A COMPARATIVE FINANCIAL ANALYSIS OF THE AUTOMOBILE AND PUBLIC TRANSPORTATION IN LONDON

by

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ABSTRACT

Automobile systems and public transportation are often organized separately within government structure inhibiting a comparative analysis between the two modes. Further complicating the comparison is that in public transportation systems, not only is infrastructure but vehicles and operators are usually provided by government or contracted private sector partners, while in the automobile system, infrastructure is normally government owned but costs of vehicle ownership and operation and parking are private.

However, these private actions have enormous costs. In total in FY 2004-05 in London, private automobile spending was over 14 times greater than public automobile spending, as public spending on the automobile was about £1.4 billion while private spending on the automobile was about £20.9 billion. For public transportation, public spending was about £2.0 billion while private spending was about £2.3 billion.

On a normalized basis, when not including time costs, the automobile was 3.7 times more expensive than public transportation on a per trip basis, and 2.0 times more expensive on a per passenger-kilometer basis. When including time costs and segmenting trips by travel zone, we found that public transportation enjoys an advantage for all travel zone combinations, with the advantage being the greatest for trips between outer London and inner London and for trips within inner London. At the household level, we estimated that households well-served by public transportation spend 15 to 18 percent less out-of-pocket on transportation than the average London household, although these savings are outweighed by additional time costs.

From our findings in this research, we see significant opportunity for the London region to achieve a more cost-efficient transportation system. First, measures should be pursued to increase the share of variable automobile costs as a percentage of total costs. Policy such as pay-as-you-drive insurance and road pricing or policy inducing greater awareness of parking costs would help shift the burden. Second, public authorities should consider the private expenditures on automobiles and parking, as they are relatively large compared to the public spending on automobiles, when allocating resources between transportation modes.

Thesis Advisor: Frank Levy, Department of Urban Studies and Planning

Thesis Reader: Frederick P. Salvucci, Department of Civil and Environmental Engineering

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"Success comes from knowing that you did your best to become the best that you are capable of becoming." – John Wooden

The journey is more important than the end. And this journey through MIT has been an experience I am truly grateful to have had. Many people have made this journey possible, and I have the better part of 543 words to try to write about all of them.

There would be no way I would be here today without my family. My parents provided me with a tremendous upbringing and nurtured in me the foundation that allowed me to become who I am today. My brother and sister were unbelievable role models growing up, teaching me valuable life lessons only the way a sibling can from day one.

MIT is no cakewalk and I have been blessed with an amazing set of friends who not only provided an outlet to have a good time and forget about the impossible problem set due the next day but were also a consistent base of support when the going got tough.

I thank Nigel Wilson for the chance to become involved with transit research. Working with him as an undergraduate researcher exposed me to a fascinating field and provided me with tremendous opportunities later in my MIT career, from the research in this thesis to several internship experiences.

It has been a privilege and honor to work with Fred Salvucci these past two years. Whenever I met with Fred, I went into pure listening mode as I never knew what snippet of wisdom I would get to hear that day. His pragmatic approach combined with his insights into the political process are traits I will always remember and have very much shaped my own thinking.

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To Justin Antos, Hazem Zureiqat, Giorgia Favero, Mikel Murga, and Fred: our weekly meetings over the past two years have been an incredible learning experience for me. Learning about your research and having the chance to think aloud about my progress greatly expedited my process up the learning curve of transit finance. I will truly miss these meetings. Special thanks to Justin who over these past two years always had a willing ear no matter if I wanted to talk about whether I really had a legitimate thesis topic, which I still sometimes question, to what life was like in London.

And about London, many thanks to Shashi Verma, Will Judge, and Simon Fine at Transport for London for welcoming me into their team as an intern in the Fall of 2006. They provided me with a once in a lifetime experience of living in a great city while working on extremely exciting projects and providing me a base to begin my thesis research.

I have come nowhere close to acknowledging all the people I ought to have acknowledged but space is running out unfortunately. I am very glad and proud of the opportunities I have had these past five years and know that I will always look back at my time at MIT and my time working on transit research with the fondest of memories.

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1. INTRODUCTION

1.1. OVERVIEW

The purpose of this research is to financially compare the private automobile system and the public transportation system (only services provided by Transport for London) in London, United Kingdom in the Fiscal Year 2004-05 (April 1, 2004 to March 31, 2005). Expenditures borne by both public and private actors are included in the scope of the research to account for all costs. In addition to a financial comparison of the automobile and public transportation in London, we explore transport cost patterns in 20 prominent cities across the world, estimate local and non-local spending for each mode, analyze travel costs by the geographic distribution of trips (including time costs), and investigate the relationship between travel costs and public transport accessibility levels. From these tasks, our hope is that we can assess how London can achieve a more cost-efficient transportation system. While findings from this research are most applicable to the London region, metropolitan areas of a similar scale can also learn from them.

In this chapter, we will describe the specific analytical tasks of the research, briefly discuss the motivation underpinning the research, provide a snapshot of the methodology behind each task, and present the overall structure of the thesis.

1.2. ANALYTICAL TASKS

In order to assess how London can achieve a more cost-efficient transportation system, the following sub-tasks were developed:

1. Using a database of transport-related measures for 20 cities for the years 1995 and 2001, explore the relationship between changes in passenger transport costs and public transportation capacity and use and automobile capacity;
2. Collect data on all passenger transportation costs, public and private, for FY 2004-05 in order to compare public transportation with the private automobile on a per trip and per kilometer basis – as part of this comparison, we will measure the relative share of passenger transport costs for each mode that stay within the London economy;

3. Building off the aggregate comparison in Task 2, investigate how each mode compares for different types of geographic trips (e.g. within inner London, between inner London and outer London, and within outer London) while including travel time costs; and

4. Analyze the relationship between private household transportation costs and public transit accessibility levels.

Combined, these tasks will allow us to financially compare the automobile and public transportation and identify opportunities for the London region to realize a more cost-efficient transportation system.

1.3. Motivation

Automobile systems and public transportation are often organized separately within government structure. While this may be beneficial in terms of specialized knowledge, it inhibits a comparative analysis between the two modes. Further complicating the comparison is the fact that in public transportation systems, not only is infrastructure but vehicles and operators are usually provided by government or contracted private sector partners, while in the automobile system, infrastructure is normally government owned but costs of vehicle ownership and operation and parking are private.

However, these private actions have enormous costs which are a direct result of modal choice. An analysis of expenditures in the Boston, MA region showed that these private expenses on automobiles outweighed public expenditures on infrastructure by a factor of 14.[1] A similar piece of work for the Toronto, Canada region determined a ratio of 12 dollars of private spending for every public dollar spent on the automobile system.[2] An analysis of expenditures spent on parking infrastructure in the United States estimated that parking-related expenditures are three times as large as total expenditures on public roads and more than half as large as total expenditures on private vehicles.[3] Clearly

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[1] Kothari, and Antos, "Public and Private Transportation Costs in Boston, MA."

[2] Kennedy, "A comparison of the sustainability of public and private transportation systems."

[3] Litman, *Transportation Cost and Benefit Analysis - Parking Costs.*

these private automobile and parking costs are significant and must be considered when financially comparing transportation modes.

Existing literature examining public transportation and the private automobile system lacks in accurately financially comparing both modes. Literature has tended to focus more on the modal decisions of individuals between public transportation and the automobile and less on what mode exhibits greater financial efficiency when including private expenditures. In the cases where overall efficiency is assessed, the literature tends to focus on a particular project or omits all or certain private expenditures and consequently provides an incomplete picture.

Given the compartmentalized governance structure that often exists between public transportation and the automobile system, there is limited need at first glance to determine each mode's financially efficiency. Furthermore, while at the national level in the United Kingdom decisions are made allocating funding between the two modes, a comparative analysis has limited appeal given that the results of such an analysis would likely differ from city to city.

However, for a single metropolitan area, a comparative analysis would yield credible evidence as to what the financial efficiency of a mode is relative to another mode. Results could be used to support either decreasing or increasing the level of public spending on a given mode and be used to inform relevant regulatory decisions. That is the aim of this research – compare both at an aggregate level and disaggregate level the financially efficiency of the automobile and public transportation when including public and private costs, understand the relationship between public transport accessibility and travel costs, and determine ways that London can achieve a more financially efficient transportation system.

Why do we believe this research is necessary? In short, because there are many inherent features of the automobile and public transportation systems that decrease the likelihood that London, or any metropolitan area, is already at a financially efficient allocation level. In the automobile system, private actors pay for the vehicles and their usage as well as absorb the majority of parking costs. Equivalent costs on the public transportation system – the vehicles and their operation and stations – are not the responsibility of the private sector but rather the public sector. Because different actors – public actors, private businesses, and private individuals – do not pay for the equivalent costs for each mode, the possibility of misallocation by both public and private actors is strong. In addition, many aspects of a transportation system have a significant fixed cost component to them which in turn distorts marginal decisions. For example, an individual who already owns an automobile has already paid the majority of the automobile's cost whether it is used or not and thus that individual is biased on the margin to use the automobile. Furthermore, because public involvement is needed for each mode, many political complexities could exist that would decrease the likelihood of an efficient allocation. All combined, these traits of transportation mean that there is a low probability that a given metropolitan area is minimizing its transportation costs. For additional detail on why we believe this research is necessary, please refer to Chapter 2.

1.4. METHODOLOGY

The following section describes the methodology undertaken to perform the necessary analysis for each task.

1.4.1. Task 1 – Mobility in Cities Analysis

The Mobility of Cities database and its predecessors contain a wealth of transport and urban related data for many of the world's largest urban areas. After a thorough analysis of data quality of all years of data (1960, 1970, 1980, 1990, 1995, 2001), we determined that reliable and consistent data exists for approximately 20 cities (mostly Western European) in the years 1995 and 2001. This set of data will form the backbone of completing Task 1.

By analyzing this time-series panel database, we can identify useful patterns relating transport investment decisions and modal use with overall transport costs in these 20 cities from 1995 and 2001. Through this analysis of macro-level data across a range of cities, we hope to strengthen the basis for digging deeper into one city's transportation costs.

1.4.2. Task 2 – Modal Comparison

This task digs deeper into London's transportation costs. First, for both the automobile and public transportation, we will gather all relevant cost data and walk through each expenditure's data source(s) and assumptions. Second, we will collect modal usage statistics to allow for a normalized comparison on a trip and distance basis. And lastly, we will compare local spending for each mode by using estimates from existing literature and applying them to London's expenditures.

1.4.3. Task 3 – Geographic Analysis and Time Costs

The London Area Travel Survey (LATS) provides sample data of trips on a typical weekday in London. Respondents to the LATS complete a travel log and include information on the mode used, travel time, parking costs, the origin and destination, and etc. Using this trip-specific data, we will investigate possible ways to segment trips geographically and compare the automobile and public transportation at a disaggregate level. In addition, because we have a reported travel time for each trip, we can include travel time costs in our comparison. By breaking down the comparison geographically and including time costs, we will produce a more accurate and fine-grained comparison between the automobile and public transportation.

1.4.4. Task 4 – Private Costs and Public Transport Accessibility

Two different data sources – the London Area Travel Survey (LATS) and the Public Transport Accessibility Level (PTAL) Index – will be used to measure the effect of public transport accessibility on private transportation expenditures. A cost function using findings from Task 2 will be built for each trip in the LATS and these costs will then be tested against the PTAL Index, which serves as a measure to the availability of public transport in a given area.

1.5. Overview of Chapters

This thesis is divided into the following seven chapters:

1. Introduction – The introduction will explain the overall research focus, the sub-tasks of the research, the motivations behind the research, the methodological approaches behind the research, and the structure of the thesis.

2. Motivation and Literature Review – In this chapter, we will present why the analysis in this thesis is necessary by presenting the features inherent in the passenger transportation market which complicates the allocation decision between both modes by both public actors and private actors.

3. Mobility in Cities Analysis – In this chapter, we will analyze the relationship in 20 cities of how transport costs changed from 1995 to 2001 with how the capacity and use changed of both the automobile system and the public transportation system.

4. Modal Transport Costs – In this chapter, we will collect data on all expenditures for both the automobile and public transportation in London in FY 2004-05. For each expenditure, we will explain the data source(s) and methodology used to determine the magnitude of the expenditures. We will also collect modal usage statistics so that we can financially compare each mode on a per trip and per kilometer basis. We will also estimate the share of expenditures for each mode that stay within the local economy.

5. Geographic Distribution and Time Costs – In this chapter, we will build off the aggregate cost data from the previous chapter and incorporate actual trip data to compare the automobile and public transportation at a disaggregate level. Time costs will be included in this analysis.

6. Travel Costs and Public Transport Accessibility Levels – In this chapter, we will examine the relationship between private transportation costs and public transport accessibility levels.

7. Recommendations – In this chapter, we will summarize our findings, propose how London can achieve a more cost-efficient transportation system, and suggest areas of future research.

The thesis also contains two appendices: a bibliography (Appendix A) and a list of acronyms (Appendix B).

2. WHY SHOULD WE CARE ABOUT TRANSPORTATION COSTS?

2.1. INTRODUCTION

In this chapter, our main objective is to establish why we should care about the research in thesis. First, we will develop a basis of why it is important to include both public and private expenditures when comparing transportation modes; and second, we will describe characteristics of passenger transportation that make it highly unlikely for a city or region to naturally achieve a cost-efficient modal allocation.

2.2. WHY SHOULD WE CARE?

2.2.1. Overview

According to the Bureau of Transportation Statistics, the ultimate objective of most travel is access, the ability to obtain desired goods and activities.[4] In other words, transportation is not an end in itself – people travel because they derive more utility from the opportunity at the end of the trip than the disutility they face in travel costs. This implies that we as a society should try to meet our transportation needs through the most efficient combination of modes. Strictly speaking, transportation's cost (or disutility) should be minimized while still serving society's mobility needs. But what does this mean in a metropolitan area such as London? What costs should we include when comparing transportation modes? How do transportation modes compare in aggregate? How do transportation modes compare in disaggregate? Are there opportunities to achieve a more cost-efficient transportation system? These questions, from the viewpoint of a government unit with an eye over London, are the focus of our research.

Central to answering these questions is ensuring that private expenditures in addition to public expenditures are included in any comparison study. Why should a unit of government concern itself with private expenditures? If a given amount of public spending leverages a high level of private spending to meet an objective, is that not a

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4 "Transportation Statistics Annual Report 1997."

better outcome from a public perspective than an alterative where a higher amount of public spending leverages a lower level of private spending to meet that same objective? In this chapter, I argue that the answer to that question is not necessarily yes in the context of passenger transportation.

Let's say we assume private expenditures do matter, what evidence is there that each transportation mode is not already at a cost-efficient level? In other words, what makes comparing transportation modes different than most other goods and services? Why is transportation different in the sense that a reasonably optimal combination of modes might not already exist?

The remaining portion of this chapter attempts to address these two issues – why private expenditures matter and what makes passenger transportation complex. Through looking at previous studies and exploring the income effect, we will establish a rationale for including private expenditures. In addition, by illustrating that transportation is complex along the following dimensions – public versus private spending, fixed versus variable spending, and political complications – we will show that there are differences in the passenger transportation market that do not pertain for many goods and services and consequently, there are likely to be opportunities to realize a more cost-efficient transportation system.

2.2.2. Private Expenditures are Significant

In order to quickly determine the relative magnitude of private automobile expenditures against public automobile and public transportation expenditures, a fellow student and I conducted an analysis of transportation spending in the Boston, MA region in 2005. We determined the ratio of private spending on the automobile outweighed public spending by a factor of over 14 while on the public transportation side, public spending outweighed private spending by a ratio of about 2.3.[5] This drastic difference provides evidence that a modal comparison that neglects private expenditures would be heavily biased to favor

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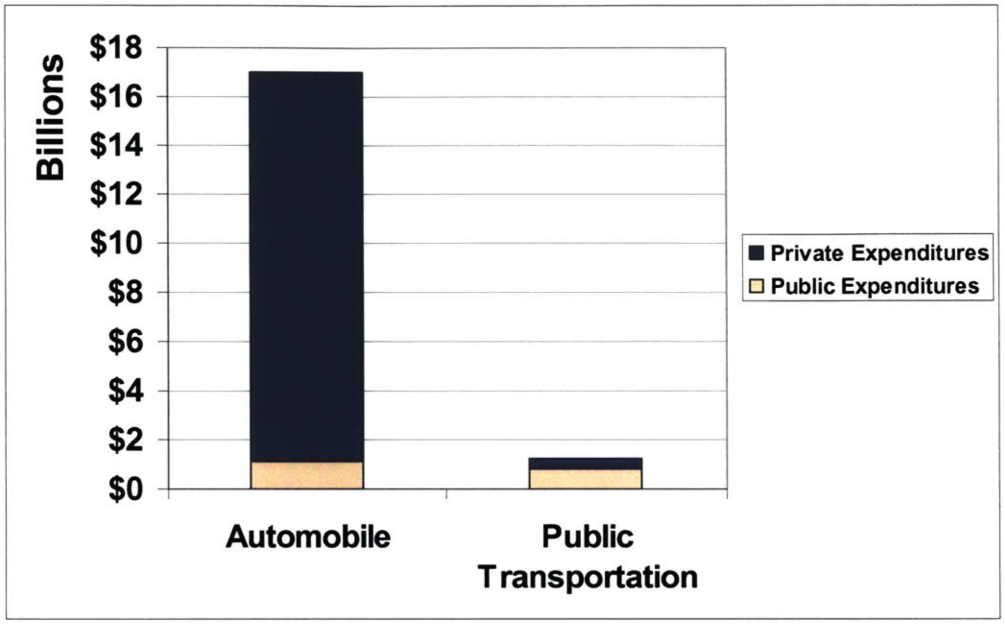
[5] Kothari, and Antos, "Public and Private Transportation Costs in Boston, MA."

the automobile. Figure 2.1 illustrates transportation expenditures by both public and private actors in Boston in 2005.

Figure 2.1 – Public and Private Transportation 2005 Spending in Boston by Mode



While the work on Boston provided evidence that both public and private expenditures need to be included when comparing transportation modes, the work was limited as it did not relate cost data with output. A cost per passenger-mile and a cost per trip were not computed as part of the analysis. Furthermore, given the quick nature of the work, several assumptions about public spending on the automobile were made.

A 2003 report on transport expenditures in the Paris region provided numbers of similar magnitude, as private automobile expenditures outweighed public automobile expenditures by a ratio of over 13.[6] In total, €23.8 billion was spent on the automobile, 93 percent of which was spent by private individuals while the remaining seven percent was spent by public authorities. On the public transport side, €6.8 billion was spent, 68 percent of which was spent by private individuals while the remaining 32 percent was spent by public authorities. On a per-kilometer distance basis, public transport was

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6 "Compte Déplacements de Voyageurs en IDF Pour L'année 2003 - Edition 2005."

calculated to be 34% cheaper than the automobile in the Paris region. These numbers are consistent with numbers presented for London in Chapter 4.

Kennedy in his 1991 and 1996 studies compared the sustainability of public and private transportation systems in the Greater Toronto Area (GTA).[7] Defining transportation as a product, a driver, and a cost, he assessed the automobile and public transportation on economic, environmental, and social dimensions from the perspective of the region as an economic unit. Table 2.1 summarizes his results for 1996 in comparing the costs of each mode; the numbers presented in his analysis are consistent with those that are presented for London in Chapter 3.

Table 2.1 – Costs of Public and Private Transportation in the Greater Toronto Area in 1996

	Daily no. of trip	Mean km.	Person km.	Total cost ($ per day)	$ per person trip	$ per person-km
Auto. driver	5,623,498	9.8	55,253,966			
Auto passenger	1,441,814	7.5	10,826,969			
Total auto.	7,065,312		66,080,934	36,556,897	$5.17	$0.55
Local transit	1,154,298	8.1	9,345,249	3,309,701	$2.87	$0.35
GO transit	101,054	30.8	3,112,463	756,860	$7.49	$0.24
Total public	1,255,352		12,457,712	4,066,561	$3.24	$0.33

While using a thorough and well-explained methodology, Kennedy's results for the GTA show that public transit costs significantly less than the automobile on both a trip and person-kilometer basis.

Litman in his analysis of the benefits and costs of parking estimated that parking facility costs totaled more than $500 billion in the United States in 2000.[8] He arrived at this estimate by multiplying an amortized cost per parking space for different types parking facilities by the total number of parking spaces for each type of facility. His estimate of $500 billion means that parking expenditures in the United States were more than three

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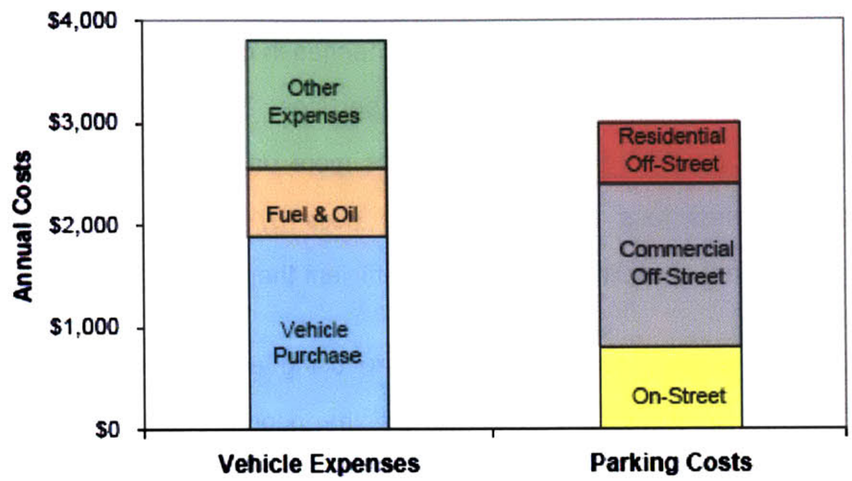
[7] Kennedy, "A comparison of the sustainability of public and private transportation systems."

[8] Litman, *Transportation Cost and Benefit Analysis - Parking Costs.*

times as large as total public expenditures on roadways and more than half as large as total expenditures on private vehicles. Figure 2.2 illustrates this comparison.

Figure 2.2 – Comparing Vehicle and Parking Expenditures in the United States



In summary, the four pieces of work reviewed here directly analyzed both public and private spending for both the automobile and public transportation. Kennedy's work in Toronto was the most methodologically complete and showed public transportation as more cost-efficient than the automobile, the Paris and Boston work provided evidence that both public and private expenditures need to be included in a modal comparison, while Litman showed that parking expenditures are significant relative to other transportation expenditures. Combined, the work on Boston, Paris, Toronto, and Litman's work on parking costs clearly show that private expenditures are significant large and must be included when financially comparing transportation modes.

2.2.3. The Income Effect

Now that the magnitude of private expenditures has been established, we will extend the logic one step deeper by showing a situation where an increase in public spending on transportation leads to a decrease in private spending for a hypothetical household. The income effect is defined as a change in the demand for a good or service caused by a change in the income of consumers rather than a change in consumer preferences. In the context of transportation, if an individual has to spend more to meet his or her transportation needs, he or she has fewer monetary resources to spend on other products and services. Conversely, if an individual can spend less to meet his or her transportation needs, he or she has more monetary resources to spend on other products and services. Both scenarios act as income effect, as changes in transportation spending rather than changes in consumer preferences affect the demand the individual has for other goods or services. This logic underpins the argument that a situation in which government spends more on transportation but the private individual than spends less on transportation (less by a greater amount than the increased government spending) is more cost-efficient than the status quo.

Let's imagine a hypothetical scenario using actual spending data from UK Office of National Statistics (ONS) to illustrate the income effect.[9] In our example, we have a household that spends according to average London figures provided in the ONS survey. According to survey results, they spend £25,151 annually and £3,118 on transportation annually. Let's say that a new rail line or a new bus route opens near the household so that they use their automobile less, perhaps even selling an automobile, and rely more on public transportation so that their annual transportation spending drops to £1,500. To finance this new rail line or bus route, let's also say this household was taxed an additional £200. This leaves the household with an extra £1,418 to spend on other products or services that they presumably derive more utility from than transportation. Assuming that the household's spending distribution is equivalent to their original spending, the second column in Table 2.2 reflects their new spending amount in each category in the lower transportation spending scenario. The third column represents the change in spending between the two scenarios.

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[9] "Family Spending - 2004/05 Expenditure and Food Survey."

Table 2.2 – London Household Expenditures – Two Transportation Scenarios

		Average Transportation Spending	Lower Transportation Spending	Change
Average grossed number of households (thousands)		2,880		
Total number of households in sample (over 3 years)		1,875		
Total number of persons in sample (over 3 years)		4,539		
Total number of adults in sample (over 3 years)		3,354		
Weighted average number of persons per household		2.5		
Commodity or service				
1	**Food & non-alcoholic drinks**	**£2,328**	**£2,478**	**£150**
2	**Alcoholic drinks, tobacco & narcotics**	**£558**	**£593**	**£36**
3	**Clothing & footwear**	**£1,385**	**£1,474**	**£89**
4	**Housing (net)[1], fuel & power**	**£2,995**	**£3,188**	**£193**
5	**Household goods & services**	**£1,715**	**£1,825**	**£110**
6	**Health**	**£277**	**£295**	**£18**
7	**Transport**	**£3,118**	**£1,500**	**-£1,618**
8	**Communication**	**£747**	**£795**	**£48**
9	**Recreation & culture**	**£2,960**	**£3,150**	**£190**
10	**Education**	**£600**	**£639**	**£39**
11	**Restaurants & hotels**	**£2,313**	**£2,461**	**£149**
12	**Miscellaneous goods & services**	**£2,014**	**£2,144**	**£130**
1-12	**All expenditure groups**	**£21,010**	**£20,543**	**-£467**
13	**Other expenditure items**	**£4,141**	**£4,408**	**£267**
14	**Change in Taxes**		**£200**	**£200**
Total expenditure		**£25,151**	**£25,151**	**£0**

From Table 2.2, we see that the household increases their spending on other categories by a significant amount. For example, they now spend £150 more on food and non-alcoholic drinks, £193 more on housing, £190 more on recreation and culture, and £149 more on restaurants and hotels. They also save more money than before. This hypothetical example shows how an increase in public spending on public transportation can cause a decrease in private transportation spending and how these private savings are beneficial for the local and national economies.

2.2.4. Transportation's Complexities

If we think of another market with two possible products or services – let's say white and wheat bread – we would be fairly confident that the quantities produced of each were at the right level and that their prices would reflect competitive economic conditions. The bread market is competitive – bread manufacturers have complete information about the costs to produce either white or wheat bread, they know the demand level from their customers, and they know how customers respond to changes in prices.

The same cannot be said about the passenger transportation market for three primary reasons. First, different actors – governments, businesses, and private individuals – all pay for various aspects of a transportation system. Second, because public resources are needed for both the automobile and public transportation, decisions are often made through the political process, further complicating the ability to achieve a cost-efficient transportation system. And third, because many components of a transportation system are decided on a multi-year basis, the marginal cost to use only reflects a small portion of the system's costs.

Existing studies and work in this thesis show that many actors pay for various aspects of a transportation system. On the automobile side, governments pay for roadway infrastructure and maintenance but private individuals and companies pay an order of magnitude more to purchase and operate vehicles and provide and maintain parking facilities. On the public transportation side, governments pay for nearly everything (although they do collect fare revenue from private individuals). Because we have multiple actors all contributing to a transportation system, it is hard for any one entity to have complete information on a mode's total costs and thus there is a lower probability of a cost-efficient allocation between the automobile and public transportation when compared to the allocation between white and wheat bread.

In addition to involving multiple actors spanning many levels of society, transportation is more complex than bread because there is significant public sector involvement. This involvement necessitates a political process, which may or may not produce efficient outcomes. We can assume though that because a political process is necessary for a large share of transportation decisions, there is a lower probability of achieving an efficient allocation of transportation modes than there is of bread manufacturers achieving an efficient allocation of white and wheat bread.

Lastly, consumers of transportation, especially automobile users, pay marginal prices that do not come close to reflect actual costs. This occurs, as will be shown in Chapter 4, because over 70 percent of a cost of the vehicle is strictly attributable to ownership and not use, and ownership decisions are typically made on a multi-year basis. Furthermore, because the majority of parking costs are absorbed in construction costs and parking construction decisions are typically made on a multi-decade basis, parking costs are seldom reflected in their marginal prices of use. Moreover, parking is often provided for free to consumers and consequently its costs are absorbed by employers and retailers. Combined, this creates a situation where the marginal price of automobile use reflects less than ten percent of the total cost of the automobile system while the remaining portion of costs are not decided upon for years or even decades.

In summary, significant differences exist between the allocation decision between white and wheat bread and between the automobile and public transportation. In the bread market, bread manufacturers have complete information on the costs and the marginal price of bread reflects these costs and market conditions. In the transportation market, we as a society lack information on total costs and the marginal price of automobile usage only reflects a portion of total costs. Research in this thesis attempts to fulfill the information gap by measuring all transportation costs, regardless of who pays for them.

2.3. Conclusion

In this chapter, we argued the importance of including both public and private expenditures when financially comparing transportation modes and why we believe a cost-minimizing allocation of transportation modes is unlikely to already exist in a given city. From this base, we will now move on to our analysis. Before diving into London's transportation costs, we will first review transportation cost data from 20 worldwide cities in Chapter 3 to see if there are patterns between changes in transportation costs and changes in roadway and public transportation infrastructure and use. In Chapters 4 and 5, we will conduct our comparison between the automobile and public transportation. In Chapter 4, the comparison will be at an aggregate level and include all direct costs. In Chapter 5, the comparison will be at a disaggregate level and include travel time costs in addition to all direct costs. Our analysis will close in Chapter 6, where we will explore the relationship between public transportation accessibility and travel costs. In Chapter 7, we will conclude the thesis by summarizing our key findings and offering recommendations for London to realize a more cost-efficient transportation system and areas for additional research.

3. MOBILITY IN CITIES ANALYSIS

3.1. INTRODUCTION

The Mobility in Cities Database (MCD)[10] and its predecessors[11] contain a wealth of transportation-related data for many of the world's largest urban areas. By analyzing this time-series panel database, we can identify useful patterns relating transport investment decisions and overall transport costs in these 20 cities from 1995 and 2001. In our analysis, we find the following:

- As public transportation's mode share of mechanized trips increases, the amount spent on passenger transport as a percentage of GDP decreases.
- As the per capita length of motorways increases, the amount spent on passenger transport as a percentage of GDP increases.
- As the per capita amount of public transit service miles increases, the amount spent on passenger transport as a percentage of GDP decreases.

We will first review previous work in this area before describing the methodology employed in our analysis and our results.

3.2. REVIEW OF PREVIOUS WORK

Given the methodological approach I have chosen for this task, there is limited relevant literature aside from the report written by Jean Vivier that was published with the release of the MCD in 2006. Authors, such as Peter Newman and Jeffrey Kenworthy, of precursors of the MCD dataset have also published their findings and are similar in nature to Vivier's work. In its 2001 version, the MCD includes data on 120 transport-related measures for 52 cities. Of these 52 cities, about 20 have consistent data for both

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10 "Mobility in Cities Database."

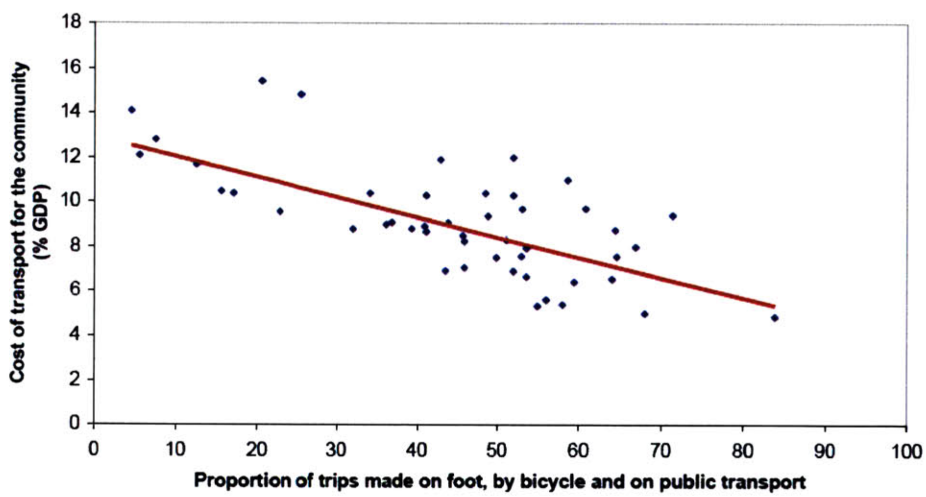
11 Newman, and Kenworthy, *Sustainability and Cities: Overcoming Automobile Dependence.*

1995 and 2001. In his review of the 2001 data, Vivier identifies several important patterns pertaining to transport costs:

- The cost of transport for the community ranges from five percent in dense cities with high public transportation use to over 15 percent in sprawling cities where the car is the dominant mode of transportation.

- The overall cost of passenger transport as a percent of GDP for a region decreases as the modal share of non-automobile modes increases. See Figure 3.1 for a visual representation of this relationship.

Figure 3.1 – Cost of Transport to the Community vs. Modal Split



- In cities where the GDP per inhabitant is higher than €10,000, the automobile costs the region 1.75 times more than public transit on a per passenger kilometer basis. Public transport's advantage is greater in less affluent cities.

While of great insight, Vivier's work is limited by only having one time-point of data for each city. More relationships can be uncovered with data from multiple time-points as is attempted in this chapter. In addition, the MCD and its precursors suffer from unreliable data, as the database attempts to collect a vast amount of information from many different data sources for over 50 cities – an impossible task to complete perfectly. Because of a lack of documentation on the methodology of how a measure is calculated for a given metropolitan area, we are unable to assess how accurate certain data-points are.

However, the MCD data and its precursors present a great starting point to build upon. The analysis presented in this chapter builds off the work of MCD authors by using longitudinal data from 1995 and 2001. By having two time-points of data for around 20 cities, the ability to test specific hypothesis is more robust that relying on only one time-point of data. Instead of focusing on the value of a particular measure we can focus on the change in value of a particular measure and thus control for the initial state.

3.3. Data Selection

Data exists from 1960, 1970, 1980, 1990, 1995, and 2001; however, in most cases data from one year is not comparable to data from another year as both the specific measures captured in a given year and the methodology behind several of the measures are seldom consistent from year to year. Furthermore, geographical boundaries of central business districts, city limits, and metropolitan areas often change from year to year.

After spending much time over the past year working with the MCD data and its predecessors, the only data that we feel is consistent from year to year are for a handful of measures from 1995 and 2001 for about 20 cities. When the 2001 version was released, the MCD authors went back for these 20 cities and reviewed their values from 1995, often times making corrections to the original value to ensure consistency to the 2001 measure.

3.4. Data Description and Objectives of Analysis

The cities included in our analysis are listed in Table 3.1.

Table 3.1 – Cities in the Mobility in Cities Database

Amsterdam	Hong Kong
Berlin	London
Bern	Madrid
Bologna	Manchester
Brussels	Nantes
Chicago	Newcastle
Copenhagen	Oslo
Glasgow	Paris
Graz	Stockholm
Helsinki	Zurich

In our sample, we have one city from North America (Chicago), one city from Asia (Hong Kong), and 18 cities from Europe.

Possible measures to include in our analysis are listed in Table 3.2.

Table 3.2 – Available Measures in the Mobility in Cities Database

Population Density
Motorization Rate
Number of Parking Spaces/1,000 jobs in the CBD
Length of Motorways/Inhabitant
Length of Reserved Routes/Inhabitant
Average PT Operating Speed
PT Vehicle x KM/Hectacre
PT Vehicle x KM/Inhabitant
PT Boardings/Inhabitant/Year
PT Market Share (mechanized and motorized trips)
PT Farebox Revenue per Boarding
PT Operating Costs per Boarding
PT Operating Costs per Vehicle x KM
PT Investment per Year and per Inhabitant
Total Cost of Transport (% GDP)

Given the objectives of our analysis, four variables have the greatest relevance:

1. Total cost of transport (% GDP)
2. PT market share (mechanized and motorized trips)
3. Length of motorways/inhabitant (KM/million inhabitants)
4. PT vehicle-kilometers/inhabitant

By having data on each of the above variables from 1995 and 2001, we can measure the relationship between the changes of each variable. This allows us to control for 1995 conditions and isolate changes between 1995 and 2001. With the four variables listed above, we can see how total costs changed relative to roadway capacity, public transit capacity, and public transit usage relative to the automobile. We did not include a measure on parking spaces as data was only available for Central Business District parking and parking costs were not included in the Total Cost of Transport (% GDP) measure.

Table 3.3 consists of 1995 values:

Table 3.3 – Mobility in Cities Data from 1995

City	Cost of Passenger Transport as % of GDP	Percentage of Daily Mechanised Trips by Public Transport	Length of Motorways (kilometers per million inhabitants)	Public Transit Service (vehicle kilometers per inhabitant)
Amsterdam	7.0%	20.9%	95.0	57.6
Berlin	8.2%	37.8%	18.4	115.0
Bern	10.2%	29.6%	155.0	136.0
Bologna	7.6%	20.1%	n.a.	34.9
Brussels	9.4%	24.5%	36.9	85.0
Chicago	12.1%	6.2%	87.5	37.4
Copenhagen	7.3%	18.0%	119.0	104.0
Glasgow	9.3%	17.5%	98.1	102.0
Graz	7.0%	23.3%	73.0	44.9
Helsinki	6.3%	34.5%	97.6	112.0
Hong Kong	4.6%	71.8%	13.0	146.0
London	8.5%	23.9%	9.6	145.0
Madrid	12.0%	27.2%	93.6	67.4
Manchester	8.2%	12.9%	60.5	57.5
Nantes	8.0%	17.9%	127.3	34.0
Newcastle	10.2%	26.7%	100.0	92.5
Oslo	7.9%	19.2%	132.0	91.2
Paris	6.8%	27.1%	66.8	71.5
Stockholm	8.8%	28.5%	n.a.	125.0
Zurich	9.3%	27.6%	112.0	127.0
Average	**8.4%**	**25.8%**	**83.1**	**89.3**

Table 3.4 consists of 2001 values:

Table 3.4 – Mobility in Cities Data from 2001

City	Cost of Passenger Transport as % of GDP	Percentage of Daily Mechanised Trips by Public Transport	Length of Motorways (kilometers per million inhabitants)	Public Transit Service (vehicle kilometers per inhabitant)
Amsterdam	6.2%	19.9%	n.a.	67.4
Berlin	9.7%	33.2%	20.2	127.0
Bern	9.8%	30.3%	157.0	141.0
Bologna	6.9%	19.2%	152.0	41.1
Brussels	10.3%	18.6%	36.3	91.0
Chicago	11.7%	6.7%	95.3	38.9
Copenhagen	8.3%	15.0%	125.0	109.0
Glasgow	10.4%	13.7%	111.0	99.7
Graz	7.9%	23.1%	79.6	50.0
Helsinki	5.6%	34.6%	90.8	119.0
Hong Kong	4.9%	73.9%	16.5	172.0
London	7.5%	26.8%	9.9	157.0
Madrid	10.4%	30.2%	98.3	85.0
Manchester	8.8%	11.8%	70.9	58.5
Nantes	9.0%	16.2%	122.6	37.0
Newcastle	11.9%	21.6%	129.0	84.0
Oslo	8.9%	19.5%	170.0	89.6
Paris	6.7%	27.5%	69.5	84.0
Stockholm	7.5%	28.9%	269.0	147.0
Zurich	9.2%	30.9%	109.0	137.0
Average	**8.6%**	**25.1%**	**101.7**	**96.8**

Table 3.5 consists of the changes between 1995 and 2001:

Table 3.5 – Changes in Mobility in Cities Data Between 1995 and 2001

City	Percentage Change in transport costs as % of GDP	Absolute Change in % of Daily Mechanised Trips by Public Transport	Percentage Change in Length of Motorways per 1000 Inhabitants	Percentage Change in Public Transit Vehicle Kilometers per Inhabitant
Amsterdam	-11.4%	-1.0%	n.a.	17.0%
Berlin	18.3%	-4.6%	9.8%	10.4%
Bern	-3.9%	0.7%	1.3%	3.7%
Bologna	-9.2%	-0.9%	n.a.	17.8%
Brussels	9.6%	-5.9%	-1.6%	7.1%
Chicago	-3.3%	0.4%	8.9%	4.0%
Copenhagen	13.7%	-3.0%	5.0%	4.8%
Glasgow	11.8%	-3.8%	13.1%	-2.3%
Graz	12.9%	-0.2%	9.0%	11.4%
Helsinki	-11.1%	0.1%	-7.0%	6.3%
Hong Kong	6.5%	2.1%	26.9%	17.8%
London	-11.8%	2.9%	3.6%	8.3%
Madrid	-13.3%	3.0%	5.0%	26.1%
Manchester	7.3%	-1.1%	17.2%	1.7%
Nantes	12.5%	-1.7%	-3.7%	8.8%
Newcastle	16.7%	-5.1%	29.0%	-9.2%
Oslo	12.7%	0.3%	28.8%	-1.8%
Paris	-2.2%	0.4%	4.0%	17.5%
Stockholm	-14.8%	0.4%	n.a.	17.6%
Zurich	-1.1%	3.3%	-2.7%	7.9%
Average	**2.0%**	**-0.7%**	**8.6%**	**8.7%**

3.5. RESULTS

To meet the objectives listed above, our first step was to run simple single variable regressions in which the percentage change in transport costs as a percent of GDP were regressed on each the remaining three variables. Key findings, all of statistical significance, include:

- For a one percent gain in public transit mode share of mechanized trips, transport costs as a percent of GDP decreased by 2.72 percent.
- For a one percent increase in the length of motorways per a million inhabitants, transport costs as a percent of GDP increased by 0.44 percent.
- For a one percent increase in the vehicle kilometers of public transit per inhabitant, transport costs as a percent of GDP decreased by 0.76 percent.

After examining the results from the single-variable analysis, a multi-variable model was constructed to improve our understanding of the factors affecting the change in transport costs. This model included the percentage change in per capita length of motorways and the absolute change in public transit mode share of mechanized trips as independent variables. This analysis produced similar results as above but of stronger statistical significance and in total explained about 68 percent of the variation in the change in transport costs.

The following sections contain greater detail on the results of both the single-variable and multiple-variables regression analyses.

3.5.1. Public Transit Mode Share and Transport Costs

In this analysis, all 20 cities were included. On average, transport costs as a percentage of GDP increased by 2.0 percent while public transit mode share of mechanized trips decreased by 0.7 percent. For every one percent increase in public transit's share of motorized trips, transport costs as a percentage of GDP decreased by 2.72 percent. The standard error of this coefficient is 0.77, resulting in a t-statistic of -3.55. The 95 percent confidence interval on the coefficient is from -1.11 to -4.32.

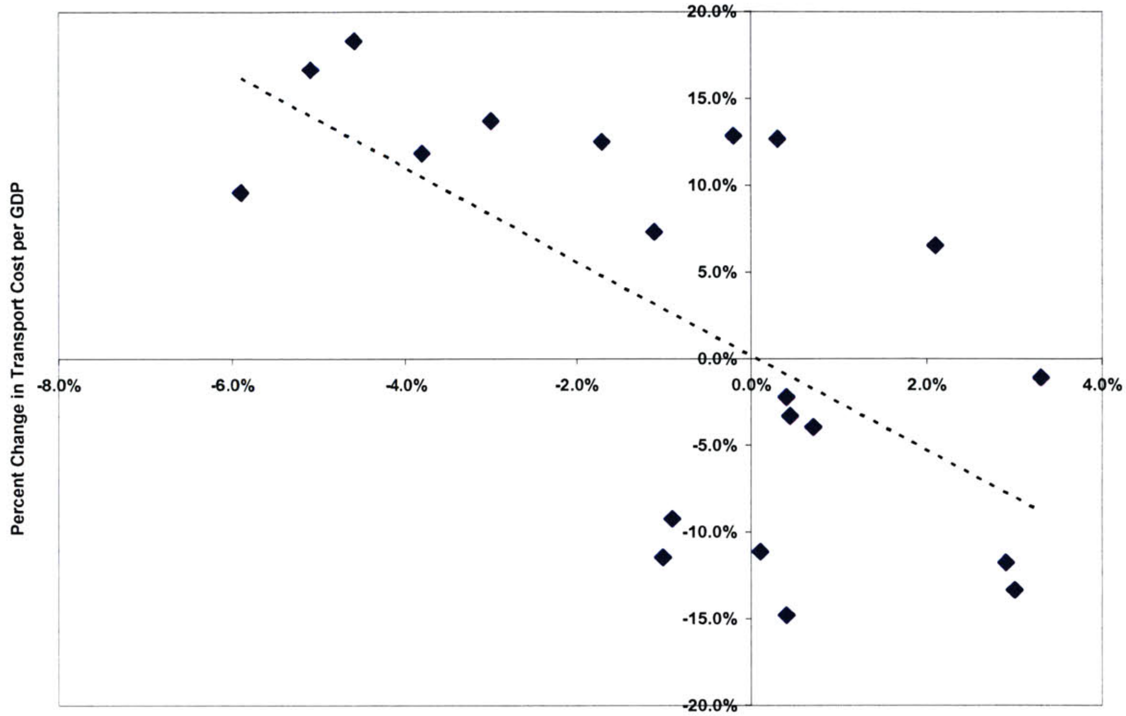
Table 3.6 shows a summary of the regressions results while Figure 3.2 shows a plot of the two variables for the 20 cities.

Table 3.6 – Public Transit Mode Share – Regression Results

Regression Statistics	
Multiple R	0.64
R Square	0.41
Adjusted R Square	0.38
Standard Error	0.09
Observations	20.00

	Coefficients	*Standard Error*	*t Stat*	*Lower 95%*	*Upper 95%*
Intercept	0.00	0.02	0.07	-0.04	0.04
Change in PT mode share	-2.72	0.77	-3.55	-4.32	-1.11

Figure 3.2 – Public Transit Mode Share Plot



3.5.2. Length of Motorways and Transport Costs

In this analysis, only 17 cities were included as motorway data for both 1995 and 2001 were not available for Amsterdam, Bologna, and Stockholm. On average, transport costs as a percentage of GDP increased by 2.0 percent while the length of motorways per inhabitant increased by 8.6 percent. For every one percent increase in the per capita length of motorways, transport costs as a percentage of GDP increased by 0.44 percent. The standard error of this coefficient is 0.21, resulting in a t-statistic of 2.08. The 95 percent confidence interval on the coefficient is from -0.01 to 0.89.

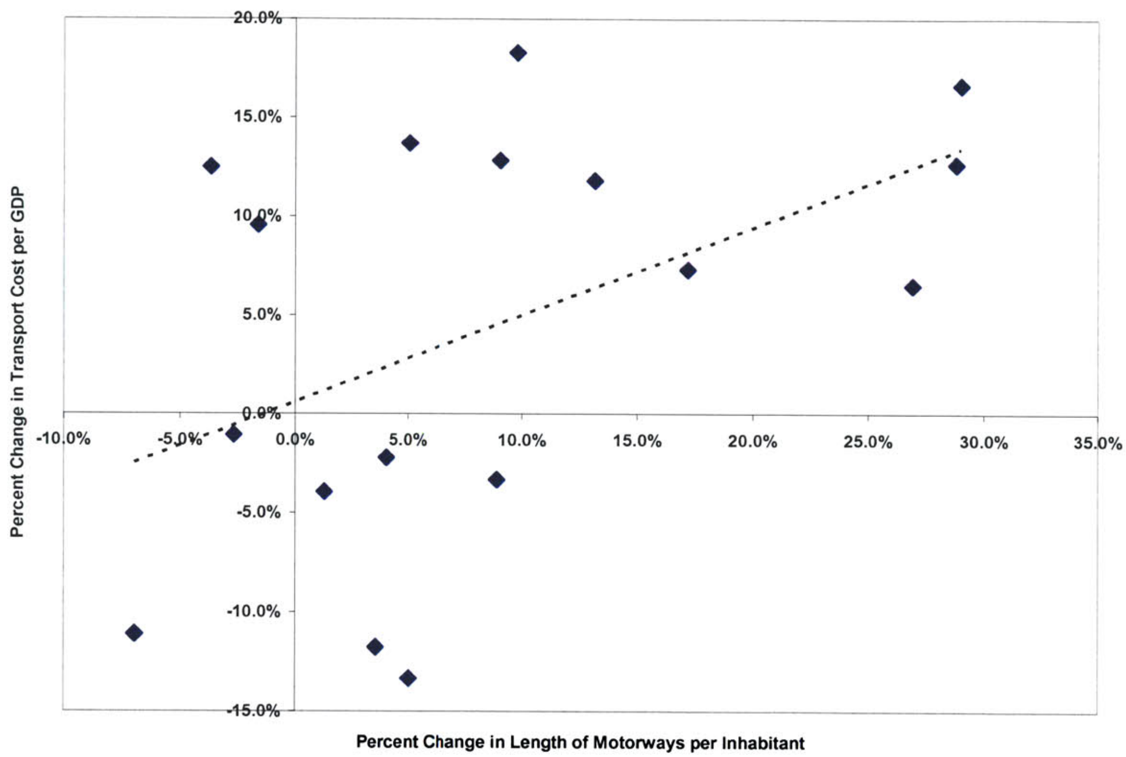
Table 3.7 shows a summary of the regressions results while Figure 3.3 shows a plot of the two variables for the 17 cities.

Table 3.7 – Length of Motorways – Regression Results

Regression Statistics	
Multiple R	0.47
R Square	0.22
Adjusted R Square	0.17
Standard Error	0.10
Observations	17.00

	Coefficients	*Standard Error*	*t Stat*	*Lower 95%*	*Upper 95%*
Intercept	0.01	0.03	0.21	-0.06	0.07
Motorway Change	0.44	0.21	2.08	-0.01	0.89

Figure 3.3 – Per Capita Change in the Length of Motorways Plot



3.5.3. Public Transit Provision and Transport Costs

In this analysis, all 20 cities were included. On average, transport costs as a percentage of GDP increased by 2.0 percent while the amount of public transportation vehicle miles increased by 8.7 percent. For every one percent increase in the per capita length of motorways, transport costs as a percentage of GDP decreased by 0.76 percent. The standard error of this coefficient is 0.26, resulting in a t-statistic of -2.97. The 95 percent confidence interval on the coefficient is from -1.30 to -0.22.

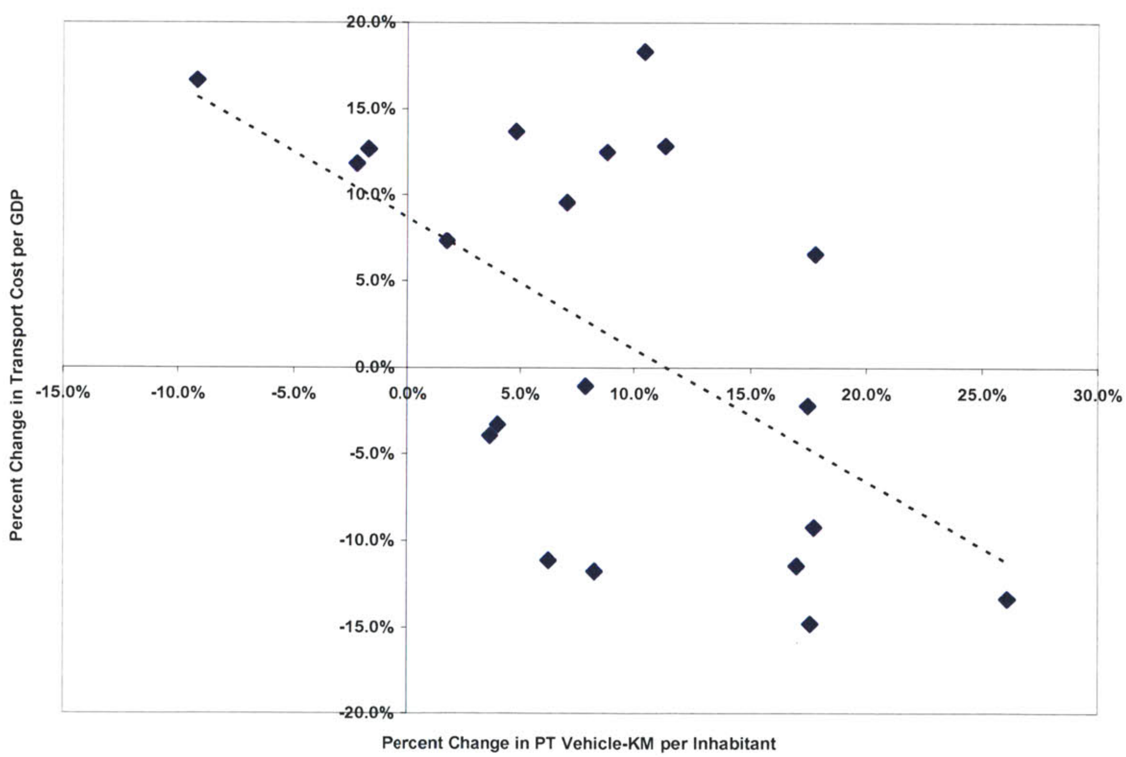
Table 3.8 shows a summary of the regressions results while Figure 3.4 shows a plot of the two variables for the 20 cities.

Table 3.8 – Public Transit Provision – Regression Results

Regression Statistics	
Multiple R	0.57
R Square	0.33
Adjusted R Square	0.29
Standard Error	0.10
Observations	20.00

	Coefficients	*Standard Error*	*t Stat*	*Lower 95%*	*Upper 95%*
Intercept	0.09	0.03	2.79	0.02	0.15
PT vehicle-km	-0.76	0.26	-2.97	-1.30	-0.22

Figure 3.4 – Public Transit Provision Plot



3.5.4. Multiple Variable Analysis

As discussed in the introduction of this section, in addition to the single-variable regressions, we constructed a model incorporating more than one explanatory variable. Figure 3.5 depicts the model equation.

Figure 3.5 – Multiple Variable Regression Equation

Change in Transport Costs = $\beta_0 + \beta_1$*Absolute Change in Public Transit Mode Share + β_2*Percentage Change in Length of Motorways per Inhabitant + μ

These two variables were chosen as they have a weak relationship between them (correlation coefficient of -0.14) and they measure different aspects of a passenger transportation system. Changes in public transit mode share were used instead of changes in public transit supply as it more accurately reflects changes in the passenger transportation market. Table 3.9 contains the results of the regression model.

Table 3.9 – Multiple Variable Regression Results

Regression Statistics	
Multiple R	0.83
R Square	0.68
Adjusted R Square	0.64
Standard Error	0.06
Observations	17.00

	Coefficients	*Standard Error*	*t Stat*	*Lower 95%*	*Upper 95%*
Intercept	0.00	0.02	-0.21	-0.05	0.04
Change in PT Mode Share - β_1	-2.46	0.55	-4.48	-3.64	-1.28
Change in Motorways - β_2	0.36	0.14	2.50	0.05	0.66

From our model, we see that for every one percent gain public transit's mode share of mechanized trips, transport costs as a percentage of GDP decrease by 2.46 percent and for every one percent increase in the per capita length of motorways, transport costs as a percentage of GDP increase by 0.36 percent. As expected the value of these coefficient are smaller in magnitude than the single variable regressions but the statistical significance of each coefficient is stronger in the multiple variable regression. Combined, these two explanatory variables explain around 68 percent of the variation in the change in transport costs as a percentage of GDP.

3.6. CONCLUSION

From our analysis of the MCD data from 1995 and 2001, we identified relationships between the change in transport costs and changes in public transportation and roadway capacity and mode split. We saw a decrease in overall transport costs associated with an increase in public transportation mode share. We saw an increase in overall transport costs associated with an increase in the per capita length of roadways. We saw a decrease in overall transport costs associated with an increase in the per capita supply of public transit.

However, in order to fully understand the driving factors behind changes in transport costs, MCD data is not sufficient by itself. The cost data is only provided at an aggregate level and the methodology behind how each measure was calculated is unclear. In addition, despite the consistency checking process employed by the MCD authors, we cannot be certain that the methodology and geographic definitions were identical in 1995 and 2001. Simply put, we need more fine-grained information on costs for both the automobile and public transit systems. To achieve this, research in this thesis will analyze transport costs in London for FY 2004-05. We will present detailed cost information for each mode and analyze these costs both in aggregate and for different types of trips within London in the ensuing chapters. While we lose the multi-year and multi-city approach of this section, we will gain a deeper understanding of the driving factors behind passenger transport costs.

4. MODAL TRANSPORT COSTS

4.1. INTRODUCTION

In this chapter, we financially compare public transportation services provided by Transport for London (TfL) with the private automobile in the Greater London Area. To perform the comparison, cost data was gathered for four different subgroups:

1. Public TfL costs
2. Private TfL costs
3. Public automobile costs
4. Private automobile costs

To accurately compare TfL services with the automobile, data on modal usage was also obtained, allowing for the normalization of costs on a journey and distance basis.

From our analysis, we calculated that it cost the London region as a whole £5.57 per automobile journey (including private expenditures on automobiles and parking) and £1.50 per journey on TfL services. In terms of passenger-kilometers, it cost £0.57 per automobile passenger kilometer and £0.29 per TfL passenger kilometer. Approximately, 93.5 percent of the automobile's cost was private, compared to 53.6 percent private cost for TfL services. See Table 4.1 for additional detail.

Table 4.1 – Summary Modal Comparison

Mode	Public Actors (mil)	Private Actors (mil)	Total (mil)	Per Journey	Per Passeneger-KM
Public Transit	£2,015	£2,265	£4,280	£1.50	£0.29
Automobile	£1,449	£20,855	£22,305	£5.57	£0.57

4.2. MONETARY SOURCES

In this section, I provide an overview of monetary sources for both Transport for London and the automobile. Both public and private actors are included. In section 4.2.1., I focus on Transport for London and in section 4.2.2., I focus on the automobile.

4.2.1. Transport for London

Public – Transport for London Monetary Sources[12]

Public funding for TfL originates from national government. Her Majesty's Treasury, the United Kingdom's economics and finance ministry, through the Department for Transport (DfT) provides the Greater London Authority (GLA) with a transport grant. National-level grants for TfL are normally negotiated every two years (with estimates of the funds likely to be granted in the third year) within the National Spending Review procedure; however, in 2004, London and the DfT reached an agreement that secures the amount of the grant (£14.5 billion) for a five year period.[13]

In recent years, two separate grants have been provided to TfL from the DfT via the GLA.[14] The first grant in FY 2004-05 was for £1.4 billion and was used to subsidize daily transit operations. The second grant in FY 2004-05 was for £0.9 billion and was used to finance the Public Private Partnership (PPP) with private partners Tube Lines and Metronet for maintenance and refurbishment work on the London Underground. In total, government funding provided TfL with £2.26 billion in FY 2004-05.

However, given that TfL spent £520 million in FY 2004-05 on automobile-related expenditures (see section 4.3.2), the £2.3 billion in government grants needs to be adjusted to reflect resources strictly spent on public transportation. As presented in the next sub-section, approximately £2.54 billion of TfL's budget is generated from private sources. Dividing the £520 million spent on automobile-related expenditures proportionally on public and private sources resulted in approximately £2.02 billion in public funds spent on TfL public transportation services.

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12 "Transport for London - Q4 FY 2004-05 Finance and Performance Report."

13 Favero, *Fiscal Decentralization and Urban Public Transport.*

14 "Department for Transport Annual Report 2005."

Private – Transport for London Monetary Sources[15]

Private funding for TfL operations stem from two sources: individuals and businesses. Individuals provide TfL fares for passenger services and congestion charge payments. Fares for public transport services provided TfL with about £2.17 billion in FY 2004-05. Other private sources, such as income from transport policing and enforcement, provided TfL with £0.18 billion in FY 2004-05. Table 4.2 provides a listing of all TfL funding from private sources.

Table 4.2 – Private Transport for London Monetary Sources (in millions)

Source	Amount
TfL LU Traffic Revenue	£1,240
TfL Surface - Bus Network Revenue	£869
TfL Surface - Other London Buses Revenue	£17
TfL London Rail - DLR Revenue	£43
TfL Surface - Transport Policing & Enforcement	£21
TfL Surface - Other Income	£38
TfL Group Directorates	£120
TfL Surface - Congestion Charging Revenue	£192
Total	**£2,540**

Income from businesses, which represent about two percent of TfL's overall budget (£93 million), are not included in our analysis as they are not a direct spend on transportation. For example, one component of income from businesses is rental income for real estate in London Underground stations. This transaction from business owner to TfL should be treated no differently than the rental transaction from the business owner just outside the station to his or her property owner and thus should not be considered as transportation spending.

Similar to public TfL monetary sources, we need to discount the £2.54 billion from private sources to account for TfL's automobile-related expenditures. This results in a total of £2.27 billion in private funds spent on TfL's public transportation services.

15 "Transport for London - Q4 FY 2004-05 Finance and Performance Report."

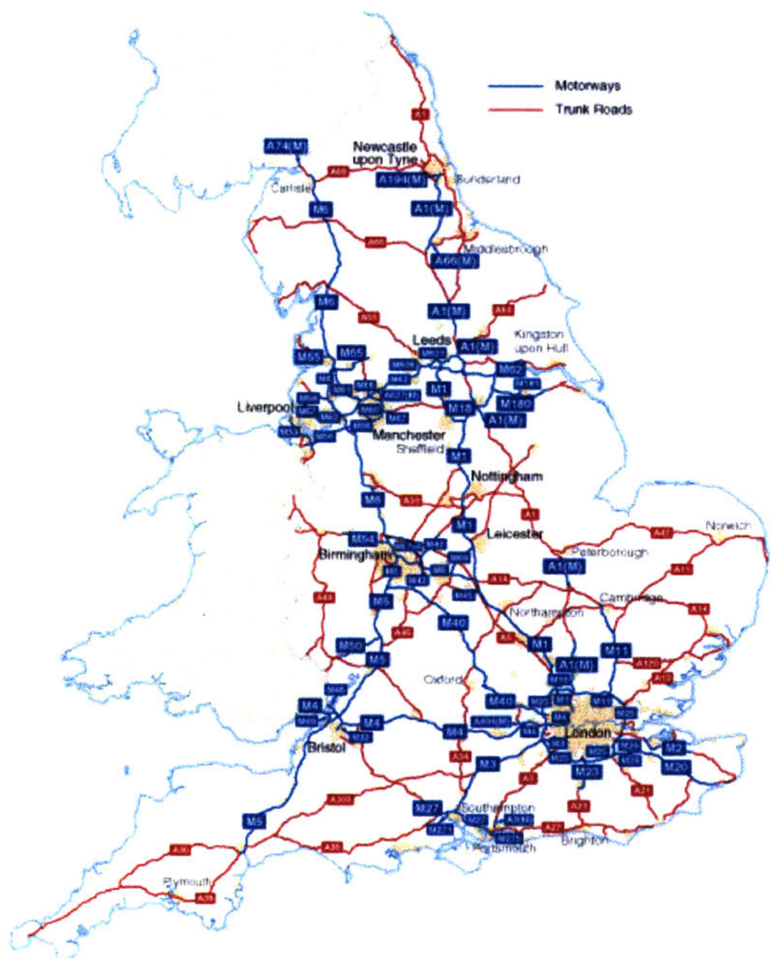
4.2.2. Automobile

Public – Automobile Monetary Sources

Public funding toward the automobile system originates from a number of government entities including TfL. The following listing describes the main entities involved in roadway construction and maintenance and estimates the amount these entities spent from public sources in FY 2004-05 in London.

- **UK Highways Agency** – The UK Highway Agency is in charge of all major roadways in the United Kingdom and operates under the auspices of the Department of Transport. Figure 4.1 is a map of roadways the Highway Agency manages.

Figure 4.1 – Map of UK Highway Agency's Roadways



In FY 2004-05, the UK Highways Agency had an overall budget of £4.2 billion.[16] As slightly more than four percent of roadways the UK Highway Agency manages are located within London (on a lane-kilometer basis), approximately £170 million in costs are included in our analysis as attributable to London. While this is a rough estimate, data and time limitations preclude us from acquiring more accurate information.

- **Transport for London** – In addition to providing public transport services, TfL maintains control over a portion of London's roadway network (about five percent) and manages streetlights, the congestion charge, and overall road network performance. Expenditures for automobile-related categories totaled £520 million in FY 2004-05, approximately 11% of TfL's overall budget.[17] Assuming that this £520 million came from both public and private sources in proportion with TfL's overall funding sources, about £245 million from public sources was spent on automobile-related expenditures.
- **London Boroughs –** Any road not managed by the UK Highways Agency or TfL falls under the control of one of the 32 local boroughs or the City of London. Figure 4.2 is a map of borough boundaries.[18]

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[16] "U.K. Highways Agency Annual Report 2004/2005."

[17] "Transport for London - Q4 FY 2004-05 Finance and Performance Report."

[18] "London Borough Map."

Figure 4.2 – Map of London Boroughs

Roadway and other automobile-related expenditures for each borough and the City of London were examined for FY 2004-05.[19] Table 4.3 contains a listing of all automobile-related expenditures for the 32 London boroughs and the City of London.

[19] Annual reports for all 32 boroughs and the City of London were reviewed to determine FY 2004-05 spending. These reports were found on each borough's website.

Table 4.3 – Roadway Spending by London Boroughs (in millions)

Borough	Amount Spent On Roads	Borough	Amount Spent On Roads
Barking and Dagenham	£19.0	Hounslow	£23.6
Barnet	£34.0	Islington	£42.5
Bexley	£28.6	Kensington and Chelsea	£36.4
Brent	£30.7	Kingston upon Thames	£26.4
Bromley	£23.2	Lambeth	£42.7
Camden	£47.7	Lewisham	£21.1
City of London	£31.1	Merton	£19.4
Croydon	£36.4	Newham	£30.9
Ealing	£42.1	Redbridge	£29.9
Enfield	£40.0	Richmond upon Thames	£22.2
Greenwich	£30.0	Southwark	£29.5
Hackney	£36.1	Sutton	£17.6
Hammersmith and Fulham	£24.6	Tower Hamlets	£27.0
Haringey	£30.8	Waltham Forest	£35.5
Harrow	£29.0	Wandsworth	£31.0
Havering	£20.5	Westminster	£61.9
Hillingdon	£34.6		

TOTAL	£1,036.0

In total in FY 2004-05, London boroughs and the City of London collectively spent £1.04 billion on roadways and other automobile related expenditures.

In total, the UK Highways Agency, Transport for London, the 32 London boroughs, and the City of London collectively spent £1.45 billion from public sources on roadways and automobile-related expenditures in FY 2004-05. See Table 4.4 for a summary.

Table 4.4 – Public Sources of Automobile Spending

Entity	Amount
UK Highways Agency	£169
Transport for London	£245
London Boroughs	£1,036
Total	**£1,449**

Private – Automobile Monetary Sources

Private funding for the automobile originates from TfL's private sources, from private individuals owning and operating private vehicles, and from parking expenditures.

Transport for London

As £245 million of the £520 million spent by TfL on automobile-related expenditures originated from public sources, the remainder, £275 million, is assumed to have originated from private sources.

Ownership and Operation of Private Vehicles

Three sources of information were used to calculate the amount of automobile-related private expenditures. First, data on the number of vehicles in London and on the average distance driven in a year by one vehicle were obtained. Second, data on the cost of owning and operating an automobile were gathered. Third, a fleet model distribution of London was constructed to more accurately use cost data.

More information on each data source and the methodology employed to estimate the total amount of private expenditures to own, operate, and maintain vehicles in London is explained in the remainder of this section:

- *The London Travel Report* – This annual publication produced by TfL contains a wealth of data relating to passenger transportation within London. [20] Data on the number of automobile registrations was used to determine how many automobiles there are in London. Table 4.5 contains automobile registration data from 1996 to 2005. Data from 2005 was used in this analysis.

Table 4.5 – Automobile Registrations in London (thousands), 1996 to 2005

Year	Greater London	Inner London	Outer London
1996	2,262	679	1,583
1997	2,259	688	1,571
1998	2,287	697	1,590
1999	2,319	707	1,611
2000	2,331	709	1,622
2001	2,379	721	1,657
2002	2,390	717	1,672
2003	2,397	714	1,682
2004	2,438	718	1,720
2005	2,473	724	1,750

20 "London Travel Report."

In addition to automobile registrations, the London Travel Report provides information needed to calculate the annual average distance driven per automobile. By dividing the total vehicle miles driven in London – about 18.7 billion – by the total number of vehicles in London – about 2.5 million – we estimate a distance of 7,689 miles as the average annual distance driven in London per vehicle. This calculation assumes that the distance driven by Londoners outside London is equal to the amount of miles driven by non-Londoners inside London.

- The AA Motoring Trust – The AA Motoring Trust, an automobile services membership organization similar to the American Automobile Association in the United States, annually publishes the cost of owning and operating an automobile.[21] Table 4.6 and Table 4.7 contain the Motoring Trust's cost estimates for 2005 for both petrol and diesel automobiles. These costs are provided for different price bands of the vehicle's initial purchase price. Fixed costs represent the cost of simply owning a vehicle and driving it just once, while variable costs are directly affected by the distance traveled by the vehicle.

Table 4.6 – Fixed and Variable Costs for Petrol Cars

	Purchase price of the car when new:				
	Up to £10,000	£10,000 to £13,000	£13,000 to £20,000	£20,000 to £30,000	Over £30,000
Fixed Costs per Year					
Road Tax	£125	£150	£165	£165	£165
Insurance	£406	£426	£554	£769	£1,027
Cost of capital	£269	£392	£547	£803	£1,295
Depreciation	£1,073	£1,674	£2,255	£3,207	£5,507
Total	**£1,873**	**£2,642**	**£3,521**	**£4,944**	**£7,994**
Variable Costs, pence per mile					
Petrol	8.69	9.54	12.22	13.96	16.29
Tires	0.78	0.98	1.12	1.35	1.85
Service labor costs	2.92	2.83	2.88	3.34	3.76
Replacement parts	1.65	2.09	2.52	3.03	4.45
Total	**14.04**	**15.44**	**18.74**	**21.68**	**26.35**

21 "The Cost of Motoring - 2005."

Table 4.7 – Fixed and Variable Costs for Diesel Cars

	Purchase price of the car when new: Up to £10,000	£10,000 to £13,000	£13,000 to £20,000	£20,000 to £30,000	Over £30,000
Fixed Costs per Year					
Road Tax	£115	£135	£135	£160	£170
Insurance	£406	£426	£554	£769	£1,027
Cost of capital	£292	£394	£503	£855	£1,130
Depreciation	£1,189	£1,680	£2,366	£2,934	£4,306
Total	**£2,002**	**£2,635**	**£3,558**	**£4,718**	**£6,633**
Variable Costs, pence per mile					
Petrol	7.88	8.19	8.53	10.24	13.65
Tires	0.88	0.95	1.06	1.24	1.52
Service labor costs	2.78	2.86	3.08	3.47	3.91
Replacement parts	1.72	2.15	2.54	3.04	4.06
Total	**13.26**	**14.15**	**15.21**	**17.99**	**23.14**

- *The Society of Motor Manufacturers and Traders (SMMT)* – The SMMT, a trade association of automobile manufacturers and traders in the United Kingdom, annually publishes a fact book on the motor industry.[22] From the 2006 fact book, data on new car purchases allowed a model based on initial purchase price and engine type to be constructed for London. This enables more accurate use of the AA Motoring Trust data.

  To determine the distribution of initial purchase price, national sales figures for 2005 for 45 top-selling models (53% of total sales) were used. Table 4.8 provides information on these 45 models while Table 4.9 calculates a distribution based on initial purchase price for the year 2005. Key assumptions underpinning this approach include the following:

  - The remaining 47% of total sales for which data is not provided are proportionally equivalent to the 53% of sales on which data was available.

  - London's automobile fleet is equivalent to the national automobile fleet – While London has higher incomes than the rest of the country, the average age of an automobile in London is 7.4 years compared to a national average of 6.8 years – in net these two facts counteract each

[22] "Motor Industry Facts - 2006."

other in terms of how equivalent London's automobile fleet is to the rest of the country.

- The price distribution of vehicles purchases (in 2005 dollars) in years prior to 2005 is equivalent to the 2005 distribution.

Table 4.8 – United Kingdom Automobile Sales Data for 45 Models in 2005

Maker	Model	Registrations	Price Band	% of Total
1. Suzuki	Alto	7,584	Up to £10,000	0.6%
2. Chevrolet	Matiz	4,772	Up to £10,000	0.4%
3. Vauxhall	Agila	3,808	Up to £10,000	0.3%
4. Suzuki	Wagon R+	3,218	Up to £10,000	0.2%
5. smart	City coupe	1,448	Up to £10,000	0.1%
1. Vauxhall	Corsa	89,463	£10,000 to £13,000	6.9%
2. Ford	Fiesta	83,803	£10,000 to £13,000	6.4%
3. Peugeot	206	67,450	£10,000 to £13,000	5.2%
4. Renault	Clio	56,538	£10,000 to £13,000	4.3%
5. MINI	MINI	44,770	£13,000 to £20,000	3.4%
1. Ford	Focus	145,010	£13,000 to £20,000	11.2%
2. Vauxhall	Astra	108,461	£13,000 to £20,000	8.3%
3. Renault	Mégane	87,093	£13,000 to £20,000	6.7%
4. Volkswagen	Golf	67,749	£13,000 to £20,000	5.2%
5. Peugeot	307	44,276	£13,000 to £20,000	3.4%
1. Ford	Mondeo	57,589	£13,000 to £20,000	4.4%
2. BMW	3 Series	44,844	£20,000 to £30,000	3.4%
3. Vauxhall	Vectra	44,626	£20,000 to £30,000	3.4%
4. Volkswagen	Passat	35,594	£13,000 to £20,000	2.7%
5. Audi	A4	35,005	£20,000 to £30,000	2.7%
1. Mercedes	C Class	29,071	£20,000 to £30,000	2.2%
2. BMW	5 Series	18,140	£20,000 to £30,000	1.4%
3. Mercedes	E Class	14,620	Over £30,000	1.1%
4. Audi	A6	11,016	£20,000 to £30,000	0.8%
5. Volvo cars	70 Series	9,902	Over £30,000	0.8%
1. BMW	7 Series	2,017	Over £30,000	0.2%
2. Bentley	Continental	1,923	Over £30,000	0.1%
3. Jaguar	XJ	1,814	Over £30,000	0.1%
4. Mercedes	S Class	1,635	Over £30,000	0.1%
5. Audi	A8	1,558	Over £30,000	0.1%
1. Mercedes	SLK	6,310	Over £30,000	0.5%
2. Audi	TT	5,616	Over £30,000	0.4%
3. Vauxhall	Tigra	5,563	£13,000 to £20,000	0.4%
4. Mazda	MX-5	5,182	£13,000 to £20,000	0.4%
5. Mazda	RX-8	4,971	£20,000 to £30,000	0.4%
1. Land Rover	Freelander	17,723	£13,000 to £20,000	1.4%
2. Honda	CR-V	16,700	£20,000 to £30,000	1.3%
3. Toyota	RAV4	14,234	£20,000 to £30,000	1.1%
4. Land Rover	Discovery	13,212	Over £30,000	1.0%
5. Nissan	X-Trail	11,642	£13,000 to £20,000	0.9%
1. Vauxhall	Zafira	40,923	£13,000 to £20,000	3.1%
2. Volkswagen	Touran	12,706	£20,000 to £30,000	1.0%
3. Ford	Galaxy	9,298	£20,000 to £30,000	0.7%
4. Kia	Sedona	5,865	£13,000 to £20,000	0.5%
5. Chrysler	Voyager	5,199	£20,000 to £30,000	0.4%
Total Sample Sales		1,299,941		
Total Sales		2,439,717		

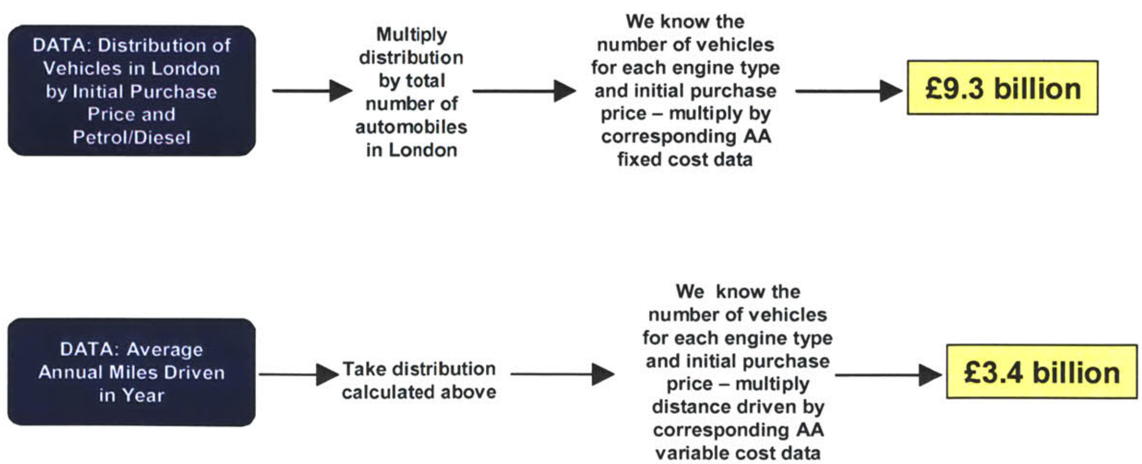
Table 4.9 – Automobile Distribution by Purchase Price

Distribution	
Up to £10,000	1.6%
£10,000 to £13,000	22.9%
£13,000 to £20,000	52.1%
£20,000 to £30,000	18.9%
Over £30,000	4.5%

In addition, sales data in the SMMT Motor Industry Fact Book by engine type for the past seven years were used to approximate the division between petrol and diesel engines.

Given the data described above, how were total private vehicle expenditures calculated? First, the distribution of vehicles by initial purchase price and engine type from the SMMT data was multiplied by the total number of vehicles in London. This provided us with the number of automobiles in London for each engine type and initial purchase price combination. Next, the number of vehicles for each combination was multiplied by the corresponding AA fixed cost data. Summing these amounts together resulted in an estimate of £9.3 billion in fixed automobile ownership costs. To calculate operation and maintenance costs, a similar process was employed. The average annual miles driven in a year was multiplied by the AA variable cost data for each combination of engine type and initial purchase price, resulting in an estimate of £3.4 billion in costs to operate and maintain a vehicle. The next section provides information on the breakdown of both fixed and variables cost. Figure 4.4 illustrates the processes described above.

Figure 4.3 – Calculating Private Vehicle Expenditures



Parking

Parking costs are included in our analysis as parking is a necessary component of the automobile system. In order to determine total parking costs, we estimated them from the perspective of the owner of the parking space, not from the individual paying a parking fee. Approaching parking from the perspective from the viewpoint of the owner and not the user is more accurate for the purposes of our research given the high-level of free-parking that is available.

To estimate annual parking expenditures in London, a number of different data sources were used. First, we needed an estimate on the supply of parking in London. Using a stratified sampling method of seven different land use categories within London, Dale and Smith estimated London's parking supply by parking space type and location.[23] Their results are provided in Table 4.10.

Table 4.10 – London's Parking Supply

	Public Off-Street	Private Non-Residential		Private Residential	On-Street Non-Controlled	On-Street Controlled	Total
		Employee	Other				
Central Area	29,000	46,000	7,000	80,000	111,000	82,000	**355,000**
Rest of Inner London Boroughs	22,000	117,000	33,000	376,000	708,000	52,000	**1,308,000**
Outer London Boroughs	178,000	395,000	177,000	2,235,000	2,167,000	32,000	**5,184,000**
Total	**229,000**	**558,000**	**217,000**	**2,691,000**	**2,986,000**	**166,000**	**6,847,000**

Having parking supply information, our next step was to estimate a per space cost for each parking category. Given that the public sector owns on-street parking spaces and that we have already included the expenditures borne by public authorities on roadways, we discard both the on street non-controlled and on-street controlled spaces.

To estimate a per space cost for each parking category, we drew upon Transit Cooperative Research Program (TCRP) Report 95[24] and Litman's literature review of

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[23] Dale, and Smith, "Estimating London's Parking Space Capacity."

[24] "Transit Cooperative Research Program Report 95: Chapter 18 – Parking Management and Supply."

parking benefits and costs.[25] In TCRP Report 95 report, a review of several estimates of non-residential parking costs is provided. While the data is specific to the United States, it is the most complete set of estimates of parking costs available and it provides a base for us to adapt to London. Table 4.11 contains TCRP's estimates of parking construction costs.

Table 4.11 – TCRP Parking Construction Cost Estimates (1997 Dollars)

	Surface Lot			Above-Ground Structure			Below Ground Structure		
	Low	High	Average	Low	High	Average	Low	High	Average
Land	$600	$12,000	$6,300	$500	$1,000	$750	$0	$0	$0
Construction	$1,500	$4,000	$2,750	$8,800	$20,000	$14,400	$16,000	$40,000	$28,000
Design, Contingecy	$200	$800	$500	$1,800	$5,000	$3,400	$3,200	$10,000	$6,600
Total Construction Costs	**$2,300**	**$16,800**	**$9,550**	**$11,100**	**$26,000**	**$18,550**	**$19,200**	**$50,000**	**$34,600**

Litman's report provided data on operation and maintenance costs and residential parking costs. His estimates of operation and maintenance costs are provided in Table 4.12 while he simply estimated the residential cost as $600 per space.

Table 4.12 – Parking Operating and Maintenance Costs (2002 dollars)

Type of Facility	Annual O & M Costs
Suburban, On-Street	$200
Suburban, Surface, Free Land	$200
Suburban, Surface	$200
Suburban, 2-Level Structure	$300
Urban, On-Street	$200
Urban, Surface	$300
Urban, 3-Level Structure	$400
Urban, Underground	$400

From this set of base data, we performed the following operations to generate London-specific costs for both an urban setting and suburban setting.

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[25] Litman, *Transportation Cost and Benefit Analysis - Parking Costs.*

- Average construction and design contingency costs from the TCRP report were inflated by the CPI to 2004 dollars[26] and converted from US Dollars to Great Britain Pounds at the average exchange rate for FY 2004-05.[27] Similarly, operating and maintenance costs from Litman were inflated and converted.

- Land value data from the UK Valuation Office Agency was obtained from the January 2005 Property Market Report.[28] Table 4.12 provides UK data.

Table 4.13 – United Kingdom Land Value – January 2005

REGION	Small Sites	Bulk Land	Sites for flats or maisonettes
	£s per ha	£s per ha	£s per ha
North East	2,340,000	2,210,000	2,650,000
North West	2,550,000	2,520,000	2,840,000
Merseyside	1,250,000	1,120,000	1,340,000
Yorkshire and the Humber	2,610,000	2,320,000	2,530,000
East Midlands	2,220,000	2,010,000	2,270,000
West Midlands	2,210,000	2,120,000	2,300,000
Eastern	3,100,000	3,425,000	3,750,000
South East	3,160,000	2,960,000	3,590,000
South West	2,490,000	2,200,000	2,790,000
Wales	2,240,000	2,180,000	2,200,000
England & Wales (excluding London)	2,590,000	2,460,000	2,830,000
Inner London	9,370,000	7,800,000	10,810,000
Outer London	6,280,000	5,990,000	7,340,000
Scotland	1,450,000	1,680,000	2,690,000
Northern Ireland	1,790,000	1,675,000	1,879,000

For our purposes, the small site values for Inner and Outer London were used. After converting from hectares to acres, we used Litman's standard of 120 spaces per acre for surface lots and assuming four as the average number of levels per structure, we used 480 spaces per acre for above-ground structures.

- We discarded Litman's rough estimate of residential parking costs and calculated residential parking costs as the construction and land costs for a surface space either.

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26 *Consumer Price Index Home Page, "Consumer Price Index."*

27 "FXHistory - Historical Currency Exchange Rates."

28 "Property Market Report January 2005."

Based on the steps outlined above, Table 4.14 consists of per space parking estimates for both Inner London and Outer London. To amortize construction and land costs, we assumed an amortization period of 30 years and an interest rate of eight percent.

Table 4.14 – Per Space Parking Cost Estimates

	INNER LONDON				OUTER LONDON		
	Surface Lot	Above-Ground Structure	Below-Ground Structure	Residential	Surface Lot	Above-Ground Structure	Residential
Land	£31,600	£7,900	£0	£31,600	£21,179	£5,295	£21,179
Construction	£1,759	£9,211	£17,910	£1,759	£1,759	£9,211	£1,759
Design, Contingecy	£320	£2,175	£4,222	£0	£320	£2,175	£0
Annual Amoritized Cost	£2,992	£1,713	£1,966	£2,963	£2,066	£1,482	£2,038
O & M	£171	£228	£228	£0	£114	£171	£0
Total Annual Cost	**£3,162**	**£1,941**	**£2,194**	**£2,963**	**£2,180**	**£1,652**	**£2,038**

Now that we have per space parking cost estimates and parking supply information, we can estimate total parking costs. We assumed the supply in Central London for all spaces is 50 percent below-ground structures and 50 percent above-ground structures. For Inner London, we assumed the supply is 10 percent below-ground, 50 percent above-ground, and 40 percent surface. For Outer London, we assumed the supply is 20 percent above-ground and 80 percent surface. Note that because we did not have land value data specific to Central London, we used our cost estimates for Inner London when computing parking costs in Central London.

Our results are presented in Table 4.15. In total, about £7.9 billion was spent on parking in FY 2004-05.

Table 4.15 – Total Parking Costs (in millions)

	Public Off-Street	Private Non-Residential		Private Residential	Total
		Employee	Other		
Central Area	£59.9	£95.1	£14.5	£165.4	**£334.9**
Rest of Inner London	£54.0	£287.2	£81.0	£923.0	**£1,345.2**
Outer London Boroughs	£369.2	£819.3	£367.2	£4,636.1	**£6,191.8**
Total	**£483.2**	**£1,201.6**	**£462.6**	**£5,724.4**	**£7,871.8**

In total, combining TfL's automobile-related expenditures, private automobile expenditures, and parking expenditures, we reach a total of £20.86 billion in private automobile spending in FY 2004-05. See Table 4.16 for additional detail.

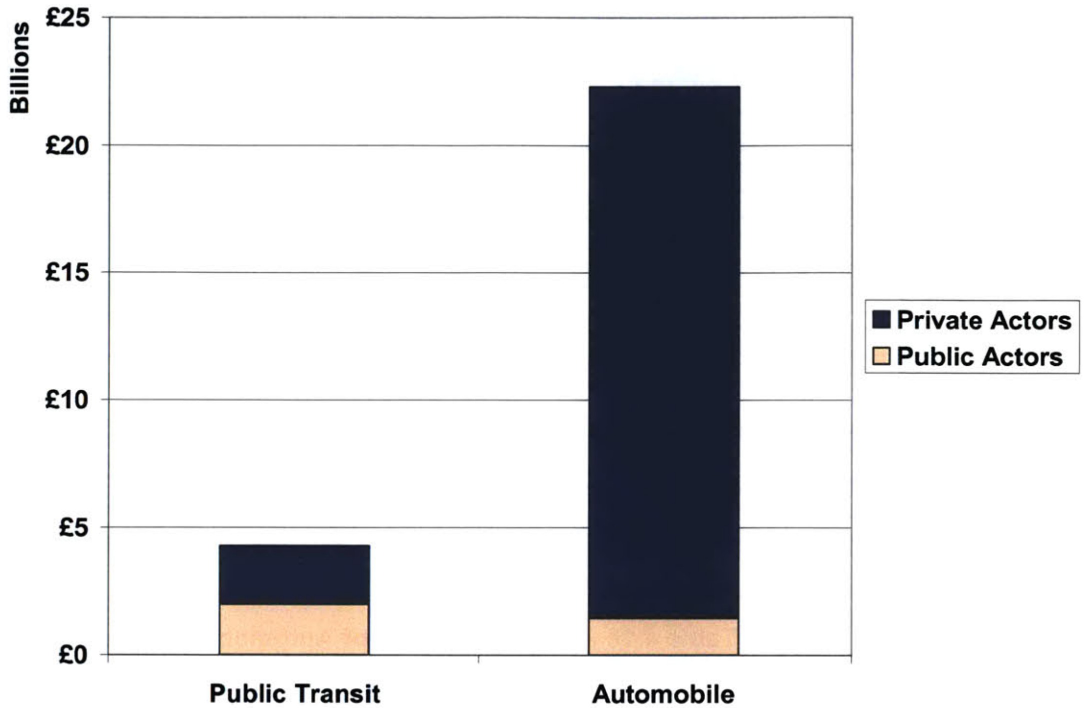
Table 4.16 – Private Sources of Automobile Spending

Description	Amount
Transport for London	£275
Automobile Fixed Costs	£9,262
Automobile Variable Costs	£3,447
Parking	£7,872
Total	**£20,855**

4.2.3. Funding Summary

In summary, about £22.3 billion was spent on automobiles and £4.3 billion was spent on TfL's public transportation services in FY 2004-05. Within automobiles, approximately 93.5% of spending originated from private sources whereas for Transport for London, approximately 53.6% of spending originated from private sources. Figure 4.4 illustrates the public vs. private distinction.

Figure 4.4 – Modal Spending by Public and Private Actors in FY 2004-05



4.3. TRANSPORT EXPENDITURES

In this section, an overview of both Transport for London expenditures and automobile-related expenditures is provided and an analysis comparing local vs. non-local spending for each mode is performed.

4.3.1. Transport for London's Public Transport Expenditures

In the Section 4.2.1., we determined that TfL received £2.0 billion in funding from public sources and £2.1 billion in funding from private sources for public transportation services in FY 2004-05. How were these resources spent? Before answering that question, we must remember the funding from private businesses – £93 million – that was not included in Section 4.2.1. but are included in our analysis of expenditures.

The vast majority of TfL's spending public transport went toward operations, although this figure is misleading as PPP payments for the maintenance and refurbishment of the London Underground are characterized as operational rather than capital expenditures.

Table 4.17 lists all operational expenditures for TfL on public transport services in FY 2004-05.[29] This represented 93.8 percent of TfL's overall expenditures on public transportation.

Table 4.17 – TfL's FY 2004-05 Public Transport Operational Expenditures (in millions)

Expenditures	Amount	Percent
LU - Operations	£590	14.4%
LU - Programmes	£1,423	34.7%
LU - Central Services	£140	3.4%
Surface - Bus Network	£1,291	31.5%
Surface - Other London Buses	£112	2.7%
Surface - Transport Policing & Equipment	£106	2.6%
Surface - Other	£96	2.3%
Rail - DLR	£71	1.7%
Rail - London Rail Core	£42	1.0%
Group Directorates	£232	5.7%
Total	**£4,103**	**100.0%**

The vast majority of TfL's operation expenditures, about 80 percent, were for Underground operations, bus operations, and PPP payments (LU – Programmes).

On the capital expenditure front, TfL spent in net a total of £273 million in FY 2004-05.[30] Table 4.18 lists all capital expenditures.

Table 4.18 – TfL's FY 2004-05 Public Transport Capital Expenditures (in millions)

Expenditures	Amount	Percent
TfL - LU - Operations	£35	12.8%
TfL - LU - Programmes	£251	91.9%
TfL - LU - Central Services	£2	0.7%
TfL - Surface - London Buses	£22	8.1%
TfL - Surface - Transport Policing & Equipment	£4	1.5%
TfL - Surface - Other	£41	15.0%
TfL - Rail - DLR	£16	5.9%
TfL - Group Directorates	£26	9.5%
TfL - Capital Receipts	-£124	-45.4%
Total	**£273**	**100.0%**

29 "Transport for London - Q4 FY 2004-05 Finance and Performance Report."

30 "Transport for London - Q4 FY 2004-05 Finance and Performance Report."

4.3.2. Automobile Expenditures

Public Agency Expenditures

Of the agencies identified in Section 4.2.2., precise spending data was only available for TfL. Table 4.19 lists TfL's automobile-related expenditures in FY 2004-05.[31]

Table 4.19 – TfL's FY 2004-05 Automobile-Related Expenditures

Expenditures	Amount	Percent
Operations - Congestion Charging	£103	19.8%
Operations - Street Management	£194	37.3%
Operations - Traffic Operations	£38	7.3%
Operations - Road Network Performance	£23	4.4%
Capital - Street Management	£91	17.5%
Capital - Director of Traffic Operations	£15	2.9%
Capital - Road Network Performance	£56	10.8%
Total	**£520**	**100.0%**

Detailed London-specific spending data from the UK Highways Agency was not available nor was detailed spending data readily available from the 32 London Boroughs and the City of London.

Private Expenditures

As mentioned previously, £12.71 billion was calculated as the amount spent by private individuals on automobiles in 2004-05 in London. Using cost allocation estimates provided by the AA Motoring Trust, an automobile-fleet model developed using data from the SSMT, and vehicle use data from the London Travel Report, we can specifically determine how the £12.71 billion was spent. Table 4.20 contains this specific listing of all private automobile expenditures for each combination of initial purchase price and engine type.

31 "Transport for London - Q4 FY 2004-05 Finance and Performance Report."

Table 4.20 – Private Automobile Expenses (in millions)

	Purchase price of the car when new: Up to £10,000	£10,000 to £13,000	£13,000 to £20,000	£20,000 to £30,000	Over £30,000	Total	Percent
Petrol Car Expenses							
Road Tax	£4	£65	£164	£60	£14	**£307**	**3.1%**
Insurance	£12	£186	£551	£277	£88	**£1,115**	**11.2%**
Cost of capital	£8	£171	£544	£290	£111	**£1,124**	**11.3%**
Depreciation	£33	£730	£2,242	£1,157	£474	**£4,636**	**46.6%**
Petrol	£20	£320	£934	£387	£108	**£1,769**	**17.8%**
Tires	£2	£33	£86	£37	£12	**£170**	**1.7%**
Service labor costs	£7	£95	£220	£93	£25	**£439**	**4.4%**
Replacement parts	£4	£70	£193	£84	£29	**£380**	**3.8%**
Total	**£90**	**£1,670**	**£4,933**	**£2,385**	**£862**	**£9,940**	**100.0%**
Diesel Car Expenses							
Road Tax	£1	£17	£40	£17	£4	**£80**	**2.9%**
Insurance	£4	£55	£163	£82	£26	**£330**	**11.9%**
Cost of capital	£3	£51	£148	£91	£29	**£322**	**11.6%**
Depreciation	£11	£217	£697	£314	£110	**£1,348**	**48.7%**
Petrol	£5	£81	£193	£84	£27	**£391**	**14.1%**
Tires	£1	£9	£24	£10	£3	**£47**	**1.7%**
Service labor costs	£2	£28	£70	£29	£8	**£136**	**4.9%**
Replacement parts	£1	£21	£58	£25	£8	**£113**	**4.1%**
Total	**£27**	**£481**	**£1,393**	**£652**	**£214**	**£2,768**	**100.0%**
Total Car Expenses							
Road Tax	£5	£83	£204	£77	£19	**£387**	**3.0%**
Insurance	£16	£241	£714	£360	£115	**£1,445**	**11.4%**
Cost of capital	£11	£222	£692	£381	£140	**£1,446**	**11.4%**
Depreciation	£44	£947	£2,939	£1,471	£583	**£5,984**	**47.1%**
Petrol	£26	£401	£1,127	£471	£134	**£2,160**	**17.0%**
Tires	£2	£42	£110	£48	£15	**£217**	**1.7%**
Service labor costs	£9	£123	£290	£121	£33	**£576**	**4.5%**
Replacement parts	£5	£91	£250	£109	£37	**£493**	**3.9%**
Total	**£118**	**£2,152**	**£6,326**	**£3,037**	**£1,076**	**£12,708**	**100.0%**

Key findings from the data presented in Table 4.20 include the following:

- About 73 percent of the cost of an automobile is fixed. The cost of the vehicle (56.9 percent), insurance (11.1 percent), and road taxes (3.0 percent) collectively totaled almost £9.3 billion in FY 2004-05.
- The most significant component of variable expenditures is petroleum (17.0 percent of total expenditures and 62.7 percent of variable expenditures).

For parking expenditures, as presented in Table 4.15, about £7.9 billion was spent in FY 2004-05. These expenditures break down into three categories – construction expenditures totaled £1.7 billion, operating expenditures totaled £0.5 billion, and land expenditures totaled £5.6 billion.

4.3.3. Local vs. Non-Local Spending

From the set of expenditures presented above, we can estimate local and non-local spending for each mode. To compute this calculation, we rely on existing literature. A short review of the literature is provided below before we present our local and non-local results.

Literature Review

Kennedy, whose research[32] was mentioned in Chapter 2, also measured expenditures external to the local economy for each mode. He included the value of automobile production in the Toronto area, incorporated costs of goods sold data for various automobile related businesses, assumed that automobile maintenance, road construction, vehicle taxes, and insurance all remained internal to the Toronto economy, and made a similar set of assumptions and calculations for public transportation. In 1996, Kennedy calculated that the external cost of the automobile was $0.24 per person-kilometer and $0.07 per person-kilometer for public transportation. In 1991, Kennedy calculated that the external cost of the automobile was $0.20 per person-kilometer and $0.03 per person-kilometer for public transportation. Kennedy concluded that it costs the Toronto region as a whole about three to six times more to transport residents using automobiles than public transportation.

Miller, Robinson, and Lahr[33] identified that there was a lack of research comparing the automobile and public transportation that included direct vehicle ownership and operating costs, while there was an abundance of modal comparisons that included total social costs but neglected the more mundane direct costs. To correct for this shortcoming, Miller, Robinson, and Lahr constructed a model for Bexar County in Texas (San Antonio) that calculated expenditure leakages out of the local economy for each transportation mode and local employment and economic activity multipliers associated with increased

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32 Kennedy, "A comparison of the sustainability of public and private transportation systems."

33 Miller, Robison, and Lahr, *Estimating Important Transportation-Related Regional Economic Relationships in Bexar County, Texas.*

spending in a mode or modal shifts. Underpinning this model was an extensive regional input-output model. For a one percent modal shift from the automobile to the bus, the authors calculated the following:

- Roughly $14 million less spent on auto-related goods and services; $4.5 million more spent on bus operating expenditures; $5.9 million in added transit capital expenditures; and $3.5 in additional general consumption expenditures

- Net increase in regional value added, a measure of regional income, of $2.9 million

- A regional gain of 226 jobs

Furthermore the authors measured changes associated with a $1 million shift in spending from the automobile to the bus. For every million dollars of reduced auto expenditures, Bexar County loses approximately $307 thousand in regional income and 8.4 jobs. This same million spent on bus operations will generate nearly $1.2 million in regional income and 62.2 jobs. The difference reflects the fact that auto expenditures tend to leak out of Bexar County more than bus expenditures do, however, the authors did not quantify local versus non-local spending.

In summary, Kennedy's approach of estimating local versus non-local expenditures by analyzing the nature of costs and making relevant assumptions has the advantage of being straight-forward to calculate and possible to replicate for transport expenditures in London. While Miller, Robinson, and Lahr's work is methodologically superior in analyzing economic linkages based on modal spending, the lack of a readily available input-output table for the London region prohibits that sort of analysis to be included in the scope of our work.

Our Analysis

Because of the unavailability of detailed expenditure data, especially for public agencies, a robust local versus non-local spending comparison between public transit and the automobile was not possible. However, through using estimates of local spending from other research, we are able to roughly determine the portion of spending within each mode that stayed local within the London economy.

Kennedy's analysis of costs in Toronto (see Chapter 2) analyzed transportation costs on a local and non-local dimension. In general, the following assumptions, based on Kennedy's work, were used in our analysis:

- Operations and maintenance expenditures on each mode were assumed to be 90 percent local.
- Capital expenditures for public transit were assumed to be 50 percent local while for the automobile, they were assumed to be 60 percent local.
- All taxes, insurance, labor, parking, and financing costs were assumed to be 100 percent local.
- Given that there is no automobile production in London, only the difference between the sale price and cost of goods sold from wholesalers to dealers and dealers to customers were considered to be London. Based on Kennedy's work in Toronto, we estimate 30 percent of all vehicle purchases are local expenditures.
- For petroleum, fuel taxes and the gap between sales price and cost of goods sold were considered local, resulting in assuming 60 percent of petroleum expenditures were local. A portion of the 40 percent that is non-local does stay within the UK given oil production in the North Sea; however, we assume that this oil would be sold on the world market regardless and use the 60 percent figure.
- Consistent with Kennedy's estimates, 60 percent of the amount spent on vehicle parts is assumed to be local. This percentage factors in profits for local retailers and wholesalers.
- Land costs for parking were assumed to be 100 percent local, operating and maintenance were assumed to be 90 percent local, and construction was assumed to be 50 percent local.

Tables 4.15 and 4.16 provide a listing of local and non-local spending for each mode. Based on the assumptions described above, we estimate that about 70.2 percent of automobile spending is local and 87.5 percent of public transit spending is local.

Table 4.21 – Automobile Local/Non-Local Expenditures (in millions)

Auto Expenditures	Total	Percent Local	Amount Local
Public Expenditures			
TfL Operations - Congestion Charging	£103	90%	£93
TfL Operations - Street Management	£194	90%	£175
TfL Operations - Traffic Operations	£38	90%	£34
TfL Operations - Road Network Performance	£23	90%	£21
TfL Capital - Street Management	£91	60%	£55
TfL Capital - Director of Traffic Operations	£15	60%	£9
TfL Capital - Road Network Performance	£56	60%	£34
London Boroughs	£1,036	75%	£777
UK Highways Agency	£169	75%	£126
Private Expenditures			
Road Tax	£387	100%	£387
Insurance	£1,445	100%	£1,445
Cost of capital	£1,446	100%	£1,446
Depreciation	£5,984	30%	£1,795
Petrol	£2,160	60%	£1,296
Tires	£217	60%	£130
Service labor costs	£576	100%	£576
Replacement parts	£493	60%	£296
Parking Construction	£1,711	50%	£856
Parking Operation and Maintenance	£523	90%	£471
Parking Land	£5,638	100%	£5,638

Total Expenditures	£22,305
Local Expenditures	£15,658
Percent Local	70.2%

Table 4.22 – Public Transit Local/Non-Local Expenditures (in millions)

	Amount	Percent Local	Amount Local
TfL Operations			
LU - Operations	£590	90%	£531
LU - Programmes	£1,423	90%	£1,281
LU - Central Services	£140	90%	£126
Surface - Bus Network	£1,291	90%	£1,162
Surface - Other London Buses	£112	90%	£101
Surface - Transport Policing & Equipment	£106	90%	£95
Surface - Other	£96	90%	£86
Rail - DLR	£71	90%	£64
Rail - London Rail Core	£42	90%	£38
Group Directorates	£232	90%	£209
TfL Capital			
TfL - LU - Operations	£35	50%	£18
TfL - LU - Programmes	£251	50%	£126
TfL - LU - Central Services	£2	50%	£1
TfL - Surface - London Buses	£22	50%	£11
TfL - Surface - Transport Policing & Equipment	£4	50%	£2
TfL - Surface - Other	£41	50%	£21
TfL - Rail - DLR	£16	50%	£8
TfL - Group Directorates	£26	50%	£13
TfL - Capital Receipts	-£124	50%	-£62

Total Expenditures	£4,376
Local Expenditures	£3,829
Percent Local	87.5%

4.4. MODAL USAGE STATISTICS

Simply comparing aggregate costs is not a fair comparison between modes. The magnitude of use for each mode must be considered in order to normalize costs. By dividing costs by the total number of trip and the total passenger-kilometers, we can compare public transit and the automobile on a fair basis.

The London Travel Report provides many of these modal usage statistics. Table 4.23 provides information on the daily number of journeys on all transport modes in London since 1993. Table 4.24 provides information on the number of passenger kilometers for each mode since FY 1993-94. Table 4.25 provides information for numbers used in our analysis for each mode.

Table 4.23 – Daily Number of Journeys (in millions)

Year	Rail	Underground	DLR	Tramlink	Bus	Taxi	Car	Motorcycle	Bicycle	Walk	All modes
1993	1.44	2.01	-		3.07	0.23	10.50	0.16	0.29	5.16	**22.87**
1994	1.42	2.07	-		3.14	0.23	10.62	0.17	0.29	5.18	**23.15**
1995	1.45	2.14	-		3.26	0.23	10.59	0.16	0.29	5.21	**23.38**
1996	1.52	2.13	-		3.37	0.23	10.71	0.17	0.29	5.24	**23.70**
1997	1.61	2.25	0.06		3.48	0.23	10.78	0.19	0.29	5.27	**24.14**
1998	1.69	2.36	0.07		3.49	0.23	10.84	0.19	0.29	5.31	**24.47**
1999	1.77	2.50	0.08		3.53	0.23	11.05	0.20	0.29	5.38	**25.03**
2000	1.83	2.64	0.10		3.68	0.23	11.00	0.20	0.30	5.43	**25.41**
2001	1.85	2.63	0.11	0.05	3.88	0.23	11.03	0.21	0.33	5.52	**25.77**
2002	1.87	2.60	0.12	0.05	4.14	0.23	11.12	0.20	0.33	5.55	**26.15**
2003	1.93	2.60	0.13	0.05	4.56	0.23	11.05	0.21	0.35	5.60	**26.66**
2004	1.92	2.69	0.14	0.06	4.93	0.23	10.97	0.20	0.37	5.64	**27.07**
2005	2.03	2.65	0.14	0.06	4.94	0.24	10.92	0.20	0.43	5.69	**27.24**

Table 4.24 – Annual Passenger-Kilometers (in millions)

Year	Underground	DLR	Bus	Tramlink	Total Public Transit	Motor
1993/94	5,814	39	3,819		9,672	39,926
1994/95	6,051	55	3,912		10,018	40,479
1995/96	6,337	70	4,018		10,425	40,509
1996/97	6,153	86	4,159		10,398	40,899
1997/98	6,479	110	4,350		10,939	41,204
1998/99	6,716	139	4,315		11,170	41,466
1999/00	7,171	152	4,429		11,752	42,502
2000/01	7,470	195	4,709		12,374	42,427
2001/02	7,451	207	5,128	97	12,883	42,487
2002/03	7,367	232	5,734	100	13,433	42,628
2003/04	7,340	235	6,431	103	14,109	42,662
2004/05	7,606	243	6,755	113	14,717	42,474
2005/06	7,586	257	6,653	117	14,613	42,461

Table 4.25 – FY 2004-05 Modal Usage Statistics

Usage Statistic	Underground	DLR	Bus	Tramlink	Total Public Transit	Automobile
Annual Journeys (millions)	981	50	1,798	22	2,851	4,004
Annual Passenger-kms (millions)	7,606	243	6,755	113	14,717	39,218
Average Journey Distance (km)	7.8	4.9	3.8	5.2	5.2	9.8

The reason for the discrepancy between the annual passenger kilometers for the automobile in Table 4.19 and the annual passenger-kilometers in the motor column in Table 4.18 is that certain classes of vehicles (such as trucks and motorcycles) were not included in Table 4.19.

4.5. COMPARISON

Table 4.1 at the beginning of the chapter provides an overall direct cost comparison between transport services provided by TfL and the automobile. From the methodology in this chapter, we calculated that it cost the London region £5.57 per automobile journey and £1.50 per journey on TfL services. In terms of passenger-kilometers, it cost £0.57 per automobile passenger kilometer and £0.29 per TfL passenger kilometer.[34] Other points of interest include the following:

- Six percent of automobile costs were public and 94 percent were private while 46 percent of public transportation costs were public and 54 percent were private.
- Seventy percent of automobile costs were internal to the local economy while 88 percent of public transportation costs were internal to the local economy.

4.6. Conclusion

In this chapter, we financially compared the automobile and public transportation services provided by Transport for London in FY 2004-05. While public costs on public transportation are relatively high compared to the public costs on the automobile, when we include private costs of both modes, we see that overall public transportation is the more cost-efficient mode. But this comparison only provided insights at an aggregate level and did not consider the spatial distribution of trips within London. It also did not include time costs. What happens when we consider the spatial distribution of trips within London and when we add time costs? How do to the two modes compare then? In the next chapter, by marrying cost data from this chapter with actual trip-level data, we will attempt to address these questions.

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[34] The closer comparison on a per distance basis than on a per journey basis reflects both the greater distance on automobile journeys and an occupancy rate of greater than one per automobile.

5. GEOGRAPHIC ANALYSIS AND TIME COSTS

5.1. INTRODUCTION

In order to accurately compare public transportation and the automobile, we must include time costs in addition to direct costs. Time costs are likely to be higher for public transportation than the automobile and given this difference, they must be included in a financial comparison. Data limitations precluded us from including time costs in the aggregate comparison in Chapter 4 but through data from the London Area Travel Survey (LATS)[35], we are able to include them in this chapter. The LATS also allows us to perform a disaggregate comparison, as we can assign the aggregate costs presented in Chapter 4 to individual trips.

Intuitively, we would expect the attractiveness (or total travel costs) of a trip to vary by the nature of the trip – for an outer London to outer London trip, the automobile can be expected to be more attractive than public transit as the trip time would likely be significantly less. However, for an inner London to inner London trip, public transit can be expected to be more attractive than the automobile given severe roadway congestion and an extensive public transit network that decreases the time advantage of the automobile in inner London. Given this expected variation, we segmented LATS data by the origin and destination's travel zone (Zones 1 through 6, with Zone 1 containing central London and Zone 6 being the outermost ring). Before diving into the results of our disaggregate analysis, we first present the methodology employed and data sources used.

5.2. METHODOLOGY

Given the long-term time horizon on which our research is focused, we are not comparing the marginal costs (fares, travel time, gas, etc.) an individual incurs for a trip, but rather we are comparing all the fixed costs of that trip, everything from vehicle

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[35] "London Area Travel Survey - 2001."

ownership costs to the fixed costs of a public transportation system, including expenses from both public and private actors. More specifically, the formulas we use in our analysis are shown in Figures 5.1 and 5.2 below:

Figure 5.1 – Automobile Travel Cost Formula

$$\text{Trip Travel Cost} = \frac{\text{Automobile Ownership Cost}}{\text{Trip}} + \text{Automobile Use Cost} + \frac{\text{Public Automobile Expenditures}}{\text{Trip}} + \text{Parking Cost} + \text{Travel Time Cost}$$

Figure 5.2 – Public Transit Travel Cost Formula

$$\text{Trip Travel Cost} = \frac{\text{Public: Public Transit Expenditures}}{\text{Trip}} + \text{Fare Paid} + \text{Travel Time Cost}$$

5.2.1. Explanation of Terms

The following section consists of explanations of how each term in Figures 5.1 and 5.2 is calculated.

Automobile Ownership Cost / Trip

As described in Chapter 4, information sources on private automobile costs included the Society of Motor Manufacturers and Traders (SMMT), the AA Motoring Trust, and the London Travel Report. From the SMMT, a distribution of vehicles by initial purchase price was constructed.[36] From the AA Motoring Trust, cost information tabulated by initial purchase price was provided.[37] In order to determine an automobile ownership cost per trip, we weighted cost information from the AA Motoring Trust by the vehicular distribution from the SMMT. This resulted in an expected annual ownership cost for an automobile of £3,745. In order to arrive at a cost per trip, we divided the ownership cost

36 "Motor Industry Facts - 2006."

37 "The Cost of Motoring - 2005."

by the average number of trips per automobile in a year. The average number of trips per automobile per year was calculated to be 1,619 from data in the London Travel Report.[38] Dividing the ownership cost by the number of trips resulted in a £2.31 cost to be assigned to each automobile trip.

Automobile Use Cost for Trip

Using the same methodology and data sources as above resulted in an expected per kilometer cost of £0.32 for automobile use (e.g., gasoline and maintenance). This amount was multiplied by the trip distance to calculate an automobile use cost for each trip.

Public Automobile Expenditures / Trip

This term accounts for public automobile expenditures on a trip basis. Using data sources described in Chapter 4 and dividing by the total number of automobile trips in a year in London, public automobile expenditures were calculated to be £0.36 per trip.

Parking Cost for Trip

Parking costs were treated two different ways. In one set of calculations, we discarded parking cost data that was presented in Chapter 4 and used the self-reported parking cost in the LATS. In the other set of calculations, we divided the total parking cost from Chapter 4 by the total number of automobile trips and applied a uniform parking cost to each trip.[39] This was computed to be £1.97. Results are presented for both sets of parking numbers.

Public: Public Transit Expenditures / Trip

This term measures public transit expenditures by public actors on a trip basis and was calculated to be £0.71.

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[38] "London Travel Report."

[39] A uniform parking rate is justified as the higher construction costs of parking in Central London are roughly equivalent to the land savings in Central London as parking there is less reliant on surface lots.

Fare Paid by User

Using a TfL 2005 fare table and accounting for pass discounts and peak period differential pricing, a fare table for all zonal combinations was computed. Table 5.1 contains all public transportation fares used. Fares for different zones are only applicable for Underground trips as buses operate on a flat fare regime.

Table 5.1 – Transport for London Fare Table

Trip Type	Fare
Bus Fare	£0.80
Zone 1-1	£1.20
Zone 1-2	£1.48
Zone 1-3	£1.88
Zone 1-4	£1.88
Zone 1-5	£2.44
Zone 1-6	£2.44
Intra-zone (non Zone 1)	£0.80
Zone 2-3	£0.80
Zone 3-4	£0.80
Zone 4-5	£0.80
Zone 5-6	£0.80
Zone 2-4	£1.25
Zone 2-5	£1.25
Zone 2-6	£1.25
Zone 3-5	£1.25
Zone 3-6	£1.25
Zone 4-6	£1.25

Travel Time Cost for Trip

Travel time is a self-reported measure in the LATS. Assuming a value of time that is equal to about two-thirds the average wage of in London[40] – £10 per hour – we are able to calculate a travel time cost for each trip.

5.2.2. London Area Travel Survey

Description

The LATS contains a sampling of trips for a typical weekday in Greater London and is typically conducted every 10 years. Analysis in this thesis uses the most recently

40 *Guardian Unlimited, "Londoners 'Wealthiest in UK'."*

available LATS, the 2001 version. In that version, a total of 176,447 trips were recorded. Relevant to this research, measures included in LATS includes the following:

- **Travel Mode** – Self-reported measure of the primary mode of travel used for the trip (e.g. automobile driver, automobile passenger, bus, underground, national rail, walking, cycling, and etc.)
- **Origin Fare Zone** – Fare zone (Zones 1 through 6) of the trip's origin
- **Destination Fare Zone** - Fare zone (Zones 1 through 6) of the trip's destination
- **Trip Duration** – Self-reported measure of the time duration of the trip
- **Trip Length** – Distance automatically calculated based on origin and destination of trip
- **Trip Speed** – Trip length divided by trip duration
- **Trip Parking Cost** – Self-reported measure of the parking cost, if any, for the trip

Process of Filtering the LATS

Given the self-reported nature of the LATS, many trip records exist that do not accurately reflect reality. In addition, there are a set of trips that are beyond the scope of this thesis. Combined, these two facts necessitate a process of filtering the LATS to include only trips relevant to this thesis that have reliable data. To achieve this goal, the following rules were used to filter the LATS:

- **Analyze only trips of relevant modes** – To achieve this objective, a trip whose primary mode was not the automobile, bus, or underground was eliminated. This eliminated about 51,000 walking trips, 13,000 cycling trips, 8,000 National Rail trips, and 2,000 taxi trips, resulting in a total of about 102,000 trips. However, trips on these modes are not strictly beyond the scope of this research as there are interactions between these modes and the automobile and public transit. In particular, as will be presented in the next chapter in Section 6.6., a significant relationship exists between public transport accessibility and walking trips – as public transport accessibility improves, the share of walking trips increase. By not including walking trips in our comparison between the automobile and public transit, we are potentially neglecting a significant benefit of public transit.

- **Remove trips of unreasonable speeds** – Given the self-reported nature of the LATS, many trips have extraordinary travel speeds, ranging from 0.0004 kilometers per hour to 5280.8 kilometers per hour. To compensate for reporting errors, only trips with travel speeds of between 1.0 and 150.0 kilometers per hour were included. This eliminated about 1,000 trips.

- **Only include trips within London –** Given the geographic scope of Transport for London services, including trips beyond Zone 6 has limited comparison value. Removing any trip that originated or terminated outside Zone 6 reduced the number of trips to be analyzed by about 10,000, resulting in about 91,000 total trips.

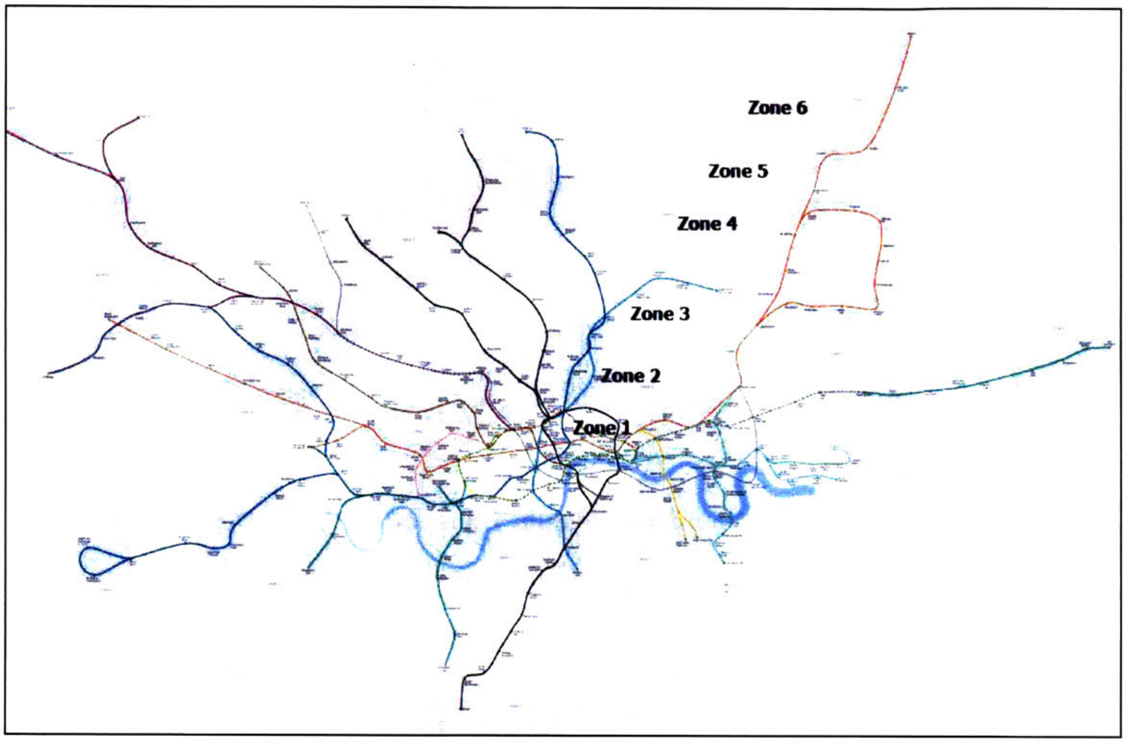
5.2.3. Categorizing Trips

As a proxy for measuring trip types by origin and destination locations, the fare zone system in London was used. There are a total of six zones in London. Zone 1 contains central London with each zone concentrically expanding around Zone 1. Figure 5.3 is a map of the London Underground that illustrates the zonal system.

Instead of running the trip cost analysis for all 21 zonal combinations, Zones 4, 5, and 6 were grouped as one zone, as in these outer areas of London, land use patterns are fairly similar to each other. This reduced the number of zonal combinations to ten. Zone 1 consists of the core of London and contains the majority of London's iconic sites and destinations. It has relatively high densities, high marginal parking expenses, and easily available public transport in all areas. Zone 2 surrounds Zone 1 and still is very urban in nature. While not as ubiquitous as Zone 1, most areas in Zone 2 enjoy quality public transport accessibility. As we move out to Zone 3, only certain areas enjoy quality public transport accessibility and densities are lower than Zones 1 and 2. Zones 4, 5, and 6 enjoy fewer areas of quality public transport accessibility and most areas within these zones are very suburban and automobile-oriented.

Through the use of zones, we have a simple proxy for trip types. Trips within the first three zones are urban in nature, both at the origin and destination. Trips within the outer three zones are suburban in nature, both at the origin and destination. And trips between the inner three zones and outer three zones have an urban origin or destination and a suburban destination or origin.

Figure 5.3 – London Travel Zone Map



From the LATS, we can estimate the distribution of trips between zones. Figure 5.4 depicts automobile trips while Figure 5.5 depicts public transportation trips.

Figure 5.4 – Automobile Trip Distribution

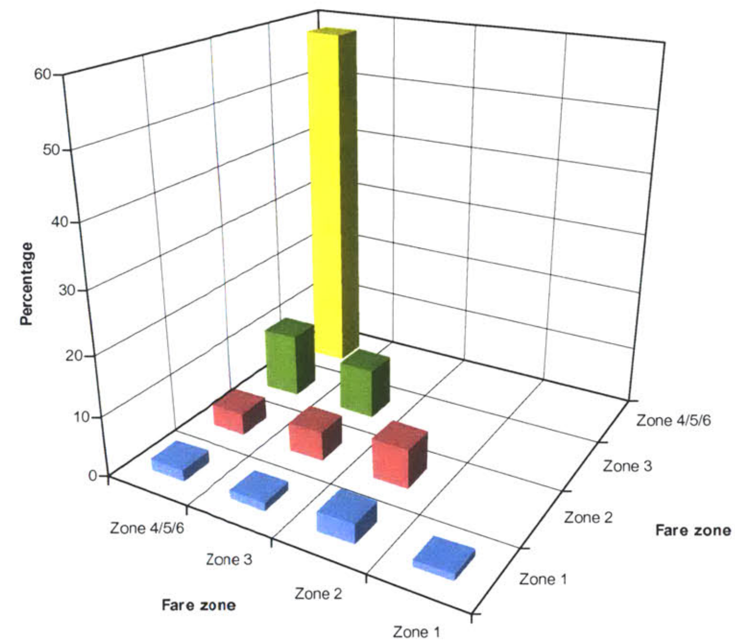
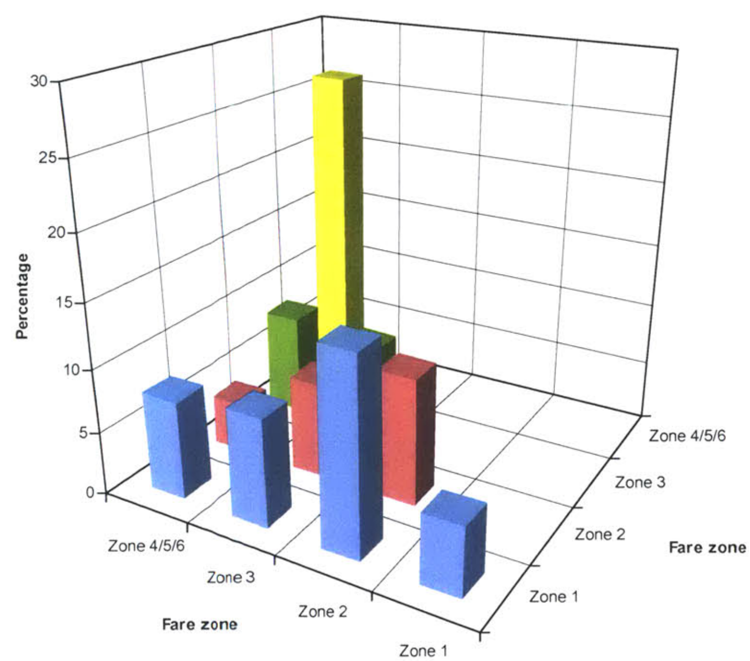


Figure 5.5 – Public Transportation Trip Distribution



5.2.4. Limitations to Methodology

The methodology explained above is not without its limitations. Limitations include the following:

- **Ascribing fixed costs on a trip basis** – The methodology in this analysis assumes that all fixed costs are shared equally by all trips on that mode or vehicle. Given that trips have differing lengths and require different infrastructure components, this is not an accurate assumption. For example, an automobile user might have a long trip that uses a newly built or renovated roadway but the fixed cost component of the trip, both the ownership cost of the vehicle and the public expenditure, is treated the same as an automobile trip that is two blocks long that uses a roadway built many years ago.

- **Reliance on self-reported data** – For both parking costs and trip duration, the LATS relies on self-reported measures as there simply is no feasible alternative. This distorts the accuracy of the data as individuals are neither going to be perfectly accurately about the time duration of the trip nor are they likely to count parking costs correctly if for example they have a monthly pass or their employer subsidizes their parking spot.

- **Using 2001 trip data** – Much about commuting in London has changed in recent years since the introduction of the Congestion Charge. The Congestion Charge profoundly affects the economics of commuting in many areas of Zone 1. In addition there has been a significant improvement in the bus network as ridership has increased by 42 percent from 2000 to 2005.[41] Unfortunately, the most recent trip-level data is from 2001.

- **Uniform value of time** – It is well accepted that individuals value time differently for different situations (e.g. waiting time is more costly than in-vehicle time). Moreover, different individual have different value of times. Unfortunately, data and time limitations prohibit us from attempting to account for these realities as we are only able to apply a uniform value of time for all trips.

5.3. RESULTS

Table 5.2 summarizes the results of running the equations in Figures 5.1 and 5.2 on each trip using self-reported parking costs. Table 5.3 summarizes results using total parking costs. Please note that each zonal combination includes all trips with that origin-destination pair, regardless of which zone was the origin or the destination.

Table 5.2 – Travel Costs by Zonal Combinations (Self-Reported Parking Costs)

Zonal Combination	Mode	Number of Journeys	Relative Mode Share	Average Journey Length (km)	Travel Cost per KM	Travel Cost per Journey	% Time Cost	% Public Cost	% Private Cost (non-time)
Zone 1 - Zone 1	Automobile	658	29.4%	2.1	£3.07	£6.3	51.2%	5.7%	43.1%
	Public Transit	1,578	70.6%	3.0	£2.43	£7.3	75.7%	9.6%	14.7%
Zone 1 - Zone 2	Automobile	2,007	31.2%	4.2	£1.97	£8.2	55.4%	4.4%	40.2%
	Public Transit	4,430	68.8%	5.1	£1.79	£9.1	79.4%	7.6%	13.0%
Zone 1 - Zone 3	Automobile	893	26.4%	8.8	£1.43	£12.5	58.8%	2.9%	38.3%
	Public Transit	2,491	73.6%	9.1	£1.26	£11.5	79.4%	6.1%	14.5%
Zone 1 - Zone 4-5-6	Automobile	1,262	36.0%	15.6	£1.06	£16.4	54.7%	2.2%	43.1%
	Public Transit	2,248	64.0%	15.7	£0.88	£13.8	80.3%	5.0%	14.7%
Zone 2 - Zone 2	Automobile	4,068	58.2%	2.3	£2.48	£5.8	51.6%	6.2%	42.2%
	Public Transit	2,919	41.8%	3.3	£2.33	£7.6	80.3%	9.2%	10.5%
Zone 2 - Zone 3	Automobile	2,987	57.8%	5.0	£1.97	£8.3	55.2%	4.4%	40.4%
	Public Transit	2,179	42.2%	5.8	£1.60	£9.2	83.8%	7.6%	8.7%
Zone 2 - Zone 4-5-6	Automobile	2,315	66.9%	12.2	£1.15	£14.1	55.8%	2.6%	41.7%
	Public Transit	1,147	33.1%	12.3	£1.06	£13.1	86.2%	5.3%	8.5%
Zone 3 - Zone 3	Automobile	5,106	70.8%	2.3	£2.38	£5.5	49.7%	6.6%	43.7%
	Public Transit	2,106	29.2%	2.9	£2.46	£7.1	78.9%	9.8%	11.3%
Zone 3 - Zone 4-5-6	Automobile	6,586	73.9%	6.5	£1.38	£8.9	53.2%	4.0%	42.8%
	Public Transit	2,326	26.1%	5.8	£1.59	£9.2	83.4%	7.6%	9.0%
Zone 4-5-6 - Zone 4-5-6	Automobile	36,167	82.7%	3.4	£1.74	£5.9	47.3%	6.2%	46.5%
	Public Transit	7,569	17.3%	3.7	£2.01	£7.5	80.0%	9.3%	10.7%

41 "London Travel Report."

Table 5.3 – Travel Costs by Zonal Combinations (Full Parking Costs)

Zonal Combination	Mode	Number of Journeys	Relative Mode Share	Average Journey Length (km)	Travel Cost per KM	Travel Cost per Journey	% Time Cost	% Public Cost	% Private Cost (non-time)
Zone 1 - Zone 1	Automobile	658	29.4%	2.1	£3.85	£7.9	40.8%	4.6%	54.6%
	Public Transit	1,578	70.6%	3.0	£2.43	£7.3	75.7%	9.6%	14.7%
Zone 1 - Zone 2	Automobile	2,007	31.2%	4.2	£2.39	£9.9	45.7%	3.6%	50.6%
	Public Transit	4,430	68.8%	5.1	£1.79	£9.1	79.4%	7.6%	13.0%
Zone 1 - Zone 3	Automobile	893	26.4%	8.8	£1.63	£14.3	51.4%	2.5%	46.0%
	Public Transit	2,491	73.6%	9.1	£1.26	£11.5	79.4%	6.1%	14.5%
Zone 1 - Zone 4-5-6	Automobile	1,262	36.0%	15.6	£1.16	£18.1	49.7%	2.0%	48.3%
	Public Transit	2,248	64.0%	15.7	£0.88	£13.8	80.3%	5.0%	14.7%
Zone 2 - Zone 2	Automobile	4,068	58.2%	2.3	£3.29	£7.7	38.8%	4.7%	56.5%
	Public Transit	2,919	41.8%	3.3	£2.33	£7.6	80.3%	9.2%	10.5%
Zone 2 - Zone 3	Automobile	2,987	57.8%	5.0	£2.05	£10.2	44.9%	3.5%	51.6%
	Public Transit	2,179	42.2%	5.8	£1.60	£9.2	83.8%	7.6%	8.7%
Zone 2 - Zone 4-5-6	Automobile	2,315	66.9%	12.2	£1.30	£16.0	49.2%	2.3%	48.5%
	Public Transit	1,147	33.1%	12.3	£1.06	£13.1	86.2%	5.3%	8.5%
Zone 3 - Zone 3	Automobile	5,106	70.8%	2.3	£3.23	£7.4	36.7%	4.9%	58.4%
	Public Transit	2,106	29.2%	2.9	£2.46	£7.1	78.9%	9.8%	11.3%
Zone 3 - Zone 4-5-6	Automobile	6,586	73.9%	6.5	£1.68	£10.9	43.8%	3.3%	52.9%
	Public Transit	2,326	26.1%	5.8	£1.59	£9.2	83.4%	7.6%	9.0%
Zone 4-5-6 - Zone 4-5-6	Automobile	36,167	82.7%	3.4	£2.31	£7.8	35.5%	4.6%	59.9%
	Public Transit	7,569	17.3%	3.7	£2.01	£7.5	80.0%	9.3%	10.7%

Key findings from this analysis include the following:

- *Self-reported parking costs are only a small portion of total parking costs* – Ranging from 29.9 percent in Zone 1 to 1.1 percent in Zone 4, self-reported parking costs did not come close to covering full parking costs. For a breakdown by destination zone, see Table 5.4.

Table 5.4 – Self-Reported Parking Cost as a Percentage of Full Parking Cost

Destination Zone	Average Self-Reported Parking Cost	% of Total Parking Cost
Zone 1	£0.59	29.9%
Zone 2	£0.09	4.6%
Zone 3	£0.04	2.2%
Zone 4	£0.02	1.1%
Zone 5	£0.04	1.8%
Zone 6	£0.04	2.1%

- *In general, intuition about which mode should exhibit greater cost-efficiency for given type of trip holds* – Using self-reported parking costs, public transportation on a trip basis is more cost-efficient for trips between outer London and inner London. On a distance basis, public transportation is more cost-efficient for all zonal combinations except outer London to outer London. Figures 5.6 and 5.7 shows costs per trip and per kilometer when using self-reported parking costs.

Figure 5.6 – Costs per Trip (Self-Reported Parking Costs)

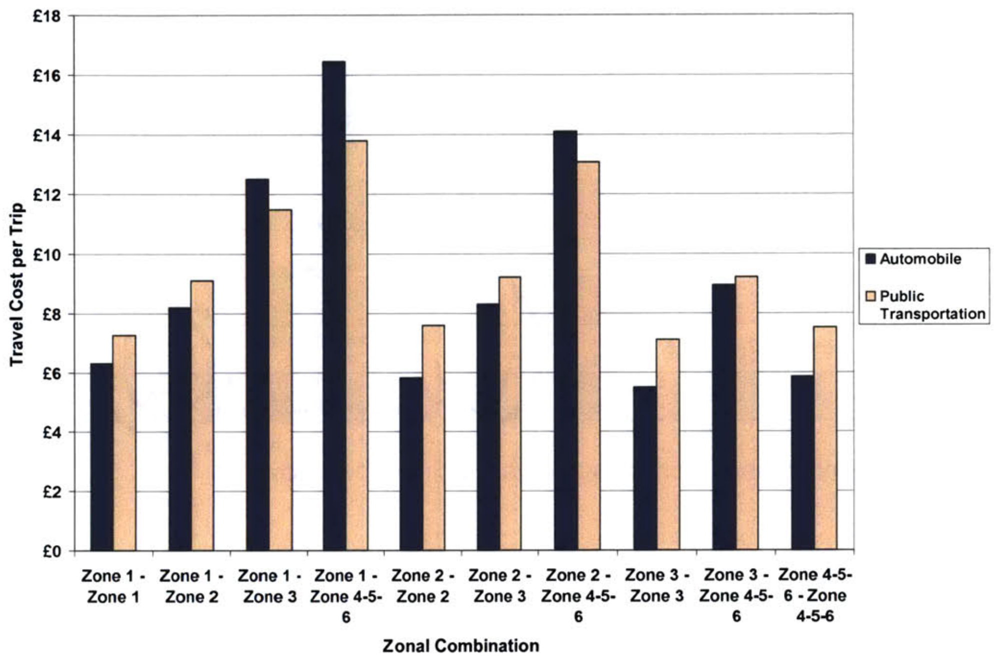
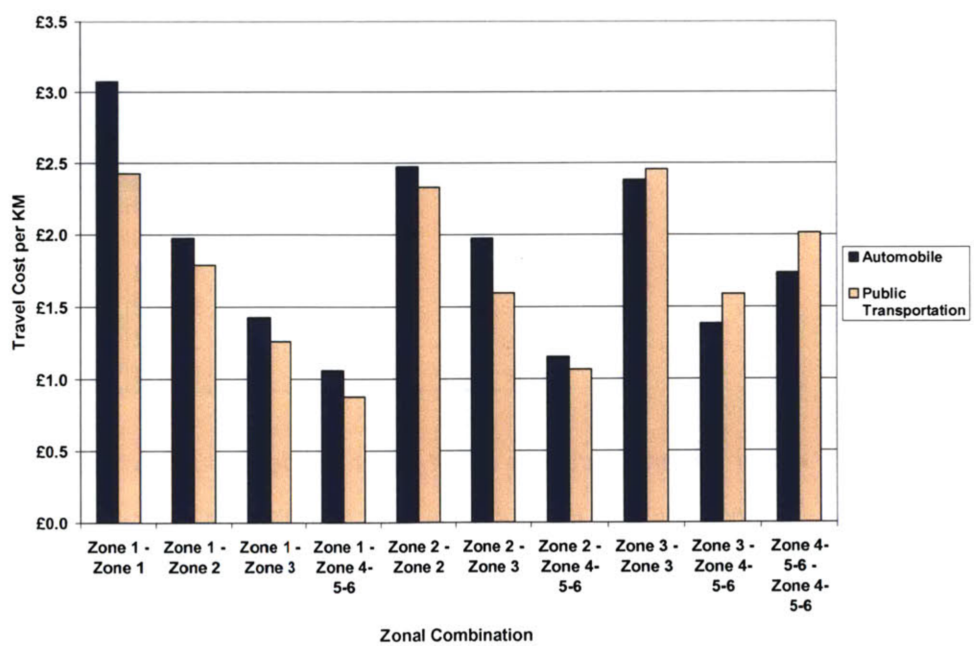


Figure 5.7 – Costs per Kilometer (Self-Reported Parking Costs)



- *When including full parking costs, public transportation has a clear advantage over the automobile* – On a trip basis, public transportation's costs is less than or equal to the cost of the automobile. On a distance basis, public transportation has a clear advantage for all zonal combinations. Figures 5.8 and 5.9 shows costs per trip and per kilometer when using full parking costs.

Figure 5.8 – Costs per Trip (Full Parking Costs)

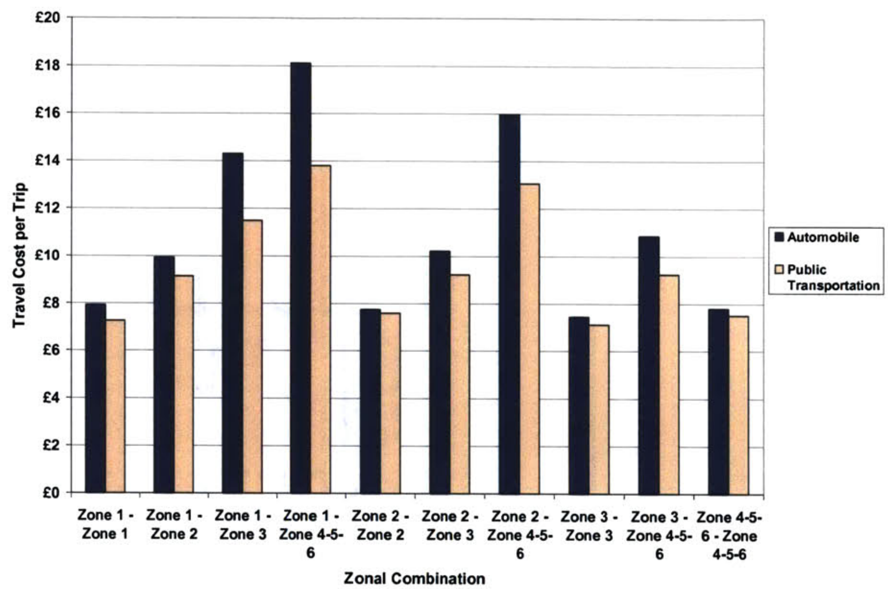
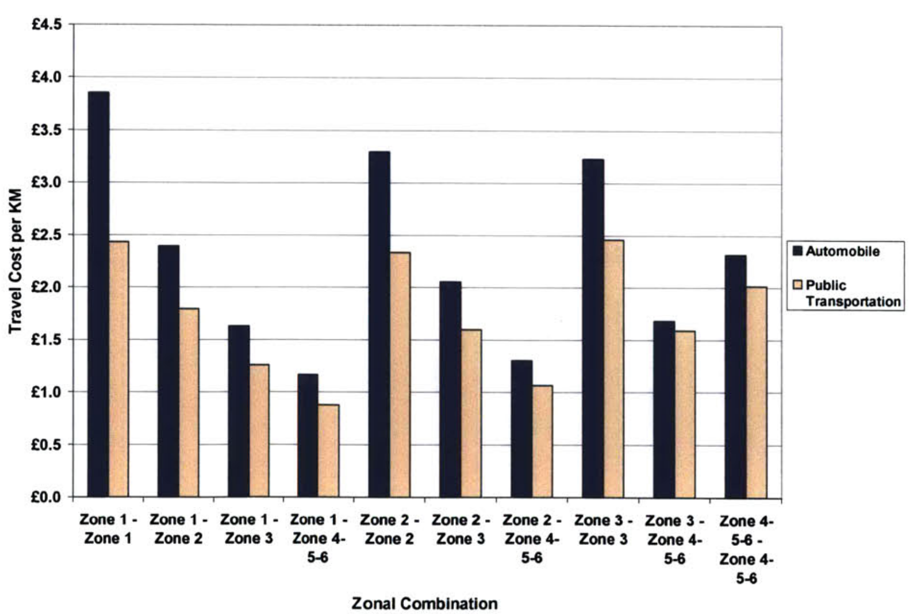
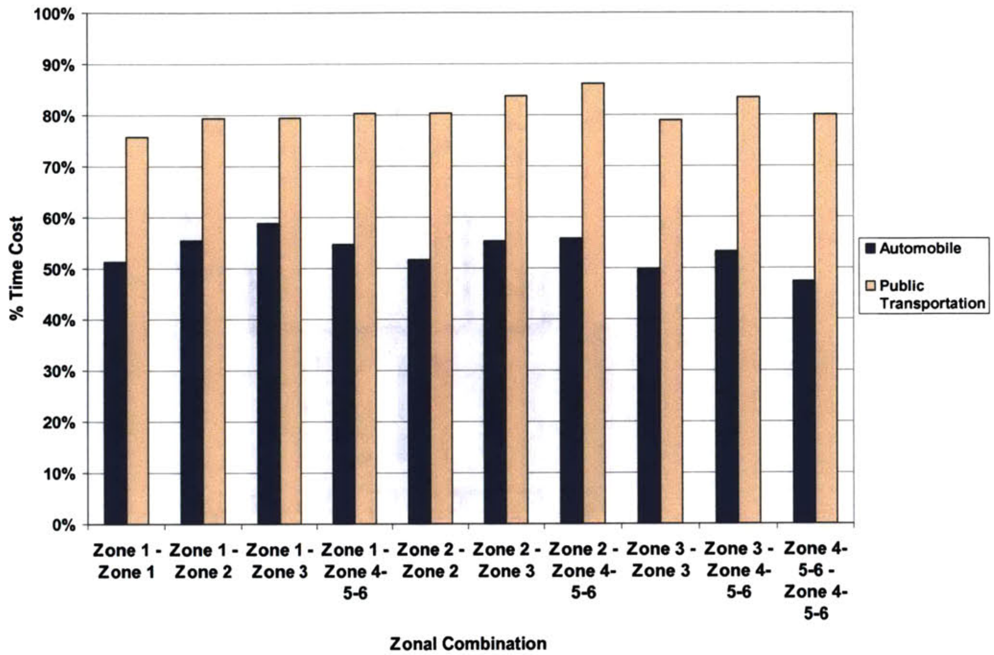


Figure 5.9 – Costs per Kilometer (Full Parking Costs)



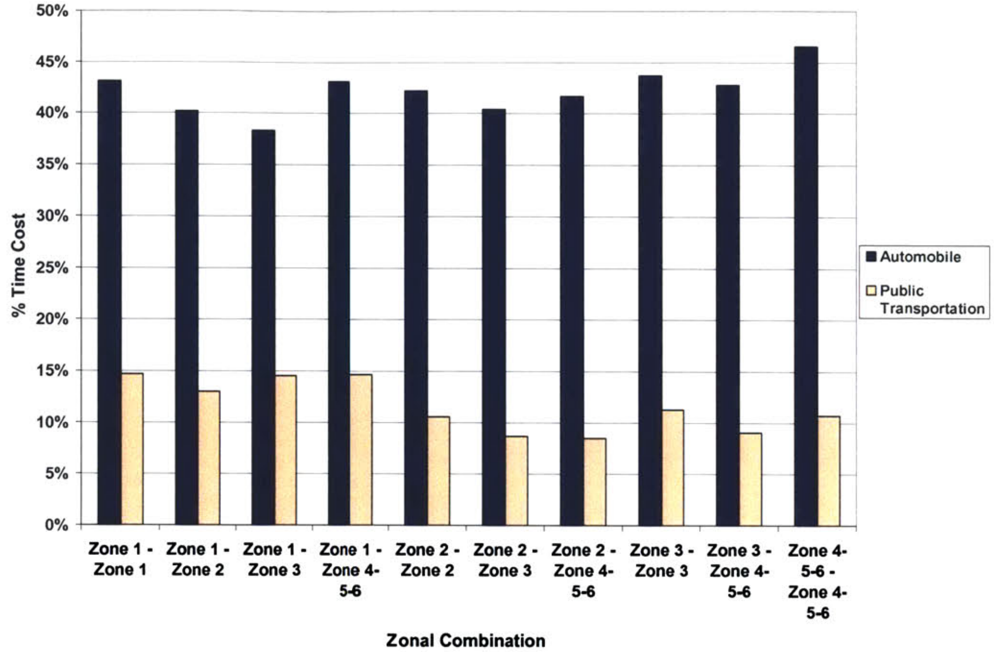
- *Including time costs significantly detracts from public transportation's advantage.* On average when using self-reported parking costs, time costs contributed about 81 percent of the entire trip's cost on public transit but only 50 percent of the entire trip's cost on automobiles. See Figure 5.10 for additional detail.

Figure 5.10 – Time Costs as a Percent of Total Travel Costs



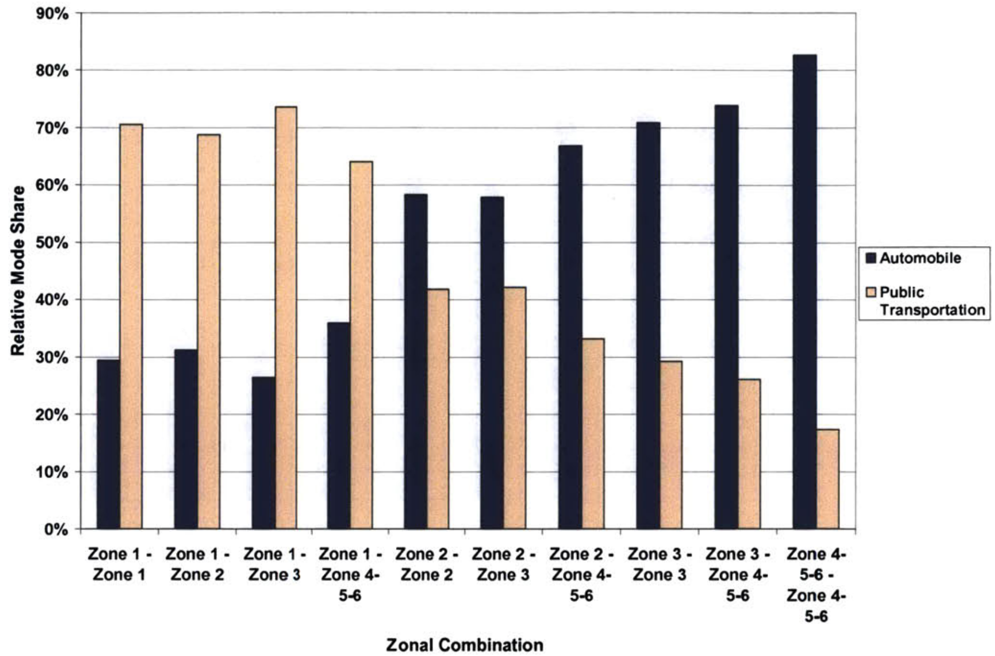
- *Private non-time expenditures are a significantly higher share of total trips costs for the automobile than public transportation* – On average when using self-reported parking costs, private non-time expenditures ranged from 38.3 percent to 46.5 percent of total travel costs for the automobile compared to a range from 8.5 percent to 14.7 percent for public transportation. See Figure 5.11 for additional detail.

Figure 5.11 – Private Non-Time Costs as a Percent of Total Travel Costs



- *Public transportation's mode share was strongest in central London and progressively decreases in outer zones.* For trips within Zone 1, public transit's relative mode share was about 71 percent while for trips within Zones 4, 5, and 6, public transit's relative mode share was only about 17 percent. Figure 5.12 shows relative mode shares for all zonal combinations.

Figure 5.12 – Relative Mode Shares by Zonal Combination



5.4. CONCLUSION

In this chapter, we were able to extend our research by comparing travel costs at a zonal combination level and by including time costs. This represents a significant improvement from the aggregate analysis in the previous chapter. When using self-reported parking costs, we found that hat public transportation compared most favorably for trips from outer London to inner London and for trips within inner London. When full parking costs were used, public transportation even compared favorably for outer London to outer London trips. In the next chapter, we will build off the work in this chapter and segment trip data by public transit accessibility instead of travel zones.

6. TRAVEL COSTS AND PUBLIC TRANSIT ACCESSBILITY LEVELS

6.1. INTRODUCTION

In addition to measuring travel costs by zonal origin and destination combinations as in the previous chapter, another way to disaggregate travel cost data is by the Public Transport Accessibility Level (PTAL) index. The PTAL is a detailed measure of the accessibility of a given point to the public transport network. The measure takes into account both the walk access time and service availability from the given point. The final output of the PTAL is an assignment of 0 through 6 that indicates the level of public transport available to each point. Through matching trip-level data from the London Area Travel Survey (LATS) with the PTAL, we can focus on the question of whether public transit accessibility affects private transportation spending.

6.2. LITERATURE REVIEW

Within the past couple of years, several researchers in measuring cost of living affordability have expanded the definition of affordability to include transportation expenditures in addition to housing expenditures. By including transportation expenditures in measuring affordability, these researchers are hypothesizing that transportation expenditures vary by location within a metropolitan area. Given that 19 percent of household expenditures in the United States are on transportation[42] and that transportation is the largest spending category for households in London[43], it is worth assessing the factors that influence how much a household spends on transportation.

In January 2006, the Brookings Institution published a report titled *"The Affordability Index: A New Tool for Measuring the True Affordability of a Housing Choice"*.[44] In this

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[42] "Consumer Expenditures in 2005."

[43] "Family Spending - 2004/05 Expenditure and Food Survey."

[44] "The Affordability Index: A New Tool for Measuring the True Affordability of a Housing Choice."

report, using the Minneapolis-St. Paul, MN metropolitan area as an example, the argument is made that transportation costs need to be considered when assessing the affordability of a neighborhood, as they are not simply driven by household income and size but also by neighborhood characteristics. Furthermore, Brookings also found that the combined costs of housing and transportation are most affordable in areas well served by public transit.

In addition to the Brookings work in the Twin Cities, a handful of other authors have also recently focused on combining housing and transportation costs.[45] Combined these studies provide evidence to merit researching transportation costs in London and also a methodological base to conduct an analysis. In particular, I will measure if public transport accessibility affects the amount a household spends on transportation using two independent data sources – the Public Transit Accessibility Index and London Area Travel Survey.

6.3. DESCRIPTION OF PTAL

First developed in 1992 by the London Borough of Hammersmith and Fulham, the PTAL is used by several government agencies in the Greater London area.[46] For each specified point, the process of calculating the PTAL is as follows:

1. For each public transport service in the catchment area from the specified point, the PTAL incorporates a measure of frequency by calculating an average wait time for each service and a measure of reliability for each service. Bus services are considered in the catchment area if the walk time is less than eight minutes while rail services are considered in the catchment area if the walk time is less than 12 minutes. An average walk speed of 4.8 kilometers per hour is used to measure time. The morning peak is the time period used to determine what transport services to include in the PTAL.

2. The PTAL then calculates an Equivalent Doorstep Frequency (includes walking time, service frequency, and service reliability for each point) by summing the

[45] Please refer to the Center for Transit Oriented Development, Center for Neighborhood Technology, and the Center for Urban and Regional Policy (Northeastern University)

[46] Cooper, *Sub Matter 5b Parking Strategy, TfL Written Submission - Annex 1.*

individual Equivalent Doorstep Frequency for each service in the catchment area of the point.

3. The PTAL is then categorized into nine different values – 0, 1a, 1b, 2, 3, 4, 5, 6a, and 6b – with 0 representing no public transport accessibility within the catchment area, 1a representing the lowest level of public transport accessibility, and 6b representing the highest level of public transport accessibility.

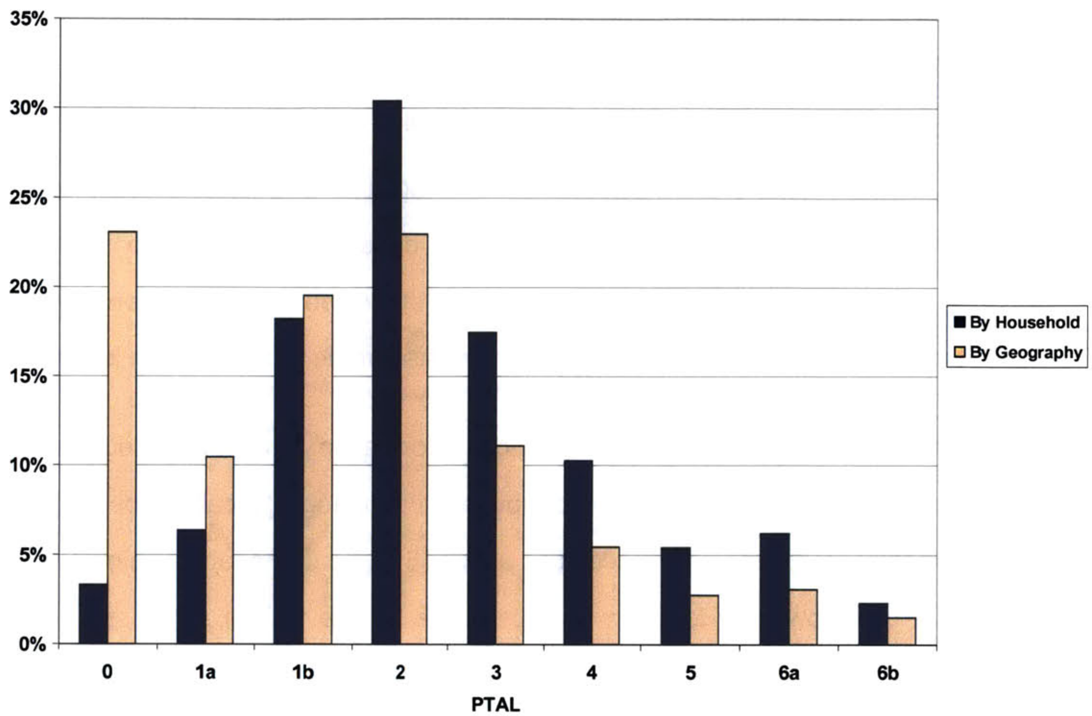
In summary, the PTAL reflects the walking time and the reliability and frequency of available public transport services but it does not consider the speed of accessible services, potential crowding, and the route of available transport services (e.g., a route to the city center carries the same weighting as a route to a suburban location).

Table 6.1 and Figure 6.1 provide information on the distribution of PTALs – geographically and by location of households. Geographically, most of London does not benefit from good transit access as about 76 percent of space within London has a PTAL of 2 or below. By location of households (in the LATS), the distribution of PTALs is centered around PTAL 2, while about 10 percent of household are at the extreme of no to little public transport accessibility (PTAL of 0 or 1a) and about 14 percent of households enjoy very good public transport accessibility (PTAL of 5 or above).

Table 6.1 – PTAL Geographic and Household Distribution

PTAL	Geographic Location		Household Location	
	Number	Percent	Number	Percent
0	36,799	23.1%	755	3.3%
1a	16,689	10.5%	1,451	6.4%
1b	31,141	19.5%	4,152	18.2%
2	36,623	23.0%	6,923	30.4%
3	17,689	11.1%	3,975	17.5%
4	8,683	5.4%	2,340	10.3%
5	4,392	2.8%	1,234	5.4%
6a	4,931	3.1%	1,412	6.2%
6b	2,387	1.5%	520	2.3%

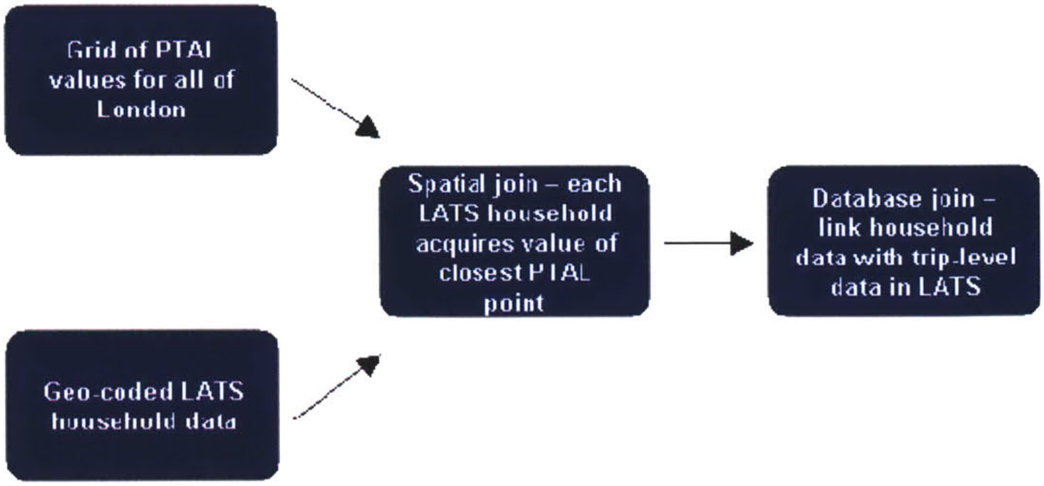
Figure 6.1 – PTAL Geographic and Household Distribution



6.4. METHODOLOGY

In order to link the PTAL index with LATS trip-level data, a spatial join operation in GIS software was performed. The spatial join added a field to LATS household data that contained the value of the nearest PTAL. Due to the dense grid of PTAL points, the average distance from a household in the LATS to a PTAL point was only 38.5 meters with a maximum distance of 91.7 meters for any one household. To complete the link with trip-level data, a database join operation was performed to connect households to trips. Figure 6.2 illustrates the methodology used to link PTAL data with LATS data.

Figure 6.2 – Linking PTAL with LATS



With these operations complete, it is now possible to analyze household's trip-level data by the accessibility of public transportation for that household. Both aggregate household patterns and costs at a trip-level basis were analyzed by PTAL. The results of both analyses are presented in the next section.

6.5. RESULTS – HOUSEHOLD ANALYSIS

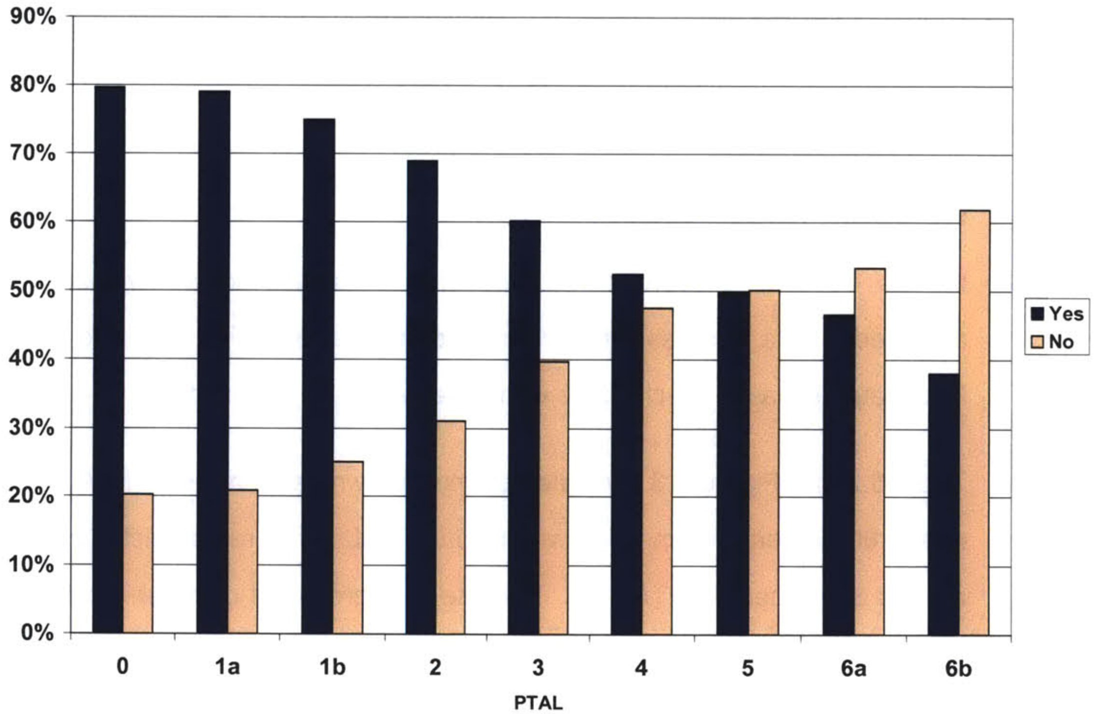
In this section, household level patterns pertaining to automobile ownership are analyzed. Data sources for this analysis include the PTAL grid and LATS household level data. Data on specific trips within the LATS are not used.

Table 6.2 and Figure 6.3 illustrate automobile ownership rates by PTAL. From a high of nearly 80 percent automobile ownership in PTALs of 0, rates quickly trend downward to around 38 percent in PTAL 6b. The rate of decrease of ownership rates appears to be linear – as transit accessibility increases, automobile ownership rates decrease proportionally.

Table 6.2 – Does Household Own at Least One Vehicle?

PTAL	Yes	%	No	%	Total
0	602	79.7%	153	20.3%	755
1a	1,148	79.1%	303	20.9%	1,451
1b	3,114	75.0%	1,038	25.0%	4,152
2	4,774	69.0%	2,149	31.0%	6,923
3	2,394	60.2%	1,581	39.8%	3,975
4	1,228	52.5%	1,112	47.5%	2,340
5	615	49.8%	619	50.2%	1,234
6a	658	46.6%	754	53.4%	1,412
6b	198	38.1%	322	61.9%	520
Total	**14,731**	**64.7%**	**8,031**	**35.3%**	**22,762**

Figure 6.3 – Does Household Own at Least One Vehicle?



The LATS also asks respondents who do not own an automobile their reason(s) for not owning one. Looking at these responses by PTAL (see Table 6.3) reveals several interesting patterns:

- As PTAL improves, the share of households who state they cannot afford an automobile decreases.

- As PTAL improves, the share of households who say they can get everywhere by other means and that it is easier to get around without an automobile increases.

- As PTAL improves, the reason that no-one can drive in general becomes less likely.

- The reasons of not wanting to pollute the environment, that it is cheaper to travel by public transit, and that they do not travel enough show no discernable pattern by PTAL level.

Table 6.3 – Reasons Why Households Do Not Own an Automobile

PTAI	Can't Afford	Too Expensive	No-One Can Drive	Can Get Everywhere Needed by Other Means	Easier to Get Around Without Car	Don't Want to Pollute Environment	Cheaper to Travel by Public Transit	Don't Travel Enough
0	34.6%	6.5%	37.9%	9.2%	13.7%	0.7%	10.5%	3.3%
1a	26.7%	8.3%	48.2%	9.9%	5.9%	0.7%	3.6%	3.3%
1b	31.0%	10.7%	41.1%	12.7%	9.8%	1.7%	6.4%	4.7%
2	32.7%	10.7%	40.1%	13.5%	11.9%	2.0%	7.6%	3.9%
3	33.7%	10.8%	33.6%	14.2%	12.4%	2.3%	8.3%	4.4%
4	32.6%	11.5%	34.6%	15.5%	15.0%	4.0%	8.3%	4.8%
5	30.5%	14.1%	31.8%	16.0%	15.3%	3.9%	8.4%	5.0%
6a	29.2%	11.0%	30.2%	21.6%	21.9%	3.2%	10.9%	4.4%
6b	24.8%	11.5%	22.4%	22.0%	28.6%	3.7%	4.3%	4.0%
Average	**31.7%**	**11.0%**	**36.2%**	**14.9%**	**13.8%**	**2.6%**	**7.8%**	**4.3%**

Looking at ownership rates for only those households that own at least one automobile indicates that both the average number of vehicles in a household and the average number of household members increases as the PTAL decreases. Combined this shows that the number of automobiles per household member, for households that own at least one automobile, is relatively constant throughout all PTALs. Table 6.4 provides this information.

Table 6.4 – Automobile Ownership Rates for Households that Own at Least One Car

PTAI Value	Average Number of Vehicles	Average Number of HH Members	Vehicles/HH Member
0	1.61	2.75	0.58
1a	1.56	2.69	0.58
1b	1.51	2.74	0.55
2	1.43	2.70	0.53
3	1.32	2.60	0.51
4	1.27	2.48	0.51
5	1.26	2.40	0.53
6a	1.21	2.36	0.51
6b	1.13	1.97	0.57
Average	**1.41**	**2.64**	**0.54**

Looking at ownership rates for all households – those that do and do not own at least one vehicle – we see definite patterns in per capita ownership. As shown in Table 6.5, a household with a PTAL of 0 on average owns 0.43 vehicles per household member while a household with PTAL of 6b on average owns 0.24 vehicles per household member.

Table 6.5 – Automobile Ownership Rates for All Households

PTAl Value	Average Number of Vehicles	Average Number of HH Members	Vehicles/HH Member
0	1.08	2.54	0.43
1a	1.23	2.50	0.49
1b	1.13	2.50	0.45
2	0.99	2.42	0.41
3	0.79	2.27	0.35
4	0.67	2.12	0.31
5	0.63	2.10	0.30
6a	0.56	2.02	0.28
6b	0.43	1.76	0.24
Average	**0.91**	**2.33**	**0.39**

One a per capita basis, households with a PTAL of 6b spend 37.1 percent less than average London household on automobiles and 42.4 percent less than households with a PTAL of 0. This is a cost savings on the order of £2500 to £3400 at the household level per year (accounting for household size, this is a savings of £750 to £950 per year per individual household member).

In summary, in analyzing household automobile ownership rates, we see a clear relationship between the level of transit accessibility and automobile ownership rates and thus total transportation spending. In section 6.6., we will incorporate trip level data with the household analysis to further quantify how public transportation accessibility affects private transportation spending.

6.6. Results – Trip Level Analysis

6.6.1. Overview

In order to analyze trip-level data by PTALs, we employed a process nearly identical to that of Chapter 5. The exact same cost equations (see Figures 6.5 and 6.6), definition for each term, and process for filtering the LATS data were used in this analysis. We only use self-reported parking figures in our analysis given our focus on private out-of-pocket costs. Please refer to section 5.2. (except section 5.2.3.) for a more detailed explanation of the methodology behind analyzing trip-level data.

Figure 6.4 – Automobile Travel Cost Formula

$$\text{Trip Travel Cost} = \frac{\text{Automobile Ownership Cost}}{\text{Trip}} + \text{Automobile Use Cost} + \frac{\text{Public Automobile Expenditures}}{\text{Trip}} + \text{Parking Cost} + \text{Travel Time Cost}$$

Figure 6.5 – Public Transit Travel Cost Formula

$$\text{Trip Travel Cost} = \frac{\text{Public: Public Transit Expenditures}}{\text{Trip}} + \text{Fare Paid} + \text{Travel Time Cost}$$

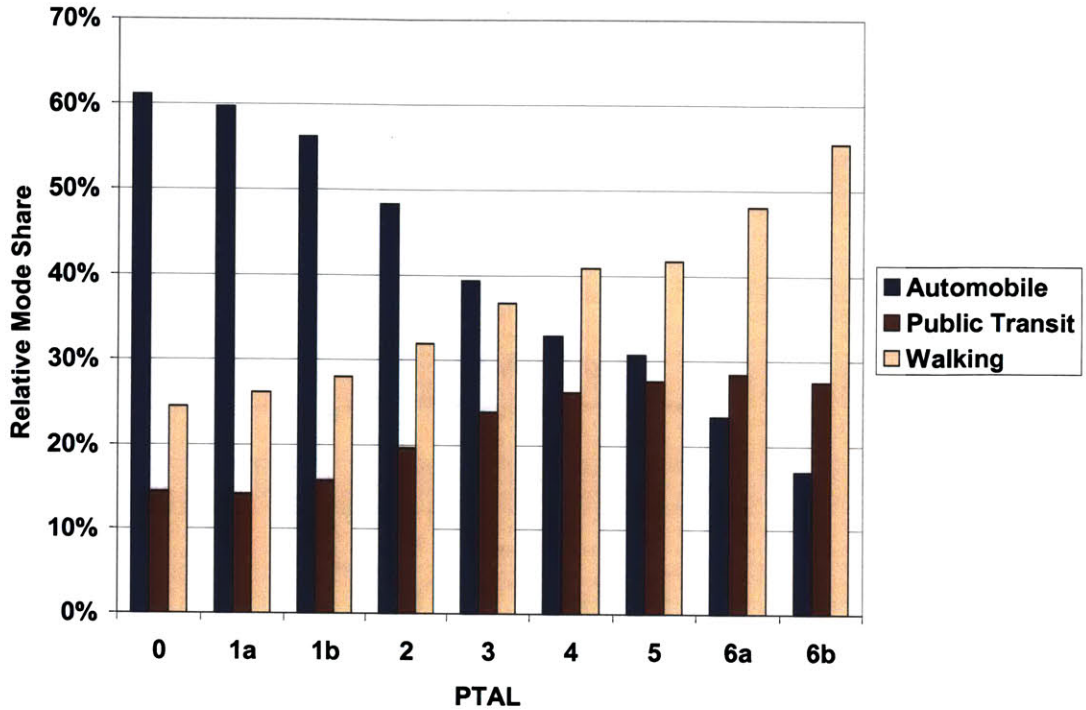
6.6.2. Walking Trips

In this analysis and the analysis in the preceding chapter, walking trips were not included as a transportation mode. While walking trips are beyond the scope of this research, there are interactions between walking and public transport accessibility that are worth noting. Using the PTAL index and trip-level data from the LATS, we can see if a relationship exists between public transport accessibility and the frequency of walking trips. Table 6.6 and Figure 6.6 provide results of the relative mode shares for the automobile, public transit, and walking.

Table 6.6 – Relative Mode Shares Including Walking Trips

PTAL Value	Mode	Number of Journeys	Relative Mode Share
0	Automobile	2,778	61.1%
	Public Transit	656	14.4%
	Walking	1,114	24.5%
1a	Automobile	5,162	59.7%
	Public Transit	1,226	14.2%
	Walking	2,264	26.2%
1b	Automobile	14,187	56.2%
	Public Transit	3,985	15.8%
	Walking	7,088	28.1%
2	Automobile	19,090	48.4%
	Public Transit	7,758	19.7%
	Walking	12,621	32.0%
3	Automobile	8,001	39.4%
	Public Transit	4,851	23.9%
	Walking	7,467	36.7%
4	Automobile	3,776	32.9%
	Public Transit	3,016	26.3%
	Walking	4,689	40.8%
5	Automobile	1,845	30.7%
	Public Transit	1,659	27.6%
	Walking	2,506	41.7%
6a	Automobile	1,630	23.4%
	Public Transit	1,980	28.5%
	Walking	3,348	48.1%
6b	Automobile	367	16.9%
	Public Transit	598	27.6%
	Walking	1,205	55.5%

Figure 6.6 – Relative Mode Shares Including Walking Trips



From Table 6.7 and Figure 6.7, we see a clear relationship between PTALs and the share of walking trips – as public transport accessibility improves, the share of walking trips increases. While this is not captured in our financial analysis, this relationship of greater amount of walking trips in areas with high public transit accessibility represents a potential benefit of public transportation.

6.6.3. Travel Costs by PTAL

The main difference between the analysis in this chapter and that of the previous chapter is that instead of breaking down costs for each zonal travel combination, we break down costs for each PTAL value of the household making the trip. Table 6.7 summarizes the results of running the equations in Figures 6.5 and 6.6 on each trip.

Table 6.7 – Travel Costs by PTAL and Travel Mode

PTAL Value	Mode	Number of Journeys	Relative Mode Share	Average Journey Length (km)	Travel Cost per KM	Travel Cost per Journey	% Time Cost	% Public Cost	% Non-Time Private Cost
0	Automobile	2,778	80.9%	4.5	£1.53	£6.8	49.4%	5.3%	44.1%
	Public Transit	656	19.1%	7.8	£1.26	£9.9	81.0%	7.0%	11.9%
1a	Automobile	5,162	80.8%	4.3	£1.57	£6.8	48.6%	5.3%	43.3%
	Public Transit	1,226	19.2%	6.6	£1.45	£9.6	81.6%	7.2%	11.1%
1b	Automobile	14,187	78.1%	4.2	£1.59	£6.7	49.3%	5.4%	43.8%
	Public Transit	3,985	21.9%	6.2	£1.49	£9.3	81.3%	7.5%	11.2%
2	Automobile	19,090	71.1%	4.2	£1.62	£6.9	50.4%	5.3%	45.2%
	Public Transit	7,758	28.9%	6.0	£1.51	£9.1	81.0%	7.7%	11.3%
3	Automobile	8,001	62.3%	4.2	£1.69	£7.1	51.9%	5.1%	46.8%
	Public Transit	4,851	37.7%	5.8	£1.56	£9.1	80.7%	7.7%	11.6%
4	Automobile	3,776	55.6%	4.3	£1.71	£7.4	53.0%	4.9%	48.1%
	Public Transit	3,016	44.4%	5.3	£1.68	£8.9	80.5%	7.8%	11.7%
5	Automobile	1,845	52.7%	4.1	£1.77	£7.3	51.9%	5.0%	46.9%
	Public Transit	1,659	47.3%	5.2	£1.65	£8.6	79.7%	8.1%	12.2%
6a	Automobile	1,630	45.2%	4.2	£1.82	£7.7	54.4%	4.7%	49.7%
	Public Transit	1,980	54.8%	4.8	£1.74	£8.4	78.9%	8.3%	12.8%
6b	Automobile	367	38.0%	4.8	£1.73	£8.2	56.1%	4.4%	51.7%
	Public Transit	598	62.0%	4.4	£1.84	£8.0	77.8%	8.7%	13.6%

Key findings from this analysis include the following:

- The travel cost per kilometer tends to increase for both modes as PTALs improve (see Figure 6.8) – This trend is most likely due the fact that as PTALs improve, trip lengths decrease for public transit (see Figure 6.9) and travel speeds decrease for the automobile, and consequently there is less distance to divide the fixed cost and fares of public transit trips by and more time costs for automobile trips.

Figure 6.7 – Travel Costs per KM by PTAL

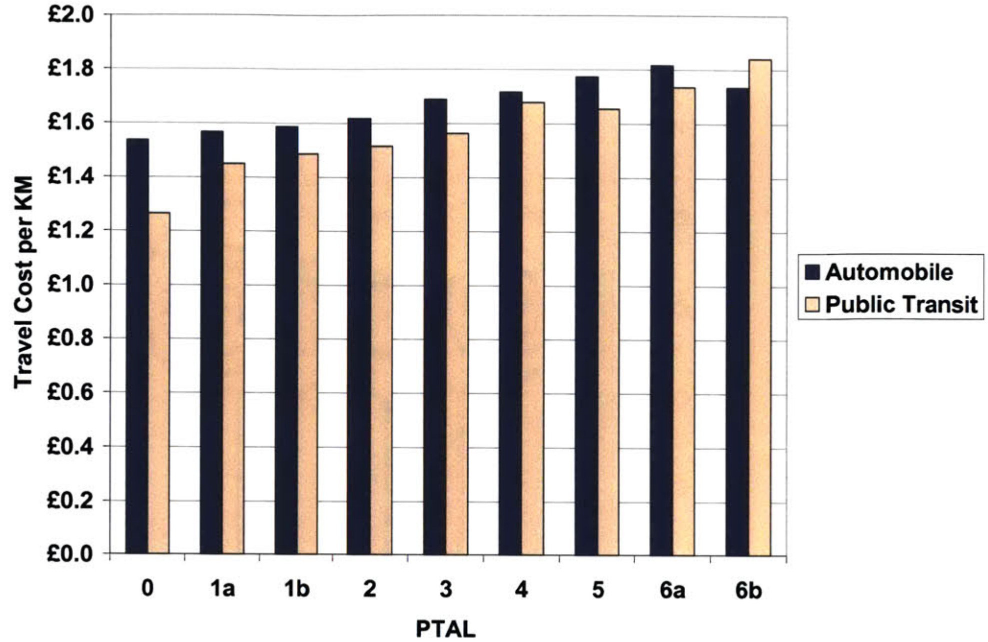
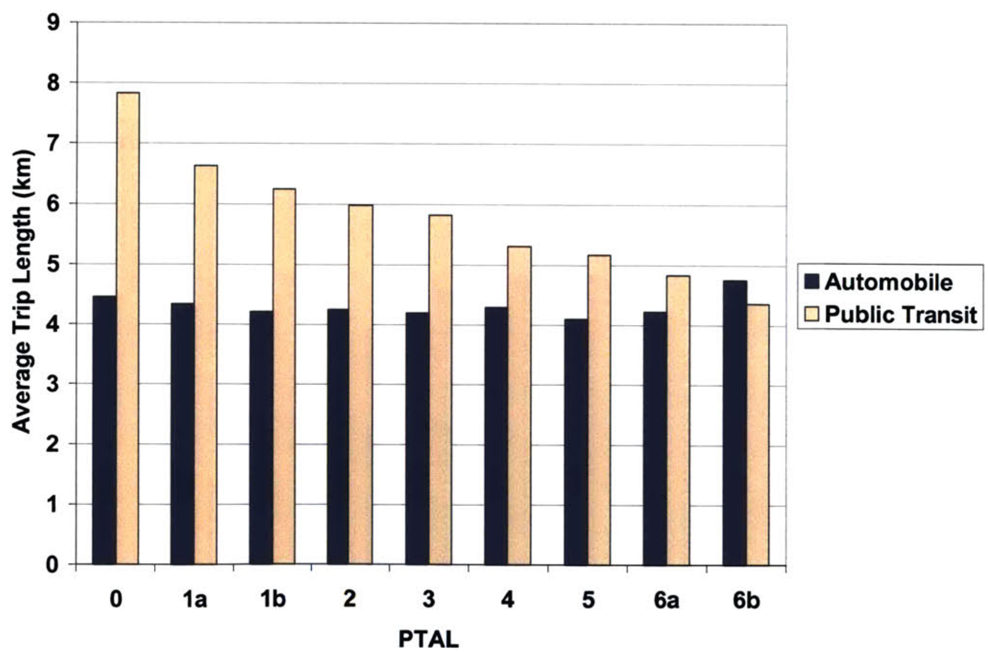
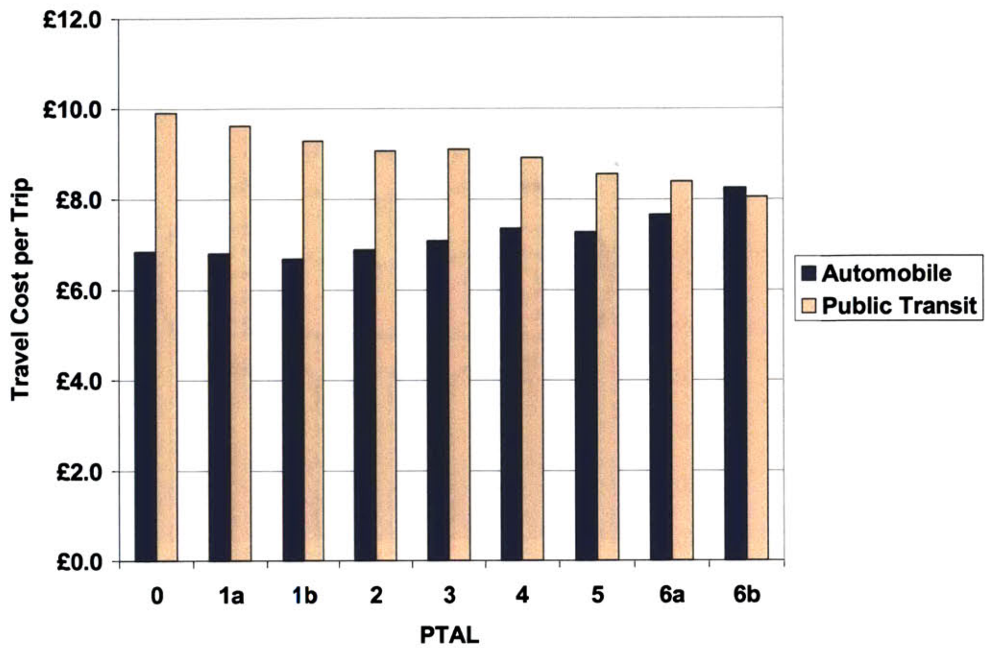


Figure 6.8 – Average Trip Lengths by PTAL



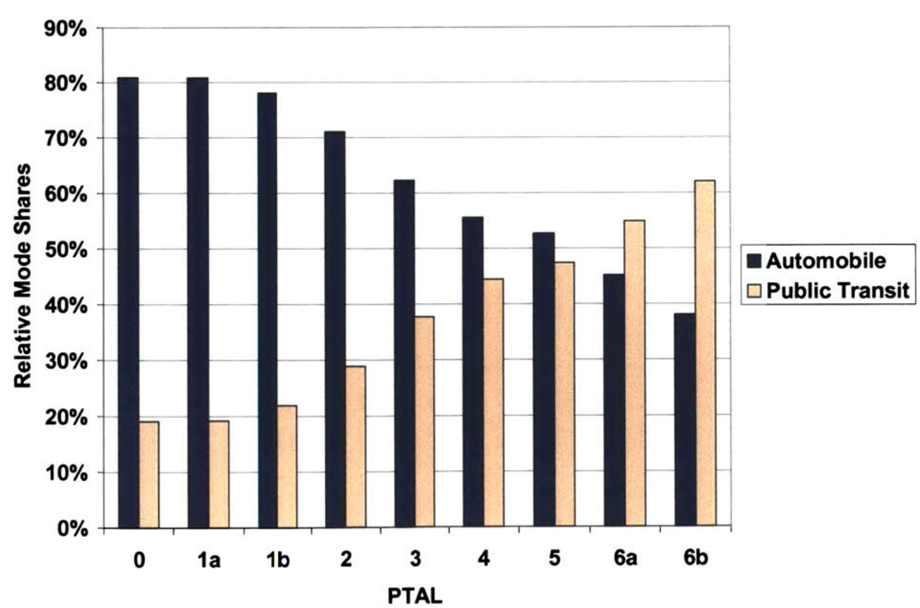
- As seen in Figure 6.7 above, aside for PTAL 6b, public transit compares favorably when comparing costs on a distance basis. On the contrary, as seen in Figure 6.10 below, only for PTAL 6b does public transit compare favorably when comparing costs on a trip basis.

Figure 6.9 – Travel Costs per Trip by PTAL



- Public transit's mode share improves as PTALs increase. For households with PTALs of 0 and 1a, transit has about a 19 percent relative mode share while for households with a PTAL of 6b, public transit has about a 62 percent mode share. Figure 6.11 illustrates relative mode shares for all PTALs.

Figure 6.10 – Relative Mode Shares by PTAL



In order to only analyze private direct and time costs, the set of calculations for each trip was performed again but with public costs removed. Table 6.8 provides results.

Table 6.8 – Private Travel Costs by PTAL

PTAL Value	Mode	Private Non-Time Cost per Trip	Private Non-Time Cost per KM	Private Cost per Trip (inc time)	Private Cost per KM (inc time)
0	Automobile	£3.28	£0.74	£6.47	£1.45
	Public Transit	£1.75	£0.22	£9.20	£1.17
1a	Automobile	£3.30	£0.76	£6.43	£1.48
	Public Transit	£1.64	£0.25	£8.91	£1.34
1b	Automobile	£3.21	£0.76	£6.32	£1.50
	Public Transit	£1.61	£0.26	£8.58	£1.37
2	Automobile	£3.23	£0.76	£6.51	£1.53
	Public Transit	£1.59	£0.27	£8.36	£1.40
3	Automobile	£3.24	£0.77	£6.72	£1.60
	Public Transit	£1.63	£0.28	£8.40	£1.44
4	Automobile	£3.29	£0.77	£6.99	£1.63
	Public Transit	£1.61	£0.30	£8.20	£1.55
5	Automobile	£3.33	£0.81	£6.91	£1.68
	Public Transit	£1.60	£0.31	£7.86	£1.52
6a	Automobile	£3.33	£0.79	£7.30	£1.73
	Public Transit	£1.62	£0.34	£7.69	£1.59
6b	Automobile	£3.46	£0.73	£7.88	£1.66
	Public Transit	£1.64	£0.38	£7.34	£1.68

- Private non-time costs per trip and per kilometer show little variation for different PTALs for automobile trips. Equivalent costs for public transit do not exhibit variation when comparing costs on a trip basis across PTALs but do exhibit variation when comparing costs on a distance basis. Please refer to Figures 6.11 and 6.12 below.

Figure 6.11 – Private Non-Time Costs per KM by PTAL

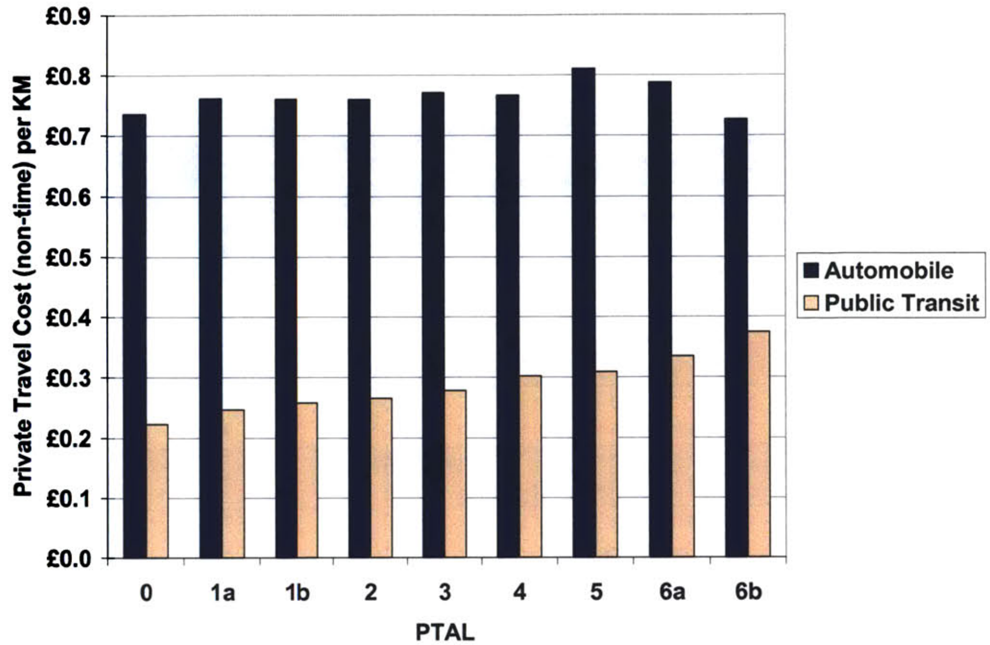
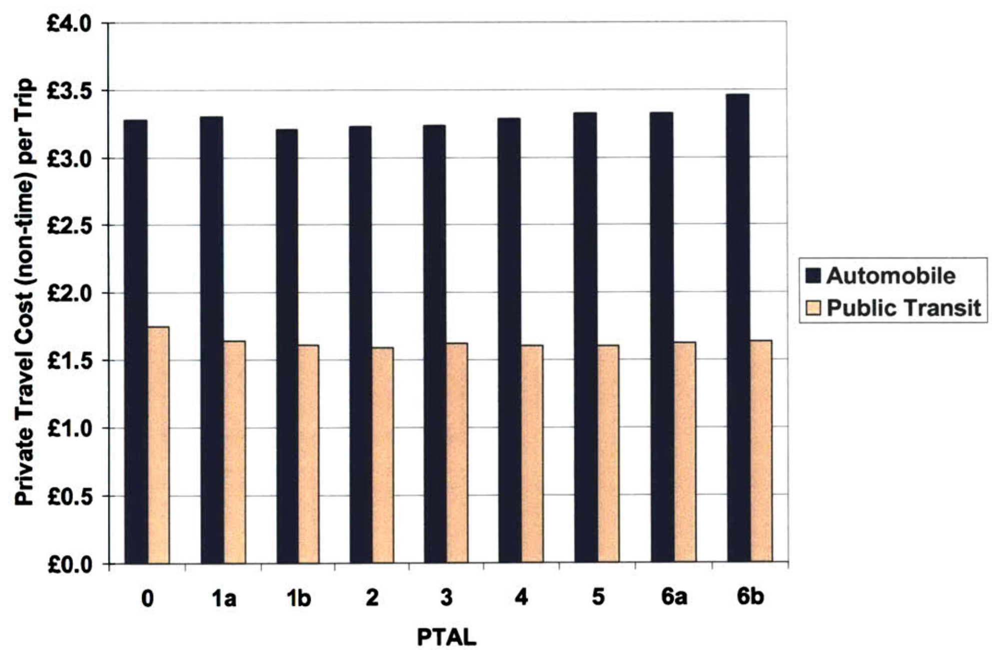


Figure 6.12 – Private Non-Time Costs per Trip by PTAL



- When including time costs, we see that on a distance basis in Figure 6.13, public transit compares favorably to the automobile in all PTALs except 6b. Similar to before, in Figure 6.14, we see that the automobile has an advantage on a trip basis for all PTALs except 6b.

Figure 6.13 – Private Costs per KM by PTAL

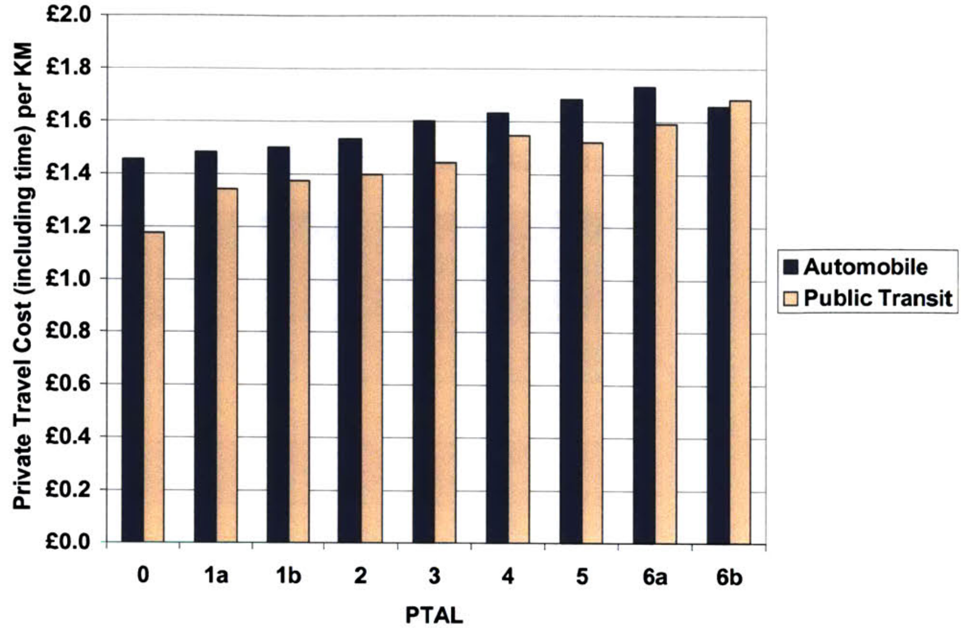
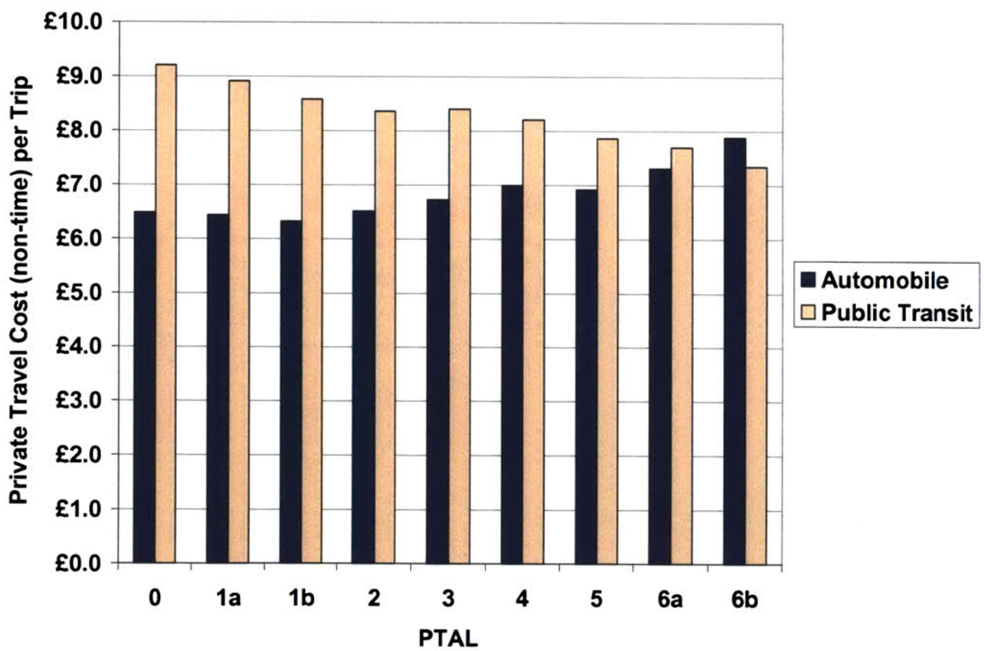


Figure 6.14 – Private Costs per Trip by PTAL



Weighting the private non-time travel cost by the relative mode shares provides an expected travel cost per kilometer and per trip. This can be used to measure the effect public transit accessibility has on private transportation expenditures. Table 6.9 provides average costs weighted by relative mode shares for private non-time travel costs. Table 6.10 provides average costs weighted by relative mode shares for private travel costs including time.

Table 6.9 – Weighted Private Non-Time Travel Costs

PTAL Value	Weighted Private Trip Non-Time Cost	Weighted Private Non-Time Cost per KM
0	£2.99	£0.64
1a	£2.98	£0.66
1b	£2.86	£0.65
2	£2.75	£0.62
3	£2.63	£0.59
4	£2.54	£0.56
5	£2.51	£0.57
6a	£2.39	£0.54
6b	£2.33	£0.51

Table 6.10 – Weighted Private Travel Costs Including Time

PTAL Value	Weighted Private Trip Cost (inc time)	Weighted Private Non-Time Cost per KM (inc time)
0	£6.99	£1.40
1a	£6.91	£1.46
1b	£6.81	£1.47
2	£7.04	£1.49
3	£7.35	£1.54
4	£7.53	£1.59
5	£7.36	£1.61
6a	£7.51	£1.65
6b	£7.55	£1.67

From Tables 6.10 and 6.11, we see that while weighted costs do decrease as public transit accessibility increases, the direct cost savings is less than the additional time costs public transit users incur compared to automobile users.

6.7. Conclusion

In this chapter, we used actual household and trip level data, travel cost data, and a public transport accessibility index to answer the question does public transport accessibility affect transportation spending at a household level. This process reveled several interesting findings about automobile ownership and trip-level cost data for different PTALs but in the end, we found that only when time costs are not included, do we actually see savings in transportation spending for households in areas with higher public transport accessibility.

7. RECOMMENDATIONS AND CONCLUSION

7.1. KEY FINDINGS FROM RESEARCH

In this thesis, we sought to financially compare the automobile and public transportation in London. The comparison included all direct costs spent on each transportation mode from both public and private actors as well as time costs. On the automobile side, public actors spent money to construct and maintain roadways, private individuals and businesses spent money to obtain and use automobiles and to construct, maintain, and operate parking spaces. On the public transportation side, private individuals spent money on fares which in turn was combined with a public subsidy to operate, maintain, and expand the public transportation system.

Starting from a cross-sectional and time panel analysis transportation costs in 20 international cities, we found that on average a one percent gain in public transportation's modal share of motorized trips was associated with a 2.46 percent decrease in overall transportation costs as a share of regional GDP. We also found that a one percent gain in the per capita length of motorways in a city was associated with a 0.36 percent increase in overall transportation costs as a share of regional GDP. While these statistically significant findings provided a base for digging deeper into one city's transportation costs, the ability to draw conclusions from them was limited by the crudeness of the data.

Digging deeper into London's transportation costs by aggregating all public and private expenditures on either the automobile or public transportation, we found that the automobile was 3.7 times more expensive than public transportation on a trip basis, and 2.0 times more expensive on a distance basis. In comparing the share of expenditures that stayed within the United Kingdom's boundaries, we found that about 88 percent of all public transportation expenditures stayed within the London area, compared to 70 percent for the automobile. However, our aggregate comparison was lacking as it did not include time costs and it only analyzed expenditures at an aggregate city-level, making no distinction between different spatial combinations of trips.

Through the LATS, we were able to include time costs and trip-level data, allowing us to compare the automobile and public transportation at a disaggregate level. When including time costs and self-reported parking costs and using London's transport zone system as a proxy for location, we found that while public transportation was still the more efficient mode for several zonal combinations, its advantage was weakened by time costs. Even with time costs though, we found that public transportation compared favorably to the automobile on trips between inner London and outer London and for trips within inner London. For when full parking costs were used, we found that public transportation was clearly the more cost-efficient transportation mode, even with time costs.

In addition to analyzing costs by zonal combinations, we were able to analyze trip costs by the level of public transport accessibility. We found that while individuals who benefit from the highest level of public transit accessibility spend on average about 15 to 20 percent less on transportation expenditures, these savings are cancelled out by additional time costs. Building off our key findings, in this chapter we will propose a set of recommendations for London to realize a more cost-efficient transportation system and identify areas for future research.

7.2. Recommendations

The following are recommendations for London to improve its transportation system's cost efficiency:

'Unhide' costs of the automobile – For every pound spent on owning and operating a vehicle and on parking, only 17 pence is paid at the time of actual use. The marginal decision of whether to use an automobile or public transportation is favored to the automobile because the bulk of this cost has already been paid by the user or by someone else. Several policy decisions could be pursued to transform fixed costs of the automobile to variable costs and consequently the bias toward using the automobile can be reduced. These policy decisions include the following:

- **Pay as you drive insurance** – This will shift the approximately £1.4 billion of current insurance expenditures from being fixed to being variable. Assuming a revenue-neutral scheme, this will increase the variable costs of automobile usage from 17 percent of total private expenditures to 24 percent.

- **Require employers to equalize parking and transit subsidy –** Dividing total parking costs by the number of automobile trips in London, we estimate a per trip parking cost of £1.97. From self-reported parking costs in the LATS, only a small portion of those costs are actually paid by automobile users while the majority of parking costs are absorbed by employers and retailers. A mandate that would require employers to provide equal subsidies to public transportation use as parking would incentivize reducing the current parking subsidy and high amount of free parking currently available. This strategy is likely more politically feasible that requiring full marginal pricing of parking.

- **Promotion of car-sharing services –** In recent years both in the United States and in Europe, car-sharing services that charge users an hourly rate to rent an automobile such as Flexcar and Zipcar have emerged. This is effectively short-term automobile ownership and increasing use of it has the potential to reduce automobile ownership levels and shift a greater share of automobile costs from being fixed to being variable, leading to a more efficiently priced transportation system.

Incorporate private costs into public-decision making process – Governments, businesses, and individuals have differing roles in paying for either the automobile or public transportation systems. At the individual level, the cost of owning and operating the vehicle and occasionally parking costs are the only perceived costs on the automobile sid,e while fares are the only perceived cost of using public transportation. At the business level, there are no perceived costs for public transportation while supplying parking capacity is the only major cost on the automobile side. For governments, on the automobile side, providing and maintaining roadways infrastructure is the only major cost – private individuals and companies pay for everything else. On the public transportation side, government has to pay for everything – vehicles, track infrastructure, stations, operators, etc.

This difference in which government is only financially responsible for a small part of the automobile system and for nearly everything in the public transportation system has important implications. First, a strict comparison of the public dollars needed for system expansions between the two modes is biased as parking and vehicles costs are not included for the automobile but the equivalent costs on the public transportation side are included. Second, because government is only responsible for a small share of costs in the automobile system, decisions to expand automobile system capacity are much less lumpy than decisions to expand the public transportation system.

For example, the decision to build and operate Crossrail is very public and requires large amount of public resources. It is a lumpy process. The decision to expand the automobile system by an equivalent capacity amount as Crossrail would provide is much less lumpy as it requires fewer public resources. But simply comparing the public resources needed for either Crossrail or expanding the automobile system is biased. In addition to the public costs, the comparison needs to consider the marginal costs of increased parking capacity and the added private expenditures on automobiles that would be result from the expansion of the automobile system. For comparison purposes, the proposed cost of Crossrail is less than the total annual spending on the automobile.

Targeted opportunities for public transportation – Based on the travel zone analysis, we've identified the following opportunities to extend public transportation's reach:

- Public transportation was clearly shown as the more efficient mode for trips from the outer London to Zone 2, yet public transportation's mode share for those trips did not reflect this advantage. This is likely due to the fact that the public transportation accessibility is highly variable within Zone 2 as there are a number of areas that do not benefit from good accessibility. Improving the reach of the network within Zone 2 and encouraging dense land uses near points of high public transportation accessibility would induce greater public transportation use would likely be a very overall cost-efficient transportation investment. This strategy makes additional sense given the limited ability to expand the land use density within Zone 1.

- Parking is a hidden cost that only has a portion borne by automobile users. If part of this cost can be unhidden and paid by the automobile user, public transportation will compare more favorably against the automobile and likely experience increased mode share.

- Public transportation's biggest financial disadvantage relative to the automobile are travel time costs. On average, travel time constituted about 80 percent of the costs of public transportation trips while only 50 percent of the costs of automobile trips. This gap is significant and measures and regulatory decisions to improve this gap should be pursued. Completion of the work in the PPP maintenance and renewal contracts will help as has the congestion charge. Other measures to explore are to increase the amount of bus-only lanes, improve congestion management in the Underground to decrease dwell times, continue the move to cashless buses, and improve the process of paying for fares. Many of these areas are the focus of other MIT research efforts sponsored by TfL.

7.3. AREAS FOR FUTURE RESEARCH

The following are areas identified for further research:

Include more travel modes – In this analysis, we restricted ourselves to only comparing the automobile and public transportation services provided by TfL. Transportation modes of significant use were neglected such as National Rail, walking, and cycling. While National Rail costs are complicated as they are spread amongst many private companies and public agencies, not including National Rail is a definite shortcoming of this research given it high share of use as a daily transport mode (see Table 4.24). Walking and cycling trips are also very significant in London – there are approximately 5.69 million walking trips per day in London and 0.43 million cycling trips per day. While a financial comparison including walking and/or cycling would likely be fruitless, ways to measure the costs and benefits of either mode relative to public transportation and the automobile would be useful for policymakers to help assess to what extent should walking and cycling be promoted.

Costs going forward – In this analysis, we measured transportation costs at a particular point in time – FY 2004-05. This provided cost information at an average level – they do not reflect the marginal costs of expansion going forward, which are almost certainly not equal to average costs. Most likely the marginal costs of expansion are higher than the average costs found in this study as presumably transportation investments with the greatest cost efficiencies have already been built. Research comparing the infrastructure costs of expansion for both modes to achieve increases in transportation capacity – combined with data in this research on per kilometer usage costs – would provide a more complete modal comparison from the viewpoint of a policymaker.

Relationship between public and private decisions – At the individual level, dollar and time costs of various transportation modes explain modal decisions reasonably for various time points – true marginal costs explain the decision on what mode the individual chooses in the morning and on a longer time basis roughly explain the decision on whether to purchase an automobile. But understanding how these choices are affected by public policy is not as clear. How would Crossrail affect travel choices by individuals? Would it reduce automobile ownership and parking needs? Conversely, how would a massive roadway project affect these travel choices, automobile ownership, and parking needs? While causality is near impossible to prove, research looking into the effect public decisions has on private decisions would be insightful and help crystallize to what extent should private costs be considered when a public agency is comparing whether to invest in the automobile system or in public transportation.

Congestion Charge and bus improvements impact – Due to data limitations, we only had trip-level data from 2001. Since then the Congestion Charge has been implemented and expanded. At £8 per day, it greatly changes the economics of driving in Central London and because it reduces congestion, it improves the travel speed of buses. Furthermore, Transport for London has invested extensively in its bus network since

2000 and from 2000 to 2005 saw about a 42 percent increase in bus trips. Neither these improvements in the bus network nor the Congestion Charge are reflected in our trip data but have caused significant change in travel patterns within London. As soon as a new version of the LATS is released, it would be insightful to see how travel patterns and costs have changed.

Parking costs – Given time and data limitations, the estimation of parking costs in this analysis is not as rigorous as it could be. Considering the order of magnitude though of parking costs presented in this research, it would be worthwhile to estimate them using a more thorough methodology with data sources more relevant to London. Additionally, policy-measures that could be pursued to 'unhide' parking costs should be explored and assessed in greater detail.

Local Spending – In this thesis, we were able to estimate the share of expenditures for each transportation mode that stayed within the local economy. For the automobile, we estimated that 70 percent of spending stays within the London economy and for public transportation, we estimated that 88 percent of spending stayed within the local economy. However, these estimates are only step one of a local economic impact analysis. Further work refining these estimates and quantifying a local multiplier effect for each mode would be logical next steps.

Transportation's externalities – In this analysis, we restricted ourselves to financial costs of the automobile and public transportation. We made no mention of either externalities inherent in a transportation system or the relationship between the automobile and public transportation. Antos's work for the Chicago region showed that there are significant differences between the automobile and public transportation in terms of energy consumption, emissions of pollutants, safety, and congestion and that these costs are frequently not borne by those causing it. His thesis would be an excellent starting point for conducting a similar analysis in the London region.[47]

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[47] Antos, *Paying for Public Transportation: the Optimal, the Actual, and the Possible.*

Sensitivity on energy prices – As energy prices continue its upward trend of the past few years, analysis into how sensitive the findings in this thesis are to changing energy prices would be insightful. Antos's work for the Chicago region provides a methodological reference of how to estimate energy use for transportation modes. His findings for the Chicago region indicated that the automobile was about twice as energy intensive as public transportation on a passenger kilometer basis.

Combined housing and transportation costs – In chapter 6, we were able to estimate how private household transportation spending varied by public transport accessibility. This is only one term of the equation though of overall affordability with housing being the other major cost of living expenditure that varies by location. Efforts to integrate transportation and housing costs would be the logical next step in analyzing cost of living affordability throughout London.

7.4. Conclusion

From our findings in this research, we see significant opportunity for the London region to achieve a more financially efficient transportation system. In the short to mid term, prices need to better reflect marginal decisions – for example, a shift to pay as you drive insurance, policy that replaced road taxes with a pay as you drive toll, and greater internalization of parking costs would replace fixed or hidden costs of the automobile system with tangible variable costs. In the long-term, public authorities must realize the private expenditures on automobiles and parking are relatively large compared to the public spending on roadways and that this private spending must be considered in allocating resources between the automobile and public transportation.

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APPENDIX B: LIST OF ACRONYMS

DfT: Department for Transport

FY: Fiscal Year

GLA: Greater London Authority

LATS: London Area Travel Survey

MCD: Mobility in Cities Database

PT: Public Transportation

PTAL: Public Transport Accessibility Level

ONS: Office of National Statistics

SMMT: Society of Motor Manufacturers and Traders

TfL: Transport for London