, as discussed earlier, in industries characterized by increasing returns to scale, this implies that firms are unable to recover costs and hence cease production over time.

$$\text{That is, } p < AC(x) \Rightarrow p'x - C(x) = \pi < 0 \text{ if } p = MC \quad 4.7$$

Welfare maximization in such a scenario could take into account a revenue adequacy constraint by charging an entry fee or fixed price in addition to the variable price. The fixed fee is set to extract just enough of the consumer surplus to cover the deficit arising from marginal cost pricing. The entry fee in this case is a payment for the privilege of being able to consume the service and the variable price is the payment for consuming each additional unit of the service. This leads to non-linear pricing since total payment for consuming the service falls with each additional unit consumed.

Following Ng et al. (1974) and Berg et al. (1988), the problem can then be set up as follows:

$$\max \psi(x) \text{ subject to } \pi = p_v X + p_F I - C(x) \geq 0 \quad 4.8$$

where  $\psi(\cdot) = \int_0^I V(p_v, p_F, w(I), I) f(I) dI$  is a measure of consumer welfare and  $f(I)$  is the density function of consumers<sup>19</sup>.  $X = \int_0^I x_i f(I) dI$  is the total demand of  $I$  consumers,  $p_v$  and  $p_F$  are the variable and fixed price components, respectively.  $C(\cdot)$  is the total cost of producing, and  $\pi$  is the profit. Solving the above system gives a variable part that equals marginal costs, and fixed price equals the difference between cost and the revenue from the variable price divided between all customers<sup>20</sup>.

Hence,

$$p_v = \frac{dC(x)}{dx} = MC(x) \quad 4.9$$

$$\text{and } p_F = \frac{C(x) - p_v x}{I} \quad 4.10$$

<sup>19</sup> The expression for consumer welfare here ignores any normative weighting that a social planner may assign to different consumers. In addition, income effects are ignored while aggregating welfare across consumers.

<sup>20</sup> Refer to Berg et al. (1988) for a detailed derivation.

where  $p_v$  is the variable price component,  $p_F$  is the fixed price component, and  $I$  is the total number of consumers.

Such a two-part tariff regime would lead to the same output equilibrium as marginal cost pricing. The analysis here is contingent on the fixed price being charged, analogous to a lump sum tax, and hence not influencing consumption at the margin. This is important for if demand is sensitive to income effects, then such access charges would lead to a change in the demand from the optimal level.

### 4.3.Literature review

In general, empirical pricing research can be categorized based on two broad approaches. The first approach uses a comprehensive framework that includes all consumer categories and products, including substitutes and compliments. For instance, the PETS report (European Commission (2000)), de Borger et al. (1997), and Proost et al. (2002) include all transport modes in the regions under consideration and carry out a comprehensive analysis of pricing issues including direct and indirect costs of providing transport services. Hence, private transport modes and other public transport modes are included in addition to bus based public transport. Moreover, external costs due to noise and pollution, and user costs, are also considered in the analysis apart from only costs of production. For instance, the general pricing principles elucidated in the PETS report attempt to capture the total social costs of making transport services available including the actual costs of production, costs associated with using the services such as costs associated with waiting, transit time, and comfort, and finally, external costs for all modes of transport (European Commission (2000)).

The second approach focuses on firms and analyzes the pricing policies given the structure of the direct cost of production, and the demand faced by the firm. There are numerous applications of various pricing strategies in network industries. Much of the research on infrastructure pricing applied Ramsey pricing and is largely from the United States (Hayashi et al. (1987); Nelson et al. (1987)).

In the public bus transit sector, the literature on empirical applications of pricing by a firm or in an industry is limited. Most studies have focused on the impact of price changes on transit ridership using price elasticity of demand (Cervero (1990)). There is also a rich theoretical literature that has developed analytical techniques for designing different pricing strategies and assessing their impacts. For instance, Pedersen (2003) provides a framework for different pricing policies for urban transit depending on capacity constraints and external effects.

As a result, literature presented below reviews one study from the public transit sector and two studies from other sectors. The studies assess pricing from the point of view of the firms addressing only the direct cost of production in the absence of substitutes or compliments. These form the basis of the estimations carried out below and the recommended pricing strategy for public bus transit in India.

#### *4.3.1. Bus and Underground in London*

Bos (1986) presents marginal and Ramsey pricing solutions for the bus and Underground railway system in London operating under the management of London Transport. A time series dataset for 1958–1982 was constructed using London Transport's Annual Reports and Accounts. Prices are based on two different cost estimates. First, marginal cost estimates are obtained by estimating Translog factor demand functions for labour and capital inputs used in production. Another set are based on marginal costs estimated from linear cost functions used by London Transport. Marginal costs are further distinguished between short run and long run. Short run marginal costs comprise marginal changes in total costs due to labour inputs only. In the long run marginal cost estimates, both labour and capital input changes are accounted for. Demand estimates are obtained from estimating an Almost Ideal Demand System model for buses, the Underground, taxis, and personal vehicles. The demand estimation reveals that both the bus service and the Underground are price inelastic though the elasticity values are higher than those reported in Chapter 3. Price elasticity of demand of buses though is lower than that of the Underground.

The pricing analysis reveals that marginal cost pricing in the short run would require an increase in bus fares while those of the Underground would come down. In addition, bus fares would be twice as large as the Underground. In the long run, once capital costs are taken into account for pricing of the Underground, the fares are similar between the two services, with Underground fares also rising over time. In comparison to marginal cost pricing, Ramsey pricing leads to lower fares in the short run, and higher fares in the long run. Given that price elasticity of bus services is smaller, the price increase is larger in the case of bus services compared to the Underground.

#### *4.3.2. Electricity tariffs of private utilities in the United States*

Naughton (1986) analyzes the two-part tariffs charged by 78 privately owned electric utilities in the United States to assess equity and efficiency issues. This is done by estimating a Translog variable cost function. Costs here include both generation and distribution. Consumer categories are distinguished into wholesale, residential, commercial, and industrial consumers. Output is further differentiated into connections provided and

electricity supplied. Fuel, labour, and power purchased are the three variable inputs, while capital is the fixed input.

The sample of firms selected is such that only firms with a similar production technology are included. In addition, all firms in the sample have a similar mix of consumer groups. Finally, utilities that do not primarily serve one state are excluded from the analysis since they are regulated by more than one regulatory commission. The results obtained are then assumed to apply to a representative firm at its mean. This is similar to the approach used in this study where the estimated cost function is applied to a representative firm at the median.

The estimated marginal and average costs are then compared to the current prices for the various consumer categories and consumption patterns. In case of Economies of Scale, marginal cost pricing is the first best solution. However, if the profit constraint is binding, then the optimal two-part tariff regime is more complicated. In general, two-part tariffs better reflect electricity cost structures than uniform prices.

#### *4.3.3. Water pricing in French water utilities*

Garcia et al. (2004) evaluate the pricing of a panel of 50 French water utilities in the Bordeaux area during 1995–1998 by first estimating the structure of costs and water demand. A short run Translog variable cost function is estimated taking labour, electricity, and materials as the variable inputs, and capital as the fixed input. Network and environmental characteristics are incorporated in the analysis by the number of metered connections and the length of the network. Demand is specified as a log linear form with the explanatory variables being price, income, and other hedonic variables describing characteristics of industrial and domestic consumers. The cost function along with share equations for the factor inputs, and the demand function are all then estimated as a system of equations. The marginal costs and the average capital expenditure obtained from the above exercise are then compared with actual average marginal prices and average fixed charges for different classifications of firms. Firms are classified based on the network length in the first comparison, and the number of consumers in the second.

Garcia et al. (2004) conclude that pricing is inefficient in almost all cases based on the differences between marginal costs and marginal prices. On average, prices are statistically significantly lower than marginal costs, though the standard deviation is small. This is attributed to the constant returns to scale observed in the industry, and hence the marginal and average costs are very close. Since the industry focuses on revenue adequacy and relies on average cost pricing, the prices obtained are close to the marginal cost estimates. In addition, the fixed charge is much larger than capital expenditures. This is recognized as a



strategy of the industry to recover at least part of the variable costs through fixed charges and hence reduce some financial risks that arise from volatility in demand.

However, welfare gains from the above described pricing regime are not significant. This is in a large measure due to the low elasticity of demand for water estimated, and hence the small changes in demand that take place with price increases. In addition, the current prices are already very close to the estimated optimal prices. Finally, the fixed charge is included in this analysis only as a lump–sum transfer from the consumers to the firms.

#### **4.4. Efficient transit pricing in India**

The estimation of an efficient pricing regime requires estimates of marginal costs and demand elasticities. The subsidy and equity considerations are then described by comparing the prices to marginal costs, and evaluating the impact on public bus transit demand, consumer surplus, and profits (Naughton (1986)). In the present research, estimates for user costs and external costs are not available and only production costs for firms that have been estimated in chapter 2 are used. Hence, marginal social costs comprise only production costs in this research. As noted earlier, the focus of the pricing regimes in this section is on the public bus transit firms in a partial equilibrium framework following Naughton (1986) and Garcia et al. (2004) and not the entire transit sector, as is the case in the PETS project.

Cost and demand functions have been estimated in earlier chapters. These are briefly described below. Following that, the three tariff regimes for single product monopolies described in section 4.2 are estimated. These are average cost pricing, marginal cost pricing, and a second best two–part tariff. While average cost pricing and the two–part tariff ensure complete cost recovery, marginal cost pricing could lead to losses in the presence of Economies of Scale.

In all the literature that is available for review, this is the only study that looks at efficient transit pricing in India. A comprehensive analysis has been attempted, including the estimation of an aggregate demand function for India and a cost function for all public transit firms in the country. In addition, the specifications used for estimation in both cases have included significant variables to capture heterogeneity in consumer behaviour and operating environment of the firms. The pricing strategies that are assessed focus on both economic efficiency as well as revenue adequacy.

##### ***4.4.1. Production technology and cost characteristics***

From the several specifications of the cost function using different methods estimated in chapter 2, only results from the Random Effects model, with a specification including network length, are used for the pricing analysis. Including network length leads to an

improved fit compared to the specification without network length. Moreover, the Random Effects model captures the variation for each firm over time, and between firms. Random Effects estimates can also be used to make out of sample predictions. Using the specification estimated in chapter 2 and assuming that the representative firm is characterized by median values for all variables, the total cost function can be simplified as follows:

$$\text{Ln}C = \alpha_0 + \alpha_y \text{Ln}pkm + \frac{1}{2} \alpha_{yy} \text{Ln}pkm^2 \tag{4.11}$$

Here  $pkm = \frac{pkm_i}{\text{median}(pkm)}$ , that is, each observation has been normalized at the median.

The estimated parameter values for 4.11 are presented in Table 4.4.1.

**Table 4.4.1. Parameter values for cost equation**

Parameter	Estimated value
$\alpha_0$	-0.832
$\alpha_y$	0.650
$\alpha_{yy}$	0.359

Then, the expressions derived from 4.11 for average and marginal costs are the following<sup>21</sup>:

$$AC(pkm) = pkm^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0} \tag{4.12}$$

$$MC(pkm) = (\alpha_y + \alpha_{yy} \text{Ln}pkm) pkm^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0} \tag{4.13}$$

These are then used to estimate various pricing regimes.

#### 4.4.2. Demand elasticities

As with the cost function, several static models and dynamic demand models have been estimated in chapter 3. The static model provides a more stable specification. Within the various static models estimated, the Random Effects estimates can be applied outside the sample for predictions, and also compliment the cost estimates used in this chapter (Cameron et al. (2005)). Hence, the results from the static Random Effects model are used in the following pricing analysis.

<sup>21</sup> From 4.11, we have  $\text{Ln}C = \alpha_0 + \alpha_y \text{Ln}pkm + \frac{1}{2} \alpha_{yy} \text{Ln}pkm^2$ . Then,

$$C = e^{\alpha_0 + \alpha_y \text{Ln}pkm + \frac{1}{2} \alpha_{yy} \text{Ln}pkm^2}$$

$$\therefore \frac{dC}{dpkm} = MC(pkm) = \frac{e^{\alpha_0 + \alpha_y \text{Ln}pkm + \frac{1}{2} \alpha_{yy} \text{Ln}pkm^2} (\alpha_y + \alpha_{yy} \text{Ln}pkm)}{pkm}$$

$$\text{Thus } MC(pkm) = (\alpha_y + \alpha_{yy} \text{Ln}pkm) pkm^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0} \text{ and } AC(pkm) = pkm^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0}$$

From the demand function specified in chapter 3 and the estimation results there, and using median values to characterize a representative consumer, the demand function can be expressed as the following<sup>22</sup>:

$$\text{Ln}pkm = d + \alpha_p \text{Ln}p \quad 4.14$$

Then, the following is the inverse demand function for a representative consumer that can be used to evaluate the different pricing regimes<sup>23</sup>.

$$p = \left( pkm \cdot e^{-d} \right)^{1/\alpha_p} \quad 4.15$$

Finally, for estimating changes in consumer surplus, the use of the Marshallian demand curve is appropriate, if and only if, income effects are absent (Braeutigam (1989)). However, in empirical analyzes, it is difficult to estimate and use a compensated or Hicksian demand curve. In addition, Willig (1976) shows that consumer surplus measures estimated from either of the demand schedules are similar in magnitude. Hence, the Marshallian demand curve is used for analysis in this research.

Using the demand curve given above,

$$CS(p) = \int_{p_1}^{p_0} e^d p^{\alpha_p} = \frac{e^d p^{\alpha_p + 1}}{\alpha_p + 1} \Big|_{p_1}^{p_0} \quad 4.16$$

where  $CS(\cdot)$  is the consumer surplus, evaluated in the interval  $\{p_1, p_0\}$ .

### 4.4.3. Pricing regimes

The optimal prices have been estimated using the cost function and the inverse demand function given above. This is a pair of non-linear equations in  $p$  and  $pkm$ . The three tariff regimes for single product monopolies described in section 4.2 are estimated. These are average cost pricing, marginal cost pricing, and a second best two-part tariff. For average

<sup>22</sup> The static demand function specified in chapter 3 is the following:

$$\text{Ln}pkm = \alpha_o + \alpha_p \text{Ln}p + \alpha_w \text{Ln}w + \alpha_q \text{Ln}q + \alpha_s \text{Ln}s + \alpha_{pop} \text{Ln}pop + \alpha_{work} \text{Ln}work + \alpha_{lit} \text{Ln}lit + \varepsilon_i$$

Now if the representative consumer is characterized by the median values of all variables, then let,  $d = \alpha_o + \alpha_w \overline{\text{Ln}w} + \alpha_q \overline{\text{Ln}q} + \alpha_s \overline{\text{Ln}s} + \alpha_{pop} \overline{\text{Ln}pop} + \alpha_{work} \overline{\text{Ln}work} + \alpha_{lit} \overline{\text{Ln}lit}$ , where,  $\bar{x} = \text{median}(x)$ . Then, substituting in the demand function, we obtain 4.14.

<sup>23</sup> From  $\text{Ln}pkm = d + \alpha_p \text{Ln}p \therefore pkm = e^{d + \alpha_p \text{Ln}p} = e^d p^{\alpha_p}$  Thus  $p = \left( pkm \cdot e^{-d} \right)^{1/\alpha_p}$

cost pricing, the estimated price and quantity is the solution of the following system of equations:

$$\begin{cases} p_a = AC(pk m_a) = pk m_a^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0} \\ pk m_a = e^d p_a^{\alpha_p} \end{cases} \quad 4.17$$

For marginal cost pricing, the estimated price and quantity is the solution of the following system:

$$\begin{cases} p_m = MC(pk m_m) = (\alpha_y + \alpha_{yy} \text{Ln} pk m_m) pk m_m^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0} \\ pk m_m = e^d p_m^{\alpha_p} \end{cases} \quad 4.18$$

In the case of two part tariffs, the pricing system can be described as following<sup>24</sup>:

$$\begin{cases} p_v = MC(pk m_m) = (\alpha_y + \alpha_{yy} \text{Ln} pk m_m) pk m_m^{\alpha_y + \alpha_{yy} - 1} e^{\alpha_0} \\ p_F = \frac{pk m_m^{\alpha_y + \alpha_{yy}} e^{\alpha_0} - p_v pk m_m}{pax} \\ pk m_m = e^d p_v^{\alpha_p} \end{cases} \quad 4.19$$

where  $\overline{pax}$  is the median value of the number of passengers.

The results are presented in terms of equilibrium prices in rupees per passenger kilometers (rupees per passengers in the case of the fixed component of the two-part tariff), and quantities in terms of million passenger kilometers. For estimating the change in demand and consumer surplus, the current market price and quantity is required. However, the current market outcome is not a Walrasian equilibrium as defined by a market clearing price such that public bus transit demand equals its supply. In other words, the current market outcome can be described as a quantity constrained equilibrium where the market price and quantity are exogenously enforced by the government. In our analysis, this market outcome is characterized by the median value for output and the bus transit fare. Thus, the observed median values for output and the traffic revenue per passenger kilometer for the most recent year have been taken to reflect the current market outcome<sup>25</sup>.

<sup>24</sup> In case of the two-part tariff, the deficit of the firm is recovered by a lump sum transfer from the consumer to the firm, such that the reduction in consumer surplus is just enough to cover the losses of the firm.

<sup>25</sup> The median bus fare reported in 2004 was 0.135 rupees per passenger kilometer in 1989/90 prices. A low standard deviation of the bus fares in 2004 of only 0.040 indicates that this is quite representative of the bus fare charged by a representative firm.

Finally, the change in profit is also presented. Efficiency gains from moving towards an efficient pricing regime are then obtained as a sum of the change in consumer surplus and the change in profits. All prices are presented in terms of 1989/90 rupees.

**Table 4.4.2 Pricing regimes for public bus transit in India<sup>#</sup>**

Pricing regime	Price		Quantity	Change in demand	Change in Consumer Surplus	Change in Profit	Efficiency gain
Current market*	0.135		11,493.580	–	–	–	–
Average cost pricing	0.709		4,571.527	–60.23%	–33,017.406	27,982.136	–5,035.270
Marginal cost pricing	0.232		6,795.726	–40.87%	–7,164.625	9,571.812	2,407.180
Two-part tariff	Fixed	Variable	6,795.726	–40.87%	–25,578.880	27,982.136	2,407.180
	3.080	0.232					

<sup>#</sup>Price estimates were also obtained for varying network structures with network lengths at 25<sup>th</sup> and 75<sup>th</sup> percentile, apart from the results at the median network length reported above. These results were similar to the ones reported here in terms of the direction of change in consumer surplus, profits, and efficiency gains, and are hence not presented here.

\* Median output and public bus fare.

Solving equations 4.17, 4.18, and 4.19, the equilibrium prices and quantities reported in Table 4.4.2 are obtained. Given that this is an industry that is characterized by declining average costs and hence is a natural monopoly, the estimated equilibrium price is higher with average cost pricing than with marginal cost pricing. Average cost pricing calls for an increase in the public bus fares by more than 425% compared to the current median fare. The price increase required for marginal cost pricing is much more modest, about 72%. This is also reflected in the larger decrease in quantity that would come about from average cost pricing, compared to marginal cost pricing. It should be noted that this is the change with respect to the current supply level where the price and quantity are exogenously imposed. Nevertheless, with both average cost pricing and with marginal cost pricing, there is a significant decrease in quantity from the current levels. In the case of two-part tariffs, the equilibrium variable price and quantity is the same as in the case of marginal cost pricing. The fixed component is obtained in terms of rupees per passenger. Hence, a move towards efficient pricing would lead to a fall in public bus transit ridership, and this fall would probably lead to an increase in personal vehicles. This is clearly a cause for concern.

The change in consumer surplus also mirrors the change in prices. The much larger price increase required in the case of average cost pricing is reflected in the larger fall in the consumer surplus caused by the price increase. With public bus transit fares fixed such that all costs are recovered, the quantity consumed falls by more than 60% and the consumer surplus falls by nearly 35%. On the other hand, with marginal cost pricing, the fall in consumer surplus is just 7.5%. Nevertheless, the fall in consumer surplus is restrained by the inelastic demand for public bus transit in India. Even a fall in demand of over 40% in the case

of marginal cost pricing leads to only a 7.5% fall in consumer surplus. There is a substantial fall in the consumer surplus with the two-part tariff given the large transfer from consumers to the firms that is effected through the fixed price.

For the firms, average cost pricing and two-part tariffs lead to zero profits by design. Again, given the natural monopoly characteristics of the firms, marginal cost pricing leads to losses, due to falling average costs. Nevertheless, with efficient pricing, the change in profits is always positive. Since marginal cost pricing leads to some losses, the change in profits is greater in the case of average cost pricing and two-part tariffs.

Finally, summing the change in consumer surplus and profits gives the gains due to efficient pricing. As is expected, these gains are positive in the case of marginal cost pricing and two-part tariffs based on marginal costs. Since average cost pricing is not motivated by efficiency and only by cost recovery, efficiency gains are negative here. This is in large measure due to the loss of consumer surplus from the large fare increase required in the case of average cost pricing. In addition, efficient pricing implies a fall in consumer surplus and a rise in profits. Thus, distributional issues arising from efficient pricing could be significant. Recalling that non-price attributes, such as access to public transport networks have a much larger impact on travel demand as reported in chapter 3, the role of efficient pricing in meeting policy objectives other than economic efficiency is limited. Hence, it is important to recognize the limitations of a pricing policy that focuses solely on economic efficiency, while addressing the mobility and other developmental concerns in a developing economy. Moreover, since the rise in bus fares would probably lead to a shift towards personal vehicles, these efficiency gains would need to be compared to the additional costs due to higher personal vehicle usage such as higher emissions and congestion.

## 4.5. Conclusions

This chapter estimates three different pricing regimes for public bus transit in India in a partial equilibrium framework, and estimates their impact in terms of changes in demand and consumer surplus. The pricing strategies focus on both economic efficiency as well as revenue adequacy. Three tariff regimes are estimated, namely average cost pricing, marginal cost pricing, and a second best two-part tariff. While average cost pricing and the two-part tariff ensure complete cost recovery, marginal cost pricing could lead to losses in the presence of Economies of Scale.

The price regimes have been estimated using the cost function obtained from the estimation in chapter 2 and the aggregate demand function estimated in chapter 3. This is a pair of non-linear equations in price and quantity. Solving these equations, equilibrium prices and

quantities are obtained. With all three pricing regimes, there is a significant decrease in quantity from the current levels.

Since the industry is characterized as a natural monopoly, the estimated equilibrium price is higher with average cost pricing than with marginal cost pricing. Conversely, the fall in quantity that would come about from average cost pricing is larger compared to marginal cost pricing. Two-part tariffs lead to the same equilibrium quantity and variable price as in the case with marginal cost pricing. In addition, the change in consumer surplus also mirrors the change in prices with a much larger fall in the consumer surplus in average cost pricing compared to marginal cost pricing. For the firms, average cost pricing and two-part tariffs lead to zero profits by design. However, due to the natural monopoly characteristics of the firms, marginal cost pricing leads to losses due to falling average costs. Importantly, a significant efficiency gain is obtained from marginal cost pricing and two-part tariffs.

Hence, in the context of optimal pricing by a natural monopoly firm in the public bus transit industry in India, a move to efficient pricing has significant economic gains. However, as discussed earlier, an optimal pricing regime based on marginal costs of service delivery may not lead to socially optimal prices and outcomes. In particular, external and user costs in the transit sector need to be accounted for while estimating marginal social costs. In addition, prices of services that are substitutes or compliments to public bus transit should also be at their marginal cost levels. Moreover, the fall in public bus demand that comes about due to price increases in the three regimes discussed above could lead to, at least in part, a higher modal share of personal vehicles. In such a scenario, external costs due to higher emissions and increased congestion could become significant.

The pricing analysis in this chapter demonstrates the impact that efficient pricing strategies would have on public bus transit demand in India. It also highlights the fall in demand and consumer surplus that would come about from such pricing policies. Given the mobility needs and the developmental concerns of a growing economy such as India, the challenge for policy makers would be to balance the gains in economic efficiency in the public bus transit sector against other social, political, and developmental goals.

## 5. Conclusions and policy directions

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The economic growth that India has witnessed over the last few years has resulted in rapidly rising transport needs. Simultaneously, concerns are being raised about the sustainability of the transport sector in the country given a significant and rising share in emissions, both global and local. A well-developed transport system has positive implications for access to healthcare, education, and other basic needs. In the case of passenger road transport, meeting mobility requirements efficiently and addressing environmental and developmental concerns requires a greater share of bus transport in aggregate travel demand. This calls for an increase in the capacity of public bus transport and significant improvements in the quality of service delivery.

The public bus transport sector in India is overwhelmingly a government owned monopoly that is not regulated using incentive regulation instruments. The sector is also plagued by continued losses, which could in part be due to inefficiencies in operations and the size of the firms. In addition, the current pricing regime in the sector does not reflect the cost of service delivery and is motivated by social and political objectives. With prices being lower than average costs and there being no attempt to compensate public bus companies for this deficit, these firms have been suffering losses. Moreover, there does not appear to be any signal from the pricing regime to either the firms or the consumers as to the need for allocative efficiency. On the other hand, rising per capita incomes and the introduction of modern and cheap two wheelers and cars have contributed to making personal vehicles more affordable.

To increase the share of public transport and to ensure financial viability, public bus transport companies in India have to be restructured to ensure efficiency in service delivery and cost recovery. To identify the relevant policy directions and reform strategies, this research addresses the following issues in the public bus transport industry in India:

- Economies of Density and Scale.
- Impact of the management form of firms on the cost structure.
- Empirical analysis of demand and price elasticity.
- Impact of alternative pricing regimes by the firms on travel demand, and consumer welfare.

This research adopts a neo-classical microeconomic approach for studying the theoretical aspects of the study. The empirical estimations rely on econometric panel data models. The



research elements include the estimation of a cost function, an aggregate demand function, and subsequently using the same to develop alternative pricing regimes.

A thorough empirical assessment of the production and cost structure of public bus transit industry in India, of consumer behaviour, and of how these economic agents interact in the market is provided. In comparison to other studies that have studied the cost structure of public transport in India, the cost function estimation uses a more comprehensive dataset, and a much richer specification that includes the impact of the operating environment and management structure on costs. Thus, it is possible to distinguish between Density and Scale Economies in this analysis. The aggregate demand estimation presented in this research is possibly one of the very few studies that use dataset from a developing country. Again, a comprehensive national analysis is attempted, while controlling for differences in size, quality of service, and demographic and social characteristics across the various states in India. In terms of the estimation techniques used, this study applies several panel data models to estimating both the cost and demand functions, comparing results from several econometric models, some of which have not been explored fully in such applications. Finally, this is possibly the only study that estimates efficient pricing regimes for public bus transport in a developing country, and assesses the impact of the same in terms of the market outcomes.

## 5.1. Summary of results

The results of the research are summarized in terms of the three components that comprise the study, namely the cost estimation, the demand estimation, and the pricing regimes.

The ***Cost Estimation*** of the industry reveals that there are significant Scale Economies. With a longer panel, but without including network characteristics, almost all firms report significant Economies of Scale. While using a shorter panel that also includes network characteristics, a majority of firms still demonstrate significant Economies of Density and Scale though these fall as output rises. The results are similar to those obtained in other studies in India that use only a sub-sample of the dataset that is used in this analysis. Thus, with average costs falling for most public bus companies in India, there is a need for regulating the industry.

In addition, firms with mixed operations covering rural and urban areas are generally more cost effective compared to firms operating in urban areas only, indicating some economies from joint operation of rural and urban routes. Finally, the regulatory and legislative oversight does not vary between the four different management structures of the public bus companies that are currently in existence. From the cost estimation in this study, it is observed that the impact of the management structure of a bus company depends on the

specification adopted and the estimation technique used. Hence, the impact of a change in the management structure on cost is ambiguous.

The **Aggregate Demand Estimation** for public bus transport at the state level in India revealed that the price elasticity obtained was significant and less than unity. The importance of public bus transport in meeting passenger road travel demand in India and the unavailability of close substitutes within the road public transport sector could explain the price inelastic demand observed. The literature reports a negative relationship between public bus transport demand and income. This is sometimes ascribed to the positive correlation between vehicle ownership and income, and the negative correlation between vehicle ownership and public bus transit demand. In this research, vehicle ownership was included in the specification of the demand function in addition to income, to separate the income effect from that of vehicle ownership. The income effect obtained from such estimations were not significant and were negative. As expected, vehicle ownership had a significant and negative impact on public bus transit demand. The most significant policy variable influencing demand was access to the public bus transport network, which was included as a variable describing the quality of service. Clearly, in a developing country context, access to public transport services is of great import. Access to public transport is also a more effective policy instrument for increasing the ridership of public bus transport compared to only on bus pricing. Finally, in terms of demographic variables, a larger working population implies a higher demand for public transport, while a higher literacy rate implies a lower demand. The significance of such demographic and social variables reflects the complex nature of public bus transport demand in India.

The **Pricing Regimes** based on the cost and demand functions estimated are assessed not just in terms of the gains in economic efficiency, but also in changes in travel demand and consumer surplus. Three different and feasible pricing strategies for the sector are developed in a partial equilibrium framework with the objective of improving economic efficiency and ensuring revenue adequacy, namely, average cost pricing, marginal cost pricing, and two-part tariffs. The estimated partial equilibrium price is higher in all the three pricing regimes when compared to the current prices. As a result, consumer surplus falls in all three cases. The price increase would be much larger with average cost pricing compared to marginal cost pricing or two-part tariffs, and hence a larger fall in demand and consumer surplus comes about due to average cost pricing. Nevertheless, given that price elasticity of public bus transit demand is low, the fall in demand is proportionally lower than the price increase. For the firm, average cost pricing and two-part tariffs ensure revenue adequacy, while marginal cost pricing leads to losses. It must be noted, however, that while there is a gain in economic efficiency from marginal cost pricing and two-part tariffs, this improvement comes at the expense of reduced public bus transit demand and consumer surplus, given the price inelastic

public bus transit demand estimated for India. In addition, any increase in the use of personal vehicles due to a modal shift caused by rising public bus transit prices would result in higher emissions and congestion. Finally, the pricing regimes estimated in this research are limited to a partial analysis for a representative firm in the public bus transport industry. A more comprehensive exercise based on total social costs of all modes of transport would reveal changes in prices and taxes required for all modes in the transport sector, such that net social benefits are maximized.

## 5.2. Policy implications

Most small and medium firms in the sector report significant Economies of Density and Scale. Hence, cost savings are possible for these firms from a reorganization of production in the industry. This reorganization could be brought about by merging smaller firms and firms operating in neighbouring areas, such that each firm is operating at its optimal size. Firms that operate only in urban areas could also obtain cost savings from merging with operations in rural areas. In general, for the majority of firms, competition in the market with firms competing in the same network is not a useful strategy for reducing costs since the industry demonstrates Economies of Density. For the very few large firms that report Diseconomies of Scale, there exist potential cost gains from introducing competition.

However, there are not expected to be any perceptible gains in cost efficiency from a change in the organizational management of the government owned firms, at least within the four alternatives that exist currently. The role of such management changes is limited given that the legislative oversight that regulates the incentive structure and the pricing regime does not vary across the various management structures. As a result, focusing on the management structure of a bus company as a means to achieve cost efficiency within the four options currently available for the public sector is not a credible strategy.

In terms of factors influencing demand, the role of pricing is limited with public bus transit demand being price inelastic. Factors such as demographic changes and social variables have a larger influence on demand. In particular, access to a public bus transport network has a much larger impact on aggregate demand and hence is possibly a more effective policy variable.

From the pricing analysis, while a change in the pricing policy from the current price level does imply an improvement in economic efficiency, this gain comes about at the expense of a fall in demand and consumer surplus. To the extent that this leads to an increase in the use of personal vehicles, social costs would rise due to higher emissions and congestion. Given the mobility needs and the developmental concerns of a growing economy such as India, the

challenge for policy makers would be to balance the gains in economic efficiency in the public bus transit sector against other social, political, and developmental goals.

### 5.3. Further research

This research provides a thorough empirical assessment of the government owned public bus industry in India. The analytical framework used here is grounded in neo-classical economics and panel data econometrics. In all the literature available for review, this is the first study that addresses issues of productive and economic efficiency, consumer behaviour, and partial market equilibrium for the Indian public bus sector. However, the scope of this research has been limited by the dataset available in terms of the cross sectional depth and the time series length that is considered here. Some further research possible if a larger panel dataset covering more transport modes and variables were available is highlighted in this section.

A more comprehensive analysis could be possible if information were available on all modes of transport. In particular, an analysis of public bus transport in conjunction with other passenger modes would reveal greater detail on the possibility of substitution and complementarity. The modes that could be considered here would include not just personal vehicles such as cars and two-wheelers, but also intermediate public transport modes peculiar to India such as three-wheelers. This could be useful while considering the optimal structure of the sector, and the issues of Scope Economies could be addressed in addition to Scale Economies.

Secondly, estimates for user costs and external costs would add value to the analysis by allowing a more comprehensive assessment of marginal social costs, and hence optimal pricing. In particular, with estimates of marginal social costs that include external and user costs for all passenger transport modes, optimal pricing could then take into account the possibility of price discrimination across modes and hence increase net social benefits. Further price discrimination would be possible if estimates of price elasticities across different consumer categories and time of day were available. This would allow pricing based on Ramsey pricing and Peak Load pricing to be analyzed and assessed. Moreover, enforcing optimal pricing could be done either through direct regulation of public bus transit fares or other regulatory approaches such as yardstick regulation or franchise auctions. The performance of these alternative regulatory strategies needs to be assessed to ensure that an appropriate regulatory framework is put in place.

The demand analysis could be further enriched if data on aggregate household expenditure were available, differentiated into commodity groups, such that demand for public bus transit could be separated. This would allow all cross product influences to be included. At the very

least, prices of substitutes and complements, particularly personal vehicle usage, could be included in the analysis.

Finally, the distributional issues arising from efficient pricing need to be analyzed in greater detail. As is clear from the analysis in chapter 4, efficient pricing would lead to a fall in demand and losses. It would be of value to identify how the losses and gains in the economy are spread, and which consumer and population groups benefit from such policies.

# Bibliography

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- Abrate, G., M. Piacenza and D. Vannoni (2007). The Impact of Integrated Tariff Systems on Public Transport Demand: Evidence from Italy. XIX Riunione scientifica SIEP, Pavia.
- Agashe, L. G. (1999). "Financing State Transport Undertakings." Indian Journal of Transport Management: 173-180.
- Appelbaum, E. and J. Berechman (1991). "Demand conditions, regulation, and the measurement of productivity." Journal of Econometrics 47(2-3): 379-400.
- Arellano, M. and S. Bond (1991). "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations." The Review of Economic Studies 58(2): 277-297.
- Arellano, M. and O. Bover (1995). "Another look at the instrumental variable estimation of error-components models." Journal of Econometrics 68(1): 29-51.
- Avery, R. B. (1977). "Error Components and Seemingly Unrelated Regressions." Econometrica 45(1): 199-208.
- Balcombe, R., R. Mackett, N. Paulley, J. Preston, J. Shires, H. Titheridge, M. Wardman and P. White (2004). The demand for public transport: a practical guide. Transportation Research Laboratory Report. Transportation Research Laboratory, London.
- Baltagi, B. H. (1986). "Pooling under Misspecification: Some Monte Carlo Evidence on the Kmenta and the Error Components Techniques." Econometric Theory 2(3): 429-440.
- Baltagi, B. H. (2002). Econometric Analysis of Panel Data. New York, John Wiley. pp.293.
- Baltagi, B. H. and D. Levin (1986). "Estimating Dynamic Demand for Cigarettes Using Panel Data: The Effects of Bootlegging, Taxation and Advertising Reconsidered." The Review of Economics and Statistics 68(1): 148-155.
- Baltagi, B. H. and P. X. Wu (1999). "Unequally spaced panel data regressions with AR(1) disturbances." Econometric Theory 15(6): 814-823.
- Battese, G. E. and T. J. Coelli (1992). "Frontier production functions, technical efficiency and panel data: with application to paddy farmers in India." Journal of Productivity Analysis 3(1): 153-169.
- Baumol, W. J. and D. F. Bradford (1970). Optimal Departures from Marginal Cost Pricing. American Economic Review, 60 (3): 265-83.
- Baumol, W. J., J. C. Panzar and R. D. Willig (1982). Contestable Markets and the Theory of Industry Structure. San Diego, Harcourt Brace Jovanovich.
- Beck, N. and J. N. Katz (1995). "What to do (and not to do) with Time-Series Cross-Section Data." The American Political Science Review 89(3): 634-647.
- Beierlein, J. G., J. W. Dunn and J. McConnon, James C. (1981). "The Demand for Electricity and Natural Gas in the Northeastern United States." The Review of Economics and Statistics 63(3): 403-408.
- Berechman, J. (1983). "Costs, Economies of Scale and Factor Demand in Road Transport." Journal of Transport Economics and Policy 17(1-24).
- Berechman, J. (1987). "Cost structure and production technology in transit : An application to the Israeli bus transit sector." Regional Science and Urban Economics 17(4): 519-534.
- Berechman, J. (1993). Public Transit Economics and Deregulation Policy. Amsterdam, North-Holland.
- Berechman, J. and G. Giuliano (1984). "Analysis of the cost structure of an urban bus transit property." Transportation Research Part B: Methodological 18(4-5): 273-287.
- Berechman, J. and G. Giuliano (1985). "Economies of scale in bus transit: A review of concepts and evidence." Transportation 12(4): 313-332.
- Berg, S. V. and J. Tschirhart (1988). Natural Monopoly Regulation: Principles and Practices. Cambridge, Cambridge University Press. pp.576.
- Berndt, E. R. and L. R. Christensen (1973). "The translog function and the substitution of equipment, structures, and labor in U.S. manufacturing 1929-68." Journal of Econometrics 1(1): 81-113.
- Berndt, E. R. and M. S. Khaled (1979). "Parametric Productivity Measurement and Choice Among Flexible Functional Forms." The Journal of Political Economy 87(6): 1220-1245.
- Bhattacharyya, A., S. C. Kumbhakar and A. Bhattacharyya (1995). "Ownership structure and cost efficiency: A study of publicly owned passenger-bus transportation companies in India." Journal of Productivity Analysis 6(1): 47-61.
- Blackorby, C., D. Primont and R. R. Russell (1977). "On testing separability restrictions with flexible functional forms." Journal of Econometrics 5(2): 195-209.
- Blundell, R. and S. Bond (1998). "Initial conditions and moment restrictions in dynamic panel data models." Journal of Econometrics 87(1): 115-143.
- Bos, D. (1986). Public Enterprise Economics: Theory and Application. 23. Amsterdam, North-Holland. pp.471.

- Braeutigam, R. (1999). Learning About Transport Costs. Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer. J. Gomez-Ibanez, W. Tye and C. Winston. Washington, D.C., Brooking Institution Press.
- Braeutigam, R. R. (1979). Optimal Pricing in the Intermodal Competition. American Economic Review. **69**: 38–49.
- Braeutigam, R. R. (1984). "Socially Optimal Pricing with Rivalry and Economies of Scale." The RAND Journal of Economics **15**(1): 127-134.
- Braeutigam, R. R. (1989). Optimal policies for natural monopolies. Handbook of Industrial Organization. R. Schmalensee and R. D. Willig, Elsevier: 1289-1346.
- Bresson, G., J. Dargay, J. L. Madre and A. Pirotte (2003). "The main determinants of the demand for public transport: a comparative analysis of England and France using shrinkage estimators." Transportation Research Part A: Policy and Practice **37**(7): 605–627.
- Bun, M. J. G. and J. F. Kiviet (2001). The Accuracy of Inference in Small Samples of Dynamic Panel Data Models. Tinbergen Institute Discussion Papers. No 01-006/4. Tinbergen Institute, Amsterdam.
- Bun, M. J. G. and J. F. Kiviet (2003). "On the diminishing returns of higher-order terms in asymptotic expansions of bias." Economics Letters **79**(2): 145-152.
- Bun, M. J. G. and F. Windmeijer (2007). The Weak Instrument Problem of the System GMM Estimator in Dynamic Panel Data Models. Cemmap Working Paper No. CWP08/07. The Institute for Fiscal Studies, Department Of Economics, University College London, London.
- Button, K. and K. J. O'Donnell (1986). "The costs of urban bus provision in Great Britain." Transportation Planning and Technology **10**: 293–303.
- Cameron, A. C. and P. K. Trivedi (2005). Microeconometrics: Methods and Applications. New York, Cambridge University Press. pp.1034.
- Caves, D. W. and L. R. Christensen (1980a). "Global Properties of Flexible Functional Forms." The American Economic Review **70**(3): 422-432.
- Caves, D. W., L. R. Christensen and J. A. Swanson (1980b). "Productivity in U.S. Railroads, 1951–1974." Bell Journal of Economics **11**(1): 166–181.
- Caves, D. W., L. R. Christensen and J. A. Swanson (1981). "Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955–74." The American Economic Review **71**(5): 994–1002.
- Caves, D. W., L. R. Christensen and M. W. Tretheway (1984). "Economies of Density versus Economies of Scale: Why Trunk and Local Service Airline Costs Differ." RAND Journal of Economics **15**(4): 471–489.
- Caves, D. W., L. R. Christensen, M. W. Tretheway and R. J. Windle (1985). Network effects and the measurement of returns to scale and density for US railroads. Analytical Studies in Transport Economics. A. F. Daughety. Cambridge, Cambridge University Press: 97-120.
- Census of India 2001 (2001). Census of India 2001, Office of the Registrar General India, Government of India.
- Cervero, R. (1990). "Transit pricing research: A review and synthesis." Transportation **17**(2): 117-139.
- Chambers, R. G. (1988). Applied production analysis: a dual approach. New York, Cambridge University Press. pp.331.
- Christensen, L. R., D. W. Jorgenson and L. J. Lau (1973). "Transcendental Logarithmic Production Frontiers." The Review of Economics and Statistics **55**(1): 28–45.
- CIRT (Various years). State Transport Undertakings: Profile and Performance. Central Institute of Road Transport, Pune.
- Clements, K. W. and S. Selvanathan (1994). "Understanding consumption patterns." Empirical Economics **19**(1): 69-110.
- Colburn, C. B. and W. K. Talley (1992). "A firm specific analysis of economies of size in the U.S. urban multiservice transit industry." Transportation Research Part B: Methodological **26**(3): 195–206.
- Costa, A. (1998). Public Transport Efficiency and Effectiveness: Metro de Madrid. Transport Networks in Europe: Concepts, analysis and policies. K. Button, P. Nijkamp and H. Priemus, Edward Elgar: 248–263.
- Cowie, C. G. and F. R. Fitzroy (1993). Deregulation and the Demand for Scottish Bus Transport. CRIEFF Discussion Papers 9508. Centre for Research into Industry, Enterprise, Finance and the Firm, Fife.
- Cowie, J. and D. Asenova (1999). "Organisation form, scale effects and efficiency in the British bus industry." Transportation **26**(3): 231–248.
- Cubukcu, K. M. (2006). Cost of Urban Bus Transit Operations and Geography of Service Territory. International Conference on Regional and Urban Modeling, Brussels, Belgium.
- Dalen, D. M. and A. GÅmez-Lobo (2003). "Yardsticks on the road: Regulatory contracts and cost efficiency in the Norwegian bus industry." Transportation **30**(4): 371–386.
- Dargay, J. and M. Hanly (1999). Bus Fare Elasticities. Report to the UK Department of the Environment, Transport and the Regions. ESRC Transport Studies Unit, University College London, London.

- Dargay, J. M. and M. Hanly (2002). "The Demand for Local Bus Services in England." Journal of Transport Economics and Policy **36**(1): 73-91.
- de Borger, B., S. Ochelen, S. Proost and D. Swysen (1997). "Alternative transport pricing and regulation policies: A welfare analysis for Belgium in 2005." Transportation Research Part D: Transport and Environment **2**(3): 177-198.
- de Borger, B. L. (1984). "Cost and Productivity in Regional Bus Transportation: The Belgian Case." The Journal of Industrial Economics **33**(1): 37-54.
- de Rus, G. (1990). "Public transport demand in Spain." Journal of Transport Economics and Policy **24**(2): 189-201.
- Deaton, A. and J. Muellbauer (1980). Economics and Consumer Behavior. Cambridge, Cambridge University Press. pp.464.
- Deb, K. (2001). Transport Services. Directions, Innovations, and Strategies for Harnessing Action for sustainable development. R. K. Pachauri and R. K. Batra. New Delhi, TERI: 368.
- Deb, K. (2003). "Restructuring Urban Public Transport in India." Journal of Public Transportation **5**(3): 85-102.
- Demsetz, H. (1968). "The Cost of Transacting." The Quarterly Journal of Economics **82**(1): 33-53.
- Denny, M. and M. Fuss (1977). "The Use of Approximation Analysis to Test for Separability and the Existence of Consistent Aggregates." The American Economic Review **67**(3): 404-418.
- Department of Transport (1984). Buses. Cmnd 9300. Her Majesty's Stationery Office, UK, London.
- Diewert, W. E. (1992). "Fisher ideal output, input, and productivity indexes revisited." Journal of Productivity Analysis **3**(3): 211-248.
- Doel van den, I. T. and J. F. Kiviet (1995). "Neglected Dynamics in Panel Data Models: Consequences and Detection in Finite Samples." Statistica Neerlandica **49**: 343-361.
- EPWRF (2003). Domestic Product of States of India: 1960-61 to 2000-01. Mumbai, Economic and Political Weekly Research Foundation.
- European Commission (1995). Towards Fair and Efficient Pricing in Transport Policy. Policy Options for Internalising the External Cost of Transport in the European Union. Green Paper. COM (95) 691. European Commission, Brussels.
- European Commission (2000). Pricing European Transport Systems. ST 96 SC 172. European Commission, Brussels.
- Evans, A. W. (1991). "Are urban bus services natural monopolies?" Transportation **18**(2): 131-150.
- Farsi, M., A. Fetz and M. Filippini (2007). "Economies of scale and scope in local public transportation." Journal of Transport Economics and Policy **41**(3).
- Farsi, M. and M. Filippini (2004). "An Empirical Analysis of Cost Efficiency in Nonprofit and Public Nursing Homes." Annals of Public and Cooperative Economics **75**(3): 339-365.
- Farsi, M., M. Filippini and M. Kuenzle (2005). "Unobserved Heterogeneity in Stochastic Cost Frontier Models: An Application to Swiss Nursing Homes." Applied Economics **37**(18): 2127-2141.
- Farsi, M., M. Filippini and M. Kuenzle (2006). "Cost Efficiency in Regional Bus Companies: An Application of Alternative Stochastic Frontier Models." Journal of Transport Economics and Policy **40**(1): 95-118.
- Fazioli, R., M. Filippini and P. Prioni (1993). "Cost Structure and Efficiency of Local Public Transport: The Case of Emilia Romagna Bus Companies." International Journal of Transport Economics **3**: 305-324.
- Feigenbaum, S. and R. Teeple (1983). "Public Versus Private Water Delivery: A Hedonic Cost Approach." The Review of Economics and Statistics **65**(4): 672-678.
- Filippini, M. (1996). "Economies of scale and utilization in the Swiss electric power distribution industry." Applied Economics **28**(5): 543-550.
- Filippini, M. (1997). Elements of the Swiss Market for Electricity. Contributions to Economics. Heidelberg, Physica-Verlag. pp.229.
- Filippini, M., R. Maggi and P. Prioni (1992). "Inefficiency in a Regulated Industry: The Case of the Swiss Regional Bus Companies." Annals of Public & Cooperative Economics **63**(3): 437-455.
- Filippini, M. and P. Prioni (1994). "Is scale and cost inefficiency in the Swiss bus industry a regulatory problem? Evidence from a frontier cost approach." Journal of the Economics of Business **1**(2): 219-231.
- Filippini, M. and P. Prioni (2003). "The influence of ownership on the cost of bus service provision in Switzerland—an empirical illustration." Applied Economics **35**(6): 683-690.
- Fitzroy, F. R. and I. Smith (1993). The Demand for Public Transport: Some Estimates from Zurich. CRIEFF Discussion Papers 9308. Centre for Research into Industry, Enterprise, Finance and the Firm, Fife.
- FitzRoy, F. R. and I. Smith (1995). "The demand for rail transport in European countries." Transport Policy **2**(3): 153-158.
- FitzRoy, F. R. and I. Smith (1997). Passenger Rail Transport: Demand and Quality in a European Panel. CRIEFF Discussion Papers 9720. Centre for Research into Industry, Enterprise, Finance and the Firm, Fife.



- FitzRoy, F. R. and I. Smith (1999). "Season Tickets and the Demand for Public Transport." *Kyklos* **52**(2): 219-238.
- Fouracre, P. R. and D. A. C. Maunder (1987). Travel demand characteristics in three medium-sized Indian cities. Transport and Road Research Laboratory Research Report 121. Transport and Road Research Laboratory, Crowthorne.
- Fraquelli, G., M. Piacenza and G. Abrate (2001). Costs and Technology of Public Transit Systems in Italy: Some Insights to Face Inefficiency. Serie Speciale in Collaborazione con HERMES. CERIS-CNR, Torino.
- Fraquelli, G., M. Piacenza and G. Abrate (2004). "Regulating Public Transit Networks: How do Urban-Intercity Diversification and Speed-up Measures Affect Firms' Cost Performance?" *Annals of Public & Cooperative Economics* **75**(2): 193-225.
- Friedlaender, A. F. and R. H. Spady (1980). "A Derived Demand Function for Freight Transportation." *Review of Economics and Statistics* **62**(3): 432-441.
- Friedlaender, A. F., R. H. Spady and S. J. Wang-Chiang (1981). Regulation and the Structure of Technology in the Trucking Industry. Productivity Measurement in Regulated Industries. T. G. Cowing and R. E. Stevenson. New York, Academic Press.
- Friedlaender, A. F., C. Winston and K. Wang (1983). "Costs, Technology, and Productivity in the U.S. Automobile Industry." *The Bell Journal of Economics* **14**(1): 1-20.
- Gagne, R. (1990). "On the Relevant Elasticity Estimates for Cost Structure Analyses of the Trucking Industry." *The Review of Economics and Statistics* **72**(1): 160-164.
- Gagnepain, P. and M. Ivaldi (2002). "Incentive Regulatory Policies: The Case of Public Transit Systems in France." *The RAND Journal of Economics* **33**(4): 605-629.
- Gandhi, P. J. (1999). "Bus Nationalisation in India: Retrospective-cum-Pro prospective Reflections." *Indian Journal of Transport Management*: 181-189.
- Garcia, S. and A. Reynaud (2004). Estimating the benefits of efficient water pricing in France. *Resource and Energy Economics*. **26**: 1-25.
- Gathon, H. J. (1989). "Indicators of partial productivity and technical efficiency in the European urban transit sector." *Annals of Public & Cooperative Economics* **60**(1): 43-59.
- Gómez-Ibáñez, J. A. (1999). Pricing. Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer. J. A. Gómez-Ibáñez, C. A. Winston and W. B. Tye. Washington, DC, The Brookings Institution Press: 99-136.
- Goodwin, P. B. (1992). "A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes." *Journal of Transport Economics and Policy* **26**(2): 155-169.
- Goodwin, P. B. and H. C. W. L. Williams (1985). "Public transport demand models and elasticity measures: An overview of recent British experience." *Transportation Research Part B: Methodological* **19**(3): 253-259.
- Gorman, W. M. (1953). "Community Preference Fields." *Econometrica* **21**(1): 63-80.
- Government of India (2005). Economic Survey 2004/2005. Ministry of Finance, Government of India, New Delhi.
- Government of India (2006). Economic Survey 2005/2006. Ministry of Finance, Government of India, New Delhi.
- Gowda, J. M. (1999). "Implications of Concessional Travel Facility on the Commercial Viability of SRTC's in India." *Indian Journal of Transport Management*: 149-157.
- Greene, W. H. (2003). Econometric Analysis. New Jersey, Prentice Hall. pp.1026.
- Hanly, M. and J. Dargay (1999). Bus Fare Elasticities: A Literature Review. Report to the UK Department of the Environment, Transport and the Regions. London, ESRC Transport Studies Unit, University College London: 16.
- Harmatuck, D. J. (1981). "A Motor Carrier Joint Cost Function. A Flexible Functional Form with Activity Prices." *Journal of Transport Economics and Policy* **15**(2): 135-153.
- Hausman, J. A. (1978). "Specification Tests in Econometrics." *Econometrica* **46**(6): 1251-1271.
- Hayashi, P. M., M. Sevier and J. M. Trapani (1987). An Analysis of Pricing and Production Efficiency of Electric Utilities by Mode of Ownership. Regulating Utilities in an Era of Deregulation. M. A. Crew. New York, S. Martin's Press: 111-136.
- Hensher, D. A. (1987). "Productive efficiency and ownership of urban bus services." *Transportation* **14**(3): 209-225.
- Houthakker, H. S. (1957). "An International Comparison of Household Expenditure Patterns, Commemorating the Centenary of Engel's Law." *Econometrica* **25**(4): 532-551.
- Hsiao, C. (2003). Analysis of Panel Data. Econometrics Society Monographs. Cambridge, Cambridge University Press.
- Hsiao, C. and B. H. Sun (2000). To pool or not to pool panel data. Panel data econometrics: future directions. J. Krishnakumar and E. Ronchetti. Amsterdam, Elsevier: 181-198.

- Jara-Díaz, S. R. and C. Cortes (1996). "On the Calculation of Scale Economies from Transport Cost Functions." Journal of Transport Economics and Policy **30**(2): 157–170.
- Jha, R. and S. K. Singh (2001). "Small is Efficient: A Frontier Approach to Cost Inefficiencies in Indian State Road Transport Undertakings." International Journal of Transport Economics **18**(1): 95–114.
- Jorgensen, F., P. A. Pedersen and G. Solvoll (1995). "The Cost of Bus Operations in Norway." Journal of Transport Economics and Policy **29**(3): 253.
- Jorgenson, D. W. (1997). Aggregate consumer behavior. Dale Jorgenson's Collected Works. Welfare: Vol. 1. Cambridge, MIT Press. pp.540.
- Jovicic, G. and C. O. Hansen (2003). "A passenger travel demand model for Copenhagen." Transportation Research Part A: Policy and Practice **37**(4): 333–349.
- Justus, E. R. (1998). "Operational Efficiency in Public Passenger Road Transport-A Criteria Analysis." Indian Journal of Transport Management: 573-577.
- Kadam, V. A. (1999). "A Diagnostic Study of Viability of STUs." Indian Journal of Transport Management: 501-508.
- Kahn, A. E. (1970). The Economics of Regulation: Principles and Institutions. Cambridge, MIT Press. pp.559.
- Karlaftis, M. G. and P. McCarthy (2002). "Cost structures of public transit systems: a panel data analysis." Transportation Research Part E: Logistics and Transportation Review **38**(1): 1–18.
- Karlaftis, M. G., P. S. McCarthy and K. C. Sinha (1999). "System Size and Cost Structure of Transit Industry." Journal of Transportation Engineering **125**(3): 208–215.
- Kaserman, D. L. and J. W. Mayo (1991). "The Measurement of Vertical Economies and the Efficient Structure of the Electric Utility Industry." The Journal of Industrial Economics **39**(5): 483-502.
- Keeler, T. E. (1974). "Railroad Costs, Returns to Scale, and Excess Capacity." The Review of Economics and Statistics **56**(2): 201–208.
- Kemp, M. A. (1973). "Some evidence of transit demand elasticities." Transportation **2**(1): 25-52.
- Kennedy, P. (2003). A Guide to Econometrics. Cambridge, MIT Press. pp.623.
- Kerstens, K. (1996). "Technical efficiency measurement and explanation of French urban transit companies." Transportation Research Part A: Policy and Practice **30**(6): 431–452.
- Kiviet, J. F. (1995). "On bias, inconsistency, and efficiency of various estimators in dynamic panel data models." Journal of Econometrics **68**(1): 53-78.
- Kmenta, J. (1978). Some Problems of Inference from Economic Survey Data. Survey Sampling and Measurement. N. K. Namboodiri. New York, Academic Press: Chapter 8: 107-120.
- Kmenta, J. (1997). Elements of Econometrics. Ann Arbor, University of Michigan Press. pp.786.
- Koshal, R. K. (1970). "Economies of Scale in Bus Transport: II. Some Indian Experience." Journal of Transport Economics and Policy **4**(1): 29–36.
- Krishna, R. R. (1998). "A Study of Capital Productivity in Selected Road Transport Corporations in Tamilnadu - A New Approach." Indian Journal of Transport Management: 281-289.
- Krishna, R. R. (1999). "Debt-Equity Ratio in Public Enterprises: A Study of Selected Road Transport Corporations in Tamilnadu." Indian Journal of Transport Management: 413-419.
- Krishna, R. R., S. Annamalai and D. Rathinam (1998). "Structure and Behaviour of Costs - A Study of Selected State Transport Corporations in Tamil Nadu." Indian Journal of Transport Management: 725-741.
- Kumbhakar, S. C., and Lovell, C A K. (2000). Stochastic Frontier Analysis. Cambridge University Press. Cambridge, UK.
- Kumbhakar, S. C. and A. Bhattacharyya (1996). "Productivity Growth in Passenger-Bus Transportation: A Heteroskedastic Error Component Model with Unbalanced Panel Data." Empirical Economics **21**(4): 557–573.
- Lago, A. and P. Mayworm (1981). "Transit service elasticities." Journal of Transport Economics and Policy **15**(2): 99-119.
- Lancaster, T. (2000). "The incidental parameter problem since 1948." Journal of Econometrics **95**(2): 391-413.
- Langridge, R. and R. Sealey (2000). "Contestability in the UK bus industry? The National Bus Company, and the "Tilling Mark II" effect." Transport Policy **7**(2): 105-115.
- Lau, L. J. (1974). Applications of duality theory: Comments. Frontiers of Quantitative Economics. M. D. Intriligator and D. A. Kendrick. Amsterdam, North-Holland. **II**: 176-199.
- Lau, L. J. (1982). "A note on the fundamental theorem of exact aggregation." Economics Letters **9**(2): 119-126.
- Lee, N. and I. Steedman (1970). "Economies of Scale in Bus Transport: I. Some British Municipal Results." Journal of Transport Economics and Policy **4**(1): 15–28.
- Levaggi, R. (1994). "Parametric and Non-Parametric Approach to Efficiency: The Case of Urban Transport in Italy." Studi Economici **49**(53): 67–88.
- Lipsey, R. G. and K. Lancaster (1956). "The General Theory of Second Best." The Review of Economic Studies **24**(1): 11-32.

- Litman, T. (2004). "Transit Price Elasticities and Cross-Elasticities." Journal of Public Transportation 7(2): 37–58.
- Mackie, P. J., P. J.M. and C. A. Nash (1995). "Bus Deregulation: ten years on." Transport Reviews 15: 229–251.
- Martinez-Budria, E., S. Jara-Diaz and F. J. Ramos-Real (2003). "Adapting Productivity Theory to the Quadratic Cost Function. An Application to the Spanish Electric Sector." Journal of Productivity Analysis 20(2): 213-229.
- Mas-Colell, A., M. D. Whinston and J. R. Green (1995). Microeconomic Theory. New York, Oxford University Press. pp.1008.
- Massot, M.-H. (1994). "Sensitivity of Public Transport Demand to the Level of Transport Service in French Cities Without Underground." Transport Reviews 14(2): 135-149.
- Matas, A. (2004). "Demand and Revenue Implications of an Integrated Public Transport Policy: The Case of Madrid." Transport Reviews 24(2): 195-217.
- Matas, A. and J. L. Raymond (1998). "Technical characteristics and efficiency of urban bus companies: The case of Spain." Transportation 25(3): 243–264.
- Maunder, D. A. C. (1984). Trip rates and travel patterns in Delhi, India. Transport and Road Research Laboratory Research Report 1. Transport and Road Research Laboratory, Crowthorne.
- Maunder, D. A. C. (1986). Public transport needs of the urban poor in Delhi. CODATU III, Cairo, International Union of Railways.
- Maunder, D. A. C., P. R. Fouracre and G. Jacobs (1987). "Matching Supply and Demand in India's Public Transport." Transport Planning and Technology 8(6): 271-243.
- McCarthy, P. S. (2001). Transportation Economics - Theory and Practice: A Case Study Approach. Malden, Blackwell. pp.620.
- Mekoth, N. and B. P. George (2005). "The Case for and Against a Subsidized Future for the State Transport Undertakings: Some Assessments and Reflections." Indian Journal of Transport Management: 170-184.
- Meurs, H., T. van Eyck and P. B. Goodwin (1990). Dynamic Estimation of Public Transport Demand Elasticities. Developments in Dynamic and Activity-Based Approaches to Travel. P. Jones. Aldershot, Gower/Avebury: 371-383.
- Miller, D. R. (1970). "Differences Among Cities, Differences Among Firms, and Costs of Urban Bus Transport." The Journal of Industrial Economics 19(1): 22–32.
- Mohan, D. and G. Tiwari (1999). "Sustainable Transport Systems, Linkages Between Environmental Issues, Public Transport, Non-motorised Transport and Safety." Economic and Political Weekly. XXXIV(25): 1580-1596.
- Mohring, H. (1970). "The Peak Load Problem with Increasing Returns and Pricing Constraints." The American Economic Review 60(4): 693–705.
- MTS (Various Issues). Motor Transport Statistics. New Delhi, India, The Department of Road Transport & Highways, Government of India. 2005.
- Muellbauer, J. (1975). "Aggregation, Income Distribution and Consumer Demand." The Review of Economic Studies 42(4): 525-543.
- Muellbauer, J. (1976). "Community Preferences and the Representative Consumer." Econometrica 44(5): 979-999.
- Naughton, M. C. (1986). The Efficiency and Equity Consequences of Two Part Tariffs in Electricity Pricing. Review of Economics and Statistics. 68: 406–414.
- Nelson, J. P., M. J. Roberts and E. P. Tromp (1987). An Analysis of Ramsey pricing. Regulating Utilities in an Era of Deregulation. M. A. Crew. New York, St. Martin's Press: 85–109.
- Nerlove, M. (1963). Returns to Scale in Electricity Supply. Measurement in Economics: Studies in Mathematical Economics & Econometrics in Memory of Yehuda Grunfeld. C. F. Christ. Stanford, Stanford University Press: 167-200.
- Neyman, J. and E. L. Scott (1948). "Consistent Estimates Based on Partially Consistent Observations." Econometrica 16(1): 1-32.
- Ng, Y.-K. and M. Weisser (1974). "Optimal Pricing with a Budget Constraint--The Case of the Two-part Tariff." The Review of Economic Studies 41(3): 337-345.
- Nickell, S. (1981). "Biases in Dynamic Models with Fixed Effects." Econometrica 49(6): 1417-1426.
- Nijkamp, P. and G. Pepping (1998). "Meta-analysis for explaining the variance in public transport demand elasticities in Europe." Journal of Transportation Statistics 1(1): 1–14.
- Obeng, K. (1983). "Fare Subsidies to Achieve Pareto Optimality—A Benefit Cost Approach." Logistics and Transportation Review 19(4): 367–84.
- Obeng, K. (1984). "The Economics of Bus Transit Operation." Logistics and Transportation Review 20(1): 45–65.
- Obeng, K. (2000). "Expense preference behavior in public transit systems." Transportation Research Part E: Logistics and Transportation Review 36(4): 249–265.

- Obeng, K. and R. Sakano (2000). "The Effects of Operating and Capital Subsidies on Total Factor Productivity: A Decomposition Approach." *Southern Economic Journal* **67**(2): 381–97.
- Oehlert, G. W. (1992). "A Note on the Delta Method." *The American Statistician* **46**(1): 27-29.
- Oum, T. H. (1979a). "A Cross Sectional Study of Freight Transport Demand and Rail–Truck Competition in Canada." *Bell Journal of Economics* **10**(2): 463–482.
- Oum, T. H. (1979b). "A Warning on the Use of Linear Logit Models in Transport Mode Choice Studies." *Bell Journal of Economics* **10**(1): 374–388.
- Oum, T. H. (1989). "Alternative Demand Models and their Elasticity Estimates." *Journal of Transport Economics and Policy* **23**(2): 163-187.
- Oum, T. H. and M. W. Tretheway (1989). "Hedonic vs. General Specifications of the Translog Cost Function." *Logistics and Transportation Review* **25**(1): 3-21.
- Oum, T. H., M. W. Tretheway and Y. Zhang (1991). "A Note on Capacity Utilization and Measurement of Scale Economies." *Journal of Business & Economic Statistics* **9**(1): 119-123.
- Oum, T. H. and W. G. Waters (1996). "A survey of recent developments in transportation cost function research." *The Logistics and Transportation Review* **32**(4): 423–463.
- Oum, T. H., W. G. Waters, Jr. and J. S. Yong (1992). "Concepts of Price Elasticities of Transport Demand and Recent Empirical Estimates." *Journal of Transport Economics and Policy* **26**(2): 139–154.
- Panzar, J. C. (1989). Technological determinants of firm and industry structure. *Handbook of Industrial Organization*. R. Schmalensee and R. Willig, Elsevier: 3-59.
- Parks, R. W. (1967). "Efficient Estimation of a System of Regression Equations when Disturbances are Both Serially and Contemporaneously Correlated." *Journal of the American Statistical Association* **62**(318): 500-509.
- Paulley, N., R. Balcombe, R. Mackett, H. Titheridge, J. Preston, M. Wardman, J. Shires and P. White (2006). "The demand for public transport: The effects of fares, quality of service, income and car ownership." *Transport Policy* **13**(4): 295-306.
- Pedersen, P. A. (2003). "On the optimal fare policies in urban transportation." *Transportation Research Part B: Methodological* **37**(5): 423–435.
- Pels, E. and P. Rietveld (2000). Cost functions in transport. *Handbook of transport modelling*. K. J. Button and D. Hensher. Amsterdam, Elsevier: 321-333.
- Perry, J. and T. Babitsky (1986). "Comparative Performance in Urban Bus Transit: Assessing Privatization Strategies." *Public Administration Review* **46**(1): 57–66.
- Pham, L. and J. Linsalata (1991). *Effects of fare changes on bus ridership*. American Public Transit Association, Washington.
- Piacenza, M. (2002). *Regulatory Constraints and Cost Efficiency of the Italian Public Transit Systems: An Exploratory Stochastic Frontier Model*. Working Paper N. 2/2002. Serie Speciale in Collaborazione con HERMES, Torino.
- Pickrell, D. H. (1985). "Rising Deficits and the Uses of Transit Subsidies in the United States." *Journal of Transport Economics and Policy* **19**(3): 281–298.
- Pitt, M. M. and L. F. Lee (1981). "The measurement and sources of technical inefficiency in the Indonesian weaving industry." *Journal of Development Economics* **9**(1): 43–64.
- Planning Commission (1992). *Eighth Five–Year Plan (1997–2002) - Volume II*. Planning Commission, Government of India., New Delhi.
- Planning Commission (2002). *10th Five Year Plan (2002-2007) - Volume II: Sectoral Policies and Programmes*. Planning Commission, Government of India, New Delhi.
- Proost, S., K. Van Dender, C. Courcelle, B. De Borger, J. Peirson, D. Sharp, R. Vickerman, E. Gibbons, M. O'Mahony and Q. Heaney (2002). "How large is the gap between present and efficient transport prices in Europe?" *Transport Policy* **9**(1): 41–57.
- Ramanathan, R. and J. K. Parikh (1999). "Transport sector in India: an analysis in the context of sustainable development." *Transport Policy* **6**(1): 35-46.
- Romilly, P. (2001). "Subsidy and Local Bus Service Deregulation in Britain: A Re-evaluation." *Journal of Transport Economics and Policy* **35**(2): 161-193.
- Sakano, R. and K. Obeng (1997). "Subsidies and inefficiency: Stochastic frontier approach." *Contemporary Economic Policy* **15**(3): 113–127.
- Schankerman, M. and M. I. Nadiri (1986). "A test of static equilibrium models and rates of return to quasi-fixed factors, with an application to the Bell system." *Journal of Econometrics* **33**(1-2): 97-118.
- Schmidt, P. and R. E. Sickles (1984). "Production Frontiers and Panel Data." *Journal of Business and Economic Statistics* **2**: 367–374.
- Sevestre, P. and A. Trognon (1985). "A note on autoregressive error components models." *Journal of Econometrics* **28**(2): 231-245.
- Shephard, R. W. (1953). *Cost and Production Functions*. Princeton, Princeton University Press. pp.xi, 308.

- Sickles, R. C. (1985). "A nonlinear multivariate error components analysis of technology and specific factor productivity growth with an application to the U.S. Airlines." Journal of Econometrics **27**(1): 61-78.
- Singh, S. K. (2000). "Estimating the Level of Rail- and Road-based Passenger Mobility in India." Indian Journal of Transport Management **24**(12): 771-781.
- Singh, S. K. (2001). "A Note on the Technological Progress in Selected STUs." Indian Journal of Transport Management **25**(5): 413-429.
- Singh, S. K. (2002). "A Note on Economies of Scale in Selected STUs." Indian Journal of Transport Management **26**(2): 207-224.
- Singh, S. K. (2005a). "Costs, Economies of Scale and Factor Demand in Urban Bus Transport: An Analysis of Municipal Transport Undertakings in India." International Journal of Transport Economics **32**(2): 171-194.
- Singh, S. K. (2005b). "Review of Urban Transportation in India." Journal of Public Transportation **8**(1): 79-96.
- Small, K. A. and C. Winston (1999). The demand for transportation: Models and applications. Essays in Transportation Economics and Policy. J. Gómez-Ibañez, W. B. Tye and C. A. Winston. Washington, D.C., Brookings Institution Press: 11-56.
- Spady, R. H. and A. F. Friedlaender (1978). "Hedonic Cost Functions for the Regulated Trucking Industry." The Bell Journal of Economics **9**(1): 159-179.
- STATA (2005). Longitudinal/Panel Data Reference Manual. College Station, Texas, Stata Press. pp.349.
- Stoker, T. M. (1993). "Empirical Approaches to the Problem of Aggregation Over Individuals." Journal of Economic Literature **31**(4): 1827-1874.
- Sundar, S. and K. Deb (2004). Infrastructure Services. India 2025 Social, Economic and Political Stability. R. K. Sinha. New Delhi, Centre for Policy Research, Shipra.
- Sundar, S. and S. K. Sarkar (2000). Framework for infrastructure regulation. TERI, New Delhi.
- Thomas, R. L. (1987). Applied Demand Analysis. Longman Economics Series. London and New York, Longman. pp.112.
- Train, K. E. (1991). Optimal Regulation: economic theory of natural monopoly. London, The MIT Press. pp.338.
- Trujillo, L., S. Jara-Díaz and B. Tovar (2003). Production and cost functions and their application to the port sector : a literature survey. Policy Research Working Paper Series 3123. The World Bank,
- Uzawa, H. (1964). "Duality Principles in the Theory of Cost and Production." International Economic Review **5**(2): 216-220.
- Verbon, H. A. A. (1980). "Testing for heteroscedasticity in a model of seemingly unrelated regression equations with variance components (SUREVC)." Economics Letters **5**(2): 149-153.
- Vickrey, W. (1980). "Optimal transit subsidy policy." Transportation **9**(4): 389-409.
- Viton, P. A. (1986). "The Question of Efficiency in Urban Bus Transportation." Journal of Regional Science **26**(3): 499-513.
- Viton, P. A. (1992). "Consolidations of scale and scope in urban transit." Regional Science and Urban Economics **22**(1): 25-49.
- Viton, P. A. (1993). "How big should transit be? Evidence on the benefits of reorganization from the San Francisco Bay Area." Transportation **20**(1): 35-57.
- Wabe, J. S. (1969). "Labour Force Participation Rates in the London Metropolitan Region." Journal of the Royal Statistical Society. Series A (General) **132**(2): 245-264.
- Wabe, S. and O. B. Coles (1975). "The Short and Long-Run Cost of Bus Transport in Urban Areas." Journal of Transport Economics and Policy **9**(2): 127.
- Wan, G. H., W. E. Griffiths and J. R. Anderson (1992). "Using Panel Data to Estimate Risk Effects in Seemingly Unrelated Production Functions." Empirical Economics **17**(1): 35-49.
- Webster, F. V. and P. H. Bly (1981). "The demand for public transport: Part I. The changing environment in which public transport operates." Transport Reviews **1**(4): 323-351.
- White, P. R. (1981). "Recent Developments In the Pricing of Local Public Transportation Services." Transport Reviews **1**(2): 127-50.
- Williams, M. and A. Dalal (1981a). "Estimation of the elasticity of factor substitution in urban bus transportation: a cost function approach." Journal of Regional Science **21**(2): 263-275.
- Williams, M. and C. Hall (1981b). "Returns to scale in the United States intercity bus industry." Regional Science and Urban Economics **11**(4): 573-584.
- Willig, R. D. (1976). "Consumer's Surplus Without Apology." The American Economic Review **66**(4): 589-597.
- Willig, R. D. (1978). "Pareto-Superior Nonlinear Outlay Schedules." The Bell Journal of Economics **9**(1): 56-69.
- Windle, R. J. (1988). Transit Policy and the Cost Structure of Urban Bus Transportation. Bus Deregulation and Privatization: An International Perspective. J. S. Dodgson and N. Topham. New York, Wiley: 119-140.
- Winston, C. (1983). "The demand for freight transportation: models and applications." Transportation Research Part A: General **17**(6): 419-427.

- Wooldridge, J. (2002). Econometric Analysis of Cross Section and Panel Data. Cambridge, Massachusetts, MIT Press. pp.752.
- Xu, K., R. Windle, C. Grimm and T. Corsi (1994). "Re-evaluating Returns to Scale in Transport." Journal of Transport Economics and Policy **28**(3): 275-286.
- Ying, J. S. (1990). "The Inefficiency of Regulating a Competitive Industry: Productivity Gains in Trucking Following Reform." The Review of Economics and Statistics **72**(2): 191-201.
- Zellner, A. (1962). "An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias." Journal of the American Statistical Association **57**(298): 348-368.

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