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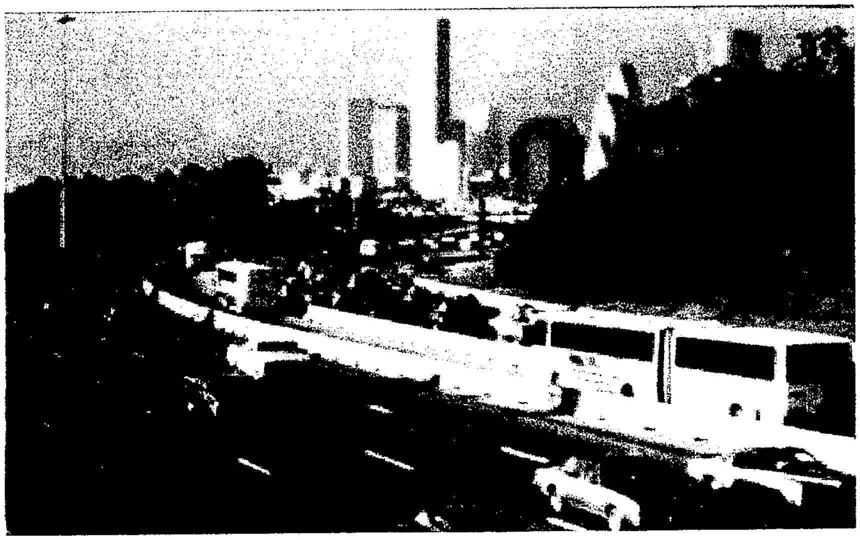
Transit Benefits 2000 Working Papers

A Public Choice Policy Analysis



An FTA Policy Paper

Office of Policy Development
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16. Abstract

This FTA Policy Paper reflects FTA's continuing effort to develop professional literature on transportation benefits and their measurement. It presents a public choice approach to measuring the benefits of transit's ongoing impact on policy goals pertaining to 1) traffic congestion, 2) affordable mobility, and 3) location efficiency. This approach is a work in progress offered to encourage more research along these lines. The working papers offer suggestions on how to translate public support for transit into the budgetary process through benefit measurement. The papers apply new research to measure transit benefits in a public choice analytical framework. In this report, researchers constructed a public choice transit benefit matrix, and cross tabulated transit's three public policy functions (low-cost mobility, location efficiency, congestion relief) against three benefit classes (market, class, spillover). Simply put, transit benefits are measured in terms of transit's impact on these three public policy functions for transit passengers and local taxpayers. In serving each function, transit produces benefits for fare-paying passengers (market benefits), local taxpayers (club benefits), and state and federal taxpayers (spillover benefits). This departure from the traditional planning framework yielded remarkable new empirical findings on the worth of transit benefits to passengers and taxpayers alike. Overall, this report consist of six chapters. It provides a historical review of transit policy analysis, and several congestion measures, including strategic transit corridor performance, and a sound methodological framework for estimating the effect of the proximity of transit on commercial property values..

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Preface

The research presented here represents the Federal Transit Administration's (FTA) continuing effort to develop the professional literature on transportation benefits and their measurement. These studies apply new measurements to the benefits of public services in the United States, particularly public transit services. The approach a work in progress, so these are truly working papers, offered in the hope of encouraging more research along these same lines.

In recent years the American policy process at all levels of government has become increasingly sophisticated in transportation issues. This is the result of the increasingly evident clashes that transportation problems and policy options generate in our communities. These political and budgetary "clashes" are also transactions in which measurable benefits are exchanged for tax revenues. The theory of public choice applied to transit here and in a recent book[1] offers a disciplined approach for cataloging the transactions that shape transportation services.

Through research such as this, public sector budgets for transit can be illuminated not only for professionals and citizens, but for the decision-makers themselves. It is our hope that local decision-makers will look into our research and see familiar patterns that routinely arise in the budgetary process for transit. They might see for the first time a means by which to weigh quantitatively the competing goals that the process sets for transit services.

Public transit is widely supported throughout the United States. Intuitively, policy-makers and citizens recognize or at least suspect that transit generates large benefits. The measurement of these benefits, however, has eluded even the most dedicated students of the subject. In political environments increasingly hungry for benefit measurements with which to compare costs, even the strongest public support falls short.

These working papers offer suggestions by which the public's support for transit can be translated into the budgetary process through the influence of benefit measurement that is not only credible and rigorous, but has intuitive appeal as well. As most people suspect, the diversion of motorists onto rapid transit does indeed improve the flow of congested highways. The benefit is demonstrable and its real dollar value is measurable. Similarly, as most people suspect, cities with intensive transit services achieve economies that make their citizens richer—and this effect is measured in these chapters.

The magnitudes of benefits uniformly exceed transit costs, whether those costs are paid through fares or taxes.

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[1] *Policy and Planning as Public Choice: Mass Transit in the United States*, by David Lewis and Fred Laurence Williams, (Aldershot: Ashgate, 1999).

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This research was conducted by the firm HLB Decision Economics (HLB) under agreements with the Federal Transit Administration and the Federal Highway Administration. The principal authors are Dr. David Lewis and Dr. Khalid Bekka, respectively President and Vice President of HLB. The project manager for FTA, Dr. Fred Laurence Williams, Office of Policy Development, compiled the research, wrote Chapter 1, and prepared this report.

Other HLB contributors included Daniel Brod, Stephane Gros, Sergio Kurlat, and Bruno Penet. Arlee Reno, Cambridge Systematics, advised on the project. Other participants were William Sumner (HLB), John Mason and Mark Swedenburg (SAIC), and Raymond Ellis (KPMG).

KPMG contributed to the work in transit's commercial and economic benefits, with assistance from Arthur Jacoby, Office of Policy, FHWA. SAIC contributed to the corridor measurements, with assistance from Wayne Berman, Office of Intelligent Transportation Systems, FHWA.

The authors wish to thank Gordon J. Linton, former FTA Administrator, and Ms. Nuria I. Fernandez, Acting FTA Administrator, whose policy research interests led to this publication.

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Executive Summary

Introduction: Transit Costs, Benefits, and Performance

Historically, the performance of transit services in the United States has been judged by patronage, efficiency, and other measures that pertain to the internal and system economies of transportation organizations. Except for project planning forecasts, the value of transit's ongoing impact on policy goals pertaining to traffic congestion, affordable mobility, and location efficiency has seldom been measured. A recent book, *Policy and Planning as Public Choice: Mass Transit in the United States*, (1999) reported on extensive new Federally-sponsored research to measure transit benefits in a public choice analytical framework. This departure from the traditional planning framework yielded remarkable new empirical findings on the worth of transit benefits to passengers and taxpayers alike.

The present report compiles subsequent FTA research in the same vein. FTA refined its method for calculating transit impacts on auto corridor and network travel times, and this method permits economic valuation. Also, a technique is introduced to facilitate periodical calculations based on changes in corridor traffic volumes. The calculation of transit's location efficiency benefits is extended from residential to commercial properties. We will report on hedonic analysis of commercial property and also the calculation of region-wide agglomeration economies.

The Public Choice Transit Benefit Matrix provides the policy-oriented analytical framework for this effort. It is displayed with illustrative measurements in Exec. Table i below.

Exec. Table i Public Choice Transit Benefit Matrix

	Public Choice Transaction Category		
Transit Policy Function	Market	Club	Spillover
Affordable Basic Mobility	*Low Fare*	*Social Budget*	*Labor Market*
Location Efficiency	*Save Auto Cost*	*Density Econ.*	*Less VMT*
Congestion Management	*Bypass Traffic*	*Less Traffic*	*Road Budget*

The estimated net national benefits of transit for 1995 are presented in Exec. Table ii, indicating that benefits exceed costs and, perhaps more importantly, the net benefit depends on the market niche or policy functions in behalf of which transit services are deployed. Transit's costs, that is, vary according to service profiles that vary with the function transit is performing. Since relatively "flat" fares prevail across the transit functions, the resulting subsidies vary according to policy function as well. Moreover, the economic value of trips to passengers also varies by policy function, so that the value of user benefits from a basic mobility trip may be twice that of a congestion bypass trip.

However, without a calculation of transit benefits to local, State and Federal taxpayers, the net benefit reported in Exec. Table ii would be misleading. Subsequent chapters report measures for these non-passenger benefits, including travel time benefits to motorists, location benefits for commercial property, and regional efficiency and productivity economies.

Exec. Table ii Per Trip Summary of Transit's Performance, 1995

Transit Policy Function	Cost	Subsidy	User Benefit*	Net User Benefit
Basic Mobility	$ 1.96	$ 1.01	$ 8.40	$ 6.44
Location Efficiency	$ 1.85	$ 0.85	$ 11.66	$ 9.82
Congestion Relief	$ 3.29	$ 2.29	$ 6.37	$ 3.07

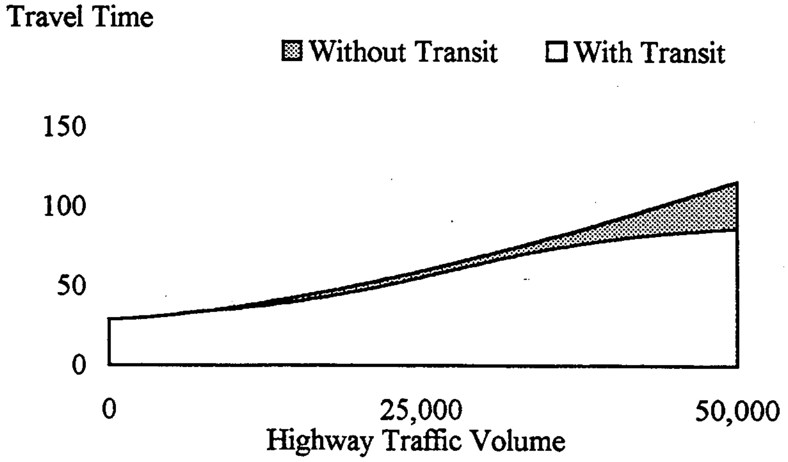
*Table 1.8 in the main text.

Source: FTA analysis of 1995 NPTS Database.

Standardized Measurement of Strategic Transit Corridor Performance

The Federal Transit Administration conducted door-to-door travel time measures, comparing the travel modes. On the basis of these measures, FTA modeled transit's impact on the other modes in the corridor. The models so derived enable researchers to calculate transit's impacts over time relative to changing travel volumes in the corridor. This procedure equips local planners to calculate transit's highway network benefits for the purposes of periodic transportation planning and budgeting.

The network effect of rapid transit in the Washington, D.C. I-270 corridor is illustrated in Exec. Fig. i, where the shaded area represents the time-volume curve if commuters did not have the Washington Metro Red Line as an option to the freeway network. This shaded area translates into person hours the value of which can be calculated from accepted estimates of the value of time.



Exec. Fig. i Transit Impact on I-270, Washington, D.C.

Exec. Table iii displays summary data on network travel time savings for six transit corridors FTA surveyed in 1998 and 1999. The reader will note that the network benefits of transit in Exec. Table iii are arrayed across the same public choice transaction categories used for transit's policy functions earlier. Indeed, taxpayers' stakes in transportation networks parallel their stakes in any public choice budgetary process. The daily travel time savings for transit passengers and motorists in these corridors amounted to over 60,000 hours, worth over $225 million annually. The order of magnitude in these results certainly justify the effort to take similar measurements wherever transit is suspected of influencing highway travel demand.

The six corridors summed up in Exec. Table iii represent only the most recently constructed transit systems—only two have rapid rail systems. Further measurements for the major transit corridors in New York, Chicago, Philadelphia, Boston, San Francisco could prove illuminating. Moreover, this approach might foster periodic updates of transit's local network effects.

Exec. Table iii Network Efficiency Benefits in Six Strategic Transit Corridors, 1999

Savings	Market	Club	Spillover	Total
Daily Hours	17,443	21,981	20,691	60,115
Daily Dollars	$ 261,633	$ 329,728	$ 310,374	$ 901,735
Yearly Dollars	$ 65,408,265	$ 82,431,833	$ 77,593,700	$225,433,798

Transit Benefits Based on Standard Congestion Index and Equilibrium Corridor Dynamics: A Conceptual Framework

Although highway performance monitoring indices track traffic volumes and congestion in urban areas around the country, the measures in use today do not track the effect of transit on highway congestion. Even though congestion management is a key objective of urban transit investment today, there are no indicators that monitor transit 's effect on the performance of urban highways.

This analysis develops a method by which to extend the Texas Transportation Institute's annual congestion index so as to quantify, on a regular basis, the impact of transit on congestion in urban areas. The paper uses FTA's inter-modal equilibrium model and tracking process to generate an algorithm that, when integrated with the TTI index, permits the index to be expressed both with and without the influence of transit.

A test of the method was conducted in two corridors served by urban rail systems. Summarized in Exec. Table iv, the results indicate that the 1999 TTI index for the I-270 corridor in Washington D.C., of 1.72, would have been 1.98 if WMATA's MetroRail had not been in operation. This means that whereas free-flow conditions were exceeded in the corridor by 72 percent during peak periods, free-flow conditions would have been exceeded by 98 percent had MetroRail not been operating. This signifies, as Exec. Table iv reports, that one branch of the MetroRail Red Line saved four million person-hours of delay in 1999. This saving was worth an estimated $62 million in fuel, time and other highway user costs in that year—all at a cost to taxpayers of $25 million. Results are also reported for the Butterfield light rail corridor in Sacramento, California.

Exec. Table iv Texas Transportation Institute Congestion Index for 1999, Extended to Give the Effect of Rail Transit

	Without Transit	With Transit	Difference
I-270 - Washington DC Corridor			
TTI Travel Rate Index	1.98	1.72	- .26
Annual Person Hours of Delay (millions)	15	11	- 4
Annual Cost Due to Congestion (millions of dollars)	247	185	- 62
Butterfield-Sacramento Corridor			
TTI Travel Rate Index	1.49	1.33	- .16
Annual Person Hours of Delay (millions)	2.61	1.75	- .86
Annual Cost Due to Congestion (millions of dollars)	43	30	- 13

Economically Optimal Transit Subsidies in the United States, An Update for 1999

This analysis updates the 1996 paper *"Economically Optimal Transit Subsidies in the United States"* in light of new empirical findings regarding traffic congestion in major U.S. metropolitan areas[2] and new statistics on transit systems across the country. The 1996 report introduced a methodology to determine the economically justifiable level of subsidy for public transit in the United States. Economically efficient subsidies arise in the absence of congestion pricing on the nation's roadways. The quantitative significance of an efficient subsidy hinges on the extent to which transit reduces the congestion externality. This in turn depends on the cross-price elasticity of demand between transit and auto, the magnitude of the social marginal cost of roadway congestion and a range of other elasticity and cost factors.

A total operating subsidy approaching *$19.4 billion* annually (in constant 1997 dollars) is justified, despite very low reported cross-price elasticities between transit and auto travel. For many congested urban areas, in the absence of road pricing, current transit fares are too high to fully exploit transit's ability to help optimize the economic contribution of highway and transit systems.

The changes in the second-best subsidy estimates in Exec. Table v are driven by four principal variables: (i) the change in the demand for auto, bus and rail travel between 1993 and 1997, (ii) the change in traffic conditions on freeways, expressways and principal arterial streets, (iii) the change in operating expenses per passenger mile and (iv) the effect of general inflation.

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[2] Texas Transportation Institute, 1999

Exec. Table v Optimal Operating Subsidy Estimates

Urbanized Area[3]	1996 Report (Millions of 1993 Dollars)	1999 Report (Millions of 1997 Dollars)	Annual Change (Millions of 1997 Dollars)
Boston	812.1	835.6	$ (22.14)
Chicago	1,421.4	1,567.1	$ (3.90)
Los Angeles	1,123.1	1,397.6	$ 50.05
Philadelphia	711.7	866.1	$ 25.20
New York City	6,290.6	7,575.7	$196.19
San Francisco	788.6	1,087.6	$ 70.56
Washington DC	665.3	695.5	$ (14.49)
National Est.	15,995.9	19,383.2	$538.71

Econometric Analysis of Transit and Agglomeration

Here we explore the relationship between transit presence, agglomeration economies and the economic efficiency of cities. Agglomeration economies refer to the decline in production costs due to the concentration of economic activity in a specified geographic area. In this context, the presence of a well-functioning transit system is thought to strengthen the impact of agglomeration economies, and thereby, to help cities function even *better*. This concept helps explain, in particular, why firms and industries located in urban areas tend to be more efficient than firms and industries located in rural areas. By extension, this concept also helps explain why larger cities tend to operate more efficiently than smaller ones. This is the hypothesis that the present analysis proposes to investigate. But, how can transit stimulate urban efficiency?

In congested areas, mass transit is often the fastest and most reliable way for people to move from one point to another. As such, transit facilitates meetings and other face-to-face communications between members of different firms and industries. In other words, transit promotes the exchange of information, ideas and concepts between firms and industries located within large metropolitan areas. By reducing transportation costs and congestion, mass transit also lowers search costs for would-be employees and recruitment costs for employers. It facilitates the transfer of workers across firms and industries and promotes the efficiency of urban labor markets. Improved public services in general, and mass transit, in particular, also attract more workers to a city. This increase in the number of workers will, through the realization of economies of massed reserves ("economies from selecting workers from a larger pool") benefit the firms located in a city. Finally, because transit reduces congestion costs, it facilitates the concentration of economic

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[3] As defined in the 1997 National Transit Database, Federal Transit Administration

activity. Other things equal, transit enables a higher degree of agglomeration which in turn results in higher productivity and stimulate economic growth.

The methodological framework proposed by HLB allows testing for the existence *and* the magnitude of the postulated impact of transit presence on agglomeration economies and the economic dynamism of cities. To perform the analysis, a sample of one hundred U.S. metropolitan areas has been selected. These metropolitan areas represent about 68% of the U.S. population and produce 73% of the U.S. Gross Domestic Product.[4] They are spread over different geographic regions in the U.S.

The analysis conducted by HLB consists of estimating the coefficients of a multi-variable relationship between urban efficiency on one-hand and city characteristics, including a measure of transit presence, on the other hand. The analysis has led to the conclusion that part of the productivity of large cities is indeed attributable to the presence of mass transit. In other words, it indicated that cities with more transit tend to be more efficient than cities with less transit. This finding has been validated by various statistical tests.

The findings of this analysis are summarized in Exec. Table vi. As the table indicates, the estimated impact of transit presence is relatively small. The impact, however, has been validated through various advanced testing procedures. All the tests have led to the conclusion that, indeed transit does help stimulate the economic efficiency and growth of urban areas in the United States.

As mentioned above, the technique used by HLB also allows quantifying the extent to which transit presence contributes to urban efficiency. The data indicate, in particular, that a 10 percent increase in transit presence, which represents about 50 extra vehicles (or about 620 extra employees in the transit sector) would raise labor productivity by about 0.4 percent annually. This increase in labor productivity would, for an average metropolitan area[5] (which, in 1996, had about 1.7 million habitants and produced about $55.9 billion worth of goods and services), create about $195 million worth of value added per year, which is about $192 per worker[6].

Furthermore, a simple model of economic growth brought support to the hypothesis that transit promotes economic growth. The analysis indicates that a 10 percent increase in transit presence would raise economic growth by about 0.2 percent. For an average metropolitan area, this would represent about $36 million worth of goods and services created annually, which is about $36 per worker.

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[4] Based on 1996 data

[5] The universe is about 276 metropolitan areas

[6] The national aggregate effect can be estimated by multiplying the value added per worker with the number of workers, about 127 million worker.

Exec. Table vi Average and Aggregate Annual Economic Impact of Transit Presence in the United States

Change in Transit Presence	Impact	Value Created Yearly due to Productivity Gains	Value Created Yearly due to Added Economic Growth	Total Annual Economic Benefits
+ 1%	Average Effect in a Metropolitan Area	$19.4 million	$3.6 million	$23.0 million
	Estimated Aggregate Effect	$2.4 billion	$0.5 billion	$3 billion
+ 10%	Average Effect in a Metropolitan Area	$194.3 million	$36.1 million	$230 million
	Estimated Aggregate Effect	$24.3 billion	$5.3 billion	$30 billion
+ 25%	Average Effect in a Metropolitan Area	$485.9 million	$90.2 million	$576.0 million
	Estimated Aggregate Effect	$60.9 billion	$13.2 billion	$75 billion

Commercial Property Benefits of Transit

The purpose of this study was to develop a methodology for estimating the impact of the proximity of transit on commercial property value. This report provides (1) a detailed review of the existing literature on the topic, (2) a sound methodological framework that can been used to actually measure the impact of transit on commercial properties and (3) an estimate of this impact for a specific area.

A careful examination of the literature leads to the conclusion that the hedonic pricing methodology is one of the--if not the--most appropriate methodology for this type of study. A hedonic price model expresses the value of a commodity as a function of its characteristics or attributes. This approach can be applied to the estimation of the impact of transit on commercial property values by regressing a measure of property value on a set of attributes, including the distance to traffic. The estimated coefficient on this variable can be used to derive an estimate for the benefits of transit.

The empirical part of this study uses data on 2,830 commercial properties located in Washington D.C. The key findings for the Washington D.C. area include:

> The distance to the closest Metro Station always enters the model with a negative sign indicating that, other things being equal, the shorter the distance between a commercial property and a Metro Station, the higher the value of the property. This impact is found significant in most of the regressions.

> Most of our coefficient estimates are reasonable and confirm the findings of the existing literature. In particular, our measure of the distance to the CBD enters the model with a negative - and significant - coefficient.
>
> In our sample, the proximity of a Bus stop does not seem to enhance the value of commercial properties. In some cases, the distance to the closest bus stop even enters the model with a coefficient significantly greater than zero. This counter-intuitive result can partly be explained by the way the distance is measured in this particular case study.

Exec. Table vii summarizes the key empirical findings of this study. On average, a 1,000 feet reduction in the distance to a Metro station raises the value of commercial properties by $2.3 per square foot. Given an average property size of 30,630 square feet, a 1,000 feet reduction in the distance to transit increases the average value of a commercial property by $70,139 or approximately 2%. Since this estimate is based on a sample of commercial properties observed at a given point in time (a cross-section analysis), it should not be affected by the business cycle.

Exec. Table vii Property Value Impacts of Transit

	Value Increase Per Square-Foot	Average Value Increase
1 Foot Decrease	$0.002	$70.1
1,000 Feet Decrease	$2.290	$70,138.5

HLB has determined that there are about 11,000 commercial properties in Washington D.C. Therefore, if the average distance to a Metro station were to fall by 100 feet other things equal, the commercial properties located in Washington D.C. would enjoy a *total* premium of approximately $71 Million.

Chapter 1. A Brief Review of Historical Transit Policy Analysis

The Specter of Transit Costs

Historically, policy analysts have examined the performance of transit investments and expenditures in the framework depicted in Figure 1.1. Efficiency is measured as service units per unit of cost or inputs. Effectiveness is measured as the number of "sales" per service unit. Cost–effectiveness is measured as costs per "sale". This straightforward scheme has served to organize the analysis of transit's *internal* performance. It is a framework that accepts as given the goals ("sales" or "patronage") established by or attributed to policymakers and restricts itself to the economic performance of transit in reaching these legitimate goals.

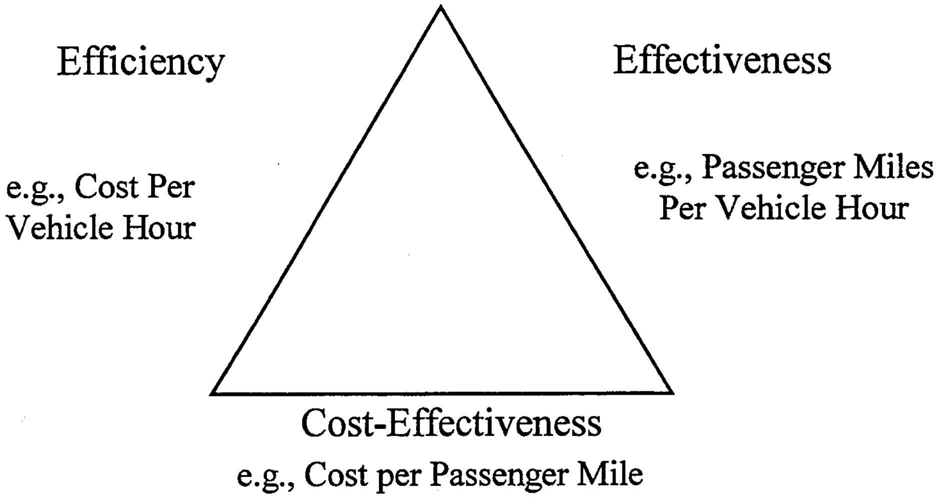


Figure 1.1 Framework for Transit Performance Analysis

During the 1970s and early 1980s, when large Federal financial aid to transit agencies was growing, this "performance framework" was used repeatedly to analyze the merits of transit expenditures at the national aggregate level. Consistently, the studies found that the influx of new funds resulted in lower efficiency and effectiveness. Generally, fare reductions and service expansions were significant. But, just as significant was "leakage" of resources into higher labor costs, reduced productivity, and decreased "sales" per service unit. These findings were reported regularly in Federal reports, in professional publications, and in the news media. Indeed, the idea that government transit subsidies created as much leakage as passenger benefits became the conventional wisdom throughout the transit industry. As stated by Douglass Lee:

> The growth in transit operating costs during the 1970s greatly exceeded the rate of inflation, and the reasons for this growth seem to be more closely related to government subsidies than to other facts either external or internal to the industry. (1983)

In creating the analytical framework sketched in Figure 1.1, transportation professionals "operationalized" the goals they perceived to be coming from transit policymakers. Specifically, the professionals translated economic and social goals into objects that could be measured on the transportation network. Obviously, they reasoned, benefits resided in the passengers of the transit system, and the dollar value of transportation policy goals could be captured in the mileage or time-savings afforded to transit passengers. A 1983 report illustrates this point of view:

> Most of the goals stated as rationales for federal operating subsidies depend upon increasing transit ridership while reducing auto travel, but because the subsidies had a minor effect on ridership they had even less effect on these indirect goals. (1983)

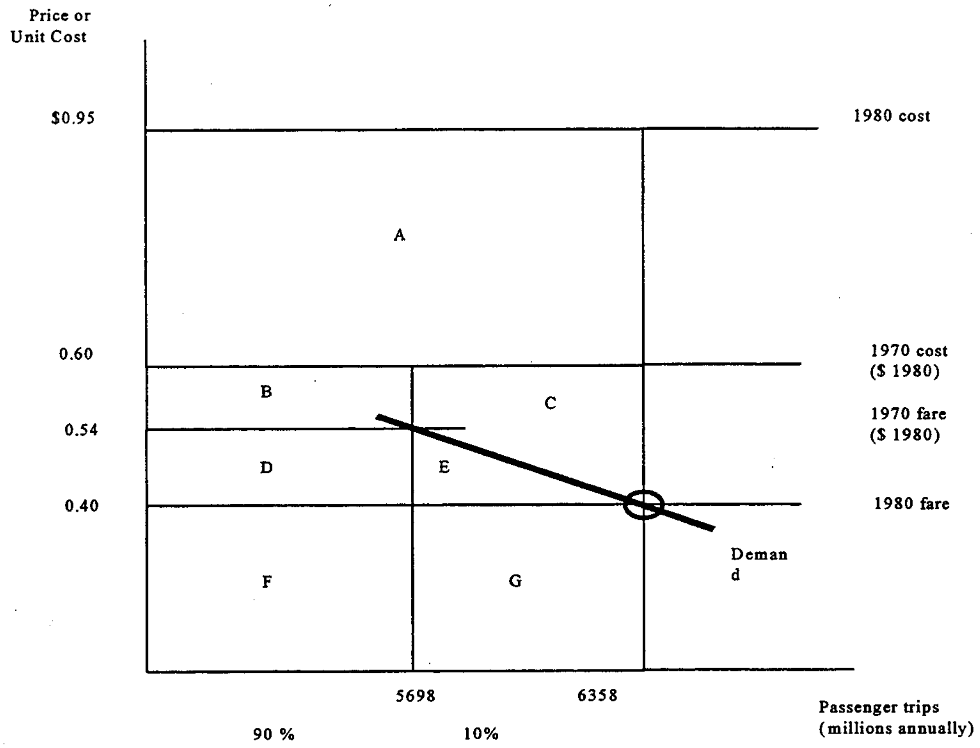
Numerous policy analyses of transit and transit subsidies were conducted in the late 1970s and early 1980s. They were commissioned in response to a widely held perception that transit costs were out of control. Two basic methods were used, both relying on patronage as the ultimate measure of transit performance. One method was known then as an "accounting approach." A unit of output or outcome, such as patronage, or average transit labor costs, was measured before and after an increase in revenues. Changes in the "after" measures were intepreted as being "where the money went." If, in the second measurement, fares were lower and patronage higher, these were considered transportation improvements. Higher labor costs or lower output per person-hour were considered "leakage" of the new monies.

One accepted version of the accounting framework is presented in Figure 1.2. The circled point in the diagram is the aggregate average fare and ridership for bus and rail transit in the U.S. in 1980. The next horizontal line up is the "before" fare, with no federal operating subsidies and only modest local subsidies. Above that is the efficient or base cost per trip, and the highest line gives the actual average cost per trip. Applying an elasticity of -.3 yields the intersection of the demand curve with the higher fare. The following explanation was offered for Figure 1.2:

- [Area "A"] represents the payments to factors of production that were above what was "needed" to produce the service, either because the factors were overpaid or because they were underutilized.
- [Area "B"] is the subsidy to "old" passengers at the efficient cost and the old fare level, while
- Area D is the additional subsidy to old passengers stemming from reduced fares.
- Area E is the incremental consumer surplus from "new" or induced riders, and
- Area C + E is the subsidy to induced riders at the efficient cost.
- Areas F and G indicate the fares paid by the two groups.

An examination of Figure 1.2 reveals no account for changes in service costs associated with service improvements. Rather, the diagram rests on the assumption that the average unit of transit service in 1980 has the same composition of factors of production as in 1970. This assumption rests on a premise that in the absence of Federal and other subsidy increments during the 1970 transit service levels and patronage would have stayed constant.

If this accounting method were classified as an experimental design, it would be classed as the "one-group pretest-posttest design" wherein one measurement is followed by a second measurement after a period of time. The period of time is selected because it includes the intervention of an explanatory variable, in this case the advent of Federal operating subsidies. Campbell and Stanley (1963) consider this design barely worth doing since it leaves numerous rival hypotheses uncontrolled. In the instance, in Figure 1.2, the introduction of subsidies was only one among a number of events that plausibly could explain large changes in transit's cost structure. Two successive national energy crises, near bankruptcy and bail-out of New York City, sharp inflationary pressures, and major transit service redeployments all affected transit costs during the 1970s. In addition, Figure 1.2 glosses over obvious ongoing historical trends affecting transit patronage and costs, trends well underway before 1970. Most significantly, the historical increasing trends in auto ownership and decentralization undermined transit and would naturally undermine the implicit null hypothesis that transit costs and patronage would have stayed the same in the absence of the financial events of the 1970s.

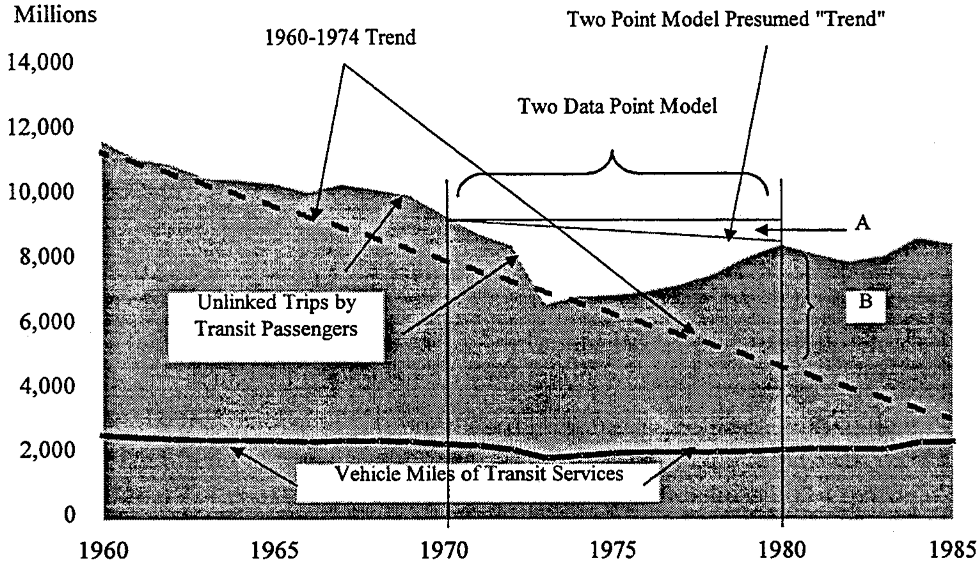


Source : Douglass B. Lee, "Evaluation of Federal Operating Subsidies to Transit," Report to Federal Transit Administration by Transportation Systems Center, 1983, Figure 1.

Figure 1.2 Partition of Transit Expenditures for Accounting Framework

In actual fact, as demonstrated in Figure 1.3, during the 1970s transit service and patronage first plunged and then climbed back, thanks in part to the incremental subsidies. To achieve this recovery, the transit industry re-deployed transit services, resulting in a marked shift in the composition and therefore the cost per unit of service. Most importantly, services were re-deployed for commuters from the suburbs. Transit patronage in costly peak-period services between suburban residential areas and central cities increased by over 50 percent in the 1970s. Transit planning and marketing employment increased, and maintenance costs increased with the increase in higher quality air-conditioned vehicles. Therefore, rather than signifying "overpaid" or "underutilized" factors, some part of area "A" in Figure 1.2 represents improved transit services, a measurable change in the transit's "production function."

Figure 1.3 plots the 1970-1980 trend line addressed in Figure 1.2--based on two data points--against the annualized trend in transit patronage. Transit's patronage trend, based on average change from 1960 to 1974 is extrapolated to 1985. Figure 1.2's discussion of patronage (and by implication, service) is confined to the area designated as "A" in Figure 1.3, premised on the notion that patronage would have remained essentially constant in lieu of subsidies. In fact, the trend was sharply downward, requiring serious change to reverse the actual trend. Thus, Area "B" in Figure 1.3 reflects the costly transformation from an industry in long term decline to one of growth and, after 1982, stability. The costs of this transformation surely included some "leakage" into higher compensation and lower productivity. But the lion's share of the transformation costs were devoted to improvements in equipment and services as measured by longer trips in higher quality services, discussed more fully below. There simply is no category in Figure 1.2 to count these service improvements, so their costs are dismissed as "overpaid" or "underutilized" factors of production.



Source: Calculated by the auther from FTA, National Transit Database and APTA, Transit Fact Book (1991).

Figure 1.3 Historical Transit Patronage and the Two Observation Model

The story suggested in Figure 1.3 is more subtle than one of misplaced largesse. Rather, it is a story of transformation in which transit efficiency and service qualities improved, winning the financial support of local constituents and restoring equilibrium in transit patronage. Why were these subtleties overlooked?

In addition to weaknesses in the design of these studies themselves, there were significant lapses in the comprehension of public policy. Apart from the usual ideological material that influenced some transit research, there were dubious assumptions from research folkways.

One important custom was the widespread assumption among researchers that tax dollars held a lower value to transit managers than "earned" fare revenues. Tax dollars were often considered "found money" that a transit manager, it was assumed, was more likely to squander than fare dollars earned from the transit fare box. On more than one occasion, transit managers were said to be "addicted" to Federal subsidies, as if a manager's character was undermined by Federal transit legislation.

Seldom considered was the testable proposition that local tax dollars were tied to service constituencies who insisted on more services for more subsidies. Few analysts considered the probability that Federal dollars might be *more* highly valued and guarded because, apart from Federal guidelines, Federal subsidies carried no constituency strings. Indeed, one researcher found, from multiple regression analysis, that dedicated local tax dollars "worsened" performance while Federal subsidies did not.[7] He speculated that this was due to uncertainty of the Federal dollars. That the Federal dollars were free from local "political" constraints and thus, more importantly, Federal dollars were available for more business-like expenditure, was overlooked. The implications would have been the opposite from those deduced from the "found money" theory.

The policy conclusions from the transit cost studies conducted between 1975 and 1983 became transit conventional wisdom and so remained. Subsequent Federally-sponsored studies to test logical inferences from those cost studies did not always work out as expected. For instance, studies in the mid-1980s of transit compensation for workers and senior management failed to demonstrate incomes higher than other public employees. An accounting cost study that was expressly designed to capture change in the trends, i.e., with more than two observations in time, demonstrated that transit cost problems were greatest in the period *before* Federal subsidies. When the accounting approach was used on individual transit systems rather than on pooled data, the pooled cost patterns vanished.

Where Did the Resources Go?

Sometimes, it costs money to save money. As Table 1.1 shows, the "rescue" of the U.S. transit industry during the period of increased Federal assistance, especially the operating assistance program beginning in 1975, may have been driven by efficiency improvements. Although productivity and cost trends after 1975 were not yet in the black, they were a decided improvement on the same trends before 1975. After 1975, compensation per employee increased (14 percent) at less than a third the rate before 1975 (54 percent). After 1975, expense per passenger increased (20 percent) at the less than a third the rate before 1975 (73 percent).

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[7] Robert Cervero, "Cost and Performance Effects of Transit Operating Subsidies in the United States," International Journal of Transport Economics, Vol. X, No. 3 (December, 1983).

Table 1.1 Transit Cost Analysis Before and After Federal Operating Assistance

	Percent Change (Adjusted for Inflation)	
	1965 - 74	1975 - 84
Avg. Annual Federal Operating Assistance	0	$800 Million
Compensation per Employee	54	14
Transit Service per Employee	-10	-7
Expense per Transit Vehicle-Mile	87	30
Expense per Transit Passenger	73	20
Vehicle Miles of Transit Service	-5	8
Passengers per Vehicle Mile of Transit Service	-21	8
Average Fare Revenue per Passenger	20	-13

Source: Don H. Pickrell, "Developments in the U.S. Transit Industry Under the Federal Operating Assistance Program," Paper prepared for the Federal Transit Administration, (1985), Table 2.

In addition to addressing efficiency problems, in the late 1970's, the transit industry was laying down the infrastructure for a seismic shift in its market. This bore fruit in the ensuing decades when the transit patronage balance (in miles) shifted from bus to rail services. Figure 1.4 shows the patronage shift from bus to rail between 1980 and 1997.

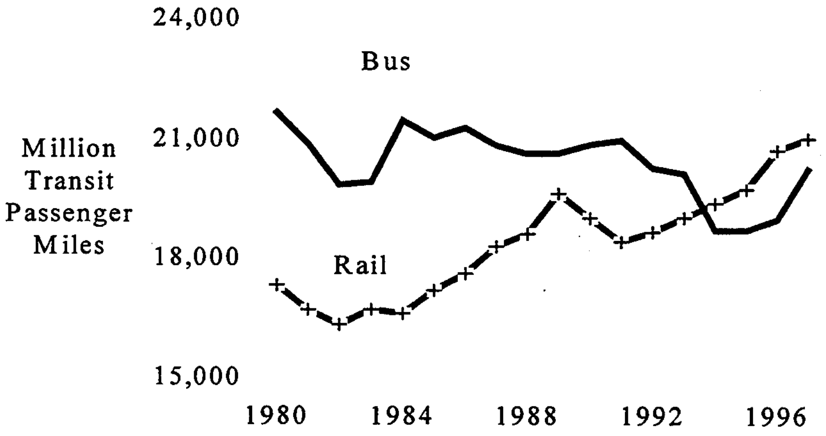

Figure 1.4 Trends in Transit Patronage by Mode, 1980 to 1995

Source: American Public Transit Association, *Transit Fact Book,* 1980-90 Editions.

This transition occurred despite the fact that the total capacity of rail services in 1997 amounted to only 55 percent of comparable bus capacity.[8] Noteworthy too is the up-tick in bus patronage in 1997, when the introduction of electronic fare media in New York City suddenly reduced the average fare for short trips.

The shift to rail paralleled a shift in average trip length, as shown in Figure 1.5. The transit industry recorded a 14 percent increase in average transit trip length in just the 13 years between 1984 and 1997.

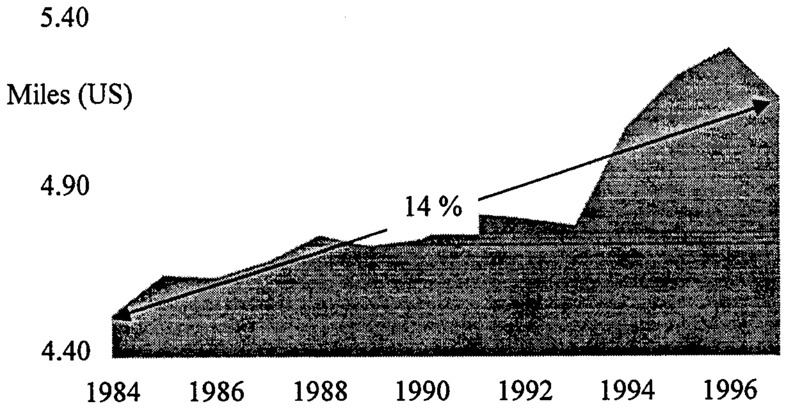

Figure 1.5 **Average Transit Trip Length, 1984 to 1997**

Source: American Public Transit Association, *Transit Fact Book*, 1999

The dividends for this transit "revolution" are suggested in Figure 1.6. During the 1970s and 1980s the number of suburban residents commuting via transit to central city jobs increased at the expense of central city residents commuting to central city jobs (commuting on transit to suburban jobs is negligible). This achievement required competing head to head against auto travel in congested corridors, counting on the travel time advantages of rapid transit services. Owing to their expense, such services required the financial support of motorists who did not use transit, but who would recognize the beneficial effects of competitive rapid transit in lessening traffic congestion.

In recent years, public transit has been viewed in many quarters almost exclusively as a means to combat traffic congestion. Transit's value to the economy, however, is not limited to its role in helping to create travel time equilibrium in congested urban corridors. The benefits of transit are just as great—and often greater—in its other economic roles.

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[8] Defined as total hours operated per vehicle times the number of vehicles, with various vehicle capacities normalized by appropriate weights. APTA, *Transit Fact Book*, 1999, Note to Table 40.

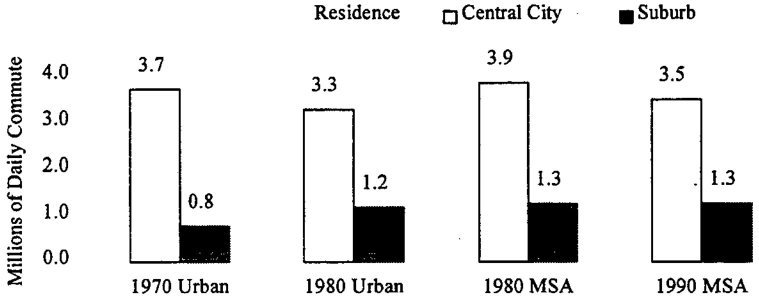


Figure 1.6 **Daily Journeys to Work on Transit to Central City Jobs**

Source: Author's Analysis of U.S. Census Data

Transit's Public Policy Functions

Public transit services in the United States perform a number of services that can be summarized in three public policy functions for transit passengers and local taxpayers. These functions recur and persist in communities throughout the U.S. First, transit provides *basic mobility* for households that cannot afford a car, for children and elderly people who cannot drive, and for persons with various disabilities that interfere with safe driving. This niche is defined in Table 1.2 as passengers from households with incomes below poverty (less than $6,000 per person) and passengers under 16 or over 74. Working age passengers with above poverty household incomes who choose not to own automobiles are classified as looking to transit for its *location efficiency* benefits. Finally, working age passengers with above poverty incomes with one or more cars in their possession are classified below as looking to transit for *congestion relief.*

Table 1.2 **Operational Definitions of Transit Market Niches**

	Poverty	Vehicle Ownership	Age
Basic Mobility	Below	All Categories	Not 16 - 74
Location Efficiency	Above	No Autos Owned	16 to 74
Congestion Relief	Above	One or More	16 to 74

Using these definitions, Table 1.3 indicates that basic mobility accounted for 2.6 billion passengers (linked trips) in 1995, or 40.1 percent of total transit passengers. Location efficiency accounted for nearly 1.7 billion or 25.3 percent of total patronage. Congestion management accounted for nearly 2.3 billion or 34.7 percent of transit patronage.

The different market niches evidence a diverse pattern of transit use, as shown in Table 1.4. Only 20 percent of the transit trips made by the basic mobility group were for worktrips, as contrasted with 38.8 percent of the trips made by the location efficient group and 58.6 percent for the congestion management group. For basic mobility, transit serves a wide variety of mobility purposes. The variety of purposes is less for location efficiency because more of its purposes are served by neighborhood walk trips. Worktrips dominate for congestion management, where non-discretionary travel needs during peak congestion periods make rapid transit an appealing alternative to the private car.

The average trip distance for basic mobility, 10.2 miles, is similar to the average auto trip distance in the U.S. The average trip distance to bypass congestion is twice as long, reflecting the appeal of rapid transit particularly for lengthy journeys to work. Transit trips are shortest for location efficiency, reflecting transit's role of distributing passengers across and around central neighborhoods and commercial centers.

Table 1.3 Public Policy Functions of Transit Services

	Linked Trips		
	Observations	Expanded	Percent
Basic Mobility	2,741	2,632,597,145	40.1%
Location Efficiency	1,869	1,659,773,575	25.3%
Congestion Relief	2,779	2,277,805,482	34.7%
Total	7,389	6,570,176,202	100%

The relatively high share of basic mobility trips (82.9 percent) on buses as compared to the other groups (60.1 and 57.3 percent, respectively) reflects the preference for modes other than the bus as incomes (and choices) increase. As a measure of ethnic homogeneity, the share of passengers from households that identify themselves as "white" is lowest among the basic mobility niche (30.5 percent) and greatest in the congestion management niche (59.1 percent). The proportion of "whites" among the location efficiency group in 1995 was 40.1 percent. Thus, by trip purpose, trip distance, mode choice, and ethnic or racial diversity, each of the three market niches is significantly different from the other two.

Table 1.4 Characteristics of Transit's Primary Market Niches

	Percent Worktrips	Trip Distance	Percent Bus	Percent White
Basic Mobility	20.0%	10.2	82.9%	30.5%
Location Efficiency	38.8%	6.9	60.1%	40.1%
Congestion Relief	58.6%	21.0	57.3%	59.1%

Source: FTA analysis of 1995 NPTS Database.

As implied by the foregoing information on income and preferences, transit's three different market niches demonstrate different expectations or "tolerances" for transit performance. Table 1.5 shows the difference in wait times and reliability across the three niches. The relative "dependency" of the basic mobility group is evident in a much higher tolerance for delay (12.1 minutes) and unreliability (13.6 minutes) than is evidenced by the other two groups. People with an auto alternative, using transit to avoid traffic congestion, have average wait times of 7.3 minutes, with 9.3 minutes in variation. Similarly, above poverty households without cars experience wait times that are a little longer than those experienced by households with cars and experience a similar reliability factor. These observations are consistent with the professional literature that indicates that higher income groups attach a higher value to time, especially when waiting for a bus or train.

Table 1.5 Transit Performance by Market Niche: Wait Times

	Wait Minutes	Reliability*
Basic Mobility	12.1	13.6
Location Efficiency	8.9	8.8
Congestion Relief	7.3	9.3

*Standard Deviation in Wait Minutes--the higher the number the lower the reliability.

Source: FTA analysis of 1995 NPTS Database.

Table 1.6 presents reflects the degree of crowding in transit vehicles, according to the function transit is performing. As can be seen, transit vehicles are crowded or at least there is insufficient transit seating capacity in all three market niches. Slightly more crowding is experienced by basic mobility passengers, the least by passengers who look to transit as an alternative to their cars. This relative "equality" of crowding reflects transit's perennial need with limited resources to maintain a balance among its three constituencies, in this case making "standees" of passengers without discrimination.

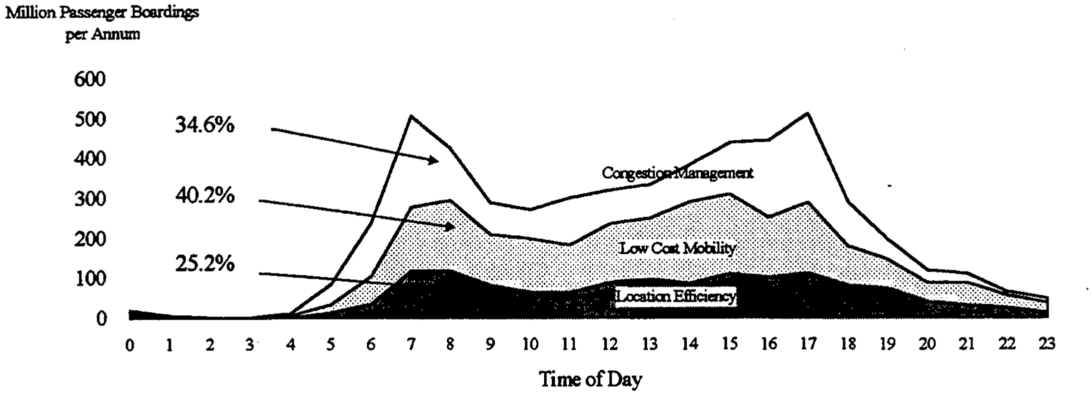
Table 1.6 Transit Performance by Market Niche: Seating Capacity

	Seat Unavailable Upon Boarding
Basic Mobility	29.7%
Location Efficiency	26.3%
Congestion Relief	25.0%

Source: FTA analysis of 1995 NPTS Database.

The following three graphs illustrate transit's cost structure in relation to transit's three market niches. Figure 1.7 arrays transit's three market niches by time of day that each trip originates. The three market niches are shown to demonstrate the cumulative effect of transit travel demand on the deployment of services and their costs. Trips made by the location efficient group, above poverty households without cars, tend to be relatively evenly distributed throughout the day, with a very mild peaking in the morning and afternoon. Trips made by people from below poverty households tend to be a little more peaked during the commuting hours. Transit use by above poverty households with cars contributes the most to the peaking of travel demand.

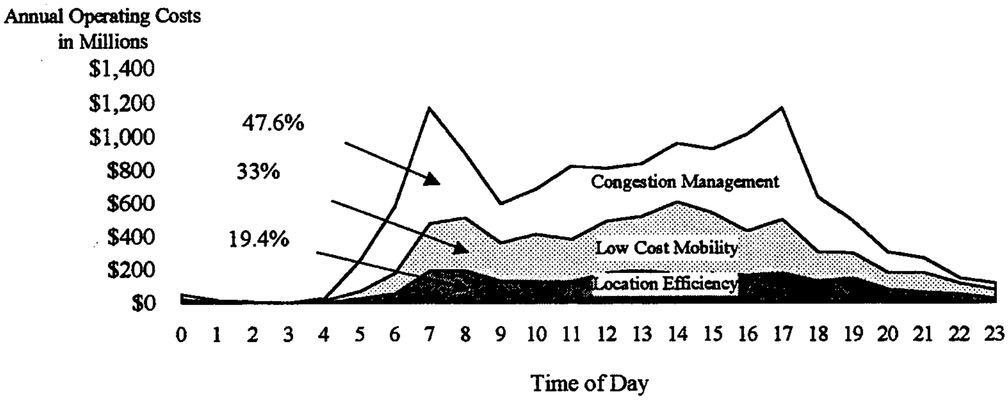
The costs of a transit trip depends on a number of variables. The most important are the time of day (peak or off-peak), vehicle type (bus or rail), and trip distance. Based upon these cost drivers, Figure 1.8 illustrates the relative contribution of each of the three market niches to transit costs in 1995. Transit services for 34.6 percent of trips made by above poverty households with cars account for 47.6 percent of costs. This cost pattern reflects the emphasis that most transit systems place on providing a means for commuters to circumvent congested highways.



*5.4 Billion Reported Trips + 1.15 Billion Missing Trips = 6.5 Billion Total Annual Trips

Figure 1.7 Transit Functions By Time of Day, Boardings, 1995

Source: *Author's Analysis of 1995 NPTS Data.*



*Approximately 21 percent of costs are not classified in this chart.

Figure 1.8 Transit Functions by Time of Day: Costs, 1995

Source: Author's Analysis of 1995 NPTS Data.

Figure 1.9 shows the costs remaining after the subtraction of fare revenues according to transit policy function. These estimates are equivalent to the subsidies that local, State, and Federal taxpayers provided to local transit operations in 1995. The greatest subsidies are incurred for congestion management, where 56.1 percent of public subsidies paid for 34.6 percent of transit trips in 1995. The 40.2 percent of basic mobility trips accounted for only 28.8 percent of public subsidies. Similarly, 25.2 percent of location efficiency trips incurred 15.1 percent of public subsidies.

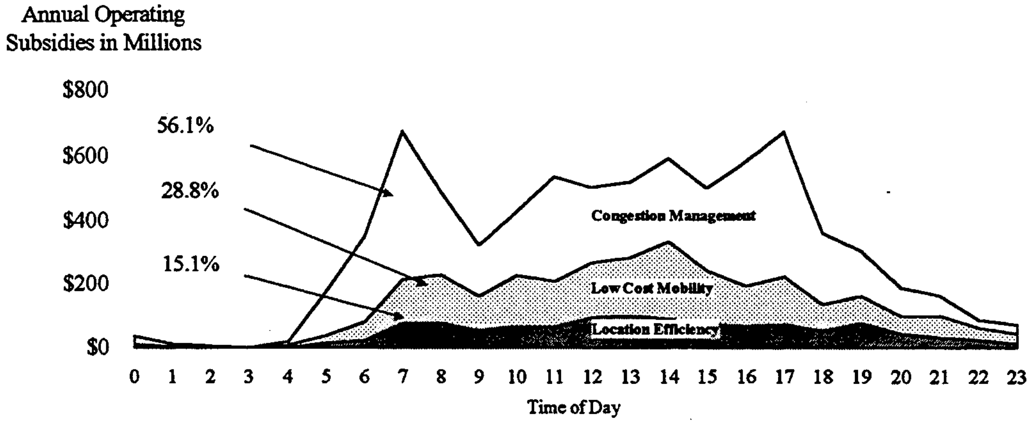


Figure 1.9 Transit Functions by Time of Day: Subsidies, 1995

Source: Author's Analysis of 1995 NPTS Data.

An analysis of transit performance is not complete without an effort to measure benefits. Table 1.7 arrays transit's benefits across the three market niches or policy functions. Using econometric consumer surplus analysis, the benefits of low cost mobility were estimated at $23 billion in 1995 (an amount unlikely to change significantly from year to year). Based on auto ownership cost savings, location efficiency was estimated to be worth $20 billion in 1995. Based on cross elasticities between auto travel on congested freeways and nearby rapid transit, the travel time savings from congestion relief are estimated at $15 billion in 1995.

These are imprecise measurements, representing an aggregation of benefits across a variety of circumstances. However, the scale and relative benefit amounts among transit's market niches are consistent with economic theory and with the willingness of local taxpayers to persistently support transit in serving these niches as worthwhile public policy functions.

Table 1.7 Transit's Estimated Benefits by Market Niche, 1995

	Aggregate Benefits (Billions)	Measurement Used*
Basic Mobility	$23	Consumer Surplus
Location Efficiency	$20	Auto Costs
Congestion Relief	$15	Travel Time

*1993 Estimates (*FTA 1996 Report: An Update*)

Source: FTA analysis of 1995 NPTS Database.

As a summary of the ground covered, Table 1.8 reports the per trip costs, subsidies, and benefits of transit, according to the public policy functions described earlier. With a per trip benefit of $11.66, location efficiency transit services appear to generate the greatest return for the lowest subsidy ($0.85). The total net benefit of location efficiency in 1995 was $9.82 per passenger. Congestion management generated the least net benefit, $3.07. Basic mobility produced a per trip benefit in the intermediate range of $6.44.

Table 1.8 Per Trip Summary of Transit's Economic Performance, 1995

	Cost	Subsidy	Benefit*	Net Benefit
Basic Mobility	$ 1.96	$ 1.01	$ 8.40	$ 6.44
Location Efficiency	$ 1.85	$ 0.85	$ 11.66	$ 9.82
Congestion Relief	$ 3.29	$ 2.29	$ 6.37	$ 3.07

*Table 1.7.

Source: FTA analysis of 1995 NPTS Database.

Conclusion

The transit profession has been focussed on cost control for many years, neglecting the benefits of transit. Much transit policy analysis premised upon a transit cost crisis overlooked the cost to modernize transit organizations, equipment, and deployment. During the 1970s, transit managers wrestled to forge local and fragmented transit services into regional mobility institutions. They not only succeeded in increasing transit's share of suburb to downtown commutes, they did so while simultaneously improving transit's cost structure.

This brief analysis points to a pattern of policy preferences that recurs throughout the U.S. transit industry. The greatest focus of large transit systems, both old and new, has been the relief from traffic congestion. This function attracts the financial support of suburban jurisdictions with many residents who must commute in severely congested travel corridors. Owing to a relatively fixed budget since the early 1980s, the expansion of commuter services has been accomplished by squeezing the budgets of services that support pedestrian-oriented neighborhoods and services for affordable mobility.

Chapter 2. Standardized Measurement of Strategic Transit Corridor Performance

Strategic Transit Corridors

The concept of Strategic Transit Corridors (STC) was developed by the Federal Transit Administration to designate travel routes where patronage on rapid transit services measurably affects the travel times of motorists traveling between similar origins and destinations. In such circumstances, "dynamic travel time equilibrium" between modes is achieved and is maintained daily by travelers "queue switching" between modes. To observe this phenomenon in the U.S., FTA in the early 1990s conducted measurements in 17 corridors that had been screened for their severe levels of traffic congestion. The measurements confirmed the so-called Mogridge-Lewis effect (named for Martin Mogridge who explored these effects in Europe and David Lewis who examined these effects in the U.S.).[9]

In a second cycle, the FTA office of policy development was charged with finding a means to measure effects between modes and to monitor the effects periodically at a lower cost. The expectation is that local planners will undertake periodically to monitor this intermodal effect. Like many other public sector services, transit infrastructure throughout the U.S. is inadequately supported because analysts have depended on crude, unconvincing, and even irrelevant indices of transit performance. More importantly, the most common measures of transit performance do not furnish discrete benefit values with which to align transit costs. The unsurprising result is an perennial budget cycle in which hard and unpleasing cost numbers are compared against hopelessly ambiguous performance measures. Periodic reports on the dollar value of travel time savings that transit services provide to taxpayers, from a methodology developed by FTA, could enlighten the local budget process for transit agencies.

The Equlibrium Model

The researchers developed a modeling approach that begins with a baseline travel time survey to empirically establish the travel time equilibrium conditions and between-mode travel behavior effects (elasticities) in a given corridor. Once in place, the resulting analytical model enables subsequent researchers to calculate transit's changing influence as travel volume changes in the corridor. In other words, with known capacity levels and the equilibrium model for the corridor, the hour savings attributable to the Mogridge effect in subsequent readings could be calculated from volume changes in the corridor, which are readily available from the Highway Performance Monitoring System (HPMS). These hour savings could, in turn, be translated into dollar savings based on accepted estimates of the value of time in the relevant urban area or labor market. Such a capability might appeal to local planning agencies to track the performance of transit and other strategies that are designed to manage corridor congestion.

Public Choice on the Network

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[9] Martin J.H. Mogridge, *Travel in Towns*, (London: Macmillan, 1990).

The travel time savings for the baseline studies are subdivided according to three concepts from the literature of public choice theory. Ordinarily, these concepts are applied globally for all functions a given transit system provides to a society. In this particular application, however, we confined our interest to travel time saving on a multiple mode transportation highway-transit network whose capacity is designed for recurring peak period travel.

In such networks there are three public choice transactions. First, the fare payment transaction between the transit passenger and the rapid transit service is a market transaction. Second, there is a "club" transaction in which travelers to the same destinations as transit passengers willingly support motor fuel taxes dedicated for highway and fungibly for transit capacity. Operationally, that is, recurring "club" auto trips are those for which transit offers a competitive travel time. In exchange for this support, "club" members who are motorists get quicker drives downtown. Third are the "spillover" transactions in which travel time savings on the radial arteries and the transit system spill over to improve conditions on roads and highways not necessarily sharing the same destinations.[10]

Methodology

The study methodology for each corridor consists of four main steps:

1. Collecting highway travel data (traffic volume, distance, travel time, and vehicle occupancy in the corridor); and rail patronage data along the corridor;
2. Conducting door-to-door travel time surveys and deriving the inter-modal travel time convergence;
3. Estimating the "with transit" and "without transit" model and related curves and estimating the hours of delay saved due to transit; and
4. Quantifying delay savings by user category, namely, (i) rail riders ("market" benefits); (ii) common segment users ("club" benefits); and, (iii) parallel highway users ("spillover" benefits).

During the first step, Hickling Lewis Brod Decision Economics (HLB) collected Highway Performance Monitoring System (HPMS) data, local arterial traffic data, and rail patronage data from the local Metropolitan Planning Organization and the principal transit agency. The data were used to estimate the model parameters.

For the second step, data was collected on site by a survey team. A corridor, as defined in this study, is a principal transportation artery into the central business district. Multiple transportation services are available to commuters who use this artery. Additionally, during the peak period a large number of commuters utilize this route in their door-to-door commute.

A statistical sample of trips was generated in the corridor by identifying random trip end points in the zones at either end of the corridor and joining them so that trips alternated between zones. These zones are catchment zones where travelers converge or diverge from either the transit

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[10] This conceptual framework for transit is presented in detail in David Lewis and Fred Laurence Williams, *Policy and Planning as Public Choice: Mass Transit in the United States*, (Aldershot, UK: Ashgate, 1999).

station or the principal highway route. In this study these zones are defined as the access segment and the component of the corridor common to all trips for a given mode, regardless of trip end location, is defined as the common segment.

Survey crews were instructed to follow specific routes that consisted of an access segment--dependent on the catchment zone considered for the trip--and a common segment. The data collected include start times and arrival times for each segment, by mode, congestion level, seating availability, weather, road conditions, and travel costs for each segment.

Data were collected over a period of three or more consecutive weeks. The days of the week were sampled to eliminate fluctuations in traffic patterns and volumes due to the day of week effects. Trips were validated to minimize the effects of unusual or circumstantial conditions. A number of valid trips were selected to ensure a statistically adequate sample size. The study employed the maps and routes connecting several zones within a residential area to several points within the central business district.

Step three consisted of estimating the "with transit" curve based on the traffic volume and the door-to-door travel time. Using the model discussed below, the contractor derived the "without transit" curve and estimated the hours of delay saved due to transit. This performance metric is defined as the vertical difference between the two curves.

In step four, the hours of delay saved due to transit are aggregated into three user categories. Savings by common highway-segment users are estimated using the traffic volume on the segment. Savings by transit rail riders are estimated using the ridership data for each station along the corridor. Savings by parallel highway users are estimated using traffic volume on parallel highways and arterials within the corridor. The magnitude of the savings decreases as the distance between the common segment and the arterial increases.

Methodolgy and Model Overview

The methodology consists of four steps:

1. Estimating the Corridor Performance Baseline
2. Estimating the Corridor Performance in the Absence of transit
3. Extrapolating Delay Savings Due to Transit
4. Estimation of Corridor Performance without Re-calibration

Estimating the Corridor Performance Baseline

<u>The Model</u> This model establishes a functional relationship between the person trip volume –all modes—and the average door to door travel time by auto in the corridor.

The door to door travel time by auto can be determined using a logistic function which calculates the door to door travel time in terms of travel time at free flow speed, trip time by high capacity rail mode, and the volume of trips in the corridor for all modes. The door to door travel time can be estimated as follows:

$$T = (T_c - T_{ff}) / (1 + e^{-(\delta + \varepsilon V1)}) \quad + T_{ff} \tag{1}$$

where T_{a1} is auto trip time,

Tc is trip time by high-capacity rail mode

T_{ff} is auto trip time at free-flow speed,

V is person trip volume in the corridor by auto, and

δ, ε are model parameters

Equation 1 implies that the door to door auto trip time is equal to the trip time at free-flow speed plus a delay which depends on transit travel time and the person trip volume in the corridor.

In other words, when the highway volume is close to zero, travel time is equal to travel time at free flow speed.($T = T_{ff}$). As the volume increases, the travel time is equal to T_{ff} plus a delay due to the high volume, but adjusted to the travel time by high capacity transit. That is the high capacity transit alleviates some of the highway trip delay as some trips shift to transit.

Equation 1 is transformed into a linear functional form before the parameters δ and ε can be estimated, the transformed equation will be:

$$\mathbf{U} = \delta + \varepsilon \mathbf{V}_1 \qquad \mathbf{(2)}$$

where $$\mathbf{U} = \ln [(\mathbf{T}_c - \mathbf{T}_{ff}) / (\mathbf{T} - \mathbf{T}_{ff}) - 1]$$

Equation 2 is estimated using Ordinary Least Squares regression.

Data The data required for the estimation of the above equations are:

- person trip volume on the highway which can be calculated by dividing the traffic volume by the average vehicle occupancy (auto and buses). This data are available through HPMS data base and MPO's traffic data.
- free flow trip time is a constant.
- high capacity trip time is a constant.

The parameters δ and ε do not have to be re-estimated each year, they are both specific to the corridor and are relatively stable over the years. So periodically, the person trips volume can be inserted into Equation 1 to estimate the door to door travel time by auto.

Estimating the Corridor Performance in the Absence of transit

The Model This model represents the concept to quantify the role of transit in congestion management. In the absence of transit, the travel time Ta is estimated as:

$$\mathbf{T_a = T_{ff} \, * \, (1 + A\,(V^*)^{\beta})} \qquad \mathbf{(3)}$$

where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door to door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

- The existing auto and bus person trips on the highway.
- The percentage of person transit trips shifting to auto
- The percentage of person transit trips shifting to bus
- The number of additional cars in the highway
- The number of additional buses in the highway
- The occupancy per vehicle in the absence of transit

The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b \qquad (4)$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor, and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: "Explorers" who are casual switchers and who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost and who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost and who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher the shift of transit riders to cars and buses. Therefore, higher degree of convergence will lead to higher delay, which translates into higher savings due to transit.

In words, Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high which translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve (as the volume increases, travel time increases at an increasing rate). Figure 2.1 illustrates the relationship between the volume and travel time both in the presence and in the absence of transit.

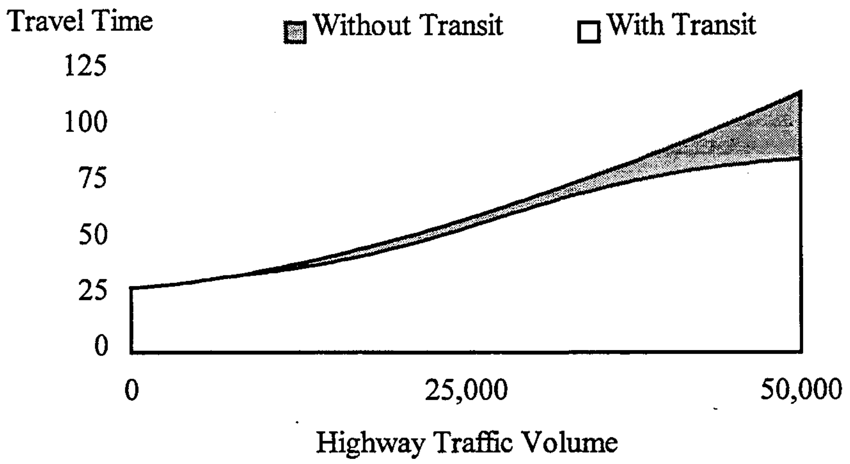

Figure 2.1 Washington, D.C. I-270 and Red Line Corridor Travel Time With and Without Transit, 1998

Source: *Hickling Lewis Brod, Inc., Method for Streamlined Strategic Corridor Travel Time Management, Report to Federal Transit Administration, (Washington, D.C.: U.S. DOT, July 1, 1999).*

<u>Data</u> *The data required to populate this model consist of:*

- Highway person trip volume (used in the previous model)
- Transit ridership data
- Fleet composition (cars and buses percentages out of the total traffic)
- Cars and buses vehicle occupancy
- Passenger car equivalent factor
- Degree of convergence to determine the percentage person trips shifting to cars and buses
- Free-flow travel time which is a constant

Equation 3 is specific to the corridor and does not need to be estimated each year. It will only be necessary to re-estimate them with an updated degree of convergence if a major change is made to the transit level of service or the highway structure.

Extrapolating Delay Savings Due to Transit

While the MLC hypothesis proves to be valid during the peak period only, the delay savings due to transit can be estimated during off-peak as well. This metric can be estimated as the vertical difference between the "without transit" curve and the "with transit" curve. That is at a specific person trip volume, the difference in travel times between the two cases can be defined as "the hours of delay saved due to transit".

The estimated hours of delay savings due to transit are an aggregation of three different user savings: savings by Metro riders (market benefits), savings by highway users (club benefits), and savings by users of parallel highways (spillover benefits).

- The market benefits are estimated based on delay saved (which depends on the distance traveled) for each rider within the common segment.
- The club benefits are estimated based on the volume on the common segment using origin-destination table and the daily trip distribution.
- The spillover benefits are estimated based on the savings per mile, traffic volume, and the distance traveled on segments parallel to the common segment. The spillover benefits are calculated by multiplying the traffic volume with a percentage of the delay savings. This percentage decreases as the distance between the common segment and the parallel highway increases.

Estimation of Corridor Performance without Re-calibration

The framework, presented above, provides an MLC-based approach to making repeated measures of transit-induced savings in corridor delay *without* the need for repeated MLC surveys. The approach rests on the theoretical proposition that a stable and measurable relationship exists between roadway traffic growth over time and the inter-modal (highway-transit) equilibrium dynamics that give rise to delay savings in a congested corridor. In the absence of major changes in the level of highway supply or transit service in the corridor, this measured relationship, or model, provides a formula-based performance measurement system in lieu of a survey-based approach. In addition to the obvious cost advantages, this approach provides FTA with (i) an efficient means of measuring and comparing transit performance in strategic corridors; and (ii) a consistent performance assessment tool for transfer to MPOs throughout the country.

The Survey Data Summarized

Travel time surveys were conducted on the six transit corridors listed in Table 2.1. The Maryland I-270 corridor was selected to test the current methodology against analogous survey data collected in 1994. The I-270 corridor is very heavily traveled, served by a ten-lane interstate highway, a main arterial (SR-355), and heavy rail transit services. For illustrative purposes, the I-270 results are displayed Figure 2.1 above. Except for the Chicago Midway corridor, served by heavy rail, the remaining corridors are less heavily traveled and are served by light rail transit.

Table 2.1 Strategic Transit Corridors, 1998 - 1999 Surveys

Butterfield	Sacramento, CA
North Hanley	St. Louis, MO
Gateway	Portland, OR
Park Lane	Dallas, TX
Washington I-270	Washington, D.C.
Midway Airport	Chicago, IL

To further illustrate the method, data for the Washington, D.C. I-270 Red Line corridor are arrayed in Table 2.2. Market benefits for transit passengers amounted to 10,095 hours saved in 1998. Motorists traveling between similar origins and destinations in the corridor were saved 8,196 hours daily as a motor "club" benefit. Spillover time savings to other motorists on the network were 5,860 hours daily. Translated into dollar values and summed annually, the total network benefit (in time savings alone) amounted to $90 million in 1998. The estimated costs of the Washington Metropolitan Area Transit Authority Red Line for these trips, at $3.66 per trip (1997), totaled about $60 million.

Table 2.2 Washington, D.C. I-270 Red Line Corridor Network Benefits, 1998

Benefit Category	Daily Savings		Yearly Savings
	In Hours	In Dollars	In Dollars
Market Benefits	10,095	$ 151,421	$ 37,855,246
Club Benefits	8,196	$ 122,945	$ 30,736,165
Spillover Benefits	5,860	$ 87,898	$ 21,974,568
Total	24,151	$ 362,264	$ 90,565,978

Table 2.3 summarizes savings over time in the Washington, D.C. I-270 Red Line transit corridor. It illustrates how the model produces new outcomes in response to travel volume change over the three-year period. The benefit amounts in the last column would concisely illumine those moments when local budgets are asked to cover Red Line services.

Row one in Table 2.4 presents the total daily time saving network benefits across the six corridors. The time savings are arrayed according to public choice transaction. In these six corridors, transit passengers saved 17,443 hours daily. By removing these would-be motorists from highway segments with the same destinations as transit, transit saved motorists an additional 21,981daily hours. Other highways on the local network received spillover savings of 20,691 daily hours.

Table 2.3 Summary Table of Delay Savings in the Washington, D.C. I-270 Red Line Corridor Based on the 1994 Convergence Data

	Travel time in the corridor (in minutes)		Hours of delay saved due to transit		
	In presence of Transit	In absence of Transit	per trip during peak period (min)	All user-categories per day (hours)	Yearly Savings in Dollars
1994	71.1	77.8	6.7	23,300	$ 87,375,600
1995	72.3	79.1	6.8	23,950	$ 89,812,666
1996	73.6	80.6	7.0	24,664	$ 92,489,113
1997	74.9	82.0	7.1	25,415	$ 95,307,355

The second row of Table 2.4 translates the daily hour savings into dollars, assuming a $15 per hour value of time during peak highway and transit travel periods. Travel time savings to commuters in these four corridors are over 901,735 per day. Again, most of these savings are to motorists ($329,728 + $310,374 = $640,102) in the six corridors. Based on the typical 250 rush hour days per year (roughly corresponding to 250 work-days), these savings sum to $225 million annually in the six corridors surveyed.

Table 2.4 Network Efficiency Benefits in Six Strategic Transit Corridors, 1999

Savings	Market	Club	Spillover	Total
Daily Hours	17,443	21,981	20,691	60,115
Daily Dollars	$ 261,633	$ 329,728	$ 310,374	$ 901,735
Yearly Dollars	$ 65,408,265	$ 82,431,833	$ 77,593,700	$225,433,798

The Appendix to this report contains the detailed case study reports for each travel corridor.

Conclusion

FTA research has created a new tool for the efficient measurement of network economies produced by rapid transit in congested urban corridors. Establishment of the corridor specific analytical model requires great care. But once in place, the model can be updated regularly with ongoing Highway Performance Monitoring System (HPMS) travel databases. With widely accepted empirical data, the model results can tell decision-makers the dollar value of transit expenditures for congestion management on a periodic basis.

1. The interaction of transportation network components produces a benefit distribution for the network that corresponds analytically to three perennial public choice budget transactions: generalized costs savings for transit passengers in exchange for their fare payments—market benefits;
2. congestion delay savings for motorists with similar destinations, whose motor fuel taxes for highways are also used for rapid transit—"club" benefits; and
3. spillover benefits--time savings for motorists, businesses, and households which rely on other portions of the general network.

Chapter 3. Transit Benefits Based on Standard Congestion Index and Equilibrium Corridor Dynamics: A Conceptual Framework

Introduction

The finding of an equilibrating effect of rail transit on highway and transit travel times suggests that the effect of rail transit on highway congestion can be predicted, and shaped, by transit policy. However, the quantitative relationship between the equilibrium effect and standard measures of congestion indices, has not been identified. The objective of this paper is to establish a conceptual framework within which the standard congestion index and the equilibrium corridor dynamics are used to develop a Transit Performance Index. This transit performance index will indicate the excess delay savings due to transit.

Conceptual Framework

The Annual Mobility Report issued by the Texas Transportation Institute (TTI) provides travel conditions, in the form of congestion indices, in major urban areas in the United States. While the report provides several congestion measures, it does not quantify nor mention the contribution of transit in congestion management in these areas. HLB, however, developed for the Federal Transit Administration (FTA), a performance metric which efficiently measures transit effectiveness in congestion management. The current paper builds on the TTI congestion index, mainly the Travel Rate Index (TRI), to derive a TRI in the absence of transit. To derive the modified TRI, the framework calls for the use of the following variables:

Peak period travel rate for both freeway and principal arterial street

Free flow travel rate for both freeway and principal arterial street

Peak Period VMT

The Convergence data that are based on door-to-door travel time surveys

Using the TTI standard congestion index TRI to derive the TRI, in the absence of transit, provides the following advantages:

TRI in the absence of transit will be consistent with the national standard congestion index TRI

Since the corridor convergence levels are stable over time, TRI in the absence of transit can be updated yearly based on the standard TRI, therefore providing a transit performance trend.

TRI in the absence of transit will be based on the widely accepted HPMS database.

Figure 3.1 illustrates the conceptual framework of deriving the TRI in the absence of transit based on the TTI congestion index TRI.

Plan of the Chapter

This chapter develops the conceptual framework for estimating the delay savings due to transit during peak period in strategic corridors. Following this introductory section, we present the methodology of the index derivation for the corridor both in the presence and in the absence of transit. This includes the calculation mechanism of the congestion index and the process to estimate the index in the absence of transit using the corridor convergence data. The methods material is followed by an example of estimating the transit delay savings. The example shows the index estimation for two corridors, I-270-Washington corridor and Butterfield – Sacramento corridor.

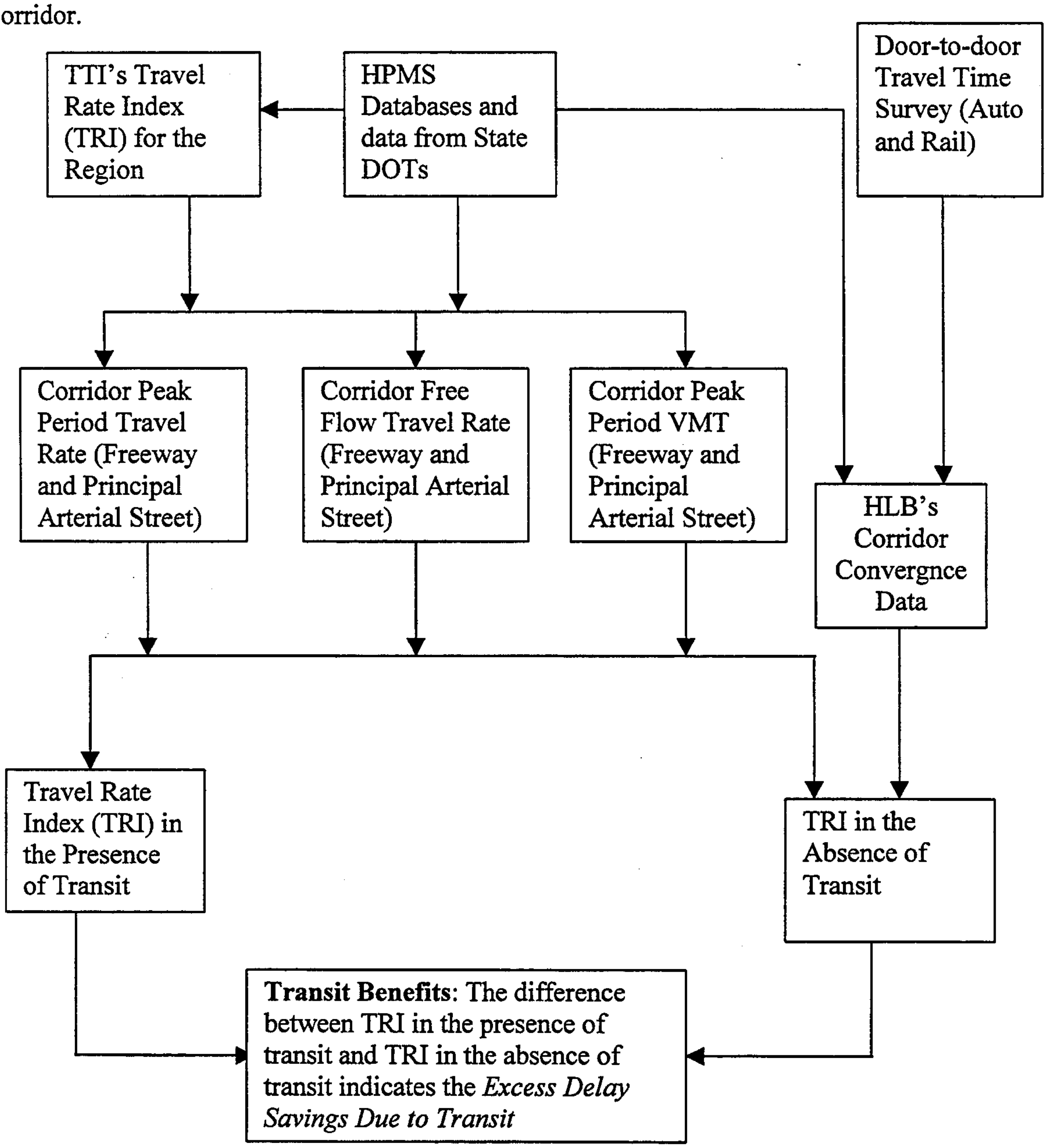

Figure 3.1 Conceptual Framework of the Transit Delay Savings Estimation Based on the Congestion Index and the Convergence Level in the Corridor

Methodology

This section provides the methodology to derive the Travel Rate Index, in the presence and in the absence of transit, based on the standard congestion index calculation and the corridor convergence data. The methodology starts by adjusting the standard TRI for a specific corridor and then uses the corridor convergence, based on the door-to-door travel time survey, to derive the TRI in the absence of transit.

TTI Congestion Indices

In its annual mobility report, the Texas Transportation Institute (TTI) provides a set of congestion measures for about 68 urban areas in the United States. These measures are categorized as individual, area-wide, and trend measures.

Individual measures consist of:

> Travel Rate Index: which is the extra amount of travel time during peak period compared to free flow travel.
>
> Delay per eligible driver and per capita
>
> Wasted fuel per eligible driver and per capita
>
> Congestion cost per eligible driver and per capita
>
> Areawide measures estimate the impact the congestion have on the entire urban area and include:
>
> Areawide annual travel delay
>
> Areawide wasted fuel
>
> Areawide congestion cost
>
> Amount of roadway needed each year to address congestion
>
> Vehicle occupancy change needed each year to address congestion

Trend measures quantify the change in congestion level (measures shown above) for each urban area over the years. The TTI database extends from 1982 to present.

To estimate the transit benefit based on congestion index, this study uses the Travel Rate Index as the basis for the calculation of transit congestion management benefits. TRI is used because it relies on HPMS data, it is estimated based on the travel speed and the VMT during peak period, and it measures the excess delay during peak period. The next section provides a definition of the TRI as well as its mathematical derivation

The Travel Rate Index (TRI)

Definition The Travel Rate Index (TRI) measures the additional travel time that is necessary for an individual to make a trip during the peak period. In other words, TRI measures how much longer it takes to make a trip than would be the case if the trip occurred in free-flow conditions. The TRI equation, shown below, is a weighted average of the peak period travel rates on the freeway and principal arterial streets. The TRI calculation includes an estimate of only the delay due to high traffic volumes that typically occur in the peak period on weekdays.

The TRI equation can be written as follows:

$$\text{TRI} = \frac{((\text{FPPTR} / \text{FFFTR}) * \text{FPPVMT} + ((\text{PAPPTR} / \text{PAFFTR}) * \text{PAPPVMT})}{(\text{FPPVMT} + \text{PAPPVMT})}$$

Where FPPTR is the freeway peak period travel rate,

FFFTR is the freeway free flow travel rate,

FPPVMT is the freeway peak period vehicle miles traveled,

PAPPTR is the principal arterial peak period travel rate,

PAFFTR is the principal arterial free flow travel rate, and

PAPPVMT is the principal arterial vehicle miles traveled.

Standard TRI Estimation

The TRI is defined as the travel rate, in minutes per mile, during the peak period, divided by the rate in the off-peak. A TRI of 1.50 indicates that the average peak trip takes 50 percent longer than a trip in free-flow conditions. For example, a 30 minute trip becomes a 45 minute trip.

The freeway and principal arterial peak period VMT is calculated as follows:

$$\text{Peak Period VMT} = \text{Daily VMT} * \text{Percentage of Travel during Congested Conditions} \tag{1}$$

The travel rate is calculated by converting the average speed, in miles per hour, to a travel rate in minutes per mile.

$$\text{Travel Rate} = 60 / \text{Average Speed} \tag{2}$$

For example, for a region of :

- freeway peak period VMT of 10 million,
- principal arterial street VMT of 5 million (about 50% of daily VMT),
- a freeway peak period travel rate of 1.3,
- a freeway free flow travel rate of 1.0,
- a principal arterial street peak period travel rate of 2.0, and
- a principal arterial street free flow travel rate of 1.5.

The TRI will be calculated as follows:

$$1.31 = \frac{((1.3 / 1.0) * 10{,}000{,}000) + ((2.0 / 1.5) * 5{,}000{,}000))}{(10{,}000{,}000 + 5{,}000{,}000)}$$

Modifying TRI From a Region Basis to a Corridor Basis Index

TRI uses the Highway Performance Monitoring System (HPMS) database compiled by the Federal Highway Administration (FHWA) using data submitted by State Departments of

Transportation (DOTs). The travel speed is estimated for each roadway link using daily traffic volume per lane values. Therefore, it is feasible to select roadways in a specific corridor instead of using the entire region roadways. In fact a TRI will be much more accurate for a specific corridor, than for the entire region, because of the small number of roadways, a much accurate traffic volume number, and a much precise traffic speed level. The TRI estimation function will be similar to the function shown as Equation 1 except that the metrics will be corridor specific.

TRI in the Absence of Transit

The TRI in the absence of transit is estimated using the door-to-door travel time survey data and the corridor convergence level. The approach consists of four main steps:

1. Estimate the corridor travel time, in the absence of transit, based on the methodology presented in Chapter 2.
2. Convert travel time to traffic rate in the absence of transit based on the roadways length, traffic volume, and the average speed.
3. Calculate the freeway and principal arterial peak period VMT, in the absence of transit based on the corridor convergence level and the rail passenger diversion into cars and buses.
4. Estimate the TRI, in the absence of transit, using Equation 1 and the variables estimated in Steps 2 and 3.

Travel Time in the Absence of Transit

Based on the methodology developed in Chapter 2, in the absence of transit, the travel time T_a is estimated as:

$$T_a = T_{ff} \; * \; (1 + A\,(V^*)^{\beta}) \tag{3}$$

Where T_a is the door to door travel time in the absence of transit,

T_{ff} is the trip travel time at free-flow speed,

V^* is the volume of person trips by auto in the absence of transit,

A is a scalar, and β is a parameter.

Equation 3 implies that the door-to-door travel time in the absence of transit depends on the travel time at free-flow speed and the level of congestion on the road in the absence of transit.

The volume of person trips by auto in the absence of transit, however, depends on several factors:

The existing auto and bus person trips on the highway.

The percentage of person transit trips shifting to auto

The percentage of person transit trips shifting to bus

The number of additional cars in the highway

The number of additional buses in the highway

The occupancy per vehicle in the absence of transit

The volume of person trips by auto, in the absence of transit, can then be estimated as:

$$V^* = V_1 + \alpha_1 V_c + \alpha_2 V_b \qquad (4)$$

Where V_1 is the existing auto volume,

V_c is the transit person trips diverted to cars,

V_b is the transit person trips diverted to buses, and

α_1, α_2 are the coefficients that incorporate the passenger car equivalent factor and the occupancy per vehicle (cars and buses).

The trips diverted to cars and buses depend mainly on the degree of convergence in the corridor. This degree of convergence reflects the transit user behavior and the composition of these users. The transit users can be divided into 3 categories:

Type 1: "Explorers" who are casual switchers who will divert to Single Occupancy Vehicles in the absence of transit.

Type 2: Commuters with low elasticity of demand with respect to generalized cost who will divert to use the bus or carpool.

Type 3: Commuters with high elasticity of demand with respect to generalized cost who will forgoes the trip.

The higher the degree of convergence (auto and rail door to door travel times are very close), the higher will be the shift of transit riders will be to cars and buses. Therefore, higher degree of convergence will lead to higher delay which translates into higher savings due to transit.

Equation 3 shows that in the absence of transit and in the case of a high degree of convergence, the person trip volume is very high. This translates into a high trip time (excessive delay). The relationship between trip time and person trip volume can be expressed as a convex curve. As the volume increases, travel time increases at an increasing rate. The figure below illustrates the relationship between the volume and travel time in the presence and absence of transit.

Converting Travel Time in the Absence of Transit to Travel Rate in the Absence of Transit

The average travel speed, in the absence of transit, can be derived using the travel time in the absence of transit and the corridor length. The travel speed in the absence of transit (TSAT) is estimated as follows:

$$\mathbf{TSAT} = \frac{\mathbf{60 * Corridor\ length}}{\mathbf{Travel\ time\ in\ the\ absence\ of\ transit}} \qquad (5)$$

The travel rate in the absence of transit can be estimated as shown in Equation 2, that is dividing the free flow travel speed by the travel speed in the absence of transit.

Estimation of Peak Period VMT in the Absence of Transit

Peak period Vehicle Miles Traveled (VMT), in the absence of transit, consists of the existing VMT (obtained from HPMS databases) and the estimated generated VMT in the absence of transit. The generated VMT in the absence of transit depends on the rail transit ridership level, the occupancy per vehicle (for cars and buses) and the level of convergence in the corridor.

Higher degree of convergence (auto and rail door to door travel times are very close) means a higher shift of transit riders to cars and buses.

The peak period VMT in the absence of transit can be estimated as follows:

$$\mathbf{VMT_1 = VMT_0 + ATL * TP * (\alpha / CVO + \beta / BVO)} \qquad (6)$$

Where VMT_1 is the overall VMT in the absence of transit,

VMT_0 is the VMT in the presence of transit,

ATL is the corridor average trip length,

TP is the transit rail passenger (ridership volume),

CVO is the corridor average vehicle occupancy for cars

BVO is the corridor average vehicle occupancy for buses

α is the percentage of rail passenger diverting to cars in the absence of transit

β is the percentage of rail passenger diverting to buses in the absence of transit

α and β depend on the convergence level in the corridor, the percentage of diversion to cars and buses is higher when a high convergence level exist between in the rail transit travel time and highway travel time.

VMT_1 will be estimated for both freeways and principal arterial streets and will replace the VMTs values shown in Equation 1. Similarly, travel rate in the absence of transit will be estimated for both the freeways and principal arterial streets and for both peek and off-peak periods to replace travel rates in Equation 1.

Estimation of TRI in the Absence of Transit

Estimating travel rate index in the absence of transit consists of updating Equation 1 using the corridor travel rates and VMTs, in the absence of transit, shown above. The TRI in the absence of transit (TRIAT) can be estimated as follows:

$$\mathbf{TRIAT = \frac{(FSL / FTSAT) * FVMT_1 + (PAFFTSAT / PATSAT) * PAVMT_1}{FVMT_1 + PAVMT_1}} \qquad (7)$$

Where FSL is the freeway speed limit,

FTSAT is the freeway peak period travel speed in the absence of transit

$FVMT_1$ is the freeway peak period VMT in the absence of transit

PAFFTSAT is the principal arterial free flow travel speed in the absence of transit

PATSAT is the principal arterial peak period travel speed in the absence of transit

PAVMT is the principal arterial peal period VMT in the absence of transit

Equation 7 will be estimated for a specific corridor instead of the region. The data to populate the model will be gathered from the HPMS databases and through the corridor travel time survey.

Transit Benefit Based on the TRI Congestion Index

Once the TRI in the presence of transit and in the absence of transit have been calculated, the transit benefit can be estimated as the difference between the two indices. This difference can be interpreted as the percentage of travel time savings solely attributable to transit during peak period. A TRI in the presence of transit of 1.3 and in the absence of transit of 1.4 indicates that the average peak trip takes 10 percent longer in the absence of transit than in the presence of transit in the selected corridor.

Using TTI measurements, the travel time percentage savings due to transit can be quantified as the annual total delay savings in the corridor, the delay per driver in the corridor, the delay per capita in the corridor, and/or the fuel consumption savings in the corridor.

Example of Transit Benefit Estimation Using TRI

We now present an application example of the methodology, using the example of two corridors, the I-270 – Washington corridor and the Butterfield – Sacramento corridor. Since the purpose of this paper is to build a conceptual framework to apply a standard congestion index to measure the transit benefits, this example relies on assumptions and proxy data when necessary.

Corridors Characteristics

The selected corridors are both listed within congested areas by the TTI. Table 3.1 summarizes HLB findings for these corridors and provides TTI findings on their respective urban areas.

Table 3.1 Corridors Characteristics

		HLB Findings			TTI Findings[11]	
Corridor	Length	Savings per mile due to transit[12]	Annual Benefits per mile*	TRI	Annual Delay per Driver	Annual Cost due to Congestion*
I-270 - Washington	20	15 seconds	$ 4.5	1.41	76 hours	$ 3,560
Butterfield-Sacramento	13	11 seconds	$ 0.5	1.24	38 hours	$ 595

* in millions of 1999 dollars

Transit Benefit Estimation for the Selected Corridors

We now apply the methodology to estimate the transit benefits for the two selected corridors.

TRI in The Presence of Transit

TRI in the presence of transit is estimated for each corridor by estimating the travel rate and the VMT for the corridor roadways only. Table 3.2 shows the data used to estimate the TRI in the presence of transit for each corridor.

---

[11] TTI findings are based on the region where the corridor is located

[12] Include savings by transit users and highway users throughout the network.

Table 3.2 Corridor Data* Used to Estimate the TRI in the Presence of Transit

Corridor	I-270 - Washington	Butterfield-Sacramento
Daily Freeway VMT**	1,756,387	523,059
Daily Principal Arterial VMT	962,500	416,259
Percentage of Travel during Peak Period	60%	50%
Freeway Peak Period Travel Speed	29.2	44.3
Freeway Free Flow Travel Speed	55	60
Principal Arterial Peak Period Travel Speed	21.1	23.2
Principal Arterial Free Flow Travel Speed	35	35
Principal Arterial off peak Travel Speed	30	30

*The figures are based on HPMS data and data from local DOTs and MPOs (see corridor case studies for detail data on each corridor).
** The estimation assumes that the I-270 corridor represents about 5% of the total Washington region VMT.

For the I-270 Washington Corridor, the TRI in the presence of transit (TRIPT) can then be estimated as:

$$\mathrm{TRIPT}_{\mathrm{Washington}}=\frac{\{(55/29.2)*(1756{,}387 * .60)\} + \{((35/21.1) / (35/30)) * (962{,}500 * .60)\}}{(1756{,}387 + 962{,}500) * .60} = 1.72$$

This TRI value of 1.72 indicates that it takes 72 percent longer to make a trip in the I-270 corridor during peak period than it would take if the travel occurred at free-flow speeds.

Similarly, the TRI in the presence of transit for the Butterfield – Sacramento corridor can be estimated as:

$$\mathrm{TRIPT}_{\mathrm{Sacramento}} = \frac{\{(60/44.3) * (523{,}059 * .50)\} + \{((35/23.2)/(35/30)) * (416{,}259 * .50)\}}{(523{,}059 + 416{,}259) * .50} = 1.33$$

The TRI value of 1.33 indicates that it takes 33 percent longer to make a trip in the Butterfield – Sacramento corridor during peak period than it would be if the travel occurred at free flow speeds. The calculation also shows that there is a higher level of congestion in the I-270 Washington corridor than in the Butterfield – Sacramento corridor, mainly due to higher traffic volume and lower speed in the I-270 corridor.

TRI in the Absence of Transit

The estimation of the TRI in the absence of transit is conducted by substituting the VMTs and travel speeds in the presence of transit with the values estimated in the absence of transit. Table

3.3 shows the data used to estimate the TRI in the absence of transit. The free flow travel speed and the percentage of travel during peak period are similar to the ones listed in Table 3.2.

Table 3.3 Corridor Data[**] Used to Estimate the TRI in the Absence of Transit

	I-270 – Washington Corridor	Butterfield-Sacramento Corridor
Daily Freeway VMT	1,826,398	546,544
Daily Principal Arterial VMT	1,009,174	431,916
Percentage of Travel during Peak Period	60%	50%
Transit Riders during Peak Period	16,334	7,445
Average Trip Length	12	10
Percentage of transit riders diverting to cars	65%	60%
Percentage of transit riders diverting to buses	11%	10%
Vehicle Occupancy: cars	1.1	1.15
Vehicle Occupancy: buses	25	25
Freeway Peak Period Travel Speed	24.51	36.9
Principal Arterial Peak Period Travel Speed	19.80	22.64

*The figures are based on HLB estimation (see corridor case studies for model estimation for each corridor).

Using the estimated values, shown in Table 3.3, the I-270 Washington Corridor TRI in the absence of transit (TRIAT) can be estimated as:

$$\mathrm{TRIAT}_{\mathrm{Washington}}=\frac{\{(55/24.51)*(1,826,398*.60)\}+\{((35/17.9)/(35/15.04))*(1,009,174*.60)\}}{(1,826,398+1,009,174)*.60}=1.98$$

This TRI value of 1.98 indicates that it would almost twice longer to make a trip in the I-270 corridor during peak period in the absence of transit than it would take if the travel occurred at free-flow speeds.

Similarly, the estimation for the TRI in the absence of transit for the Butterfield – Sacramento corridor can be estimated as follows:

$$\mathrm{TRIAT}_{\mathrm{Sacramento}}=\frac{\{(60/36.9)*(546,544*.50)\}+\{((60/22.64)/(35/30))*(431,916*.50)\}}{(546,544+431,916)*.50}=1.49$$

The TRI value of 1.49 indicates that it would take 49 percent longer to make a trip in the Butterfield –Sacramento corridor during peak period in the absence of transit than it would be if the travel occurred at free flow speeds.

Transit Delay Savings During Peak Period

The transit contribution in the reduction of travel time delays during peak period can be estimated by taking the difference between the TRI in the presence of transit and the TRI in the absence of transit.

For the I-270 – Washington corridor, the transit contribution to congestion management can be estimated as:

$$\text{TCCM}_{\text{Sacramento}} = \text{TRIAT}_{\text{Sacramento}} - \text{TRIPT}_{\text{Sacramento}} = 1.98 / 1.72 = 0.15\%$$

The value of 0.26 indicates that it would take 15 percent longer to make a trip in the I-270 – Washington corridor during peak period in the absence of transit than it would take in the presence of transit. Using the annual person hours of delay estimated by TTI for the Washington region of 216 million, and assuming that the I-270 corridor VMT represents about five percent of the total VMT in the Washington region, the total delay savings attributed to transit in the I-270 Washington corridor will be over 4 million person hours that can be valued at about $62 million per year.

Similarly, for the Butterfield – Sacramento corridor, the transit contribution to congestion management (TCCM) as:

$$\text{TCCM}_{\text{Washington}} = \text{TRIAT}_{\text{Washington}} - \text{TRIPT}_{\text{Washington}} = 1.49 / 1.33 = 0.12\%$$

The value of 0.16 indicates that it would take 12 percent longer to make a trip in the Butterfield – Sacramento corridor during peak period in the absence of transit than it would take in the presence of transit. Using the annual person hours of delay estimated by TTI for the Sacramento region of 35 million, and assuming that the Butterfield – Sacramento corridor VMT represents about five percent of the total VMT in the Sacramento region, the total delay savings attributed to transit in the Butterfield – Sacramento corridor will be around .86 million person hours that can be valued at about $13 million per year.

Conclusion

The finding of an equilibrating effect of rail transit on highway and transit travel suggests that the effect of rail transit on highway congestion can be predicted, and shaped, by transit policy. However, the quantitative relationship between the equilibrium effect and standard measures of congestion has not been identified. In fact, while the TTI publications on mobility and the congestion levels in urban areas in the United States provide a quantification of the infrastructure needs to lower congestion, they do not mention the role and the effect of transit on congestion management.

This paper develops the conceptual framework within which transit-induced changes in highway travel times (as a result of measured equilibrium effects) translate into reduced congestion, as measured by the TTI indices. The methodology in this paper uses the travel rate index TRI calculation framework to estimate the TRI in the presence of transit for a specific corridor. Then it uses the corridor convergence level to estimate the TRI in the absence of transit. The difference between the two indices measures the percentage of excess delay savings due to rail transit in the corridor.

The paper uses data from two corridors to illustrate the estimation mechanism of the transit contribution to congestion management. Using the framework developed in this paper, transit is found to save over 4 million person hours per year in excess delay during peak period in the I-270 Washington corridor and about .86 million person hours per year in the Butterfield-Sacramento corridor. These delay savings are estimated at about $61 million and $13 million, respectively.

Chapter 4. Economically Optimal Transit Subsidies in the United States, An Update for 1999

Introduction

Transit and highways together comprise a system of urban transportation. The policy imperative for transportation is to recognize the reality of political and institutional barriers and to achieve efficient use of society's resources subject to those constraints. The lack of road pricing is a significant constraint on consumer sovereignty on the transportation system. Without a pricing mechanism as a means to save their own money or time by prudent use of the road network, motorists generate inefficient levels of highway congestion. Until market-based road and parking pricing become feasible on a significant scale, therefore, the optimal policy response to traffic congestion is to subsidize the transit mode, calculated at $19.4 billion for the U.S. in 1999.

Congestion, Road Pricing and Welfare

Prospective commuters weigh the benefits and costs that they face when choosing between alternative modes (i.e., transit or highways). The costs not fully borne by the individual, including the congesting effect of an additional private vehicle on the road, do not generally enter his/her calculations. "Second-best" policy options are pragmatic responses to the reality that absent marginal cost road pricing the congesting effect of travelers do not enter private calculations.

Economic theory then suggests that all travelers, whether car users or not, can be made better off if the new users are charged a special toll. For instance, they could pay a toll to cover the additional social costs they impose (in economic terms, making consumers better off is also expressed as increasing their welfare). Of course, such a "congestion" toll (also known as road pricing) is unlikely, owing to institutional and political barriers. In effect, there remains a distortion in the price of road travel created by uncompensated social costs. Failure to address this price distortion leads to inefficient levels of congestion and slower travel times. Attendant negative effects include time and productivity losses for road users, higher costs of production, and possibly higher levels of pollution (NAS, 1994).

The Case for Subsidizing Transit

In the world as it is, all travelers can still be made better off (if not as well off as in the "first-best" world) if a "compensating variation" can be introduced into prices in other, related sectors of the economy (Laffont, 1989). Indeed, the solution may seem paradoxical: if road travel is under-priced (i.e., there exists no road pricing to discourage additional congestion), then it is justified to under-price the cost of travel on other modes. More precisely, fares on public transit would be subsidized, so that transit users would pay less than what it costs to transport them.

The reasoning behind this seeming paradox is the following: a subsidy draws potential auto travelers to transit, thus averting additional congestion (this result depends on the fact that mass transit causes less congestion than does road travel). In fact, in the absence of road pricing, subsidizing some travelers not to use roads makes everyone better off, road and transit users alike as long as the subsidy is less than the congestion costs imposed by each additional driver. Subsidies are set such that, for the last prospective auto traveler they attract to transit, they exactly offset the additional congestion costs to all current road users that would have occurred had that person decided to use a car instead.

Plan of the Report

The next section reviews research on the pricing of public transit. It focuses on how both road and transit users' welfare can be maximized in the absence of road pricing. We then introduce a methodological framework to estimate "second-best" transit subsidies in the United States.

Background

Studies by Glaister, Lewis (1978) and others in Europe during the 1970s and 80s indicate that subsidizing transit services is an economically efficient response to the political and institutional barriers to road pricing. The authors adapted the general theory of "second-best" in a methodology for calculating the optimal subsidy for public transit when roads are systematically under-priced. This methodology combines cross-price elasticities of the various transportation modes with the social marginal costs of each into a model that generates the optimal set of prices for each mode (cross-price elasticities refer to the responsiveness of consumers to price changes on alternative travel modes).

The Social Costs of Road Travel

The argument in favor of subsidizing public transit follows from the under-pricing of road travel. In the absence of marginal-cost pricing, individual drivers do not take into account the congestion they impose on others when making travel decisions. The theory of second-best says that, when prices deviate from their marginal (social) cost in one sector, then using marginal-cost pricing in other, related sectors will not lead to a social optimum. In the case at hand, road use is under-priced due to lack of tolls and intense congestion levels. Indeed, society would be better off by subsidizing transit fares, thus drawing travelers away from road use and reducing the social costs they previously imposed on other road users.

Opponents of subsidies to public transit argue that cross-price elasticities are so small and transit's share of the total transportation market so insignificant that most analysts assume the optimal transit subsidies derived by this approach would also be insignificant.

Evidence from Dr. Herbert Mohring and Dr. David Anderson (1996) suggests that, even in lightly congested urban areas such as Minneapolis/St. Paul, the optimal congestion toll on highways may be as high as $0.49 per mile (the study was conducted in 1996). Estimates of this magnitude suggest that the social costs of driving may be higher than previously thought. If the cross-price elasticities between road use and public transit were significant, then the subsidization of public transit would lead to large (social) cost savings.

Furthermore, research by HLB Decision Economics Inc. indicates that a certain class of travelers may be especially sensitive to relative prices among transportation modes. These travelers are "explorers" who frequently switch modes. They are sensitive to price when choosing travel modes and might switch to transit based on the optimal transit fare.

Taken together, the high social costs of congestion, the presence of "explorers" and the historically significant cross-price elasticities between road use and public transit argue for a thorough examination of transit subsidy policy.

The "Second-Best" Alternative

Currently, transit operations and capital spending are subsidized by many levels of government. Since the distribution of transit operating funds does not currently account for the economic efficiency of the "second-best" optimal subsidy, it is likely that some of these current subsidies are too low or too high to yield the economically efficient fare structure given road under-pricing.

Subsidies can only be "efficient" in an economy operating in what economists have called a "second-best" world. The "first best" policy response to under-priced of roads would be to price roads at the social marginal costs of driving. Marginal cost pricing is a fundamental indicator of the efficient allocation of resources. The theory of "second-best" suggests other outcomes when this "first best" outcome is unachievable.

The theory of "second-best" states, generally, that when a distortion (under-priced roads) exists in one sector, traditional optimality conditions (marginal cost pricing) do not necessarily apply in all other sectors. In essence, the results obtained in a "second-best" analysis may contradict the intuition based on a first best analysis. In this case, the optimality of transit subsidies derives from the under-pricing of roads. Since automobile travel creates negative effects in terms of congestion and pollution, reducing auto travel demand will have economic benefits as long as the marginal cost of inducing a driver to take transit is less than the marginal social cost imposed by driving.

Framework for Optimal Transportation Prices

In the 1970's, Glaister and Lewis (1978) developed a method for calculating the optimal (i.e., welfare-maximizing) fare structure for public transit when road pricing is not a viable option. The author's method has withstood scrutiny since then and remains a standard reference in the literature on economic welfare and public transit.

The argument is that since private vehicle users are charged less than their marginal social cost (the marginal social cost is the social cost associated with newest road user) of driving, particularly during congested conditions, there is an economic rationale for pricing public transport below its marginal cost to induce drivers to switch to public transit. This conclusion rests on the actual marginal social costs of driving and on the ability of reductions in transit fares to attract travelers away from road use.

This paper adopts the Glaister and Lewis method and presents a new application of the model using risk analysis techniques. These techniques account for the inherent uncertainty in many of the model's inputs. The model also incorporates recent advances in the ability to determine the marginal social costs of automobile travel.

The Framework

A detailed derivation of the model is presented in technical form Annex 4.1 "Second-Best" Technical Approach. The central element of the "second-best" theory is the congestion to all traffic caused by an additional private vehicle during peak-period automobile travel. Under congested conditions, each additional automobile in the transportation network imposes high costs in terms of congestion (lost time and inconvenience) upon all vehicles in the affected transportation network. Because each additional vehicle does not pay for the costs imposed on other transportation network users, it is referred to as an external cost.

The theory incorporates this external congestion effect to show that, when the various transportation modes are substitutes for each other, transit subsidies can be an efficient (i.e., welfare-maximizing) policy response to congestion in the absence of correct road pricing.

Implications of the "Second-Best" Result

The degree to which transit subsidization creates net benefits depends on the ability of fare reductions for transit to attract travelers away from road use and, in addition, on volumes and shares on the various modes, and the actual marginal social costs of automobile travel.

The "second-best" transit subsidy ensures that the price of transit, relative to automobile travel is optimal, or welfare maximizing. This results in the most efficient distribution of traffic across modes and ensures that transit and road users benefit mutually.

The theory suggests that the optimal fares on public transit modes are below their marginal costs in both peak and off-peak periods. Subsidies are justified in the peak period because lower fares induce mode switching from auto to public transit, which reduces traffic congestion. Subsidies during off-peak periods are justified because they induce people to travel in the off-peak period, reducing peak-period congestion.

Model Structure and Data

The second-best solution to the transit subsidy problem uses an analytical method well grounded in economic theory to combine data on (i) the marginal social cost of automobile use; (ii) the marginal social cost of transit (for bus and rail separately); (iii) the responsiveness of the demand for bus and rail service to fare changes; and (iv) the responsiveness of the demand for auto use with respect to bus and rail fares. The complete derivation of the model is presented in the Technical Annex at the end of this chapter.

Table 4.1 below presents the elasticities that were used in the analysis. These elasticities were estimated by Glaister and Lewis (1978) and represent conservative estimates compared to many recent studies in the literature (Button, 1993). They measure the responsiveness of travelers using a current mode of transportation (say, a car) to changes in the prices of other modes (say, a bus). For example, an elasticity of demand of 0.025 for auto travel with respect to bus fares would show that an increase of 100% in bus fares would lead to a 2.5% increase in the number of auto travelers.

For higher elasticities between transit and auto use, drivers are more responsive to fare reductions, which would relieve congestion more easily. The elasticities used in this model would seem low, and the resulting benefits from congestion relief would be similarly conservative. The responsiveness of automobile drivers to transit fares is estimated to be extremely small. But even small degrees of automobile driver responsiveness to transit fares can translate into significant levels of efficient subsidies (see Table 4.3).

The model is calculated using operating costs for seven metropolitan areas. It also includes capital costs in the amount used for current system renovation, maintenance and improvement, omitting all capital spending on new systems and segments.

Capital Subsidies

Governments typically provide nearly all of the capital improvement budgets for transit agencies. This issue is problematic for the calculation of the optimal subsidies because the portion of the capital budget that is directed toward expanding capacity or extending a transit line will have demand impacts in the future that will not show up in current year data.

Table 4.1 Adopted Elasticities

Mode		Bus		Rail		Auto
	Period	Peak	Off Peak	Peak	Off Peak	Peak
Bus	Peak	-0.350	0.040	0.140	0.010	0.0250
	Off Peak	0.029	-0.870	0.009	0.280	0.0016
Rail	Peak	0.143	0.013	-0.300	0.050	0.0560
	Off Peak	0.008	0.280	0.018	-0.750	0.0034

Source: Elasticity estimates based on HLB survey of available evidence and estimates.

This analysis takes the current transportation infrastructure as given. A major portion of capital expenditures represents infrastructure expansions that become usable in the future. This analysis is a tool for determining the optimal transit subsidies, given the current infrastructure, and does not give any guidance regarding the wisdom or impact of new capital expenditures. New investments should be subjected to rigorous cost-benefit analysis to determine whether they yield adequate net benefits.

Some portion of capital expenditures is used for general maintenance of the current infrastructure. This amount should be considered part of current operating subsidies since this spending is required to maintain the transportation system in its current state (see Table 4.2). Unfortunately, current data on the precise distribution of capital costs does not exist for most transit agencies.

Table 4.2 Transit Capital Funds Applied

	Percent of Capital Funds Applied ('91)			Capital Spending	Pass Miles per Yr. (Million '93)		Capital Spending per Passenger Mile	
	Bus	Old Rail	New Rail		Bus	Rail	Bus	Existing Rail
Los Angeles	20.2%	7.6%	72.2%	$350.70	1,916.1	145.2	$0.04	$0.18
Washington DC	7.2%	2.9%	89.9%	$261.50	603.4	968.0	$0.03	$0.01
Chicago	50.2%	47.0%	2.8%	$440.50	1,031.3	2,248.3	$0.21	$0.09
Boston	N/A	92.3%	7.7%	$235.40	254.5	1,018.4	$0.00	$0.21
New York City	15.9%	83.6%	0.5%	$1,405.20	2,152.1	10,238.3	$0.10	$0.11
Philadelphia	22.8%	77.2%	N/A	$253.60	471.3	775.9	$0.12	$0.25
San Francisco	34.5%	65.5%	N/A	$218.60	595.2	1,048.7	$0.13	$0.14

Source: National Transit Database, Federal Transit Administration and HLB Estimates.

Capital funds applied to the current infrastructure are estimated, based on data from the Federal Transit Administration National Transit Database (formerly Section 15 Data). Data regarding the distribution of capital costs were, in fact, collected by the Federal Transit Administration (FTA) up to 1991 only. By calculating the percentage of capital funds applied to existing infrastructure in 1991, and applying this percentage to capital funding levels in 1993, an estimate of the capital funds applied to existing infrastructure has been generated. The implicit assumption in the calculation is that the composition of capital spending in 1993 is approximately the same as 1991.

The present report considers that capital spending on existing equipment and infrastructure in 1997 is equal to what it was in 1993. Operating expenses, on the other hand, have been updated with 1997 data.[13]

Results and Conclusions

In order to account for uncertainty in model inputs, the second-best model was applied using risk analysis techniques. Rather than relying on point estimates for model inputs, the risk analysis approach uses ranges for all model inputs to account for uncertainty. The risk analysis results provide policy makers with a quantitative basis to make decisions that fully accounts for uncertainty.

Model Results

Optimal fares were calculated for seven large U.S. metropolitan areas[14] and for the nation as a whole. The simulation results are presented in Table 4.3 below. The table shows the subsidies that should be given to transit authorities in order to enable them to charge a welfare-maximizing or "second-best" fare given their current operating costs and capital expenditures on current infrastructure. Since the second-best model developed in this paper assumes that the infrastructure is given, the correct subsidy predicted by this model should be interpreted as an operating and maintenance subsidy.

Conclusions

The results of our analysis confirm that subsidizing public transportation can be the best public policy approach to utilizing the transportation infrastructure in the absence of road pricing. This analysis suggests the optimal subsidy levels in major metropolitan areas can be large (see Table 4.3) based solely on transit's congestion management benefits (transit costs include many costs not related to congestion management - examples of these are paratransit services and low-cost mobility programs, among others). The optimal subsidy exceeds the current subsidy in many of these systems and the nation as a whole.

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[13] Capital expenditures on existing equipment and infrastructure represent a relatively small portion of the social costs of operating transit systems. The impact of using 1993 instead of 1997 capital cost estimates is, therefore, likely to be small.

[14] As defined in the 1997 National Transit Database, Federal Transit Administration

The central result of this study is that all travelers on the highways and transit systems could be made better off by increasing transit subsidy levels in several major metropolitan areas. This conclusion is, of course, a "second-best" argument where alternative policies toward congestion management, such as road pricing, are deemed not feasible for political or practical reasons. The model presented here would suggest that the optimal subsidy would decline as the fees that drivers face approach the marginal social cost of automobile travel.

Table 4.3 Second-Best Subsidy Results

Urbanized Area	Optimal Operating Subsidy (Millions of 1997 Dollars)
Boston	835.6
Chicago	1,567.1
Los Angeles	1,397.6
Philadelphia	866.1
New York City	7,575.7
San Francisco	1,087.6
Washington DC	695.5
National Estimate	19,383.2

The "first best" approach would be to remove all price distortions in the transportation market. The "second-best" approach provides a means of improving the allocation of resources among the available transportation modes when the first best approach is unavailable.

Risk Analysis

We attached probability density functions to each variable in the second-best model and applied Monte-Carlo simulations in order to gain an appreciation of sensitivity in the results. Table 4.4 presents the results for the Nation as a whole, for the bus system and the rail[15] system separately. The results indicate that the 80 percent likely outcome lies within 95 percent of the mean expected outcome.

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[15] Includes heavy rail, commuter rail and light rail

Table 4.4 Second-Best Risk Analysis Results: Optimal Nation-Wide Transit Subsidy

Rail		Bus	
Value ($M per Year)	Probability of Exceeding Value to the Left	Value ($M per Year)	Probability of Exceeding Value to the Left
7,315.75	95%	7,529.69	95%
7,739.51	90%	8,459.75	90%
8,220.63	80%	8,917.83	80%
8,611.18	70%	9,484.75	70%
8,884.36	60%	9,856.04	60%
9,102.36	50%	10,138.80	50%
9,317.93	40%	10,404.30	40%
9,542.28	30%	10,677.41	30%
9,810.18	20%	10,980.10	20%
10,180.30	10%	11,257.01	10%
10,468.46	5%	11,687.74	5%
Mean = 9,016.09	Std Deviation = 974.02	Mean = 10,367.06	Std Deviation = 1,102.44

Further Research

Improved Elasticity Estimates. The model could benefit from a further refinement, given the conservatism of the elasticities used in this paper. Indeed, the likelihood of drivers switching to transit when fares decrease could be understated. The elasticities, which measure this responsiveness, could be re-estimated based on current data specific to each metropolitan area.

Incorporate Environmental Impacts into the Model. This model, in focusing on congestion costs exclusively, does not account for other costs of automobile use. Significant among these are the environmental costs of automobile emissions. Including the social marginal costs of automobile based pollution would improve the analysis and would increase the estimated optimal subsidy level. Research on the costs of pollution could be integrated into the "second-best" model in future applications.

In concluding, the results of our analysis confirm that subsidizing existing public transportation can cause congestion relief benefits. This conclusion is, of course, in a "second-best" world where significant road pricing remains either politically or institutionally infeasible.

Annex 4.1 "Second-Best" Technical Approach

Throughout this paper and in keeping with the original Glaister - Lewis framework, we use the following indices:

1 : Peak hour private vehicle
2 : Off-peak private vehicle
3 : Peak hour bus
4 : Off-peak bus
5 : Peak hour rail
6 : Off-peak rail

Elasticities

The cross-price elasticity of demand for transportation services on mode *i* with respect to prices on mode *j* will be given by the standard equation for price elasticity as follows:

$$\eta^i_j = \frac{p_j}{X^i}\frac{\partial X^i}{\partial p_j} = \frac{p_j}{X^i}X^i_j, \quad i,j = 1,\ldots,6 \tag{1}$$

Where

p_i	are the prices on mode *i* in $ per passenger mile, and
X^i	are the demands on mode *i* in passenger miles.

If cross-price elasticities of auto travel with respect to public transit fares are estimated to be zero, implying that there is no way of persuading automobile users to switch to buses or rail transit regardless of price, then the Glaister-Lewis model would predict that transit fares should be set at the marginal cost of delivering service. If these elasticities do not equal zero, some level of transit subsidy will be efficient in the absence of road pricing.

Deriving the Equation System

Glaister-Lewis conceived of the consumer's problem as a maximization of the consumer's expenditure function less the operating costs of the various public transit modes. The maximization, following the Glaister-Lewis paper, can be expressed as follows:

$$\begin{aligned}
&\max_{p_3,p_4,p_5,p_6} \{G(\alpha_3,\alpha_4,\alpha_5,\alpha_6,X^1(\alpha_3,\ldots,\alpha_6),X^3(\alpha_3,\ldots,\alpha_6),\hat{p},u) \\
&- G(p_3,p_4,p_5,p_6,X^1(p_3,\ldots,p_6),X^3(p_3,\ldots,p_6),\hat{p},u) \\
&- [C^3(X^1,X^3) - p_3X^3] - [C^4(X^4) - p_4X^4] - [C^5(X^5) - p_5X^5] - [C^6(X^6) - p_6X^6]\}
\end{aligned}$$

Where

$G(p, X^1, X^3, \hat{p}, u)$	is the expenditure function aggregated across individuals,
X^i	is the traffic level for mode i
$(p_3,\ldots,p_6)$	is a vector of transit fares,
$\hat{p}$	is a vector of all other prices including p_1 and p_2.,
u	is a vector of constant utility levels, and
C^i	are the operating costs of the public transit modes.

The expenditure function, representing the long run demand responses to prices, depends on peak car and bus traffic levels because of the negative effects of congestion on consumer utility. This relationship implies that for a given vector of prices, an increase in peak traffic requires a compensating increase in income to maintain the previous level of consumer utility. This relationship is known as the compensating variation and is given by the difference between expenditure function evaluated at the "reference" prices α_i and a lower set of prices p_i. The compensating variation is the amount of money that would be required to compensate for an increase from $p_3,\ldots,p_6$ to $\alpha_1,\ldots, \alpha_6$, where the α_i's represent higher peak-hour congestion levels than the p's.

The other terms within the [ ] are the operating subsidies required for the peak and off-peak bus and rail transit services. The compensating variation and the public transit fare revenues (p_iX^i) represent consumers' total willingness-to-pay from which the transit systems' operating expenses $(C^i(X^i))$ must be subtracted.

Equation 2 is differentiated with respect to p_3, p_4, p_5, and p_6. Differentiating Equation 2 with respect to p_3 yields one of four first-order conditions for a maximum as follows:

$$\begin{aligned}&-\frac{\partial G}{\partial p_3}-\frac{\partial G}{\partial X^1}X_3^1-\frac{\partial G}{\partial X^3}X_3^3-C_1^3X_3^1-C_3^3X_3^3+X^3\\&+p_3X_3^3-C_4^4X_3^4+p_4X_3^4-C_5^5X_3^5+p_5X_3^5-C_6^6X_3^6+p_6X_3^6=0\end{aligned} \tag{2}$$

Similar expressions are obtained from differentiating with respect to p_4, p_5 and p_6.

Using the following properties and definitions:

$$\frac{\partial G}{\partial p_i}=\sum_h\frac{\partial g_h}{\partial p_i}=\sum_h x_h^i=X^i,\quad S_1=\frac{\partial G}{\partial X^1}+\frac{\partial C^3}{\partial X^1}\ and\ S_3=\frac{\partial G}{\partial X^3}+\frac{\partial C^3}{\partial X^3}. \tag{3}$$

Where S_1 is the marginal social cost of peak automobile travel per passenger mile and S_3 represents the marginal social cost of peak bus travel per passenger mile. Substituting these expressions into the first order condition expressed in

$$-\frac{\partial G}{\partial p_3}-\frac{\partial G}{\partial X^1}X_3^1-\frac{\partial G}{\partial X^3}X_3^3-C_1^3X_3^1-C_3^3X_3^3+X^3$$

$$+p_3X_3^3-C_4^4X_3^4+p_4X_3^4-C_5^5X_3^5+p_5X_3^5-C_6^6X_3^6+p_6X_3^6=0$$

(2) and collecting terms results in the following expression:

$$(p_3-S_3)X_3^3+(p_4-C_4^4)X_3^4+(p_5-C_5^5)X_3^5+(p_6-C_6^6)X_3^6=S_1X_3^1 \tag{4}$$

Similar expressions are obtained from the other three first-order conditions after substituting and rearranging terms.

Optimal Fares and Subsidies System of Equations

The equation system that allows the calculation of the "second-best" optimal fare derives from the four first-order conditions for the maximization problem in Equation 2. The first order conditions, after converting to elasticity form, reduce to:

$$\left[\eta_3^3(p_3-S_3)X^3+\eta_3^4(p_4-C_4^4)X^4+\eta_3^5(p_5-C_5^5)X^5+\eta_3^6(p_6-C_6^6)X^6\right]\frac{1}{S_1X^1}=\eta_3^1$$

$$\left[\eta_4^3(p_3-S_3)X^3+\eta_4^4(p_4-C_4^4)X^4+\eta_4^5(p_5-C_5^5)X^5+\eta_4^6(p_6-C_6^6)X^6\right]\frac{1}{S_1X^1}=\eta_4^1$$

$$\left[\eta_5^3(p_3-S_3)X^3+\eta_5^4(p_4-C_4^4)X^4+\eta_5^5(p_5-C_5^5)X^5+\eta_5^6(p_6-C_6^6)X^6\right]\frac{1}{S_1X^1}=\eta_5^1$$

$$\left[\eta_6^3(p_3-S_3)X^3+\eta_{63}^4(p_4-C_4^4)X^4+\eta_6^5(p_5-C_5^5)X^5+\eta_6^6(p_6-C_6^6)X^6\right]\frac{1}{S_1X^1}=\eta_6^1$$

(5 a-d)

This system of equations fully identifies the optimal transit pricing structure in the absence of road pricing. This system can be written in matrix notation as follows:

$$\begin{bmatrix}\eta_3^3 & \eta_3^4 & \eta_3^5 & \eta_3^6\\ \eta_4^3 & \eta_4^4 & \eta_4^5 & \eta_4^6\\ \eta_5^3 & \eta_5^4 & \eta_5^5 & \eta_5^6\\ \eta_6^3 & \eta_6^4 & \eta_6^5 & \eta_6^6\end{bmatrix}\begin{bmatrix}(p_3-S_3)X^3\\ (p_4-C^4)X^4\\ (p_5-C^5)X^5\\ (p_6-C^6)X^6\end{bmatrix}\frac{1}{S_1X^1}=\begin{bmatrix}\eta_3^1\\ \eta_4^1\\ \eta_5^1\\ \eta_6^1\end{bmatrix} \tag{6}$$

Solving the System

The preceding system of equations is a set of four equations with four unknowns, which is solvable using linear algebra techniques. The object of this project is to determine the values of the *p*'s in the equations from which the optimal subsidy levels can be calculated.

This model can be applied to transportation systems with automobile, bus and rail modes. When rail is not available, the system of equations reduces to two equations with two unknowns as follows:

$$\left[\eta_3^3(p_3 - S_3)X^3 + \eta_3^4(p_4 - C_4^4)X^4\right]\frac{1}{S_1X^1} = \eta_3^1 \tag{7}$$

$$\left[\eta_4^3(p_3 - S_3)X^3 + \eta_4^4(p_4 - C_4^4)X^4\right]\frac{1}{S_1X^1} = \eta_4^1$$

The difficulty in solving the system increases rapidly with the number of modes and periods under consideration. This system can be expressed as a linear system and solved using matrix inversion. This system does not provide explicit solutions for the optimal fares, but these can be calculated using some assumed functional forms for the demand and cost functions.

Applying matrix inversion and solving for the auto-bus-rail system will result in a numerical solution for the column vector (the auto-bus case results in numerical solutions for the first two elements of the following vector):

$$\begin{bmatrix} (p_3 - S_3)X^3 \\ (p_4 - C^4)X^4 \\ (p_5 - C^5)X^5 \\ (p_6 - C^6)X^6 \end{bmatrix}\frac{1}{S_1X^1} \tag{8}$$

Estimates for S_i, C^i, and X^i can be obtained or estimated from secondary sources and using standard functional forms for the cost and demand functions. The p_i's can then be determined by simple algebra.

Annex 4.2 Data for the "Second-Best" Model

Secondary data sources provide a set of parameters with which to calculate the optimal subsidies for a set of transit systems. The original Glaister-Lewis paper relied on a set of secondary sources augmented by sensitivity analysis to account for uncertainty in some of their variables. This application of the methodology is augmented by risk analysis to account for uncertainty surrounding the values chosen to estimate the equation system.

Input Requirements

In order to estimate p_i, the second-best price for each mode on-peak and off, all other variables in the system, presented in Annex 4.1 "Second-Best" Technical Approach, must be estimated or identified. The inputs needed to solve this system are presented in Table 4.5.

Table 4.5 Input Requirements for Second-Best Model

Variable	Description
η^i_j	Cross-price elasticity of demand* for mode *i* with respect to prices on mode *j* for $i,j \in \{1,...6\}$.
S_1	Marginal social cost of private vehicle travel per passenger mile during peak hour.
S_3	Marginal social cost of bus travel per passenger mile during peak hour.
C^4	Operating costs of the off-peak bus transit per passenger mile.
C^5	Operating costs of the peak rail transit per passenger mile.
C^6	Operating costs of the off-peak rail transit per passenger mile.
X^1	Demand for peak auto travel in passenger miles.
X^3	Demand for peak bus travel in passenger miles.
X^4	Demand for off-peak bus travel in passenger miles.
X^5	Demand for peak rail travel in passenger miles.
X^6	Demand for off-peak rail travel in passenger miles.

** The cross-price elasticity of demand for commodity i with respect to the price of commodity j is the responsiveness of the consumers' demand for commodity i (in percentage terms) to a change in the price of commodity j (also in percentage terms).*

Data Sources and Tables

We have chosen to adopt the Glaister-Lewis estimates for the elasticities, as updated by HLB. These elasticities were derived from the economics literature and from previous work by Lewis (1977). Table 4.1 above displays the adopted elasticity estimates. The marginal social cost variables need to be determined.

The marginal social cost of bus service is a combination of congestion costs and system operating costs. The estimates used in this analysis were obtained from Mohring and Anderson (1996) and combined with bus system operating costs as reported in Section 15. The results are shown in Table 4.6 below.

Table 4.6 Marginal Social Cost Estimates

Variable	Adopted Value
Marginal Social Cost of Car Travel	$0.57 per passenger mile
Marginal Social Cost of Bus Travel	$0.46 per passenger mile

Source: Mohring, H. and D. Anderson (1996*), TTI 1999 Annual Mobility Report* and HLB estimates.

Operating costs for the public transit system are based on available system operating cost data found in the 1997 National Transit Database Transit Profiles (FTA). In the model, there are no congestion costs off-peak. The only justification, according to this modeling structure, for - subsidizing off-peak transit service is to shift travelers from peak to off-peak period travel, reducing peak congestion.

Demand estimates for 1997 were derived from the National Transit Database Transit Profiles and from the Texas Transportation Institute 1999 Annual Mobility Report (TTI, 1999). A log-linear functional form was assumed for the demand function based on price of service and the elasticity estimates in Table 4.5. Other functional forms can be used in this model depending on the preference of the analyst. The only limitation on the adoption of functional demand equations, is that functional forms must contain variables that are either determined by the model or known values, in order to maintain the solvable "four equations and four unknowns" equation system structure presented in Annex 4.1.

Table 4.7 Summary Table for Model Inputs

		BUS	RAIL	AUTO Free / Expressways	AUTO Principal Arterials
BOSTON, MA	Passenger Miles per Day - Peak	0.473	1.736	27.250	20.138
	Passenger Miles per Day - Off Peak	0.316	1.157		
	Average Trip Length	2.717	5.068		
	Operating Expense per Passenger Mile				
	Peak	$0.396	$0.201		
	Off-Peak	$0.924	$0.469		
PHILADELPHIA, PA-NJ	Passenger Miles per Day - Peak	0.785	1.396	29.425	26.988
	Passenger Miles per Day - Off Peak	0.524	0.931		
	Average Trip Length	3.033	6.937		
	Operating Expense per Passenger Mile				
	Peak	$0.378	$0.223		
	Off-Peak	$0.882	$0.519		
WASHINGTON, DC-MD-VA	Passenger Miles per Day - Peak	0.812	1.865	41.675	24.113
	Passenger Miles per Day - Off Peak	0.542	1.243		
	Average Trip Length	3.448	5.684		
	Operating Expense per Passenger Mile				
	Peak	$0.384	$0.185		
	Off-Peak	$0.896	$0.431		
SAN FRANCISCO - OAKLAND, CA	Passenger Miles per Day - Peak	1.331	2.029	53.206	17.556
	Passenger Miles per Day - Off Peak	0.888	1.353		
	Average Trip Length	2.955	9.212		
	Operating Expense per Passenger Mile				
	Peak	$0.351	$0.183		
	Off-Peak	$0.820	$0.427		
CHICAGO, IL - NORTHWESTERN, IN	Passenger Miles per Day - Peak	1.558	3.990	58.500	50.375
	Passenger Miles per Day - Off Peak	1.038	2.660		
	Average Trip Length	2.901	11.009		
	Operating Expense per Passenger Mile				
	Peak	$0.370	$0.166		
	Off-Peak	$0.862	$0.388		
LOS ANGELES, CA	Passenger Miles per Day - Peak	3.018	0.644	146.150	106.625
	Passenger Miles per Day - Off Peak	2.012	0.429		
	Average Trip Length	3.788	9.844		
	Operating Expense per Passenger Mile				
	Peak	$0.275	$0.254		
	Off-Peak	$0.641	$0.592		
NEW YORK, NY - NORTHEASTERN, NJ	Passenger Miles per Day - Peak	6.164	20.390	118.444	73.263
	Passenger Miles per Day - Off Peak	4.109	13.593		
	Average Trip Length	3.817	6.644		
	Operating Expense per Passenger Mile				
	Peak	$0.328	$0.166		
	Off-Peak	$0.766	$0.388		
NATION WIDE ESTIMATES	Passenger Miles per Day - Peak	28.763	34.690	1,277.720	802.400
	Passenger Miles per Day - Off Peak	19.175	23.126		
	Average Trip Length	3.805	6.933		
	Operating Expense per Passenger Mile				
	Peak	$0.324	$0.177		
	Off-Peak	$0.757	$0.412		

Source: The 1997 National Transit Database, Federal Transit Administration; *The 1999 Annual Mobility Report*, Texas Transportation Institute.

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Chapter 5. Econometric Analysis of Transit and Agglomeration

Introduction

This chapter provides an econometric investigation about transit and agglomeration economies. Its purpose is dual: first, it assesses the relevance of the hypothesis of a positive relationship between transit presence, agglomeration economies and productivity; second it investigates the relationship between transit presence and economic growth in metropolitan areas.

The report is organized as follows. The next section introduces a detailed methodology to test the two hypothesized relationships described above. This is followed by the data used in the analysis and then the empirical results with an interpretation.

Figure 5.1 below summarizes the methodological framework developed by HLB.

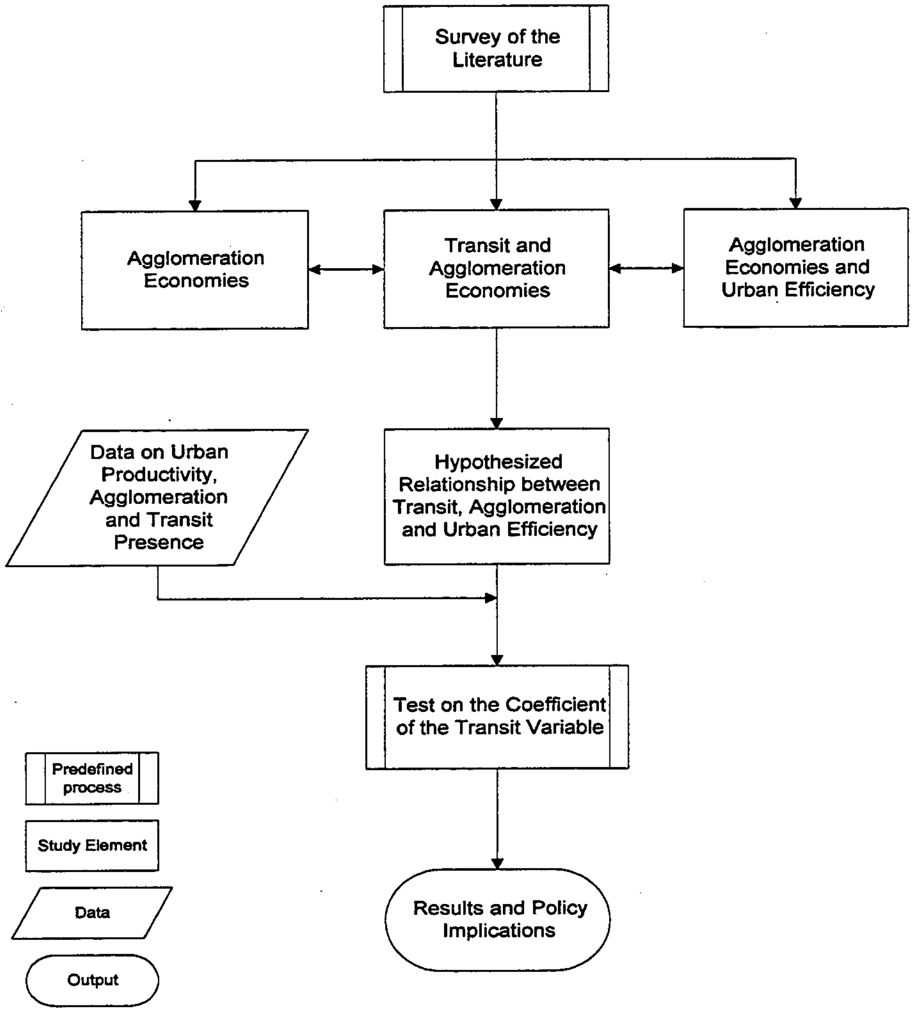

Figure 5.1 Overview of the Methodology

Methodological Framework

Here we introduce a framework to test the contribution of transit to urban efficiency and economic growth. The first hypothesis under examination is that the presence of an extended and well-functioning mass transit system promotes the realization of agglomeration economies and thereby stimulates economic efficiency (measured by labor productivity) in large urban areas. This relationship is expressed in a convenient analytical form below. The second hypothesis is that transit presence stimulates economic growth. Testing this hypothesis is the object of the succeeding section.

Testing the Relationship between Transit and Productivity

A simple functional form for the first hypothesis under examination is introduced to explain how the actual test has been implemented, drawing heavily from empirical studies in the economic literature. The framework presented here is an extension of existing models, where the presence of transit is explicitly accounted for.

A Testable Hypothesis for the Role of Transit

The null hypothesis under analysis can be summarized as follows: "Transit provides no measurable benefit to regional economic productivity."

To test this hypothesis, one needs to control for the impact of other variables: multiple regression is the most appropriate framework in this case. HLB proposes to estimate the following relationship from a cross-section of U.S. Metropolitan Statistical Areas (MSA):

$$Y_i = a + b_1 X_{1i} + b_2 X_{2i} + b_2 X_{3i} + \ldots + b_n X_{ni} \qquad (1)$$

Where Y_i is a measure of productivity in region i (e.g. output per employee, per capita income):

X_{1i} is a measure of agglomeration in region i (e.g. population, density);

X_{2i} is a measure of transit presence in region i, expressed in either a dichotomous form based on a threshold of service, or expressed in terms of normalized continuous output measure, such as transit employees per capita, revenue miles of service per capita, etc.;

X_{ji}, $j = 3 \ldots k$ are other control variables (e.g. region size, location dummies, industrial composition, capital endowment, labor force quality, etc.)

Productivity could be measured for a specific industry or for the whole economy of the region. Industry-level data would allow testing for the extent of localization economies whereas economy-wide data would allow testing for urbanization economies.

Evaluating the Coefficient on the Transit Variable

Testing the null hypothesis "Transit provides no measurable benefit to regional economic productivity" implies the following set of equations:

$$H_0: \quad b_2 = 0 \qquad (2)$$

$$H_A: \quad b_2 \neq 0 \tag{3}$$

The statistic for the test is the t-statistic associated with the coefficient on the transit variable X_2. Under the null hypothesis, this statistic follows a t-distribution with (n-k) degrees of freedom, where n is the number of observations used in the regression and k the number of explanatory variables.

If the calculated statistic departs significantly from its theoretical counterpart, i.e. from the value read in the t-table, the null hypothesis is unlikely to be "true". It can be rejected. Rejection of the null hypothesis would indicate that transit does indeed contribute to urban efficiency. On the other hand, if the calculated statistics lies within a reasonable interval form the tabulated value, the null hypothesis cannot be rejected. Failure to reject the null hypothesis would indicate that (i) transit does not contribute to urban efficiency; or (ii) transit does contribute to urban efficiency but this effect is not captured by the data at hand.

Comparing Two Regressions

The previous section offers a framework to test the impact of transit on productivity holding everything else constant, i.e. independently from any agglomeration effect (this effect being captured by the variable X_1). A slightly different hypothesis can also be tested: does transit affect the magnitude of agglomeration economies and, thereby, indirectly promote urban efficiency?

Two methods can be used to test this new hypothesis: a Chow test (or test for structural break) and the introduction of a dummy and a slope dummy variable into the estimating equation.

In a Chow test, the initial sample is divided into two sub-samples. Then, separate regressions (one for each sub-sample) are run. The Chow test determines whether the quality of the fit is significantly improved by splitting the sample. It allows determining whether the individuals in one sub-sample (the MSA in the present case) are structurally different from the individuals in the other sub-sample. Conducting a Chow test will allow to test whether MSAs with low transit presence are structurally different (with respect to the factors influencing productivity) from MSAs with extended transit presence.

The alternative approach consists of introducing a dummy and slope dummy variable in the model to test for a potential interaction between transit presence and agglomeration. If the slope dummy (transit presence dummy times measure of agglomeration) is found positive and significant, this will imply that the impact of agglomeration on productivity is stronger in areas with more extended transit presence.[16]

Testing the Relationship between Transit and Economic Growth

HLB proposes to test the hypothesis that transit affects economic growth in metropolitan areas by estimating the following equation:

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[16] As long as the transit dummy is 1 for areas with relatively more transit of course.

$$Y_i = a + b_1 X_{1i} + b_2 X_{2i} + b_2 X_{3i} + \ldots + b_n X_{ni} \qquad (4)$$

Where:

Y_i is a measure of economic growth in region i between two given years;

X_{1i} is a measure of productivity in region i in the initial year (e.g. output per employee, per capita income);

X_{2i} is a measure of agglomeration in region i in the initial year (e.g. population, density);

X_{3i} is a measure of transit presence in region i in the initial year, expressed in either a dichotomous form based on a threshold of service, or expressed in terms of normalized continuous output measure, such as transit employees per capita, revenue miles of service per capita, etc.;

X_{ji}, j = 4…k are other control variables (e.g. region size, location dummies, industrial composition, capital endowment, labor force quality, etc.)

Again, the t-test will serve as a benchmark to reject (or fail to reject) the null hypothesis.

Data Description

Now for a brief description of the data used in the study (additional descriptive statistics are provided in Annex 5.1 through Annex 5.6). First, we focus on data collection, followed by an explanation of how to populate the productivity model and the growth model.

Data Sources

Most series in the database were bought from the Minnesota IMPLAN group. Information on transit presence was also provided by the National Transit Database.

The Minnesota IMPLAN Group

The Minnesota IMPLAN Group is a private firm developing software and data sets for use in economic modeling and marketing analysis. Typically, data sets provide information about 528 industrial sectors (generally 3 or 4 digit SIC code) for all states, counties and MSA (Metropolitan Statistical Areas) in the United States.

The data were collected in 1996 (most recent available data) and in 1991 to see the impact over time of the presence of transit. Only the 100 densest MSA have been selected in the sample because they are more likely to feature well developed transit systems.

The IMPLAN data set used in the report consists of the following five main components and their respective sub-components:

1. General information
    - Population
    - Land area (square miles)
    - Density (population/area)

2. Employment (annual average number of jobs)
3. Industry output ($ millions)
4. Value added ($ millions)
    Employee compensation (wages and benefits)
    Proprietary income (self-employment income)
    Other property type income (corporate, rental income, interest income)
    Indirect business taxes (payments to Government other than end of year income taxes)
5. Final demands ($ millions)
    State & local government education purchases (expenditures for Public education)
    Gross private capital formation (purchases of capital goods and services)

In order to measure the presence of transit in terms of Value added or Employment, the following sectors are aggregated:

- (433) Railroads and related services: "establishments furnishing transportation by line-haul railroad (interurban railways), and switching and terminal establishments."
- (434) Local, Interurban Passenger Transit: "establishments primarily engaged in furnishing local and suburban passenger transportation, such as those providing passenger transportation within a single municipality, contiguous municipalities, or a municipality and its suburban areas, by bus (intercity bus lines), rail, or subway, either separately or in combination, and establishments engaged in furnishing transportation to local scenic features. Also included are establishments primarily engaged in furnishing highway passenger terminal or maintenance facilities."
- (510) Local Government Passenger Transit: portion of Local, Interurban Passenger Transit owned by State and Local Government.

The National Transit Database

Transit presence can also be measured by the number of vehicles (typically, buses and trains) directly operated in maximum service in each transit agency. The service that is provided by a transit agency is considered directly operated when the agency is responsible for generating the service to the public. These data are available online at the National Transit Library.[17] They are part of the annual report on *National Transit Summaries and Trends.*

Since an MSA usually has more than one agency, the data are aggregated at the MSA level when necessary.

Data Selection and Model Specification

From this data set, HLB proposes to define the dependent variable and the explanatory variables of each model as follows:

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[17] http://www.fta.dot.gov/ntl/database.html

Productivity model:

- Dependent variable (1996)

  Productivity = Value added / Employment

- Independent variables (1996)

  Presence of transit = Number of vehicles directly operated in maximum service in transit agencies; alternatively, Transit employment;

  Agglomeration = Population;

  Other variables = Gross private capital formation (investment);

  State and local education purchases (labor force quality);

  Economic region dummies;[18]

  Industrial composition.[19]

Growth model:

- Dependent variable (1991-1996)

  Economic growth = Percentage change in value added between 1991 and 1996.

- Independent variables (1991)

  Productivity = Value added / Employment

  Presence of transit = Number of vehicles directly operated in maximum service in transit agencies (1996);

  alternatively, Transit employment;

  Agglomeration = Population;

  Other variables = Gross private capital formation (investment);

  State and local education purchases (labor force quality);

  Economic region dummies;

  Industrial composition.

In Figure 5.2, the dependent variable of the productivity model (value added per employee) is related to a measure of transit presence (the number of vehicles directly operated in maximum

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[18] The regions used in this study are those defined by the Bureau of Labor Statistics: Region I – Boston; Region II – New York; Region III – Philadelphia; Region IV – Atlanta; Region V- Chicago; Region VI – Dallas; Region VII – Kansas City; Region VIII – Middle West; Region IX – San Francisco; Region X – Upper Northwest.

[19] Ten major sectors (SIC) were considered: Agriculture, forestry and fishing; Mining; Construction; Manufacturing; Transportation and public utilities: Wholesale trade; Retail trade; Finance, insurance, and real estate; Services; Public administration. A subcategory of Transportation was created for Transit (Railroads and related services; Local, interurban passenger transit; and Local government passenger transit).

service in transit agencies). The scatter diagram clearly shows a positive relationship between the two variables: higher levels of transit presence are associated with higher levels of productivity.

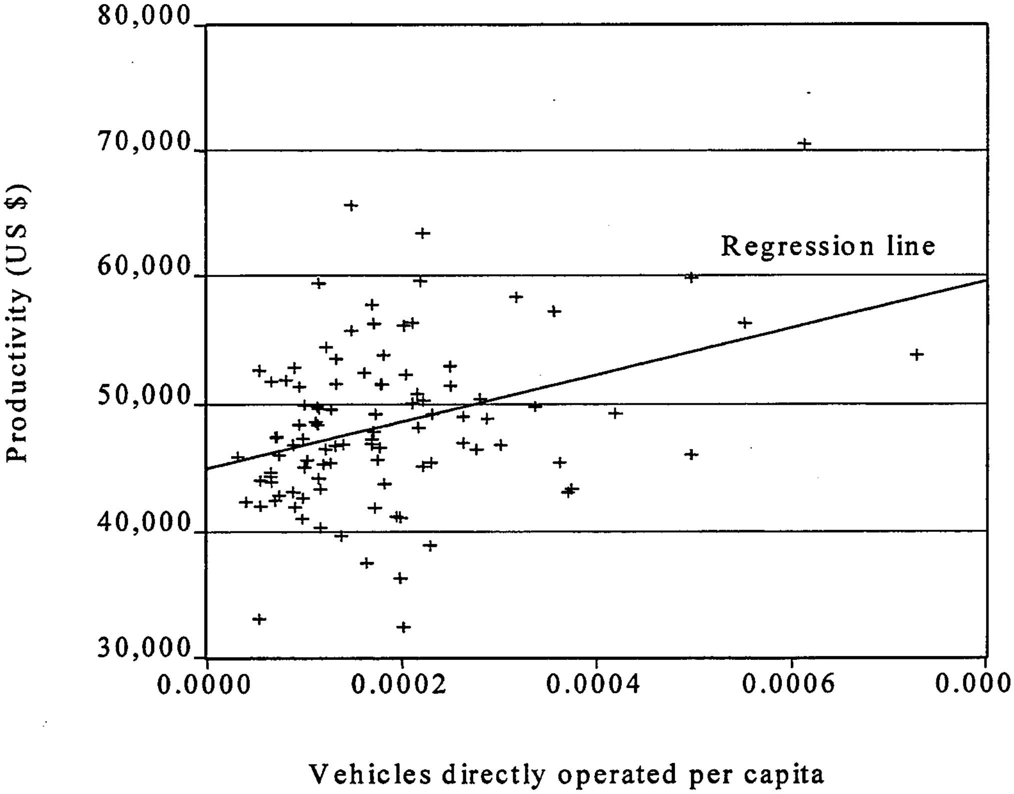

Figure 5.2 Productivity and Transit Presence

Empirical Results and Interpretation

Here we report the results of estimating the productivity model and the growth model developed by HLB. First is a summary of various descriptive statistics. Second, the results of testing the role of transit on productivity. Third, the influence of transit on economic growth.

Some Descriptive Statistics

The sample used to estimate the productivity model is described through basic descriptive statistics in Table 5.1 below.[20]

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[20] Since the number of vehicles directly operated (VDO) is missing in 9 M.S.A., the VDO per capita series is completed as follows: the series is sorted by transit employment per capita, then the average of the four VDO per capita values surrounding each M.S.A. is computed.

Table 5.1 Descriptive Statistics (1996 Data)

	Variable Name	Average	Std Dev	Minimum		Maximum	
				Value	MSA	Value	MSA
	Population	1,713,308	2,851,489	116,176	Bloomington, IN	20,175,070	NYC-Northern New Jersey-Long Island
	Density	465.36	267.26	241.71	Oklahoma City, OK	1761.25	NYC-Northern New Jersey-Long Island
	Employment	1,012,453	1,586,142	68,471	Muncie, IN	10,931,743	NYC-Northern New Jersey-Long Island
	Value added ($ millions)	55,872.6	102,144.5	2,663.5	Muncie, IN	770,660	NYC-Northern New Jersey-Long Island
	Value added per capita	29,180	5,921	11,371	McAllen-Edinburg-Mission, TX	49,111	NYC-Northern New Jersey-Long Island
	Productivity	48,385	6,351	32,415	McAllen-Edinburg-Mission, TX	70,497	NYC-Northern New Jersey-Long Island
	GPCF ($ millions)	7,849	12,550	337	Muncie, IN	76,814	Detroit-Ann Arbor-Flint, MI
	GPCF per capita	4,528	2,332	1,192	Brownsville-Harlingen-San Benito, TX	15,930	Lansing-East Lansing, MI
	State and local education purchases ($ millions)	2,987	5,101	170	Altoona, PA	40,694	NYC-Northern New Jersey-Long Island
	State and local education purchases per capita	1,838	711	949	Sarasota-Bradenton, FL	6,500	Bloomington, IN
Transit	Number of vehicles directly operated	521	1,427	15	Fort Pierce-Port St. Lucie, FL	12,374	NYC-Northern New Jersey-Long Island
	VDO per capita	0.000198	0.000134	0.00004	Greenville-Spartanburg-Anderson, SC	0.000729	Seattle-Tacoma-Bremerton, WA
	Transit employment per capita	0.003627	0.002669	0.000505	McAllen-Edinburg-Mission, TX	0.016591	Altoona, PA

Obviously, the New York – Northern New Jersey – Long Island Metropolitan Statistical Area (MSA) is predominant. Of course, one can expect this MSA to be far ahead of the others in

Employment and Value Added because of its mere size. However, it also ranks in first position in several per capita series, such as Productivity, reflecting its economic dynamism. Compared to 1991, the situation remains broadly unchanged (see Annex 3).

Transit and Productivity

Below, the productivity model is estimated with 1996 data. Various tests are performed to determine whether (more) transit contributes to urban efficiency.

Regression Results

The model has been run using the OLS method with different functional forms (semi-log, double-log) and explanatory variables (population or density; number of vehicles directly operated or transit employment). Table 5.2 reports the results of the best regression:

Table 5.2 Transit and Productivity - Regression Results Using the Number of Directly Operated Vehicles as a Measure of Transit Presence (1996 Data)

Variable Name	Coefficient	t-Statistic	Probability Value
C	9.747230	28.26363	0.0000
LPOP	0.079434	9.069550	0.0000
LVDOPC	0.039671	2.576863	0.0117
LEDUEXPPC	-0.020060	-0.661972	0.5098
LGPCFPC	0.082184	3.766898	0.0003
R1	0.021040	0.457148	0.6487
R3	-0.025857	-0.644468	0.5210
R4	-0.052164	-1.284669	0.2024
R5	-0.130856	-3.263570	0.0016
R6	-0.115202	-2.827047	0.0059
R7	-0.072179	-1.564192	0.1215
R8	-0.162415	-2.565883	0.0120
R9	0.003758	0.084664	0.9327
R10	-0.132084	-2.073174	0.0412
AGG_SER	-0.009335	-3.607165	0.0005
R-Squared	0.721408	Sum of Squared Residuals	0.470100
Adjusted R-Squared	0.675522	F-Statistic	15.72181
Standard Error of Regression	0.074368	Probability (F-Statistic)	0.000000

Where:

C = constant

LPDTY = natural log of Productivity

LPOP = natural log of Population

LVDOPC = natural log of Vehicles directly operated per capita

LEDUEXPPC = natural log of State and local education purchases per capita

LGPCFPC = natural log of Gross private capital formation per capita

R1, R3, R4, R5, R6, R7, R8, R9, R10 = dummy variables for regions I through X (region II is the default region). A dummy has a value of 1 when the MSA belongs to the region associated, and zero otherwise.

AGG_SER = percentage of Services in Total output

Half of the coefficients on the dummy variables are statistically significant. They also display a negative sign, which confirms the choice of R2 (New York) as the default region. Omitting the dummy variables does not change the significance and the sign of the other explanatory variables, but it slightly modifies their estimates.

However, all remaining explanatory variables have a significant coefficient at the 5 percent level and their respective standard errors are low, which implies the absence of multicollinearity. The only noticeable exception is the variable for Labor force quality LEDUEXPPC. Quite unexpectedly, its coefficient estimate is negative. State and local education purchases may not be the appropriate measure for this variable. As a consequence, it is dropped further in the analysis.

Since we are using a log-log model the slope coefficient b_2 measures the constant elasticity of Productivity with respect to the number of Vehicles directly operated per capita (VDOPC). For instance, a 10 percent change in VDOPC will result in a 0.4 percent change in Productivity (see Table 5.3). As expected, b_2 is positive and its t-statistic (2.58) is significant therefore the null hypothesis can be rejected.

The R-squared, measuring the goodness of fit, is rather satisfactory: its value of 0.721408 means that about 72 percent of the total variation in Productivity across the MSA is explained by variations in the explanatory variables.

The main conclusion to draw from these results is that the contribution of transit to urban efficiency, though small, is proved. Using Transit employment per capita (EMPTRAPC) as the measure for transit presence, instead of VDOPC, leads to very similar results (b_2 has a value of 0.036971 and it is significant at the 5% level, see Appendix 4) and thus confirms this interpretation.

Chow Test Results

In addition to the efficiency effect, transit may also add weight to the agglomeration effect generated by Population in the regression.

To address this issue, a Chow test is performed. First of all, the original sample is divided into two sub-samples: the first sub-sample consists of the MSA with VDOPC above the median level of employment, and the second sub-sample consists of the MSA with VDOPC below the median. Then, separate regressions are run.[21]

Table 5.3 Change in Transit Presence and Change in Productivity

Change in Transit Presence	Effect on Productivity	Margin of Error
Transit presence vs. no transit	0.04%	± 0.02%
10% Increase in Transit presence	0.40%	±0.15%
25% Increase in Transit presence	1.00%	±0.38%

To test for a structural change in the productivity model, the F-statistic is computed in the following way:

$$F[11, 78] = \frac{(0.518648 - (0.202401 + 0.252883) / 11}{(0.202401 + 0.252883) / (50 + 50 - 22)} = 0.98687$$

Table 5.4 Summary Statistics for the Restricted and Unrestricted Regressions

	Restricted Equation	Unrestricted Equation (High Transit)	Unrestricted Equation (Low Transit)
C	9.559663	9.741423	10.03547
LPOP	0.082592	0.085194	0.066193
LVDOPC	0.033416	0.023770	0.073967
LGPCFPC	0.067053	0.033706	0.078435
AGG_SER	-0.009400	-0.010298	-0.009909
Std. error of the regression	0.076338	0.072040	0.080524
Sum of squared residuals	0.518648	0.202401	0.252883

Since the critical value for an F statistic with 11 and 78 degrees of freedom is approximately 1.90 (at the usual 5 percent risk level), the null hypothesis according to which the sub-samples are not structurally different cannot be rejected. In other words, the Chow test does not seem to support the hypothesis that areas with larger transit presence are structurally different from areas with lower transit presence.

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[21] There is no MSA in Regions 8 and 10 for the Low Transit presence equation. Therefore their respective dummy variables are removed from all regressions.

Slope Dummy Regression Results

However, the Chow test applies to the entire model. Another way to test for the null hypothesis is to focus on the agglomeration variable only and insert a dummy and a slope dummy variable into the regression to measure the increase in the agglomeration effect due to transit.

Table 5.5 Regression Results with a Dummy and Slope Dummy Variable

Variable Name	Coefficient	t-Statistic	Probability Value
C	9.725277	33.52478	0.0000
LPOP	0.067583	3.679613	0.0004
LGPCFPC	0.047101	1.991721	0.0500
R1	-0.033181	-0.615634	0.5400
R3	-0.038853	-0.952268	0.3440
R4	-0.071501	-1.841619	0.0694
R5	-0.135559	-3.332609	0.0013
R6	-0.121286	-2.935082	0.0044
R7	-0.072653	-1.548613	0.1256
R8	-0.139697	-2.233720	0.0284
R9	-0.003618	-0.076052	0.9396
R10	-0.105723	-1.689656	0.0952
AGG_SER	-0.010938	-3.814205	0.0003
D_VDO	-0.551886	-1.702329	0.0928
D_VDO*LPOP	0.040483	1.699805	0.0933
R-Squared	0.727508	Sum of Squared Residuals	0.408883
Adjusted R-Squared	0.677313	F-Statistic	14.49340
Standard Error of Regression	0.073349	Probability (F-Statistic)	0.000000

Where:

D_VDO = dummy variable for Transit presence, with a value of 1 when Transit presence is above the median and zero otherwise.

D_VDO*LPOP = slope dummy variable to account for the combined agglomeration effect of Population and Transit presence.

The results show that the total agglomeration effect in MSA with high transit presence is stronger (0.067583 + 0.040483 = 0.108066) than in MSA with low transit presence (0.067583 only). Thus, they validate the hypothesis that transit strengthens the effect of agglomeration on urban efficiency.

Transit and Economic Growth

The purpose of this section is to show that there exists a positive relationship between transit presence and economic growth. It is commonly accepted that productivity is one of the main factors of growth along with investment and education. The findings of the study indicate that, indirectly, transit is contributing to economic activity via productivity. But, does transit stimulate growth independently from its effect on productivity?

The equation to be estimated differs from the initial one in the dependent variable: value added growth, as a measure of economic growth, replaces productivity, which becomes a new explanatory variable. All the other explanatory variables remain the same but they are observed in 1991. The model can be written as follows:

$$\text{Log (Value added growth)} = b_0 + b_1 \text{ Log (Productivity)} + b_2 \text{ Log (Population)} + b_3 \text{ Log (Transit Presence)} + b_4 \text{ Log (GPCFPC)} + b_5 \text{ Location Dummies} + b_6 \text{ Services} + u \qquad 4.1+$$

The dependent variable represents the increase in value added in each MSA from 1991 to 1996. Since the data for VDOPC were not available in 1991, this variable was replaced by LEMPTRAPC, measured employment in the transit sectors.

The testing procedure is based again on the null hypothesis that the coefficient on the transit variable, b_2, is equal to zero:

H_0: $b_2 = 0$

vs. H_A: $b_2 \neq 0$

As shown in Table 5.6, the model explains about 43% of the variations in growth rate across MSAs. The F-statistic and the associated probability indicate the model's coefficients are jointly different from zero.

Contrary to the previous regressions, the coefficient estimates on Location dummies are positive and are all significant at the 5 percent level. In the same way, b_2 is positive and significantly different from zero. The coefficient estimate implies that the presence of transit does contribute to economic growth. However, the coefficient on Productivity is quite unexpectedly negative.

Table 5.6 Transit and Economic Growth – Regression Results Using Employment in the Transit Sector as a Measure of Transit Presence (1991 and 1996 Data)

Variable Name	Coefficient	t-Statistic	Probability Value
C	16.62411	4.499072	0.0000
LPDTY	-1.486048	-3.544343	0.0006
LPOP	0.157273	3.604159	0.0005
LEMPTRAPC	0.102318	1.906883	0.0599
LGPCFP	0.149067	1.153178	0.2521
R1	0.434140	2.398879	0.0186
R3	0.499105	3.013435	0.0034
R4	0.658507	3.898174	0.0002
R5	0.428978	2.642363	0.0098
R6	0.562827	3.360149	0.0012
R7	0.523175	2.835229	0.0057
R8	0.785211	3.114393	0.0025
R9	0.484474	2.810975	0.0061
R10	0.675694	2.613021	0.0106
AGG_SER	-0.027453	-2.898315	0.0048
R-Squared	0.430256	Sum of Squared Residuals	7.106199
Adjusted R-Squared	0.336416	F-Statistic	4.584994
Standard Error of Regression	0.289141	Probability (F-Statistic)	0.000004

Where:

LVAGTH, the natural log of Value added growth, is the dependent variable; and

LEMPTRAPC is the natural log of Transit employment per capita.

The Economic Impact of Transit Presence

It is possible to use the coefficient estimates found in the previous sections to evaluate the average impacts of the presence of transit on productivity and economic growth. Table 5.7 and Table 5.8 summarize the results of this benefits analysis.

These numbers are reliable considering the high significance of the coefficient on the Transit variable. Moreover, similar calculations based on other estimates of transit presence lead to the same levels of benefits.

The results indicate that, on average, a 25% increase in the presence of transit creates:

> About $20 million worth of value added through the impact of transit on productivity and;
>
> About $18 million worth of value added through the impact of transit on economic growth over a 5-year period.

The two tables present benefit estimates for three possible changes in transit presence. Note that a 1% increase in transit presence represents about 5 extra transit vehicles or 62 extra employees in the transit sector in each Metropolitan Statistical Area (MSA) (evaluated at average).

Table 5.7 Impact of Transit on Productivity

Change in Transit Presence	Percentage Change in Productivity	Average Productivity Gains per Employee	Total Productivity Gains per M.S.A
+ 1%	+ 0.04%	$19	$19.4 million
+ 10%	+ 0.40%	$192	$194.3 million
+ 25%	+ 0.10%	$480	$485.9 million

Given the data at hand, the coefficient estimate of the transit variable in the growth model measures the impact of transit presence over a 5-year period. The annual impact of transit presence was derived by dividing the 5-year impact by 5.

Table 5.8 Impact of Transit on Economic Growth

Change in Transit Presence	Added Economic Growth (5-year)	5-year Growth Effect per MSA	1-year Growth Effect per MSA
+ 1%	+ 0.10%	$18.0 million	$3.6 million
+ 10%	+ 1.02%	$180.3 million	$36.1 million
+ 25%	+ 2.56%	$450.8 million	$90.2 million

Using the above results, the estimated aggregate effect by multiplying the value added per worker with the number of workers, about 127 million workers. Table 5.9 shows the aggregate effect of transit in the United States for a total of 276 MSAs.

Table 5.9 Aggregate Impact of Transit in the United States

Change in Transit Presence	Value Created Yearly due to Productivity Gains	Value Created Yearly due to Added Economic Growth	Total Annual Economic Benefits
+ 1%	$2.4 billion	$0.5 billion	$3 billion
+ 10%	$24.3 billion	$5.3 billion	$30 billion
+ 25%	$60.9 billion	$13.2 billion	$75 billion

Conclusions

This chapter reports on an investigation on the influence of transit on the economic performance of large metropolitan areas. Econometric evidence has provided support to the idea of a positive impact of transit on productivity and economic growth: the hypotheses under consideration have been supported by various testing procedures. This conclusion has been reached under different model specifications. For instance, measuring transit presence by the number of employees in the transit sectors or by the number of operated vehicles has changed neither the direction nor the significance of the results. The results provided in this paper are also consistent with the findings of previous studies of agglomeration economies (see Henderson, 1988 for example).

Annex 5.1 Economic and Demographic Characteristics of the Sampled MSA (1996 Data)

METROPOLITAN STATISTICAL AREA	PRODUCTIVITY ($)	V. A. GROWTH	POPULATION	GPCF PER CAPITA	SERVICES (% IN V.A.)
Albany-Schenectady-Troy, NY	49,246	23%	878,527	2,399	22.18%
Allentown-Bethlehem-Easton, PA	52,851	42%	614,304	4,208	17.89%
Altoona, PA	41,105	44%	131,450	2,920	18.00%
Appleton-Oshkosh-Neenah, WI	45,108	48%	340,564	7,263	10.91%
Atlanta, GA	56,318	67%	3,541,230	5,195	19.32%
Austin-San Marcos, TX	48,662	82%	1,041,330	7,059	20.06%
Barnstable-Yarmouth, MA	43,411	23%	201,970	2,673	26.46%
Baton Rouge, LA	44,371	41%	567,388	5,099	15.66%
Benton Harbor, MI	42,683	31%	161,434	4,715	15.27%
Birmingham, AL	51,351	56%	894,702	3,607	18.25%
Bloomington, IN	36,304	39%	116,176	4,553	17.13%
Boston-Worcester-Lawrence, MA-NH-ME	56,114	46%	6,639,878	4,869	23.17%
Brownsville-Harlingen-San Benito, TX	33,087	42%	315,015	1,192	20.77%
Buffalo-Niagara Falls, NY	49,073	24%	1,175,240	2,446	19.00%
Canton-Massillon, OH	42,879	33%	402,928	3,483	14.55%
Cedar Rapids, IA	49,972	43%	179,411	8,965	15.36%
Charlotte-Gastonia-Rock Hill, NC-SC	53,503	55%	1,321,068	6,612	13.60%
Chattanooga, TN-GA	45,965	42%	446,096	3,875	15.36%
Chicago-Gary-Kenosha, IL-IN-WI	59,848	45%	8,599,774	4,503	19.15%
Cincinnati-Hamilton, OH-KY-IN	50,307	40%	1,920,931	3,836	16.91%
Cleveland-Akron, OH	50,095	37%	2,913,430	4,757	17.24%
Columbia, SC	42,474	48%	488,207	3,383	17.36%
Columbus, OH	46,661	51%	1,447,646	3,962	19.09%
Corpus Christi, TX	49,621	39%	384,056	3,371	13.96%
Dallas-Fort Worth, TX	59,591	55%	4,574,561	5,958	17.98%
Dayton-Springfield, OH	47,301	18%	950,661	9,386	17.13%
Daytona Beach, FL	37,522	35%	456,464	2,158	25.56%
Denver-Boulder-Greeley, CO	52,947	53%	2,277,401	5,683	20.60%
Des Moines, IA	46,525	55%	427,436	3,992	17.81%
Detroit-Ann Arbor-Flint, MI	57,730	40%	5,284,171	14,537	15.05%
El Paso, TX	40,313	47%	684,446	1,752	13.94%
Elkhart-Goshen, IN	46,853	55%	168,941	10,192	7.98%
Erie, PA	43,807	32%	280,570	5,883	16.72%
Fayetteville, NC	51,873	117%	284,800	2,304	10.10%
Fort Myers-Cape Coral, FL	43,954	41%	380,001	3,368	23.59%

METROPOLITAN STATISTICAL AREA	PRODUCTIVITY ($)	V. A. GROWTH	POPULATION	GPCF PER CAPITA	SERVICES (% IN V.A.)
Fort Pierce-Port St. Lucie, FL	44,728	43%	287,255	2,458	20.24%
Grand Rapids-Muskegon-Holland, MI	47,495	44%	1,015,099	6,430	13.91%
Green Bay, WI	46,897	59%	213,072	5,151	13.29%
Greensboro-Winston-Salem-High Point, NC	49,860	39%	1,141,238	4,965	14.14%
Greenville-Spartanburg-Anderson, SC	42,360	41%	896,679	5,997	12.92%
Harrisburg-Lebanon-Carlisle, PA	47,353	47%	614,755	2,861	16.72%
Hartford, CT	59,448	34%	1,645,805	3,383	19.02%
Honolulu, HI	56,271	44%	871,766	2,537	21.30%
Houston-Galveston-Brazoria, TX	63,361	42%	4,253,428	4,911	15.39%
Indianapolis, IN	51,785	50%	1,492,297	3,990	16.38%
Jacksonville, FL	48,434	69%	1,008,633	3,251	19.41%
Kansas City, MO-KS	49,644	49%	1,690,343	6,063	18.60%
Knoxville, TN	41,939	56%	649,277	3,408	20.96%
Lancaster, PA	47,450	44%	450,834	4,484	13.72%
Lansing-East Lansing, MI	45,669	31%	447,538	15,930	14.62%
Lincoln, NE	39,670	41%	231,765	4,865	19.81%
Los Angeles-Riverside-Orange County, CA	56,247	27%	15,495,160	3,474	23.85%
Louisville, KY-IN	48,190	40%	991,765	7,245	15.89%
Lubbock, TX	41,910	44%	232,035	3,179	21.62%
Madison, WI	43,414	52%	395,366	4,818	18.21%
McAllen-Edinburg-Mission, TX	32,415	52%	495,594	1,304	18.32%
Melbourne-Titusville-Palm Bay, FL	46,822	31%	453,998	3,477	25.09%
Memphis, TN-AR-MS	47,863	52%	1,078,151	3,005	17.53%
Miami-Fort Lauderdale, FL	49,284	47%	1,438,228	3,653	24.00%
Milwaukee-Racine, WI	48,878	36%	1,642,658	5,385	17.12%
Minneapolis-St. Paul, MN-WI	52,614	52%	2,765,116	6,284	18.44%
Modesto, CA	45,332	32%	415,786	2,018	15.24%
Muncie, IN	38,900	32%	118,600	2,841	17.94%
Nashville, TN	46,882	61%	1,117,178	4,870	22.63%
New London-Norwich, CT-RI	53,814	44%	621,682	2,824	19.76%
New Orleans, LA	47,020	15%	1,312,890	2,443	19.88%
NYC-Northern New Jersey-Long Island, NY-NJ	70,497	40%	20,175,070	2,774	22.06%
Norfolk-Virginia Beach-Newport News, VA	52,333	90%	1,540,252	4,371	18.38%
Oklahoma City, OK	42,032	30%	1,026,657	5,097	18.78%
Omaha, NE-IA	45,723	62%	681,698	4,534	21.30%
Orlando, FL	46,047	46%	1,417,291	4,154	27.86%
Philadelphia-Wilmington-Atlantic City, PA-DE-NJ	58,331	38%	5,973,463	3,361	21.99%
Pittsburgh, PA	49,818	43%	2,379,411	3,211	21.92%

METROPOLITAN STATISTICAL AREA	PRODUCTIVITY ($)	V. A. GROWTH	POPULATION	GPCF PER CAPITA	SERVICES (% IN V.A.)
Portland-Salem, OR-WA	50,407	70%	2,078,357	5,595	18.01%
Providence-Fall River-Warwick, RI-MA	46,538	40%	1,504,124	2,793	20.21%
Raleigh-Durham-Chapel Hill, NC	49,246	66%	1,025,253	5,901	21.07%
Reading, PA	51,576	48%	352,353	3,328	14.31%
Richmond-Petersburg, VA	55,699	81%	935,174	5,501	18.33%
Roanoke, VA	45,462	53%	229,105	4,398	17.41%
Rochester, NY	51,563	10%	1,088,037	7,962	17.09%
Sacramento-Yolo, CA	51,598	46%	1,632,133	3,303	20.21%
St. Louis, MO-IL	51,427	69%	2,569,992	6,064	17.55%
Salt Lake City-Ogden, UT	43,129	62%	1,217,842	5,202	18.24%
San Antonio, TX	45,488	44%	1,490,111	2,765	19.56%
San Diego, CA	52,443	47%	2,655,463	3,499	22.95%
San Francisco-Oakland-San Jose, CA	65,612	42%	6,605,428	6,809	22.03%
Sarasota-Bradenton, FL	41,041	24%	528,803	3,230	25.64%
Scranton-Wilkes-Barre-Hazleton, PA	43,169	52%	628,073	2,270	18.31%
Seattle-Tacoma-Bremerton, WA	53,827	40%	3,320,829	5,177	20.20%
South Bend, IN	41,226	29%	257,740	5,684	20.12%
Springfield, MA	46,097	37%	663,013	2,151	21.45%
Stockton-Lodi. CA	46,801	31%	533,392	1,899	15.40%
Syracuse, NY	50,835	21%	745,691	2,758	18.89%
Tampa-St. Petersburg-Clearwater, FL	44,262	42%	2,199,231	3,281	25.10%
Toledo, OH	45,493	39%	611,417	6,791	16.85%
Topeka, KS	45,175	34%	164,938	2,788	17.84%
Washington-Baltimore, DC-MD-VA-WV	57,247	29%	7,164,519	2,889	25.67%
West Palm Beach-Boca Raton, FL	54,445	54%	992,840	3,857	22.32%
York, PA	48,468	39%	368,332	4,204	13.69%
Youngstown-Warren, OH	44,116	43%	598,582	7,562	13.50%

Annex 5.2 Sampled MSA Sorted by Measures of Transit Presence (1996 Data)

METROPOLITAN STATISTICAL AREA	Transit Employment Per Capita	METROPOLITAN STATISTICAL AREA	Transit Vehicles Per Capita*
Richmond-Petersburg, VA	0.027459	Seattle-Tacoma-Bremerton, WA	0.084878
San Francisco-Oakland-San Jose, CA	0.023106	Philadelphia-Wilmington-Atlantic City, PA-DE-NJ	0.074913
Elkhart-Goshen, IN	0.023082	Miami-Fort Lauderdale, FL	0.072501
Minneapolis-St. Paul, MN-WI	0.022471	New York-Northern New Jersey-Long Island, NY-NJ	0.056226
Madison, WI	0.021610	El Paso, TX	0.049835
New York-Northern New Jersey-Long Island NY-NJ	0.021594	San Antonio, TX	0.049397
Atlanta, GA	0.021008	Salt Lake City-Ogden, UT	0.048986
Norfolk-Virginia Beach-Newport News, VA	0.020750	Pittsburgh, PA	0.048961
Hartford, CT	0.020743	Chicago-Gary-Kenosha, IL-IN-WI	0.048945
Des Moines, IA	0.020683	Muncie, IN	0.048448
Chicago-Gary-Kenosha, IL-IN-WI	0.020584	Honolulu, HI	0.046726
Denver-Boulder-Greeley, CO	0.020501	New Orleans, LA	0.044100
Boston-Worcester-Lawrence, MA-NH-ME	0.020487	Daytona Beach, FL	0.043438
Detroit-Ann Arbor-Flint, MI	0.020467	Madison, WI	0.043410
Roanoke, VA	0.020466	Cleveland-Akron, OH	0.042891
Washington-Baltimore, DC-MD-VA-WV	0.020382	Washington-Baltimore, DC-MD-VA-WV	0.042053
Green Bay, WI	0.020203	Springfield, MA	0.040830
Dallas-Fort Worth, TX	0.020148	Dayton-Springfield, OH	0.039640
Seattle-Tacoma-Bremerton, WA	0.020137	Buffalo-Niagara Falls, NY	0.037300
Cedar Rapids, IA	0.020044	Altoona, PA	0.036685
Charlotte-Gastonia-Rock Hill, NC-SC	0.019718	Milwaukee-Racine, WI	0.035246
Honolulu, HI	0.019693	Toledo, OH	0.035202
Fayetteville, NC	0.019555	Lincoln, NE	0.034239
Indianapolis, IN	0.019523	South Bend, IN	0.034221
Harrisburg-Lebanon-Carlisle, PA	0.019386	Erie, PA	0.033130
Raleigh-Durham-Chapel Hill, NC	0.019300	San Francisco-Oakland-San Jose, CA	0.032879
Omaha, NE-IA	0.019270	Portland-Salem, OR-WA	0.031830
Milwaukee-Racine, WI	0.019226	Albany-Schenectady-Troy, NY	0.030916
Topeka, KS	0.019178	Des Moines, IA	0.030430
Nashville, TN	0.019133	Minneapolis-St. Paul, MN-WI	0.029899
Grand Rapids-Muskegon-Holland, MI	0.019076	St. Louis, MO-IL	0.029784
Rochester, NY	0.018788	Elkhart-Goshen, IN	0.029164
Houston-Galveston-Brazoria, TX	0.018657	Bloomington, IN	0.028530
Austin-San Marcos, TX	0.018654	Syracuse, NY	0.027524

*Transit Vehicles Directly Operated Per Capita (VDOPC)

METROPOLITAN STATISTICAL AREA	Transit Employment Per Capita	METROPOLITAN STATISTICAL AREA	Transit Vehicles Per Capita
Columbus, OH	0.018587	Cincinnati-Hamilton, OH-KY-IN	0.027112
Appleton-Oshkosh-Neenah, WI	0.018458	Louisville, KY-IN	0.026594
Dayton-Springfield, OH	0.018455	Stockton-Lodi, CA	0.024993
Kansas City, MO-KS	0.018438	Lubbock, TX	0.023843
St. Louis, MO-IL	0.018419	Denver-Boulder-Greeley, CO	0.023728
Philadelphia-Wilmington-Atlantic City, PA-DE-NJ	0.018368	Modesto, CA	0.023314
Lincoln, NE	0.018340	New London-Norwich, CT-RI	0.023299
Lansing-East Lansing, MI	0.018191	Rochester, NY	0.023274
Jacksonville, FL	0.018001	Norfolk-Virginia Beach-Newport News, NC	0.021916
Greensboro-Winston-Salem-High Point, NC	0.017937	Memphis, TN-AR-MS	0.021691
Memphis, TN-AR-MS	0.017924	Los Angeles-Riverside-Orange County, CA	0.021630
Portland-Salem, OR-WA	0.017867	Reading, PA	0.021432
Cleveland-Akron, OH	0.017829	Boston-Worcester-Lawrence, MA-NH-ME	0.021382
Columbia, SC	0.017785	Columbus, OH	0.021344
Toledo, OH	0.017693	Detroit-Ann Arbor-Flint, MI	0.021142
Cincinnati-Hamilton, OH-KY-IN	0.017529	McAllen-Edinburg-Mission, TX	0.020422
Louisville, KY-IN	0.017503	Topeka, KS	0.020104
Albany-Schenectady-Troy, NY	0.017421	Atlanta, GA	0.019995
Birmingham, AL	0.017408	Omaha, NE-IA	0.019903
Salt Lake City-Ogden, UT	0.017295	Barnstable-Yarmouth, MA	0.019468
Baton Rouge, LA	0.017073	Austin-San Marcos, TX	0.018799
New London-Norwich, CT-RI	0.016847	Chattanooga, TN-GA	0.018584
Reading, PA	0.016524	Green Bay, WI	0.018405
Orlando, FL	0.016407	San Diego, CA	0.018241
Greenville-Spartanburg-Anderson, SC	0.016385	Tampa-St. Petersburg-Clearwater, FL	0.018001
Sacramento-Yolo, CA	0.016314	Brownsville-Harlingen-San Benito, TX	0.017829
Bloomington, IN	0.016258	Houston-Galveston-Brazoria, TX	0.017805
San Diego, CA	0.016242	Dallas-Fort Worth, TX	0.017730
Chattanooga, TN-GA	0.016130	Raleigh-Durham-Chapel Hill, NC	0.017650
Buffalo-Niagara Falls, NY	0.016119	Providence-Fall River-Warwick, RI-MA	0.017578
Los Angeles-Riverside-Orange County, CA	0.016085	Nashville, TN	0.016761
South Bend, IN	0.016079	Lansing-East Lansing, MI	0.016229
Pittsburgh, PA	0.015985	Corpus Christi, TX	0.016221
Lancaster, PA	0.015881	Jacksonville, FL	0.015948
Syracuse, NY	0.015864	Benton Harbor, MI	0.015577
Knoxville, TN	0.015520	York, PA	0.015524
York, PA	0.015443	Sarasota-Bradenton, FL	0.015245
New Orleans, LA	0.015412	Cedar Rapids, IA	0.015118

METROPOLITAN STATISTICAL AREA	Transit Employment Per Capita	METROPOLITAN STATISTICAL AREA	Transit Vehicles Per Capita
West Palm Beach-Boca Raton, FL	0.015381	Sacramento-Yolo, CA	0.014900
Allentown-Bethlehem-Easton, PA	0.015252	Knoxville, TN	0.014874
Erie, PA	0.015251	Scranton-Wilkes-Barre-Hazleton, PA	0.014669
Oklahoma City, OK	0.015063	Allentown-Bethlehem-Easton, PA	0.014423
Muncie, IN	0.015030	Melbourne-Titusville-Palm Bay, FL	0.013705
Tampa-St. Petersburg-Clearwater, FL	0.014899	Roanoke, VA	0.013529
San Antonio, TX	0.014779	Kansas City, MO-KS	0.013197
Providence-Fall River-Warwick, RI-MA	0.014700	Orlando, FL	0.013186
Springfield, MA	0.014545	Charlotte-Gastonia-Rock Hill, NC-SC	0.012941
Miami-Fort Lauderdale, FL	0.014458	West Palm Beach-Boca Raton, FL	0.012793
Lubbock, TX	0.014325	Appleton-Oshkosh-Neenah, WI	0.012775
Canton-Massillon, OH	0.014102	Canton-Massillon, OH	0.012725
Benton Harbor, MI	0.013989	Greensboro-Winston-Salem-High Point, NC	0.011732
Melbourne-Titusville-Palm Bay, FL	0.013870	Hartford, CT	0.011640
Youngstown-Warren, OH	0.013769	Birmingham, AL	0.010826
Corpus Christi, TX	0.013738	Richmond-Petersburg, VA	0.010467
Barnstable-Yarmouth, MA	0.013463	Youngstown-Warren, OH	0.010296
Altoona, PA	0.013374	Fort Myers-Cape Coral, FL	0.009898
Scranton-Wilkes-Barre-Hazleton, PA	0.013009	Harrisburg-Lebanon-Carlisle, PA	0.009823
Sarasota-Bradenton, FL	0.012938	Baton Rouge, LA	0.009593
Fort Myers-Cape Coral, FL	0.012044	Grand Rapids-Muskegon-Holland, MI	0.009549
Stockton-Lodi, CA	0.010702	Columbia, SC	0.008793
Modesto, CA	0.010516	Lancaster, PA	0.008747
El Paso, TX	0.010477	Fort Pierce-Port St. Lucie, FL	0.008531
Fort Pierce-Port St. Lucie, FL	0.010277	Fayetteville, NC	0.008069
Daytona Beach, FL	0.008617	Oklahoma City, OK	0.007453
Brownsville-Harlingen-San Benito, TX	0.007568	Indianapolis, IN	0.006815
McAllen-Edinburg-Mission, TX	0.006778	Greenville-Spartanburg-Anderson, SC	0.006275

Annex 5.3 Descriptive Statistics (1991 Data)

Variable Name		Average	Std Dev	Minimum		Maximum	
				Value	MSA	Value	MSA
Population		1,637,445	2,771,402	110,100	Bloomington, IN	19,813,200	NYC-Northern New Jersey-Long Island
Density		443.59	261.92	206.89	Austin-San Marcos, TX	1729.66	NYC-Northern New Jersey-Long Island
Employment		916,781	1,518,284	61,144	Muncie, IN	10,738,771	NYC-Northern New Jersey-Long Island
Value added ($millions)		39,166	73,929	1,979	Bloomington, IN	550,379	NYC-Northern New Jersey-Long Island
Value added per capita		21,248	3,847	9,310	McAllen-Edinburg-Mission, TX	29,602	San Francisco-Oakland-San Jose, CA
Productivity		37,864	5,014	26,677	McAllen-Edinburg-Mission, TX	54,522	Houston-Galveston-Brazoria, TX
GPCF ($millions)		5,228	8,308	252	Muncie, IN	49,404	NYC-Northern New Jersey-Long Island
GPCF per capita		3,185	947	1,055	Brownsville-Harlingen-San Benito, TX	7,753	Elkhart-Goshen, IN
State & local education purchases ($millions)		1,377	2,329	83	Elkhart-Goshen, IN	17,712	NYC-Northern New Jersey-Long Island
State & local education purchases per capita		896	407	448	Lubbock, TX	2,773	Madison, WI
Transit Presence	Number of Vehicles Directly Operated	NA	NA	NA	NA	NA	NA
	VDO per capita	NA	NA	NA	NA	NA	NA
	Employment per capita	0.003579	0.002807	0.00056	Sarasota-Bradenton, FL	0.016925	Altoona, PA

Annex 5.4 Productivity Model Estimates Using Transit Employment as a Measure of Transit Presence (1996 Data)

LS// Dependent variable is LPDTY

Included observations: 100

Variable Name	Coefficient	Std. Error	t-Statistic	Prob.
C	9.59	0.32	29.84	0.00
LPOP	0.08	0.01	9.56	0.00
LEMPTRAPC	0.04	0.02	2.45	0.02
LEDUEXPPC	-0.02	0.03	-0.55	0.58
LGPCFPC	0.08	0.02	3.49	0.00
R1	0.01	0.05	0.23	0.82
R3	-0.04	0.04	-1.03	0.31
R4	-0.05	0.04	-1.25	0.22
R5	-0.12	0.04	-3.05	0.00
R6	-0.11	0.04	-2.54	0.01
R7	-0.09	0.05	-1.86	0.07
R8	-0.14	0.06	-2.24	0.03
R9	0.00	0.04	0.09	0.93
R10	-0.10	0.06	-1.59	0.12
AGG_SER	-0.01	0.00	-3.32	0.00
R-squared	0.72	Mean dependent var		10.78
Adjusted R-squared	0.67	S.D. dependent var		0.13
S.E. of regression	0.07	Akaike info criterion		-5.05
Sum squared resid	0.47	Schwarz criterion		-4.66
Log likelihood	125.76	F-statistic		15.57
Durbin-Watson stat	1.58	Prob(F-statistic)		0.00

Note: LEMPTRAPC = natural log of Transit employment per capita

Annex 5.5 Slope Dummy Regression Results Using Transit Employment As a Measure of Transit Presence (1996 Data)

LS// Dependent variable is LPDTY

Included observations: 100

Variable Name	Coefficient	Std. Error	t-Statistic	Prob.
C	9.73	0.28	34.28	0.00
LPOP	0.04	0.02	2.36	0.02
LGPCFPC	0.08	0.02	3.62	0.00
R1	0.00	0.05	0.08	0.94
R3	-0.04	0.04	-1.06	0.29
R4	-0.06	0.04	-1.57	0.12
R5	-0.15	0.04	-3.64	0.00
R6	-0.13	0.04	-3.22	0.00
R7	-0.09	0.05	-1.91	0.06
R8	-0.17	0.06	-2.62	0.01
R9	-0.01	0.04	-0.26	0.80
R10	-0.12	0.06	-1.92	0.06
AGG_SER	-0.01	0.00	-3.70	0.00
D_EMPTRA	-0.50	0.30	-1.67	0.10
D_EMPTRA*LPOP	0.04	0.02	1.82	0.07
R-squared	0.72	Mean dependent var		10.78
Adjusted R-squared	0.68	S.D. dependent var		0.13
S.E. of regression	0.07	Akaike info criterion		-5.06
Sum squared residual	0.47	Schwarz criterion		-4.67
Log likelihood	126.22	F-statistic		15.77
Durbin-Watson stat	1.57	Prob(F-statistic)		0.00

Annex 5.6 Growth Model Estimates Using The Number of Directly Operated Vehicles as a Measure of Transit Presence (1991 Data)

LS// Dependent variable is LVAGTH

Included observations: 100

Variable Name	Coefficient	Std. Error	t-Statistic	Prob.
C	19.49	4.85	4.02	0.00
LPDTY	-1.56	0.43	-3.62	0.00
LPOP	0.16	0.04	3.55	0.00
LVDOPC96	0.09	0.06	1.41	0.16
LGPCFPC	0.13	0.13	0.97	0.33
R1	0.45	0.18	2.47	0.02
R3	0.53	0.17	3.21	0.00
R4	0.64	0.17	3.76	0.00
R5	0.42	0.16	2.55	0.01
R6	0.53	0.17	3.17	0.00
R7	0.57	0.18	3.08	0.00
R8	0.76	0.26	2.98	0.00
R9	0.48	0.17	2.76	0.01
R10	0.63	0.26	2.37	0.02
AGG_SER	-0.03	0.01	-3.03	0.00
R-squared	0.42	Mean dependent var		3.74
Adjusted R-squared	0.32	S.D. dependent var		0.35
S.E. of regression	0.29	Akaike info criterion		-2.33
Sum squared resid	7.24	Schwarz criterion		-1.93
Log likelihood	-10.64	F-statistic		4.38
Durbin-Watson stat	2.11	Prob(F-statistic)		0.00

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Chapter 6. Commercial Property Benefits of Transit

Introduction

This Chapter reports on Commercial Property Benefits of Transit. The goal was "*to research and develop a practical methodology for estimating the effect of the proximity of transit on commercial property value.*" Therefore, the objective of this report is to present a detailed review of the literature focusing on methodological issues, to propose a methodology that allows the estimation of the impact of transit on commercial property and to describe the implementation of this methodology on a selected set of data.

Methodological Framework

Two approaches have been used in the literature to address similar issues: regional scale analyses and property level analyses[22]. The former focuses on the changes in commercial property values brought about by a change in the transit system (the opening of a new bus line for example) for a particular region; the latter concentrates on the differential impact that public transit has on surrounding properties. This Chapter used the latter approach to estimate the effect of the proximity to transit on commercial properties. The best technique to evaluate this impact consists of estimating a hedonic price model, where the value of *selected* commercial properties would be regressed on a set of property characteristics. To run these regressions, FTA collected three types of data: real estate, geographical and socioeconomic data. The estimated coefficients of the hedonic price equation were then used to evaluate the impact of transit on commercial property value within the area of study. This impact was then expressed as a dollar increment in property value per foot of proximity to transit. It was then a straightforward task to evaluate the *average* and the *total* impact of transit within the area of study.

Figure 6.1 illustrates the methodology. After this introduction, the next section presents a review of the literature. This review starts with general considerations about the benefits of transit in increasingly congested urban areas. The nature of commercial property benefits provided by transit is explored. Next, two measurement methods are described that have been commonly used in the literature: hedonic pricing and stated preference methods. Then we discuss more closely the implementation of hedonic models, concentrating on the choice of explanatory variables in existing studies of commercial property values.

We will then describe the actual methodology. After an overview of the task, some methodological issues are considered: which type of commercial properties should be included in the analysis? What is the appropriate area of study? Do different forms of public transportation have different impacts on property values? Finally, How should the properties be selected? This discussion then specifies the model; it addresses the choice of the appropriate functional form and the selection of the variables entering the model. The chapter concludes with the empirical implementation of the model, describes the data used in the study and provides estimates of the

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[22] Alex Anas and Regina Armstrong, "Land Values and Transit Access: Modeling the relationship in the New-York Metropolitan Area", Federal Transit Administration, Final Report, September 1993.

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impact of transit on commercial properties. This will include a brief presentation of the possible extensions that could be brought to this report.

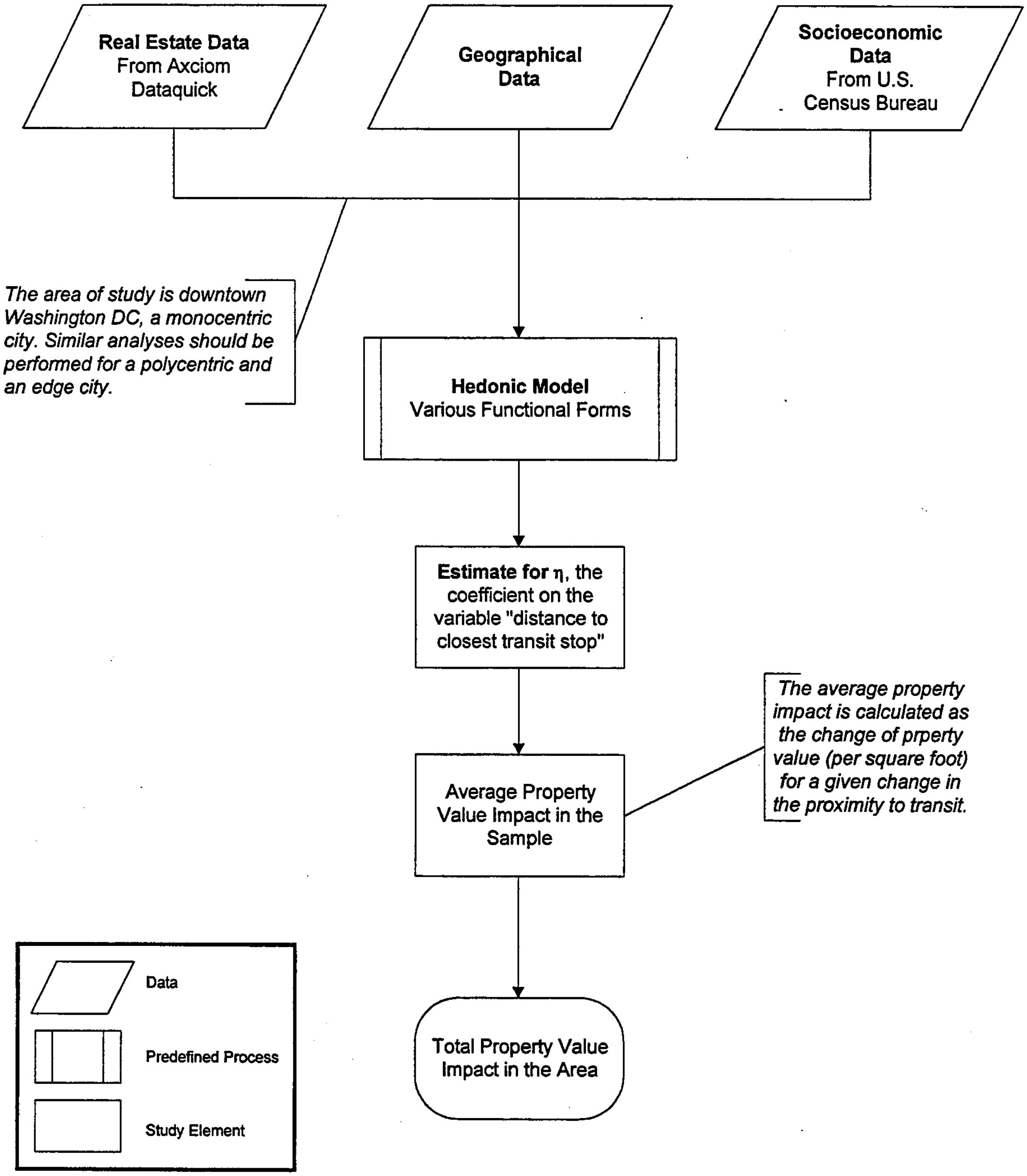

Figure 6.1 **Study Methodology Process**

Literature Review

The Policy Context

The automobile and the extensive network of highways and roads in and between cities looms large in the American physical and cultural landscape. Environmentalists are concerned with the dangerous levels of air pollutants in many cities. The inefficiencies and costs of traffic congestion and the burden it places on the regional economies worry the economists. The reliance on primarily imported oil concerns planners and policy-makers alike. Commuters, who experience the regular extended traffic congestion, complain about the associated stress and unpleasantness. In recent years, residents in hundreds of U.S. suburbs have come to regard traffic congestion as their most serious environmental problem. The statistics suggest that congestion is rising primarily in metropolitan areas that are either very large -those with a population of two million or more- or fast growing. Most strikingly, for a given area, traffic on highways can grow even faster than population and employment (that was the case, for example, for Montgomery County, Maryland, in the 1978-1988 period; see Downs (1992)). The same pattern has been observed also in national highway travel data over recent decades.

The causes of rising congestion can be divided into two basic categories: immediate and long term. At least four immediate causes can be mentioned: rapid population and job growth, more intensive use of automotive vehicles, failure to build new roads, failure to make drivers bear the full costs they generate. Long term, or indirect, causes include: concentration of work trips in time, desire to choose where to live and work, desire for low-density neighborhoods, preference for low-density workplaces, and desire to travel in private vehicles.[23]

Traffic congestion problems as well as the solutions to these problems may vary from one city to another. The next section describes the three types of city that have been identified in the literature: monocentric, polycentric and edge cities. We then introduce transit as a way to solve - or at least reduce - congestion problems.

Monocentric, Polycentric, and Edge City Models

The models of residential location in urban land markets originally developed by Alonso (1964) and Muth (1969) have long since established themselves as the foundations of urban economic theory. The fundamental results of the basic model are that the spatial distribution of land and housing prices, consumption of land (and other housing attributes), and the spatial arrangement of residents are determined by the transportation costs to the Central Business District (CBD). In particular, the principal qualitative hypotheses which the standard model generates are: (1) the price of land declines with distance from the CBD (the negative rent or land price gradient); and (2) the consumption of land per household increases with distance from the CBD (the negative density gradient). The obvious fact that only a small portion of metropolitan area jobs are found in the CBD does not necessarily undermine the predictions of a model that assumes that *all* jobs are located in the CBD[24]. Even if the fraction of CBD jobs is small, money wages would have to fall with distance from the CBD to compensate workers for longer commutes and to attract them

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[23] Downs (1992)

[24] Richardson, Harry W. (1988)

from locally available jobs. Richardson (1988) also points out that the predicted negative gradients are actually observed (in house prices, land rents, output of housing services per unit land, population densities), and their relative rates of change are plausible and internally consistent.

In the homogeneous income case, the essential condition of the standard monocentric model is that the marginal decline in housing expenditures with outward movement should exactly compensate the marginal increase in commuting costs so that households are indifferent among locations. Coulson (1991) tests the monocentric model in the framework of a hedonic model, where the selling price of a house is regarded as a function of housing attributes, including distance to the CBD. The empirical results show that housing prices fall at a rate approximately equal to the increase in transportation costs, as predicted by the model.

However, most metropolitan areas are not monocentric: they have subcenters where a substantial amount of employment is located. These subcenters are usually a result of decentralization and urban sprawl. Each of them may have rent gradients of their own, which will collide with the CBD's gradient, and with each other's. Thus, while the monocentric model can be relevant within each submarket, it will appear irrelevant for these metropolitan areas as a whole. Both the huge proportion of non-CBD employment and the continued strength of agglomeration economies (as economies of spatial concentration, *not* centralization) imply the presence of these employment subcenters that pull in workers from their immediate locale (Richardson (1988)). Muth (1985) argues that the existence of substantial non-CBD employment also explains why central vs. suburban income differentials are much narrower than those predicted by the standard monocentric model. In his framework, since local and non-local homogeneous workers have to be offered the same wage, there is no negative wage gradient. Furthermore, the sites close to the subcenter workplace will be at a premium because of the supra-equilibrium wages offered there; in other words, there is no negative land rent gradient either.

What is the driving force of the polycentric model? The strength of the CBD relies on the comparison of CBD agglomeration economies with CBD congestion costs, both as a function of city size. As the city becomes very large, the gap between the two functions narrows. By the time the functions intersect, the CBD retains no locational advantage over alternative metropolitan sites. Richardson (1988) points out that there is substantial empirical evidence to support this view. For example, Anjomani and Chimene (1982) test the monocentric density gradient hypothesis with 1950 and 1970 data. They find a significant gradient in 40 out of 46 cities in 1950 but fail to identify such gradient in more than half of the cities in 1970. In another study[25], 58 polycentric population density peaks were identified in the five-county Los Angeles area. This study also showed that a polycentric "density surface" was more appropriate than the traditional monocentric gradient for the area under examination. Richardson (1988) notes that subcenters can also be identified in terms of: office space, in- and out- commuting, employment, employment density, worker amenities, influence of suburban nodes on housing prices and land values, and significance of a CBD accessibility variable.

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[25] Gordon, P., Richardson, H., and Wong, H.: The Distribution of Population and Employment in a Policentric City: The Case of Los Angeles, ENVIRONMENT AND PLANNING (1986). Cited in Richardson, Harry W. (1988)

With respect to commutes, Richardson (1988) mentions several studies suggesting that polycentric spatial structures facilitate commuting economies. In particular, these studies have shown that: (1) residential densities and commuting times are positively associated, which is consistent with the idea that low-density metropolitan areas and their decentralized employment centers facilitate shorter work trips[26]; (2) people with the shortest commuting times are those who live and work in the suburbs, while the worst-off are those who live in the suburbs but work in the CBD (the typical commuter in monocentric cities); (3) travel speeds do not vary with city size; (4) peak travel speeds improved between 1977 and 1983. This research suggest that firms and households have been relocating and settling close to each other, facilitating shorter trips and relieving core-area congestion.

Edge cities provide another perspective on the spatial organization of production in metropolitan areas. Contrary to traditional suburbs, edge cities are not simply bedroom communities or a product of urban decentralization. They are the creation of strategically controlled office development by large-scale land developers. Edge cities are new cities, created since 1965, outside major central or core cities - they are typically based around one of the great American ports (e.g. Boston, Chicago, Houston, New York, and San Francisco) and centered around enormous tracts of mixed-use office space. They are complete cities, offering jobs, residences, shopping facilities and services for their inhabitants. They are planned entities with rules and limits to their growth. Edge city developers make strategic choices in terms of office space capacity, location vis-à-vis the central city and other edge cities, industry- and job-mix. Their location and capacity choices are strategic because they engage the passive core city and potential competitors in a struggle for the metro area resources. To illustrate this, Henderson and Mitra (1996), present a decision model for an edge city developer who chooses business district capacity and location with a view to maximize profits. Moving closer to the core city enhances production efficiency by increasing the efficiency of the exchange of information between businesses in the core and edge city. On the other hand, it increases typical residential rents and commuting costs (and hence wages demanded by employees) and weakens the developer's local monopsony power.

Assessing Transit-Oriented Solutions

Given the increasing problems associated with automobile dependence, many planners, policymakers and others are examining potential alternatives to decrease the reliance on automobile travel. Transit-oriented development for residential and mixed-used areas offers one possible solution. Public transit can be expanded through bus, fixed-rail, or light rail systems. Fixed-rail services of all types are feasible only if they converge on relatively large downtown areas. On the other hand, light rail lines cost less to build than full-scale fixed-rail systems with underground segments through downtown areas. However, aside from a few large cities with extensive mass transit systems, public transit is not widely used for work trips. Public transit usage is even lower among workers living in suburbs. According to Downs (1992), it appears that persons most likely to use public transit for work trips are those who (1) have no automotive vehicle available to their household, (2) live in a central city and work in its CBD, and (3) live in a densely settled community. However, in generating transit usage, the residential density of an

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[26] Downs (1992)

area is less significant than its location. The study also shows that the density of nonresidential clusters is much more important in generating public transportation usage than residential density, other things equal.

Among the public policies that can be implemented in order to increase public transit ridership we can mention: (1) cutting transit or bus fares, (2) cutting transit or bus running time, (3) cutting transit or bus waiting time by increasing service frequency. Downs (1992) also discusses whether greater use of public transit would be achieved by concentrating more jobs in large clusters outside the CBD. In metropolitan areas dominated by geographically large local governments, such as the county governments around Washington, D.C., additional jobs could be steered into a few major centers. This would convert now sprawling but inefficient offices in these centers into more compact, downtown-like districts and -if these centers were served by rapid transit- would encourage more commuting off the highways.

The Nature of Commercial Property Benefits from Transit

The urban economics literature has early on established that access to transit, as a positive amenity, will be "capitalized" in the value of land and residential - or commercial - property. It is the purpose of this section to explain why the proximity of transit may enhance commercial property value. It turns out that the nature of these benefits is dual: the proximity of transit may not only facilitate the access to customers but also the access to the work force. Before turning to these issues, it is necessary to introduce two important benefit concepts: present value and willingness-to-pay.

Benefit Concepts

The market value of land equals the present value of the stream of rental income generated by the land. The present value is the maximum amount that an investor is willing to pay for an asset, given an alternative investment. In other words, the market value of land is the present value of the annual rental payments from the land. In contrast with agricultural land, which can deteriorate with use, developed land does not deteriorate. Therefore, the market value of developed land equals the annual rent divided by the interest rate[27]. This concept can be extended to commercial property value.

Income from Commercial Property and Willingness-to-Pay

The maximum price a firm is willing to pay for any site is a function of its anticipated future returns when operating at the site[28]. The annual return can be thought of as the excess of total annual revenue over total annual costs, for all factors of production other than land. It follows that changes in the value of a commercial property (a stock measure) will represent the discounted anticipated changes in the income revenue from the property (a flow measure). In this context, a bid-rent function can be defined. This function indicates how much a firm is willing to pay for different office sites. Assuming perfectly competitive markets, economic profit will be

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[27] O'Sullivan, Arthur: Urban Economics (1996)

[28] Downing, Paul B.: Factors Affecting Commercial Land Values: An Empirical Study of Milwaukee, Wisconsin, LAND ECONOMICS, 49:1, Feb. 1973

zero in equilibrium and the amount paid by the firm will equal the excess of total revenue over non-land costs.[29]

From all that, commercial property value will be affected by the proximity of transit as long as transit affects anticipated future revenues or total costs.

Access to Labor Supply

The impact of transportation changes on labor markets can be quite extensive and can occur at a number of different levels. In a study about labor markets and high-speed trains, Haynes (1997) divides this impact into supply-side and demand-side effects. On the supply side, transportation affects both the micro level search behavior of job seekers and the meso level tradeoffs between commuting and labor migration. Specifically, the latter implies that transportation improvements that lower the cost of migration increase certainty by reducing information decay (i.e. the decline in information about job availability produced by distance) or search costs, lower the cost of labor market adjustments, and increase the efficiency of labor migration. On the demand side, firms that demand labor will have a broader pool to select from at lower prices (as they will have to pay a lower wage premium for extra commuting) with the potential for a more targeted or specialized fit between jobs and employees.

White (1988) examines workers' commuting behavior in an urban model with decentralized employment. This behavior will in turn influence firms in their location choice. The paper shows that in cities with decentralized employment, a "commuting indifference" property holds, but only in special cases. In general, households' rent offer curves for housing depend on their workers' job locations. It is also shown that workers' wage offer curves for different job locations vary with their households' residential locations. Specifically, workers having different job locations may segregate into different residential rings. The paper shows a pattern in which workers living in particular residential rings have preferences over where they work. In equilibrium, it is likely that workers' residential and job locations will be non-negatively related to each other. If we consider the case of workers with different skills, the model predicts that firms have stronger incentives to suburbanize as the average skill level and wage rate of their workers rise. Therefore, the composition of a firm's workforce (i.e. the relative mix of high-wage versus low-wage workers) influences the firm's location. And there is no generalized indifference property applying to commuting journey lengths in cities with decentralized employment.

Rotemberg and Saloner (1990) argue that firms locate together to commit to compete for labor and not pay monopsony wages. This effective commitment enables firms to attract labor in the first place.

Haynes (1997) explores the impact of high-speed train on labor markets for three cases: Japan's Shinkansen, France's TGV, and Germany's ICE. In Japan, station locations generated higher population growth levels when an information exchange industry (business services, banking and real estate development), universities and expressway access were also present. In general, the empirical studies indicate that transportation improvements taken together are often

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[29] O'Sullivan: op.cit.

complementary. Station effects and expressway effects also contributed to a substantial increase in per capita income. On the other hand, a heavy concentration in manufacturing industry and an aged population were growth limiting variables.

Access to Consumers

Stores and personal businesses will seek to locate close to where potential customers can access their services. First, the accessibility of a site for potential customers will directly affect anticipated future net returns. Second, the *knowledge* potential customers can have on the firm's location and existence is also likely to affect expected revenues (see Downing (1973)).

Glaeser et al. (1992) observe the presence of "urbanization" externalities: different industries locate in a city because local demand is high there, and so they can sell some of their output without incurring transport costs. In the same spirit, Krugman (1991) presents a model of city formation based on local demand. The evidence presented in Glaeser et al. (1992) strongly supports the urbanization externalities hypothesis.

Additionally, Moses and Williamson (1967) show that firm size must be taken into account when analyzing location patterns, since small firms may be more constrained regarding this issue. In other words, larger firms can move longer distances because they are more independent of suppliers or buyers at a particular location.

Property Value and Access

Sivitanidou (1996) explains that "the contemporary land market theory has early on established that differential firm access to business activity clusters must elicit significant effects on commercial land markets" (page 126). She stresses in particular "the importance of forward (clientele-related) and backward (input-related) linkages between firms providing or using such support services as advertising, accounting, financial, business, and legal" (page 127). Finally, she notes that these linkages "necessitate frequent travel by top-level executives whose time carries significant opportunity costs" (page 127).

In addressing the role that business centers play within polycentric Los Angeles, Sivitanidou (1995) presents a model that builds upon previous urban spatial studies postulating joint household and firm equilibria. In this model, property value per unit land is a function of both property specific traits and location attributes. Property traits include standard building attributes (age, area per floor, elevator, parking, etc.). Location attributes include business centers (main or secondary) accessibility and a set of control locational traits (local service and transportation access, location prestige, worker amenities, and land supply constraints). Center accessibility is measured as the distance to each center, whereas transportation access is measured as the distance to the closest major airport and freeway. The model also allows for different specifications regarding the relative importance and degree of substitutability of secondary business centers. The empirical findings based on this model not only confirm the hypothesis that firms value main center accessibility, but they also show that secondary center accessibility matters too. Both factors generate nontrivial land market effects. The study also shows that distance to airport exhibits the expected (negative) sign, and is statistically significant.

Downs (1992) suggests that public transit usage affects nonresidential density. He notes that Washington D.C.'s Metro rail system appears to have encouraged more downtown development than would otherwise have occurred. Metro rail converges on downtown from all directions, with the result that the city center has become a better labor market for employers. He concludes that one way to strengthen the market for office and other space within a business center is to build more off-road transit facilities to serve it.

Downing (1973) presents regressions of land sales prices as a function of distance to CBD, distance to shopping center, traffic level on main street, area population, median income, amenities, and area dummies. He concludes that these variables explain a substantial portion of the variations in commercial land value for the study area (the city of Milwaukee). One hypothesis of the paper is that the distance to the CBD might be associated with the firm's cost of obtaining goods and services. Although it is recognized that *travel time to CBD* would be a more appropriate variable than *distance to CBD*, the latter is used; the associated coefficients are significant only when the distance is substantial. Therefore, the empirical evidence supports the hypothesis that greater accessibility to transportation increases land values.

Nakamura and Ueda (1989) present empirical evidence of a substantial station driven commercial land value increase for the case of Japan's Shinkansen. This increase is even higher than the expressway driven value increase. For the cases of France's TGV and Germany's ICE, there is also empirical evidence of commercial land value and demand increases due to station effects.

The Measurement of Transit's Impact

Hedonic Pricing Methodology

Many commodities can be viewed as bundles of individual attributes for which no explicit markets exist. Although it would be of interest to estimate structural supply and demand functions for these attributes, the absence of directly observable attribute prices poses a problem for such estimation. A hedonic price equation is a reduced-form equation reflecting both supply and demand influences. The hedonic regression reveals implicit prices of these attributes, and may provide a starting point for recovering underlying supply and demand functions.

Unfortunately, the appropriate functional form for the hedonic price equation cannot *in general* be specified on theoretical grounds. Downing (1973) does not address the issue explicitly. He uses both linear and non-linear forms to evaluate the impact of the distance to the CBD and the distance to the nearest shopping center on land value. His results are unaffected by the choice of the functional form. However, since the non-linear form is more consistent with traditional theory and was found to substantially improve the fit in the residential land value regressions, non-linear form results are generally reported in the literature. Grass (1992) uses a semi-log form while Sivitanidou (1996) uses a log-linear, or double-log, function.

Although some earlier writers[30] had employed the Box-Cox model, it is since Halvorsen and Pollakowski's (1981) contribution that this model has become widely employed in hedonic studies. The authors stress that the lack of a firm theoretical basis for the choice of functional form is unfortunate since, in their opinion, the results obtained using the hedonic approach

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[30] Linneman, P.: Some empirical results on the nature of the hedonic price function for the urban housing market, JOURNAL OF URBAN ECONOMICS 8, 1980. Cited in Cheshire and Sheppard (1995)

depend *critically* on the functional form. Therefore, the authors recommend the use of a flexible approach that does not require the specification of a functional form per-se: the Box-Cox model.

Graves et al. (1988) address the issues of functional form and error distribution in the context of estimating hedonic prices for urban air quality. The authors point out that the empirical magnitudes of the hedonic prices may vary substantially, depending on how these issues are addressed. In order to make the functional form sufficiently general, they employ the Box-Cox model. They conclude that most of the functional forms encountered in the environmental literature can be rejected for *their* data set. However, they *cannot* assess the relative impact of functional form variations on hedonic price estimates. In fact, if the estimated prices are relatively insensitive to functional form, the commonly used forms may provide relatively precise benefit estimates. Finally, the authors want to evaluate the presence of a bias in parameter estimates derived from the assumption of normality. Their estimates from an alternative, robust estimation technique (minimum absolute deviation) do not differ substantially from least squares estimates. They conclude that least square estimation can be relied on.

In the specific case of land value, it is important to distinguish between the hedonic price of land and the amount for which vacant land might sell in the actual market. Theories of the urban land market typically focus on the intrinsic usefulness of land, and on the differential accessibility of land at various locations. The combination of these two forces determines an equilibrium price for land and it is this price that Cheshire and Sheppard (1995) define as the hedonic price of land. In normal circumstances such a price will be less than the observed sales price of vacant land since the latter would include the value of local amenities. In Cheshire and Sheppard's (1995) specification of an hedonic model applied to residential land, they group housing characteristics in dwelling-specific and location-specific. The paper outlines a technique which, under appropriate conditions, can provide estimates of the marginal value of neighborhood characteristics: value that will be capitalized into, and is often confused with, the value of land. By successively adding sets of location-specific characteristics to this model, it is possible econometrically to simulate the capitalization of these characteristics into land values. The results suggest that, if location-specific characteristics of housing are appropriately measured, monocentric models can perform well. Concerning the functional form, the authors point out that their results would justify the choice of the Box-Cox transformation.

The hedonic approach to benefit evaluation relies on the cross-sectional capitalization hypothesis which assumes mobility of people between different locations. Property prices are higher in an area with better amenities - or better public services - because otherwise many individuals would want to move into the area and would bid up property prices. Perfect mobility between different areas, therefore, ensures that property prices reflect the benefits of amenities. Kanemoto (1988) points out that the use of hedonic prices in benefit estimation tends to result in over-investment in amenities. More precisely, if the costs and the benefits of a project are evaluated at pre-improvement prices, the hedonic measure will overestimate the benefits of the project. However, this result requires the assumption that migration between regions is free and cost-less. If mobility is imperfect, capitalization tends to be less than perfect, which creates a counteracting tendency for underestimation, and the net result is uncertain.

Similarly, Bartik (1988) shows that the property value increases due to amenity improvements predicted by an hedonic function will generally be overestimated, thus allowing the *ex-ante* calculation of an upper bound for the benefits associated with these improvements. If consumer marginal willingness to pay for amenities can be estimated, a lower bound for the benefits can be computed as well. But estimating consumer willingness to pay is difficult and the upper bound will often be the best benefit measure available…

Stated Preference Methods

An alternative to the hedonic methodology is to directly ask households or individuals to state their willingness to pay for public goods using survey techniques. The survey approach for valuing public goods has received considerable theoretical scrutiny. Randall et al.(1974), Bohm (1972), and Brookshire et al. (1976) modeled the survey approach using standard concepts of consumer surplus; in addition, the latter two analyses also focus on the possibility of strategic behavior. Despite arguments that strategic bias will invalidate survey results, there is the need for an alternative to the hedonic approach, as the latter cannot always be applied. The considerable empirical evidence now available suggests that strategic bias may be of little consequence both in survey work[31] and in experimental economics[32]. The hypothetical nature of the questions used in survey analysis may substantially reduce incentives for strategic behavior. However, respondents may also have little incentive to provide accurate answers concerning willingness to pay for public goods. Thus, it has even been suggested that the survey approach produces "noise" since responses are purely hypothetical and have no necessary connection to actual budgetary decisions.

The results of using the survey approach for estimating the value of public goods appear to be internally consistent, replicable and consistent with demand theory[33]. Brookshire et al. (1982) report on an experiment designed to externally validate the survey approach by comparing it to a hedonic property value study. The authors provide a theoretical model that predicts that survey responses will be bounded below by zero and above by rent differentials derived from the estimated hedonic rent gradient. The empirical results do not allow the rejection of either of the

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[31] see the following articles:

Bishop, R., and Heberlein, T.: Measuring Values of Extra-Market Goods: Are Indirect Measures Biased?, AMERICAN JOURNAL OF AGRICULTURAL ECONOMICS, December 1979. Cited in Brookshire et al. (1982)

Brookshire, D., et al.: Experiments in Valuing Public Goods, in V. KERRY SMITH, ED.: Advances in Applied Microeconomics, GEENWICH: JAI PRESS, 1980. Cited in Brookshire et al. (1982)

Rowe, R., d'Arge, R., and Brookhire, D.: An Experiment in the Value of Visibility, JOURNAL OF ENVIRONMENTAL ECONOMICS AND MANAGEMENT, March 1980. Cited in Brookshire et al. (1982)

Schulze, W., d'Arge, R., and Brookshire, D.: Valuing Environmental Commodities: Some recent Experiments, LAND ECONOMICS, May 1981. Cited in Brookhire et al. (1982)

[32] See the following articles:

Grether, D., and Plott, C.: Economic Theory and the Preference Reversal Phenomenon, AMERICAN ECONOMIC REVIEW, September 1979. Cited in Brookshire et al. (1982)

Scherr, B., and Babb, E.: Pricing Public Goods: An Experiment with Two Proposed Pricing Systems, PUBLIC CHOICE, Fall 1975. Cited in Brookshire et al. (1982)

Smith, V.: The Principal of Unanimity and Voluntary Consent in Social Choice, JOURNAL OF POLITICAL ECONOMY, December 1977. Cited in Brookshire et al. (1982)

[33] Schulze, W., d'Arge, R., and Brookshire, D.: Valuing Environmental Commodities: Some recent Experiments, LAND ECONOMICS, May 1981. Cited in Brookhire et al. (1982)

two hypotheses, thereby providing evidence towards the validity of survey methods as a means of determining the value of public goods.

Adapting the Residential Benefits Model to Commercial Property

The impact of transit systems on urban property values has been widely studied. Since rapid transit is an important means of travel to the CBD in many cities, Dewees (1976) analyzed the relationship between travel costs by rail and residential property values. He found that replacing a street-car with a subway increased the site rent perpendicular to the facility within a one-third mile walk to the station. Damm et al. (1980) showed that the distance of a parcel to the nearest Metro station was a statistically significant determinant of the transaction price of an urban parcel, while Wolf (1979) similarly showed the positive influence of permanent transportation improvements on parcel values. The methods developed by these authors are applied in Grass (1992). This article analyzes the individual Metro station effects on residential property values, for Washington D.C.. A hedonic price equation is estimated, where the dependent variable is the average property value for each area. The equation includes among its independent variables a dummy for the "impact area" (i.e. the area less than one-quarter mile from the station). This study reveals a significant direct relationship between the opening of Metro stations and residential property values.

Implementing Hedonic Models

Hedonic price estimation is performed using multiple regression techniques. In the present study, property value would be regressed on a set of explanatory variables including property and location characteristics. This section focuses on the description of the variables that have been previously used in the literature.

Variable Selection in the Literature

Downing (1973) computes property values in terms of actual purchase price. Sivitanidou (1996) uses assessed property values but mentions that there is a high correlation between assessed and actual market values. Cheshire and Sheppard (1995) use the listed asking price, although they realize that the actual transaction price would be the usual variable to include. Finally, the dependent variable can be expressed in terms of property values per unit - per square foot for example - as opposed to non-normalized property values.

Independent variables can be grouped in different ways, but the distinction between location attributes and property-specific traits seems the most fundamental. Additionally, the former may in turn be decomposed into a set of accessibility characteristics and another set of control location traits. FTA compiled a list of explanatory variables used in the literature. This list is summarized in Table 6.1. Note that each class of variables has a reference number (2) to (18).

(2) *Distance to Central Business District.* Moses and Williamson [M&S] (1967) use this variable, as it is inversely correlated with the rent gradient. They find a significant and negative coefficient. According to Downing [D] (1973), this variable is associated with the firm's cost of obtaining goods and services, and also measures access to major transportation links. He uses the straight line distance from the site to the CBD but notes that a more appropriate measure would be the time it takes to travel from the site to the CBD. He finds that this variable is not

Table 6.1 Variable Selection in the Hedonic Measurement Literature

		Dependent Variable	Source
(1)		Purchase Value of Land	[D]
		area units	See notes on [S], [G] and [C&S]
		Independent Variables	Source
	Category	Variable	
(2)		dCBD	[D][G][M&W][S][C&S]
(3)		dSBD	[S] Sivitanidou
(4)		type of street or	[C&S] Cheshire & Sheppard
		traffic level	[D] Downing
(5)	Location Attributes:	dairport	[S]
(6)	Accessibility	dummy bus	[C&S]
(7)		dummy station or	[G] Grass
		land use rail or	[M&W] Moses & Williamson
		dstation	
(8)		dummy freeway or	[M&W]
		dfreeway	[S]
(9)		Population	[D]
(10)		Population density	[M&W]
(11)		average income or	[S]
		median income or	[D]
		blue collar or	[C&S]
		ethnic	[D] [C&S]
(12)	Other	new construction around or	[C&S] [G]
	Location	deteriorated around or	[D]
	Attributes	prestige	[S]
(13)		density commercial or	[HLB]
		%commercial use	[M&W] [C&S] [S]
(14)		worker amenities	[S] [C&S]
(15)		land supply constraints	[S] [M&W]
(16)	Property	lot size	[D] [G] [C&S]
(17)	Characteristics	corner	[D]
(18)		building traits	[G] [C&S] [S]

significant, except for the case of substantial distances. Grass [G] (1992), Cheshire and Sheppard [C&S](1995), and Sivitanidou [S] (1996) also use this variable. In Grass (1992) this variable is not significant. He points out that a possible explanation would be that the spatial pattern of parcels is not smoothly sloping. Sivitanidou (1996) shows that this variable is negative and significant.

(3) *Distance to Secondary Business District(s).* Sivitanidou (1996) provides three alternative specifications of the effect of this variable. Each specification embodies different assumptions on the degree of substitution between the service "bundles" offered by the area's centers. This variable is found negative and significant.

(4) *Type of street.* Cheshire and Sheppard (1995) divide roads into five categories from cul-de-sac to main roads. Each type of street (except one) is assigned a dummy variable. Their aim is to reflect the level of both traffic disturbance and pollution to which a site is subject. They also notice that location on larger roads might provide an increased level of accessibility and -in the case of residential property- the possibility of conversion to commercial use. The actual observed effect would be the net outcome of these two effects. Downing (1973) also mentions the possibility of using *distance from the main street* as a variable.

Downing (1973) includes *traffic level on the main street*, measured in thousands of vehicles per 24 hours. The variable is significant and has the expected (positive) sign.

(5) Sivitanidou (1996) includes *distance to closest major airport* among the variables. This variable is negative and significant.

(6) Cheshire and Sheppard (1995) use a *dummy for bus* route near the site but this variable is not significant.

(7) Grass (1992) uses a *dummy for rail station* in the area. This variable is significant and positive.

Percentage of land used for transportation other than highway in a given area is included by Moses and Williamson (1967). In their study, this variable is not significant.

(8) *Dummy for freeway.* This variable is one if there is a freeway in a given zone, and zero if there is none. It is used by Moses and Williamson (1967). The variable turns out to be not significant.

Sivitanidou (1996) includes *distance to closest freeway* in the model. Contrary to her expectations, the variable is not significant.

(9) *Population.* Downing (1973) notes that a larger population in the area surrounding the site would increase anticipated sales and thus land values. He runs separate regressions for populations living within different radii. He finds that this variable has the expected (positive) sign, but it is significant only for long radii.

(10) *Population density in a given zone.* This variable is a good measure of the availability of labor, sometimes seen as a surrogate for the wage gradient. It is introduced by Moses and Williamson (1967) but is not significant in their study.

(11) Sivitanidou (1996) uses a variable measuring *per capita income* in the census tract each property is located in. This variable is intended to capture the quality of a property's surrounding

neighborhood, and is included among "worker amenities". The results show that it is positive and significant.

Median income reflects the fact that firms expect to draw most of their customers from the area surrounding the site. Downing (1973) uses this variable; his results show that it is significant, but -contrary to what he expects- negative.

Cheshire and Sheppard (1995) include a variable representing the proportion of *blue collar* within total labor force in a given area; the variable is not significant.

Racial/Ethnic factors. Downing (1973) uses the percentage of non-white population in an area to measure the effects of racial diversity. He finds that this variable is significant and negative. In their study on two English cities, Cheshire and Sheppard (1995) use the percentage of urban Afro-Caribbean population in an area. The variable turns out to be significant but -contrary to what they expected- positive.

(12) A dummy variable for *new construction* (1 if majority of observations in the area are new) is included in Cheshire and Sheppard (1995). This variable is positive and significant for one case (city of Darlington) and not significant for the other (city of Reading). Grass uses the percentage of new houses around the site to account for this factor. The variable is found significant and positive.

Downing (1973) uses the percentage of *deteriorating* or dilapidated units in the block as a measure of visual amenities. As expected, the variable is significant and negative.

Sivitanidou (1996) uses a dummy for area *prestige*, intended to capture the positive effect of prestigious addresses on commercial property values. This variable is found to be positive and significant.

(13) Proportion of *land used for commercial purposes*. Moses and Williamson (1967) use the percentage of land in manufacturing use. This variable is significant and positive. For the same variable, Cheshire & Sheppard's (1995) results show that it is not significant. Sivitanidou (1996) uses a measure of employment concentration in finance, legal, and business services in the property's immediate environment. This variable is also called "local service". It is significant, and it exhibits the expected (positive) sign.

(14) *Worker amenities*. Perceived as important exogenous determinants of worker utility and, as such, residential land values and local wages, worker amenities are proxies in Sivitanidou (1996) by average crime rate in the city, retail and motion picture employment per resident population, and distance from each property to the ocean (the study is about Los Angeles). These variables are positive and significant. Cheshire & Sheppard (1995) use the percent of land in either accessible or inaccessible open space around the site. Although the sign is always positive, significance depends both on the sample and the kind of amenity.

(15) *Land supply constraints*. Moses and Williamson (1967) use the percentage of vacant land zoned for manufacturing and commercial purposes. In their study, this variable is not significant. Sivitanidou (1996) proxies land supply restrictions with the percentage of commercially zoned land measured at the city district level. The variable is significant and negative.

(16) *Lot size*. According to Downing (1973), a trade-off exists between the size of a lot purchased by a firm and the cost of constructing improvements. Increasing the size of a site will reduce improvement costs. However, the greater the increase in site size, the smaller the

marginal improvement cost savings. Thus, it is expected that the value of land per square foot decreases as the size of the lot increases. The empirical results show that this variable is significant and negative. This variable is also used in Grass (1992) and Cheshire & Sheppard (1995).

(17) *Corner influence* is measured by determining the last two digits of the site address, subtracting them from the last two digits of the estimated middle-of-the-block address, and squaring the result. Thereby, sites located close to the ends of a block would receive a higher weight than those located close to the center. This procedure is used in Downing (1973): the variable is found significant only for long blocks.

(18) *Building traits*. Grass (1992) uses the number of bathrooms (significant, positive) and the building size (significant, positive). Cheshire and Sheppard (1995) use the number of bedrooms (positive, significant), the number of bathrooms (positive, significant), the number of floors (positive, significant), the size in square feet (positive, significant), the width of the plot (not significant), and dummies for terrace-style (negative, significant), semi-detached (negative, significant), flat (negative, significant), parking (not significant), garage (positive, significant), and central heating (positive, significant). Sivitanidou (1996) uses the age of the building (negative and significant), the average floor area (not significant), the number of elevators (positive and significant), and dummies for metal frame (negative and significant), external glass walls (positive and significant), external wooden walls (negative and significant), and subterranean parking (positive and significant).

Additional Comments on the Selection of Variables

Area Dummies. Several articles use *area dummies* in addition to the variables listed above. Downing (1973) takes into account development intensity regulation zoning, and assigns variables to all zones, except the one where development regulations are more strict. Thus, each variable will measure the value of an allowed increase in the intensity of use over the least intense zone. It is expected that each variable will have a positive influence on land value and the value of the regression coefficients should increase with the intensity of use allowed. His results show that these variables are significant. Moses and Williamson (1967) include a dummy variable indicating whether the zone is outside the city (Chicago). It was introduced to catch the effects of zoning policies, property tax rates, etc. between the central city and the surrounding area. This variable is not significant. Finally, in their study of residential property values in two English cities, Cheshire & Sheppard (1995) include area dummies that account for the particular secondary school catchment zone where each house is located.

Differences Among Land Markets. According to Downing (1973), there are at least two reasons why residential, industrial, and commercial land uses can be treated as distinct markets for the purposes of determining the factors which affect land value. First, there are certain barriers and institutional restraints to the transfer of land from one use to another. Second, even if the land market were one market, there is every reason to believe that the different possible uses would bid for the land for different reasons. Thus, the relative importance of the different factors will vary among types of land use. In order to test this hypothesis, Downing runs two Chow tests. He rejects the hypothesis that residential and commercial data come from the same population, and reaches a similar conclusion for commercial and industrial data.

Framework and Methodology

Methodological Framework

As stated in the introduction, the purpose of this report was "to research and develop a practical methodology for estimating the effect of the proximity of transit on commercial property value." FTA looked at a cross-section, a sample, of commercial properties located in a specific urban area, to evaluate the distance between these properties and the closest transit stop and then, to estimate the impact of the proximity-to-transit attribute on the properties' value. This evaluation was performed through the use of multiple regression techniques. In the present case, the value of commercial properties was regressed on a set of characteristics, including proximity-to-transit. The estimated coefficient on this variable measured either directly or indirectly the marginal effect of a change in the distance-to-transit on property values. The theoretical underpinning of this type of approach is the hedonic model presented in the literature review.

Methodological Issues to Consider

Several methodological issues need to be addressed before discussing the estimation procedure itself: Which type of commercial properties should be included in the analysis? What is the appropriate area of study and, in particular, what is the shape of the city under examination? Do different forms of public transportation have different impacts on property values? And finally, how should the commercial properties be selected?

There are roughly four types of commercial properties: (1) retail stores, (2) personal businesses, (3) offices and (4) industrial properties such as factories or warehouses. As explained in the literature survey, the nature of the benefits of the proximity of transit will vary across property types. Public transit facilitates customer access to retail stores and personal businesses. *Other things equal*, the shorter the distance between a store and a transit stop, the larger the expected volume of sales generated by that store. This excess volume of sales will be capitalized in the "value" of the store. The value of office spaces and industrial properties is enhanced by the proximity of transit because it lowers the cost of accessing the workforce. A firm located near a transit stop will benefit from an implicit, or explicit, reduction in costs. This cost reduction will be capitalized in the value of the firm. From all that, it is preferable to differentiate between stores on the one hand and offices and industrial properties on the other hand. This can be done by either conducting two separate analyses - separate samples - or by using dichotomous - dummy--variables in a single "model".

What is the appropriate area of study?

The initial area of study will be a major metropolitan area. It will be either a monocentric city, a polycentric city or an edge city. Should we expect the proximity of transit to have a different impact in different cities? A priori, yes. The impact of transit is likely to be weaker in polycentric or edge cities where economic activity is more dispersed. Besides, the analysis of polycentric cities would require the introduction of additional explanatory variables into the model: the distances to the secondary business districts. Ideally, the analysis should be performed for one city of each type. FTA started with Washington D.C., which can clearly be viewed as a monocentric city.

Do different forms of transit have different impacts on property values?

Previous studies have shown that the proximity to a metro station had a greater impact on residential property values. Similar findings are expected for commercial property values. Thereby, the data used in this report will include the distance to the closest bus stop and the distance to the closest metro station. Separate regressions can be run to evaluate which mode of transportation has the greater impact on commercial properties.

How Should the Commercial Properties Be Selected?

In some earlier studies, commercial - or residential - properties have been selected within radiuses around a pre-defined set of transit stops. In other words, in these studies, the researcher first chose a sample of Metro stations or Bus stops and then randomly selected a set of properties located around these stations and stops. An alternative approach consists in randomly selecting a set of properties within the area of study and then, identifying the Metro stations and Bus stops located near these properties. This is the approach followed here.

Specification of the Model

Specifying a model implies several steps. The first step consists in defining the variable of interest, the variable that will be "explained" by the model. In the present study, it is the value of commercial properties located within the study area. The variations in value across properties can be explained by a limited set of characteristics, including the proximity of transit. Therefore, the most general form for the model will be:

$$Y = f(X, d)$$

With Y: the dependent variable, some measure of commercial property value;

f: a function to be specified;

X: a set of characteristics (building traits, neighborhood characteristics, etc.);

d: a variable measuring proximity to transit.

The Dependent Variable (Y)

The endogenous variable will be the assessment value, the listed asking price, of a commercial property divided by the size of the property. The unit of measurement for this variable will be dollars - or thousands of dollars - per square foot. The actual transaction price would be the appropriate variable for an hedonic study but: (1) the number of transactions is likely to be rather small, (2) the assessment value is generally a good proxy for the actual selling price and (3) the use of actual transactions might create a "selectivity bias". If actual transactions were used, the commercial properties in the sample would presumably have characteristics that explain why they have been sold during the particular period under examination. These "hidden" characteristics are also likely to influence the value of these properties. Theory shows that in this case, estimating price equations without correcting for the selection process might yield biased estimates of the model coefficients.

Explanatory Variable Selection (X and d)

The model should include a limited set of variables that account for as much variation in commercial property value as possible. Omitting relevant variables or including irrelevant variables should be avoided. Two important issues must be considered: (1) the existence of substitutes to public transportation, in particular the access to low-cost parking space or the proximity of a large, non-congested road; (2) the homogeneity of the area under examination. As stated in the review of the literature, hedonic prices reflect supply and demand equilibria. The problem is to define the *relevant market* for the study at hand. The real estate market being a collection of relatively separate sub-markets, a common problem in real estate studies consists in aggregating heterogeneous areas in the same analysis, in committing the aggregation error[34]. In order to avoid such error, the researcher can either perform separate analyses or control for the areas' attributes through the use of dummy variables. Another concern is the presence of multicollinearity, i.e. collinearity among explanatory variables. A good example here would be the relationship between employment density and proximity to transit. Holding other things constant - with or without transit stop, in particular - a property will be more expensive in a commercially active area. In such areas, we expect to find more transit stops i.e. shorter walking distances for all shops of the sample located in the area. In other words, the employment density and the proximity of transit are likely to be positively correlated. When multicollinearity is severe, it is very difficult to estimate individual regression coefficients precisely[35]. In other words, the estimation results are not reliable. In the present example, it would be very difficult to isolate the effect of proximity to transit from the pure density effect. What can be done? There are two options: the first consists in suppressing redundant variables, the second in performing factor analyses to "summarize" redundant variables into a single "factor."

From all that, the model will be specified to include a mix of *property* characteristics (real estate data) and *location* characteristics (geographical and socioeconomic data).

Real Estate Data: Relevant property characteristics will include the size of the property in square feet and a set of building attributes: age of the building, availability of parking space and other items. The value of a commercial property per square foot is likely to decrease as the size of the property increases. In other words, the coefficient associated with the size variable is likely to be negative. Other things equal, retail stores and offices located in more recent buildings are likely to be "more expensive". Similarly, the proximity of parking space is likely to enhance the value of commercial properties.

Geographical Data: The model will include various location attributes that are thought to affect the value of commercial properties: distance to the CBD, to the closest bus stop or metro station, to the closest airport, and to the closest freeway. The inclusion of "distance to the CBD" among the explanatory variables results from the conclusions of basic urban economic models where the spatial distribution of land prices is determined by the transportation costs to the CBD - the negative rent or land price gradient. Since the price of land should decline with distance from the CBD, the corresponding coefficient is expected to be negative. Distances to the closest airport and to the closest freeway account for the value associated with transportation accessibility; both are expected to have a negative coefficient. Type of street, traffic level or distance from the main street can be used to account for access to consumers, but also for the level of traffic disturbance

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[34] Mahlon Straszheim, "Hedonic Estimation of Housing Market Prices: A Further Comment", in The Review of Economics and Statistics, 1973, pp. 404-6

[35] Damodar Gujarati, "Basic Econometrics", Second Edition, 1988, pp. 283-315

to which a site is subject. As the actual observed effect would be the net outcome of these two effects, the expected sign is uncertain. The variable of primary interest is the distance to the closest transit stop. The coefficient associated with this variable is expected to be negative.

Socioeconomic Data: Various neighborhood characteristics will be included in the model: population or employment density, median income, density of commercial activities and, if possible, some proxy for the availability of worker amenities. A larger population should positively increase expected sales and labor availability. We expect this variable to have a positive sign. The neighborhood's median income reflects customers' purchasing power and the quality of a property's surrounding neighborhood. Therefore, this variable is likely to have a positive coefficient. The density of commercial activities and the availability of worker amenities are also likely to influence the value of commercial properties. While the former is intended to reflect urbanization externalities, the latter should positively influence workers' location. Both are expected to have a positive effect on commercial properties.

Functional Form Selection

In the literature, non-linear functional forms have been preferred on theoretical and empirical grounds (see Section 2.3). In particular, log-linear and semi-log models have been used repeatedly in hedonic studies. HLB proposes to try a more flexible approach: the use of a Box-Cox transformation. A rapid review of the different forms that could be used in the study is presented below.

The Linear Model:

$$P_i = \alpha_0 + \sum_{k=1}^{p} \alpha_k x_{ki} + \eta d_i + \varepsilon_i$$

With P_i: assessment value of the i^{th} commercial property;

x_{ki}: k^{th} characteristic of the i^{th} property;

d_i: distance to the closest metro station or bus stop;

ε_i: error term, what is left unexplained by the model;

α_0, α_k, η: coefficients to be estimated.

The coefficient of interest is η. The value of this coefficient can be interpreted as the average increase in property value brought about by a one-unit change in the proximity of transit. The assumption of linearity implies that whatever the distance to transit, a one-unit reduction in the distance to transit produces a constant η dollars per square-foot increase in the property's value.

The Semi-Log Model:

$$\ln P_i = \alpha_0 + \sum_{k=1}^{p} \alpha_k x_{ki} + \eta d_i + \varepsilon_i$$

Where ln P is the natural logarithm of P. η can be interpreted here as the *relative or percentage* change in property value produced by a one-unit change in the distance to transit. This model implies the existence of a linear relationship between the *log* of the dependent variable P and the explanatory variables (see Figure 6.6 in the Annex).

The Log-Linear Model:

$$\ln P_i = \alpha_0 + \sum_{k=1}^{p} \alpha_k \ln x_{ki} + \eta \ln d_i + \varepsilon_i$$

In this specification, η is the *relative or percentage* change in property value produced by a one-*percent* change in distance to transit. The log-linear, or double-log, model is sometimes referred to as a constant elasticity model: the percentage change in P for a given percentage change in d - the elasticity of P with respect to d - is constant throughout the range of the variable d.

The Box-Cox Model:

$$P_i = \alpha_0 + \sum_{k \in D} \alpha_k x_{ki} + \sum_{l \in C} \alpha_l \frac{x_{li}^{\lambda} - 1}{\lambda} + \eta \frac{d_i^{\lambda} - 1}{\lambda} + \varepsilon_i$$

With D: set of indices for dichotomous characteristics, dummy variables

C: set of indices for continuous variables

λ: transformation parameter to be estimated

The Box-Cox model allows for greater flexibility than any of the models presented so far. No functional form[36] is chosen a-priori. Instead, the choice of the "best" functional form is part of the estimation. From the above formula, it can be shown for example that if λ = 1 the model is linear but if λ = -1 it is reciprocal in the independent variables. In the estimation, λ is treated as an additional unknown parameter. In other words, the estimation procedure consists in determining the parameters *and* the functional form that best fit the data. This should be contrasted to a typical linear regression where the functional form is set, and where the estimation procedure "optimizes" over the parameters of the linear function only. Note from the formula that the dummy variables are not transformed. Finally, the right-hand side variable can also be transformed by the parameter λ:

$$\frac{p_i^{\lambda} - 1}{\lambda} = \alpha_0 + \sum_{k \in D} \alpha_k x_{ki} + \sum_{l \in C} \alpha_l \frac{x_{li}^{\lambda} - 1}{\lambda} + \eta \frac{d_i^{\lambda} - 1}{\lambda} + \varepsilon_i$$

In principle, a different transformation parameter (other than λ) could be used on the left-hand side variable. But according to Greene (1993), this transformation is often "more cumbersome than necessary." Also, it could be possible to allow for different non-linearities on the distance variable. In fact, each regressor could be transformed by a different parameter. But again "this generality becomes excessively cumbersome in most applications" Greene (1993). At any rate, the most flexible model that could be estimated for this study is:

$$\frac{p_i^{\psi} - 1}{\psi} = \alpha_0 + \sum_{k \in D} \alpha_k x_{ki} + \sum_{l \in C} \alpha_l \frac{x_{li}^{\lambda} - 1}{\lambda} + \eta \frac{d_i^{\xi} - 1}{\xi} + \varepsilon_i$$

Where: ψ is the transformation parameter for the dependent variable P;

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[36] Some authors consider the Box-Cox specification as a functional form. For the sake of clarity, we differentiate between the Box-Cox and the (traditional) functional forms: linear, log-linear, semi-log, etc.

ξ is the transformation parameter for the distance variable.

Since the regression is non-linear in the parameters, the use of non-linear-least-squares is required to estimate a Box-Cox regression model. The software Limdep uses various optimization procedures to derive estimates for the parameters α, η, ψ and λ. Limdep however does not allow for different transformation parameters on the right hand side variables. HLB will use this software to estimate the hedonic models presented in the previous pages.

Implementation of the Empirical Analysis

In this part, we present briefly the steps needed to evaluate the impact of the proximity of transit on commercial property value: data collection, estimation of the model, hypotheses testing and aggregation.

Data Collection

Real Estate Data in the form of detailed assessment records was bought from Axciom Dataquick Inc. The records used in the analysis were selected within a reduced, homogeneous time period in order to control for business cycles and potential seasonal influences on assessment values. Each observation was *randomly* selected from the population of commercial properties located in the area of study. To ensure that each part of the area of study was "equally" represented in the sample though, some stratification was necessary.

Socioeconomic Data was collected from the U.S. Census Bureau web-site at the zip-code level. Each property in the sample was given socioeconomic attributes on the basis of the zip code provided in its address.

HLB used measures of the actual walking distance from the property to the transit stop using Geographic Information System data. GIS allows for a precise measurement of this variable. The National Transit GIS in particular enables the immediate display of inventory and selected data associated with fixed route public transit facilities in the United States. It can be used to relate a variety of geographic information from various sources and analyze different relationships in either map or tabular output.

The real estate, socioeconomic and GIS data was compiled in a single database. This database contained approximately one thousand records and ten to fifteen variables. The key information in the database was summarized on a map showing the actual location of each property in the sample, as well as the "closest" transit stops.

Estimation of the Model

The empirical validation of the hedonic model was completed with the software Limdep. It involved several "steps":

- *Choice of the appropriate functional form*. First, linear, semi-log and log-linear regressions were run; results from these regressions were evaluated and discussed. Second, the Box-Cox model was estimated under different assumptions. The functional form that best fits the data while being consistent with our a-priori expectations was selected. Note that the choice of the "appropriate" functional form could rely on hypotheses testing. In particular, following Greene, it would be possible to test for linearity or for log-linearity[37].

- *Estimation of the price equation for different property types.* The model was estimated for retail stores only, for offices only and for retail stores and offices all together. Some econometric techniques allow to test for "structural breaks", i.e. to test whether the ability of the model to account for the variations in the dependent variable increases with the pooling of a priori distinct sub-samples. Such tests were performed to see whether shops and offices should be pooled in a unique sample.
- *Estimation of the price equation for different transit types.* The distance to the closest bus-stop, the distance to the closest metro station or both distances could be included in the model as explanatory variables. The results for the three specifications were included and discussed.
- Note that these various estimations were separated in three "steps" for the ease of the presentation only. In practice, each regression was a combination of three simultaneous choices: choice of the functional form, the property type and the transit type.

Hypotheses Testing

Multiple regression analyses offer a wide variety of hypotheses testing. Usual tests (t-tests, F-tests, detection of multicollinearity, etc.) were performed. Additionally, it might be worth looking at two sets of hypotheses:

Testing restrictions from the full specification. How does the suppression of a group of explanatory variables (the location attributes for example) affect the coefficient estimates of the others?

Testing for the existence of "sub-markets". Test for the significance of dummy variables. Look at the difference between low and high-income areas in particular.

Presentation of the Results and Aggregation

The final part of the study consists in presenting and commenting the estimation results for various specifications of the hedonic model. The aggregate impact of the proximity of transit on commercial property values was computed from these regression results. Again, for the sake of clarity, this final part can be segmented in a series of steps:

- Comment on the results of the regressions. Which variables are significant? Do they have the expected signs? Compare with previous studies.
- Create a summary table for the coefficient estimates under different specifications.
- From the "best model", get the coefficient estimate on the walking distance to the transit stop variable (η). This coefficient is the shadow price of the attribute "proximity to transit stop", it measures the value added to commercial properties by the proximity to transit (i.e. the change in property value brought about by a change in the distance to transit, other things

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[37] William Greene, "Econometric Analysis", 1993, Second Edition, pp. 334-35

equal). As discussed previously, the exact interpretation of the coefficient depends on the choice of the functional form.

- Compute the average distance to transit *in the sample*. The product: "change in property value per foot of proximity to transit" (this value will be derived from the coefficient estimate) times "average distance" will give the average benefit of public transportation *in the sample*.
- From the sample estimates, infer the *average* impact of transit on commercial property values for the city or area under examination. Find a proxy for the total number of shops and offices in this area. Multiplying the average impact (per property) by the total number of properties will yield an estimate of the total impact of transit on commercial property values in the area.

FTA Implementation of the Model

The selection of a site to implement the methodology mainly depends on data availability, the cost of the data, the transit infrastructure, and the city roadway network.

After reviewing these selection criteria and considering several cities, FTA concurred in implementing the methodology in Washington, D.C. This choice was based on the following features that the Washington, D.C. site offered:

- Mature transit system
- Data availability
- Relative low cost for data collection
- Simple transit and roadway network

However, Washington D.C. was not included in the 1994 study "Transit's Value in Neighborhoods" (Lewis and Williams (1999)). Therefore, the Washington D.C. case study does not strictly allow comparisons between commercial and residential property benefits.

Empirical results

Data on more than 2,800 commercial properties were purchased from the online database of Axciom Dataquick Inc. All the properties are located in the Washington D.C. area (Figure 6.4 in the Annex). Before concluding observations, it remains to describe the data through a series of tables and graphs, present the regression results obtained under different specifications, and address the issue of measuring and aggregating the benefits of transit.

Description of the Data

The sample comprises 2,842 commercial properties located in Washington D.C.. For each of these properties, FTA gathered data for the variables in Table 6.2. Standard descriptive statistics for these variables are presented in Table 6.12. Note that the actual selling price of 105 properties was available in the real estate database. FTA calculated the coefficient of correlation between these prices and the assessed property values. The coefficient turned out to be large (0.83), indicating that assessed values can be used safely instead of the actual price in the estimation of the hedonic price equation.

Table 6.2 The Variables, Source and Description

	Description	Source
	Real Estate Data	
ASSD	Assessed property value	Axciom DataQuick
IMPRV	Percentage improvement	Axciom DataQuick
LAND	Assessed value of land	Axciom DataQuick
LOTSZ	Lot size in square feet	Axciom DataQuick
SQRFT	Size of the property in square feet	Axciom DataQuick
TAXAMT	Tax amount	Axciom DataQuick
	G.I.S. Data	
BUS	Distance to nearest Bus stop	Caliper Corporation
BWI	Distance to BWI Airport	Caliper Corporation
CBD	Distance to Pennsylvania and 15th Street	Caliper Corporation
DCA	Distance to Ronald Reagan Airport	Caliper Corporation
HIGHWAY	Distance to nearest main divided highway	Caliper Corporation
IAD	Distance to Dulles Airport	Caliper Corporation
METRO	Distance to nearest Metro station	Caliper Corporation
	Socioeconomic Data	
MEDFY	Median family income	Census
MEDHHY	Median household income	Census
NEWC	Percentage of new constructions	Census
PCY	Per capita income	Census
POP	Resident population	Census
RET	Number of employees in retail as % population	Census
SERV	Number of employees in service as % population	Census

There are five types of properties in the sample: large offices, small offices, restaurants, small stores and miscellaneous stores. Table 6.3 summarizes key variables for these property types. With 752 observations, small store is the category most represented in the sample; large and small offices account for approximately 40% of the total number of observations. Interestingly, small stores and restaurants are, on average, located further away from the CBD than the other types of properties. It is also worth noting that the average assessed value per square foot varies substantially across property types: with $89 per square foot, small stores have the lowest average value, with $143 per square foot, small offices have the highest.

Table 6.3 Property Types in the Sample

PROPERTY TYPE	N	SQFT	$/SQFT	METRO*	BUS	CBD
Large Office	394	190,779	118	1,702	301	6,539
Small Office	658	7,710	143	2,203	339	8,937
Restaurant	489	3,841	106	3,260	235	13,619
Store Miscellaneous	549	5,228	90	1,692	241	6,905
Small Store	752	3,329	89	3,943	264	17,869
Total	2,842	30,631	109	2,677	277	11,304

*Average Distance to Metro Station

The properties are located within 21 different zip-code areas. Table 6.4 shows how many properties are located within each area (variable N) as well as some demographic information about these areas. FTA also calculated the average property value per square foot within each area. Interestingly, the highest values are observed in areas 20006 and 20007 with $183 and $168 per square foot respectively, while the lowest are observed in areas 20018 and 20020 with $47 and $58 per square foot. It should be kept in mind however that the reliability of these estimates depends on the number of observations within each area.

Caliper Corporation identified 44 Metro stations as being the stations closest to the properties in the sample. These Metro stations are listed in Table 6.11. For each station, FTA computed the number of neighboring properties, the average assessed value of these properties and the average distance between the properties and the Metro station.

Before turning to the multiple regression results, it is worth looking at the relationship between assessed property values per square foot and distance to the closest metro station, *without* controlling for any other factor. The scatter diagram in Figure 6.2 clearly shows a negative relationship between the two variables: shorter distances to transit are associated with higher property values. The purpose of the next section is to confirm and estimate this relationship while controlling for the influence of other variables.

Table 6.4 ZIP-Code Area Characteristics

ZIP CODE	N	$/SQFT	PER CAP INCOME	RETAIL JOBS AS PCT POP	SERVICE JOBS AS PCT POP
20001	549	89.98	10,033	7.20	17.50
20002	382	91.64	14,545	6.78	7.17
20003	232	117.18	20,311	7.82	5.69
20005	165	117.91	16,961	24.55	183.75
20006	64	183.32	11,145	94.54	615.77
20007	170	168.27	36,322	20.11	20.35
20008	43	138.65	42,397	6.36	13.94
20009	330	131.26	20,691	5.50	7.78
20010	87	69.46	13,455	1.95	3.33
20011	136	61.59	15,462	2.18	2.03
20012	27	69.55	22,586	2.63	5.26
20015	16	117.52	35,272	14.78	8.90
20016	57	115.59	38,261	9.72	12.60
20017	49	59.22	16,530	1.72	3.92
20018	43	47.41	13,709	3.81	7.09
20019	79	56.07	10,966	1.46	2.10
20020	52	57.85	11,507	1.64	1.76
20024	17	113.61	24,666	14.40	26.35
20032	24	72.62	9,331	0.90	3.78
20036	261	147.65	31,118	98.23	613.55
20037	59	145.20	34,214	10.15	100.79
TOTAL	2,842	108.56	19,138	18.38	91.12

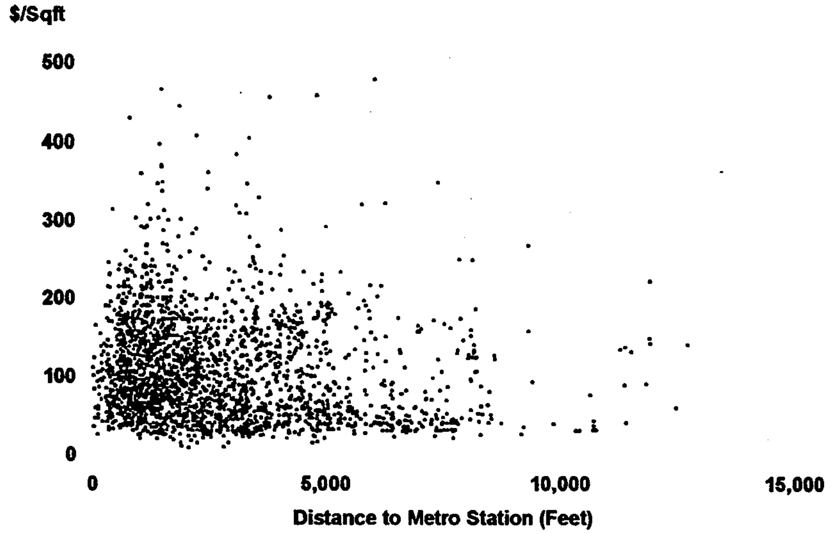

Figure 6.2 Distribution for Washington, D.C. Property Values and Distance to Transit

Estimation Results

Several regressions were run using different functional forms and different sets of explanatory variables. The following results were found for most, if not all, regressions:

- Dummy variables for restaurants, miscellaneous stores and small stores are always significant, indicating that, *other things equal*, the average value of commercial properties per square foot varies significantly across property types. Omitting these dummy variables would result in unreliable coefficient estimates on the other variables.
- The linear model is always dominated by non-linear forms in terms of goodness of fit and a-priori beliefs about the sign of the coefficients. This result is in line with the existing literature.
- The coefficient on Distance to the Closest Metro Station is negative *and* significant or, in few instances, negative but not significant. The coefficient was *never* significantly positive. On the other hand, and contrary to our expectations, the coefficient on the BUS variable (distance to the closest bus stop) was never significantly less than zero. A possible explanation for that is the method used by Caliper Corporation to measure this distance: "two street networks were used to compute BUS, which implies that the accuracy is probably at best 100 to 200 feet."[38]
- The other variables have the expected sign and are significant. The only noticeable exception is the variable HIGHWAY. In may instances, the coefficient on this variable was significantly greater than zero indicating that, other things equal, properties located further

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[38] These results were found under the three specifications: METRO only, BUS only, and METRO and BUS together.

away from a Class A10 street are "more expensive". Sivitanidou (1996) comes to a similar conclusion; she explains that this might come from increased congestion in the proximity of such streets.

- Including one of the socioeconomic variables into the model always improves the goodness of fit. This study confirms the necessity to control for area characteristics in explaining commercial property values, a crucial characteristic being the per-capita income (variable PCY).

The results of Ordinary Least Squares Regressions using three of the "traditional" functional forms: Linear, Double-Log and Semi-Log are presented in Table 6.5.

Focusing on the Double-Log and Semi-Log forms, all the variables except BUS and HIGHWAY have the expected sign. Most of them are also significantly different from zero. The F-statistics provided in the last row of the table indicate that the regression coefficients are *jointly* significant. Finally, it should be noticed that the relatively low Adjusted R-Squared around 0.35 are not surprising for this type of study.

To avoid imposing a pre-defined functional form on the data, Box-Cox regressions have also been run.[39] The results of two of these runs are presented in Table 6.6. Since the interpretation of the coefficient estimates given by the Box-Cox is often misleading, the slope coefficients are provided instead. Estimates of the transformation parameters λ and ψ are also included in the table. As a reminder, this is the model we are trying to estimate:

$$\frac{p_i^{\psi}-1}{\psi} = \alpha_0 + \sum_{k\in D}\alpha_k x_{ki} + \sum_{l\in C}\alpha_l \frac{x_{li}^{\lambda}-1}{\lambda} + \eta\frac{d_i^{\lambda}-1}{\lambda} + \varepsilon_i$$

Note that the results presented in the first column of the table have been obtained by imposing a unique transformation parameter on the left and right hand side variables ($\lambda = \psi$).

Once again, most of the variables have the expected sign. The coefficient on the variable METRO in particular is negative under both specifications.[40]

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[39] Given the algorithm used by the software Limdep, some of the variables had to be re-scaled prior to the estimation. The distance variables were divided by 100 in particular.

[40] The level of significance of this coefficient is relatively low. Based on the standard deviations provided by Limdep, the associated p-value is 0.09 for the first specification and 0.15 for the second.

Table 6.5 Ordinary Least Squares Regressions

Variables	Linear	Double-Log	Semi-Log
CONSTANT	191.99	19.670	5.8694
	(3.694)***	(6.807)***	(21.423)***
RESTAU	-29.750	-0.30175	-0.27246
	(-4.793)***	(-9.425)***	(-8.327)***
STOMIS	-49.988	-0.51565	-0.49186
	(-8.659)***	(-17.406)***	(-16.16)***
STOSMA	-27.431	-0.34681	-0.29938
	(-4.363)***	(-10.856)***	(-9.033)***
SQRFT	-0.20489E-03	-0.10844	-0.14509E-05
	(-7.527)***	(-14.218)***	(-10.109)***
IMPRV	-0.34302	-0.48263E-01	-0.11124E-02
	(-4.036)***	(-3.703)***	(-2.483)**
CBD	-0.23521E-02	-0.27800	-0.17878E-04
	(-5.430)***	(-11.287)***	(-7.829)***
METRO	0.21431E-03	-0.21235E-01	-0.21093E-04
	(0.184)	(-1.493)*	(-3.443)***
BUS	0.15431E-01	0.36665E-02	0.56409E-04
	(2.159)**	(0.641)	(1.497)
HIGHWAY	0.50675E-02	0.65037E-02	0.27765E-04
	(2.220)**	(1.949)*	(2.308)**
IAD	-0.42312E-03	-1.3462	-0.90487E-05
	(-1.180)	(-5.746)***	(-4.787)***
PCY	0.20849E-02	0.48689	0.21226E-04
	(6.750)***	(15.528)***	(13.035)***
N	2,830	2,830	2,830
R2	0.116	0.371	0.338
Adjusted R2	0.113	0.369	0.336
F-Regression	33.61	151.35	130.97

* Indicates statistical significance at the 0.2 level
** Indicates statistical significance at the 0.05 level
*** Indicates statistical significance at the 0.01 level

Table 6.6 Box-Cox Regressions

	$\lambda = \psi$, free	λ free, ψ free
CONSTANT		
RESTAU	-20.2378	-19.0671
STOMIS	-24.1275	-24.5170
STOSMA	-34.3389	-31.3042
SQRFT	-0.0216	-0.0147
IMPRV	-0.0501	-0.0369
CBD	-0.1595	-0.1338
METRO	-0.0556	-0.0373
BUS	0.0670	0.0346
HIGHWAY	0.0329	0.0111
IAD	-0.0726	-0.0834
PCY	0.1715	0.1624
λ	-0.11	-0.35
ψ	-0.11	-0.14
N	2,830	2,830
Log-Likelihood	-637.23	-275.11

The Benefits of Transit

We can use the coefficient estimates found in the previous section to evaluate the average impact of the proximity of transit on commercial property values within the study area. Table 6.7 summarizes the results found with the Semi-Log specification. These numbers should be considered as an upper bound for the benefits of transit: similar calculations based on the

Table 6.7 Property Value Impacts of Transit Proximity

Coefficient: - 0.0021093%[41]	**Value Increase Per Square-Foot**	**Average Value Increase**	**Average Property Size and Value**
1 Foot Decrease	\$0.002	\$70.1	30,360.5 sq.ft.
1,000 Feet Decrease	\$2.290	\$70,138.5	\$ 3,330,007.8
1 Meter Decrease	\$0.008	\$230.1	

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[41] The output of the Semi-Log regression indicates that a 1 foot reduction in the distance to transit raises property values by 0.0021%. Evaluated at the mean of ASSDSQF, this represents an increase of \$0.002 per square foot.

coefficient estimates found with the other specifications have yielded lower benefits (not reported here). On the other hand, the results presented below are thought to be more reliable given the high significance of the coefficient on the METRO variable in the Semi-Log case. Finally, the review of the literature has shown that this functional form has been used repeatedly in similar studies.

The above results indicate that, on average, a 1,000 feet (approximately 3-block) reduction in the distance to transit raises the value of commercial properties by $2.3 per square foot. Given an average surface of 30,630 square feet, a 1,000 feet reduction in the distance to transit increases the average value of a commercial property by $70,139 or approximately 2%.

From the database of Axciom Dataquick Inc., HLB has determined that there are 10,111 commercial properties within Washington D.C.. Therefore, if for some reasons - the opening of new Metro Stations for example - the average distance to the closest Metro station were to fall by 100 feet, the expected total premium in the value of the commercial properties within Washington D.C. would be approximately $71 Million.

Similar calculations can be made with the coefficients obtained from the Box-Cox regressions. The slope coefficients presented in Table 6.6 imply that a 1,000 feet reduction in the distance to traffic would increase commercial property value by approximately 50 cents per square foot. The exact value of these benefit estimates is presented in Table 6.8.

Table 6.8 Property Value Impacts of Transit Proximity, Box-Cox Model

Impact of a 1,000 Feet Decrease in the Distance to Transit·	**Value Increase Per Square-Foot**	**Average Value Increase**	**Average Property Size and Value**
Model 1	$0.56	$16,880.4	30,360.5 sq. ft.
Model 2	$0.37	$11,324.5	$ 3,330,007.8

The double-log specification yields an impact of approximately 85 cents per square foot for a 1,000 feet reduction in the distance to transit; this represents an average premium of approximately $26,140 per commercial property (evaluated with an average property size of 30,360.5 square feet).

Many authors have stressed that benefit measures derived from hedonic price models are quite sensitive to the choice of functional form (see Literature Survey). The results presented in this study however are *relatively* stable: the benefits of a 1,000 feet reduction in the distance to transit range between $0.37 and $2.3 per square foot, i.e. between $11,325 and $70,139 per property. Based on an evaluation of the functional forms considered in this report, see Table 6.9, HLB recommends that the semi-log is the best functional form that reflect the underline market dynamics.

Figure 6.5 shows the relationship between distance to transit and commercial property value for the ten Metro Stations with the largest number of observations: Dupont Circle (378 properties), Eastern Market (131), Foggy Bottom (123), Gallery Plazza (104), Georgia Avenue (146), McPherson Square (107), Mt Vernon Square (148), Shaw Howard University (135), U-Street Cardozo (179) and Union Station (238). It is clear from the graphs that the relationship between property value and transit is relatively "noisy" at this level of aggregation (even though high property values tend to be clustered on the left part of the X- axis). Figure 6.3 presents the average assessed value of commercial properties grouped in classes according to their distance to transit, for two Metro Stations: Dupont Circle and Union Station (the two stations with the largest number of observations). The negative relationship between property value and distance to transit found in the multivariate analysis discussed earlier appears clearly on these graphs.

Table 6.9 Functional Forms Evaluation

	Confidence Levels for Function Forms			
Criteria	**Log-Log**	**Semi-Log**	**Linear**	**Box-Cox**
Theory	0.05	0.01	0.2	0.2
Goodness of fit	0.05	0.01	0.2	0.05
Previous Analysis (literature)	0.2	0.01	0.2	0.05

Our estimates of the benefits of transit are relatively insensitive to changes in the economic outlook. These estimates are based on a cross-section analysis of commercial properties located in Washington DC. In other words, they are based on the observed differences in assessed value and in distance to transit *across* commercial properties, at a given point in time. Therefore, the business cycle would matter only to the extent that it affects commercial properties differently. If, for example, properties located further away from transit suffer a greater loss during a slump then the business cycle would matter. On the other hand, if we assume that economic conditions affect all properties equally, then there's no need for adjusting for these conditions. This is the theory. In practice however, the benefit estimates presented in this study (the $2.29 per square foot increment for a 1,000 decrease in the distance to transit) depend on the average assessed value of the sampled properties. Table 6.10 summarizes what would be the impact of a slump or a boom in the commercial real estate market on these estimates.

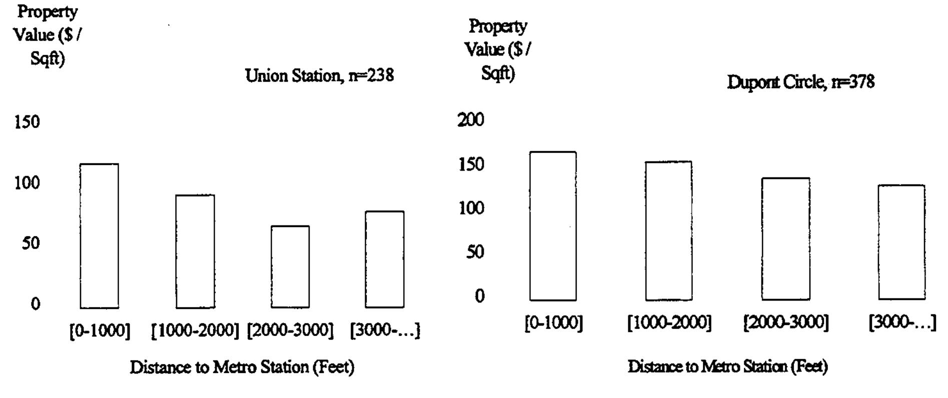

Figure 6.3 Distance to Transit and Commercial Property Value Around Two Representative Metro Stations, Washington, D.C.

If all properties were to loose 10% of there value, the coefficient estimate on the METRO variable in the Semi-Log specification would not change but the benefit estimate in dollar terms would also loose 10%. Again, and this is important, the finding that commercial properties located within a 1,000 feet distance to a Metro station enjoy a 2.109 % premium would not be affected by changes in "economic conditions".[42] The dollar value of this benefit on the other hand would change with the average dollar value of commercial properties.

Table 6.10 Sensitivity Analysis

	-20%	-10%	Base	+10%	+20%
Mean ASSDSQF	86.8	97.7	108.6	119.4	130.3
1,000 Feet	$1.83	$2.06	$2.29	$2.52	$2.75

Conclusion and Future Research

The empirical results of this study are encouraging for several reasons. First of all, the study has confirmed the existence of substantial commercial property benefits due to the proximity of transit. This important result has been found under different model specifications: different functional forms[43] and different sets of explanatory variables. Second, the results presented in this report are consistent with the findings of previous studies. For example, Parsons Brinckerhoff Quade & Douglas (1995) found that in Washington D.C., commercial properties within 1,000 feet of a transit station enjoyed premium values of $2.00 to $4.00 per square foot. Our estimate of $2.29 falls exactly within this range. Third, and this is also important, the way the commercial properties have been selected in this study - at random - insures that the results presented here are representative of the population of commercial properties located in Washington D.C.. Overall, we believe that the results provided in this report are extremely reliable given the data and the methodology we have used. This study however could be extended in several ways. A possible extension would consist in repeating the empirical analysis for a different type of city, i.e. for a polycentric or an edge city. An other possible extension would be to look at the effect of light rail, as opposed to heavy rail or bus lines, on commercial property value.

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[42] Provided that the business cycle affects all properties equally.

[43] Among those generally used in the literature.

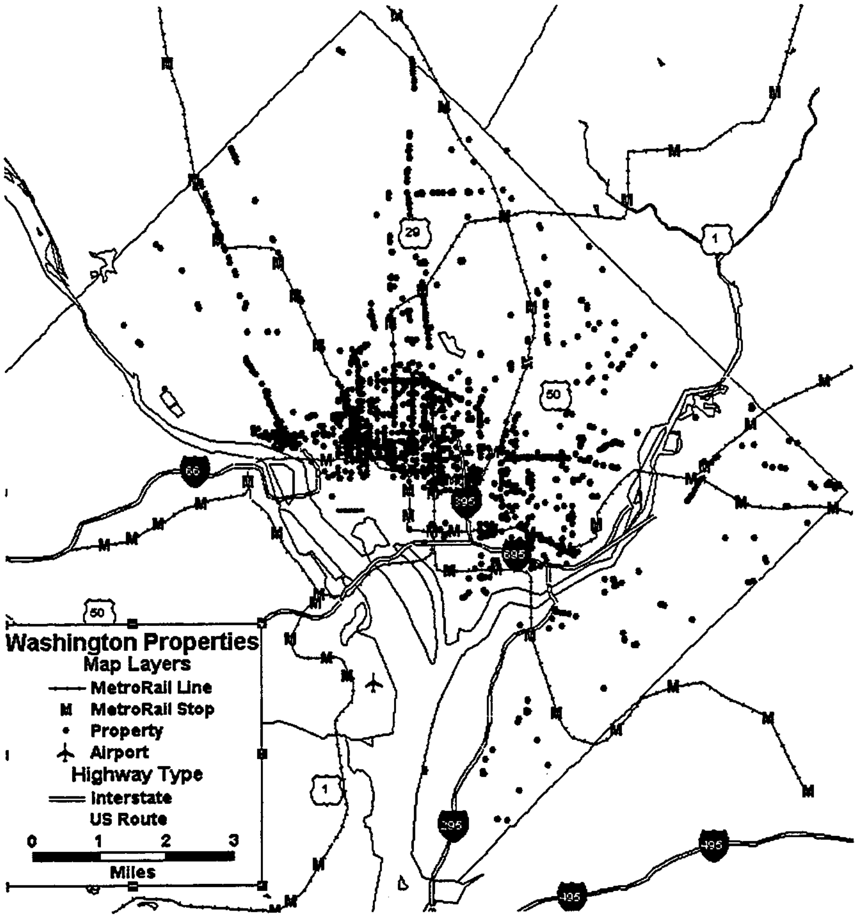

Figure 6.4 Map of the Properties Located in Washington D.C.

Table 6.11 Metro Stations in the Sample

STATION-NAMES	N	$ / SQF	METRO*	STATION-NAMES	N	$ / SQF	METRO*
Anacostia	23	51	3,346	McPherson Square	107	126	1,529
Archives-Navy Memorial	3	205	1,470	Metro Center	68	146	1,197
Benning Road	23	59	5,106	Minnesota Ave.	17	81	3,466
Brookland-CUA	58	55	3,396	Mt Vernon Square-UDC	148	78	1,630
Capitol Heights	22	45	2,620	Navy Yard	19	190	1,546
Capitol South	5	159	1,042	Naylor Road	12	63	6,278
Cleveland Park	22	134	2,236	Potomac Ave.	92	83	2,325
Columbia Heights	52	96	2,269	Rhode Island Ave.	33	98	6,603
Congress Heights	24	73	5,516	Rosslyn	55	185	5,457
Deanwood	14	44	3,878	Shaw Howard University	135	52	1,853
Dupont Circle	378	151	1,851	Silver Spring	2	123	6,433
Eastern Market	131	122	1,984	Smithsonian	1	176	1,200
Farragut North	103	120	1,168	Southern Ave.	3	62	4,448
Farragut West	49	185	1,133	Stadium-Armory	85	93	5,852
Federal Center SW	66	132	1,772	Takoma	51	60	4,462
Foggy Bottom-GWU	123	157	3,711	Tenleytown-AU	48	125	4,043
Fort Totten	27	63	4,966	U Street-Cardozo	179	86	1,687
Friendship Heights	24	116	3,044	Union Station	238	77	3,537
Gallery Pl.-Chinatown	104	88	984	Van Ness-UDC	8	142	1,411
Georgia Ave.-Petworth	146	62	3,634	Waterfront	6	71	3,205
Judiciary Square	51	193	1,871	West Hyattsville	5	31	7,459
L'Enfant Plaza	4	125	726	Woodley Park-Zoo	78	163	4,603
				TOTAL	2,842	109	2,677

* Properties' Average Distance to Metro Station

Table 6.12 Basic Descriptive Statistics

	DESCRIPTION	MIN	MAX	MEDIAN	AVG	CV
	Real Estate Data					
ASSD	Assessed property value, $	9,690.0	49,675,000.0	336,785.0	3,330,007.8	255%
ASSDSQF	Assessed property value / SQFT, $	8.4	2,604.4	90.0	108.6	96%
IMPRV	Percentage improvement, %	0.0	97.0	58.0	52.9	45%
LAND	Assessed value of land, $	4,368.0	38,762,162.0	146,360.5	1,817,146.7	262%
LOTSZ	Lot size in square feet	2.0	86,863.0	2,174.0	6,146.7	169%
SQRFT	Size of the property in square feet	122.0	670,427.0	3,676.0	30,630.5	254%
TAXAMT	Tax amount, $	208.0	1,068,012.0	6,673.0	63,447.2	268%
	G.I.S. Data (in feet along street network)					
BUS	Distance to nearest Bus stop	0.0	3,724.5	218.1	277.2	96%
BWI	Distance to BWI Airport	141,351.0	182,659.4	163,145.9	162,513.3	4%
CBD	Distance to Pennsylvania and 15th Street	977.7	37,128.4	9,289.0	11,303.8	65%
DCA	Distance to Ronald Reagan Airport	16,464.4	55,577.6	26,719.9	28,905.1	23%
HIGHWAY	Distance to nearest main divided highway	0.0	7,891.6	525.1	771.9	115%
IAD	Distance to Dulles Airport	112,468.1	171,036.6	137,268.8	138,532.7	6%
METRO	Distance to nearest Metro station	28.9	12,732.3	2,079.4	2,677.2	75%
	Socioeconomic Data					
MEDFY	Median family income, $	21,933.0	88,865.0	32,083.0	39,833.9	46%
MEDHHY	Median household income, $	19,264.0	66,819.0	27,298.0	29,769.4	31%
NEWC	Percent of new construction, %	0.0	11.0	5.3	6.5	48%
PCY	Per capita income, $	9,331.0	42,397.0	16,530.0	19,138.1	47%
POP	Resident population	2,308.0	63,092.0	34,683.0	33,495.4	54%
RET	Number of employees in retail as % population	0.9	98.2	7.2	18.4	158%
SERV	Number of employees in service as % population	1.8	615.8	7.8	91.1	211%

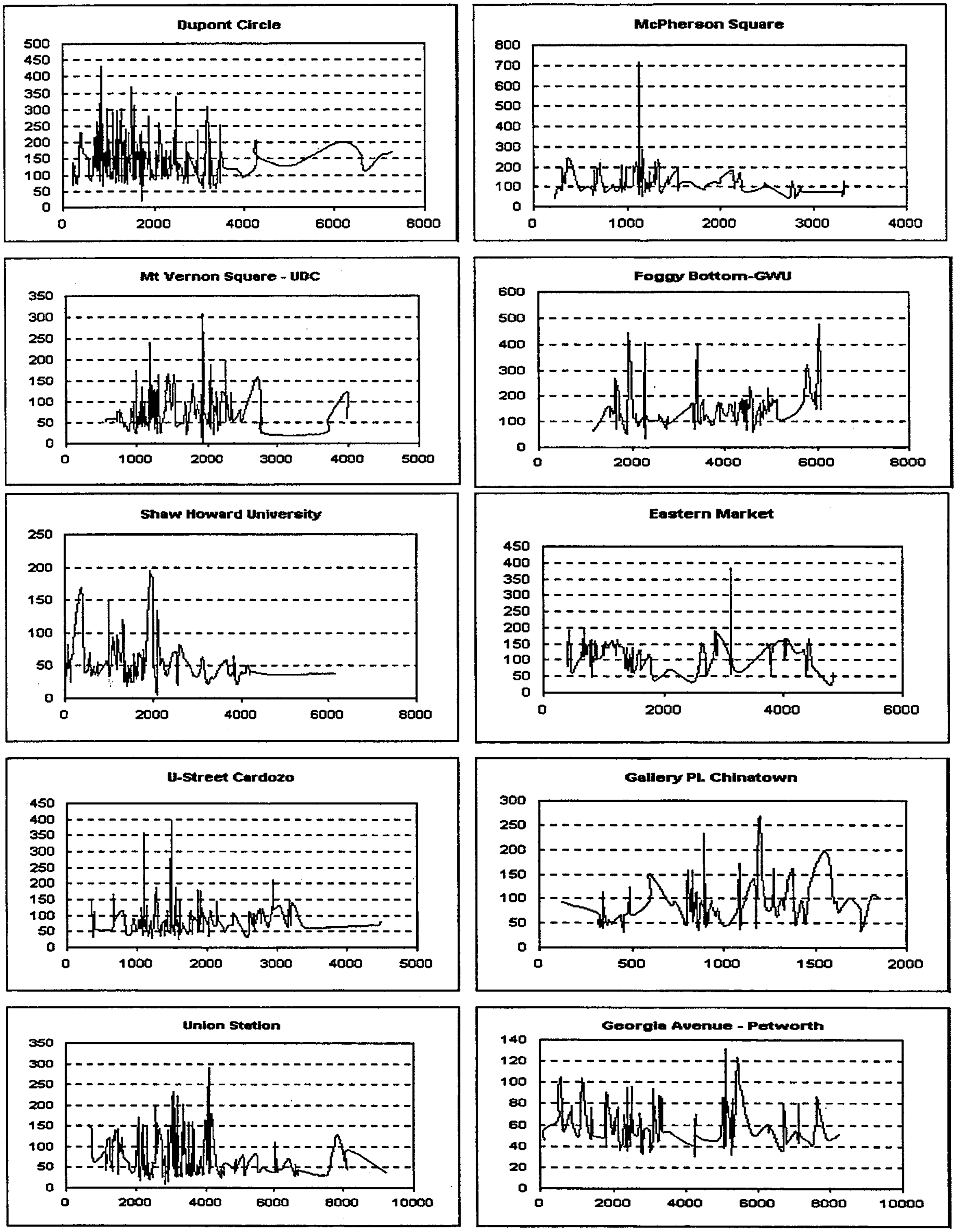

Figure 6.5 **Distance to Transit and Commercial Property Value Around Ten Metro Stations, Washington, D.C.**

The Semi-Log model assumes a linear relationship between the log of the dependent variable – the assessed property value – and the independent variable – the distance to transit Figure 6.6 (A). It follows that the relationship between the dependent variable itself and the explanatory variable is supposed to be as shown in Figure 6.6 (B).

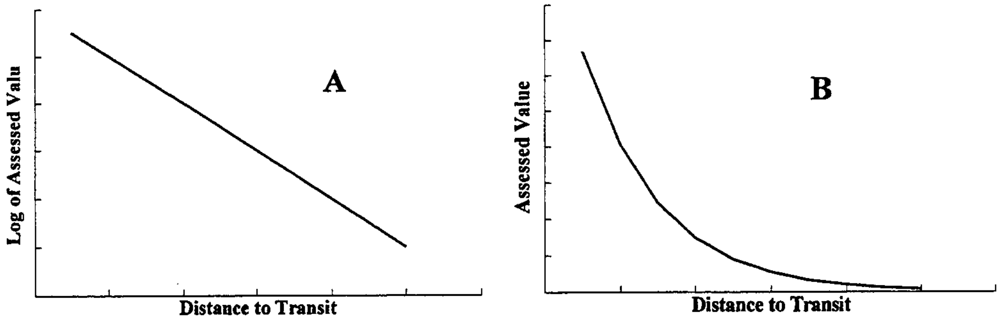

Figure 6.6 The Semi-Log Model: An Illustration

This functional form seems to "fit" the scatter plot presented in Figure 6.2 pretty well. This is one of the reasons why HLB used the Semi-Log specification to estimate the benefits of transit.

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