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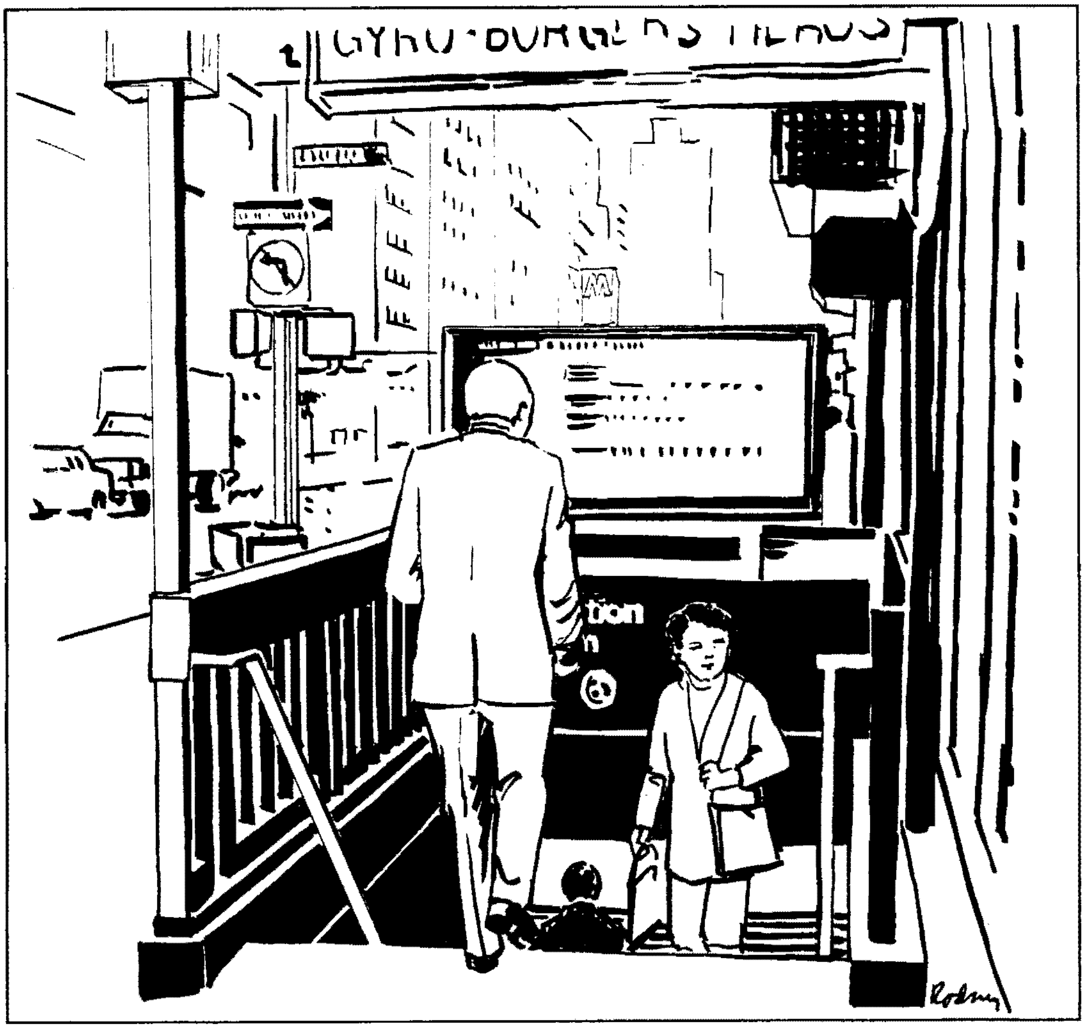

MODELING THE RELATIONSHIP IN THE NEW YORK METROPOLITAN AREA

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16. Abstract

This report presents the findings of a multiyear study on the relationship between land values and transit access, undertaken in the New York Metropolitan area, as the necessary precursor to policy recommendations on value capture financing for public transit. Initiated as an element of the Third Regional Plan for the New York/New Jersey/Connecticut Region, the results serve as a research prototype for transit systems throughout the United States. Two economic models are presented - NYREG and NYSTA - which predict shifts in land values within the Region and at a parcel scale in relation to transit stations.

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LAND VALUES AND TRANSIT ACCESS:
MODELING THE RELATIONSHIP IN THE NEW YORK METROPOLITAN AREA
An Implementation Handbook

Final Report
September 1993

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The research reported in this Handbook was supported by the Urban Mass Transportation Administration (UMTA) through a grant given to the Regional Plan Association (RPA) of New York. It presents two models for predicting changes in the relationship between land value and transit access. NYREG, the regional-scale equilibrium model, was developed by Alex Anas, Professor of Economics, State University of New York at Buffalo. Most of the work on NYREG was completed while Professor Anas was at Northwestern University. NYSTA, the station area model, was developed by Regina Armstrong, Senior Fellow - Economics, Regional Plan Association. The scope of this research project was designed and initiated by Boris Pushkarev, formerly Vice President - Research, Regional Plan Association. An Introduction to Transport Impact Studies for Regional Plan Association was prepared by Professor Britton Harris, University of Pennsylvania, a consultant to this project.

The authors are grateful to numerous people. Yen-Jong Chen and Donghyo Kim of Northwestern University provided excellent research assistance to Alex Anas. Subhash Gupta and Gretchan Hain-Paez merit much of the credit to work by Regina Armstrong. Boris Pushkarev and Britton Harris made useful comments and observations and provided direction for the research project. Robert Yaro, Jeffrey Zupan, Jack Dean, and Nancy Adamson of RPA helped with the difficult task of making data available. Thanks are also due to Edward Thomas, Ron Jensen-Fischer, Kenneth Mowll and Richard Steinman of UMTA for the benefit of a presentation in Washington and for their comments.

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CHAPTER ONE

INTRODUCTION

Since the days of the first streetcar lines, access by public transit has been known to increase land values in the areas served. Early transit entrepreneurs frequently derived their income not so much from the carrying of passengers as from the sale of land served by new lines. Indeed, the benefit of access was capitalized into the value of their land.

The advent of the automobile greatly diminished the importance of access by public transit and severed the link between the providers of accessibility and those who derived revenue from it. The former came to be mostly public bodies, highway departments or transit agencies, and the latter mostly private owners whose land happened to be located near a freeway interchange or transit station. Decades of public subsidies to highways and then transit obscured the relationship between transportation investment and land rent, irrespective of ownership.

In recent years, as constraints on public sector resources became increasingly recognized and efforts to reduce the role of subsidies in society took hold, attention has turned to the question of how the land value increment created by publicly provided transportation improvements can be captured to defray a part of their cost.

Perhaps nowhere does this issue loom larger than in New York. Restoration of worn-out capital stock to a state of good repair together with normal replacement of equipment and facilities on the Metropolitan Transportation Authority (MTA) system will require $1.67 billion per year in 1990 dollars to 2015. New initiatives required to expand capacity over the next twenty years will entail $800 million of outlays annually between 1992 and 1997. As yet, no long term funding sources of this magnitude have been identified.

A study of the relationship between land values and transit access, as the necessary precursor to value capture financing for public transit, was undertaken by Regional Plan Association as a research prototype for transit systems serving the Region and the nation, and as an input to preparation for the third Regional Plan of the New York-New Jersey-Connecticut Region. As such, the models developed for the New York Metropolitan Area, and described in this Handbook for transit industry practitioners, are now in process of extension and disaggregation within the broader MTA district and, ultimately, of application to transit policies and initiatives throughout the Tri-State area.

Purpose of the Handbook

Determining the magnitude and incidence of land value or location rent which public transit generates is of obvious importance to developing stable and equitable long term financing sources for transit systems in the nation.

In the MTA district, which ranks first overall and per capita in transit travel in the nation, some 11 million residents log 13 billion annual miles of travel on public transit. On an average business day, two million people are delivered to the Manhattan Central Business District by public transit. New York State and local governments bear the highest level of debt outstanding for public transit purposes and annually invest more than $100 per resident in the MTA system. In 1987, combined state and local governments expended $1.3 billion on public transit investment in the MTA district, or $110 per capita, and accumulated government debt in excess of $4.3 billion or $369 per capita for transit purposes.

Twenty-eight (28) other major urban areas operate fixed route rail and bus systems in the nation. With the exception of Los Angeles, most are smaller urban concentrations of one to eight million inhabitants. Though all have less densely developed transit systems and business centers, their 80 million residents log 21 billion annual miles of travel on public transit. In 1987, the 28 urban areas and 23 respective states outlayed $2.6 billion on capital funding for public transit systems, or $32 per capita. Outstanding state and local government debt for public transit purposes amounted to $5.1 billion, or $63 per capita. Compared to the MTA district, the areas collectively account for an expanded share of capital spending and population, 67 percent of annual investment and 87 percent of all residents, compared to their share of accumulated debt (54 percent) and transit ridership (62 percent) on all public transit systems in the nation.

This Handbook makes possible the application of research models establishing the relationship between transit access and land value benefits, measured in the nation's most extensive public transit district, to an array of existing and potential transit financing opportunities for the MTA system and those of 28 other major public transit systems in the nation. It describes in detail the processes by which statistically reliable relationships were established and can be applied to a range of policy options, service characteristics, and density settings. It presents an approach to regional and station area modeling that can be replicated elsewhere by calibration with locally available data. Implementation is also discussed in terms of hardware and software requirements, training and support service needs.

In a generic way, the research effort documented in this Handbook contributes to a technical basis for value capture financing by advancing our knowledge in several areas:

o It makes possible linking financing of transit more closely to the benefits transit produces. This will improve the efficiency of the urban economy, reduce the need for more arbitrary forms of taxation, provide secure funding to maintain existing systems in a state of good repair, and help improve or expand systems where sufficient benefits can be captured.

o It makes possible measuring not simply how the market for land responds to transit access, but also how it responds to different qualities of access, including: service frequency, speed, reliability, equipment condition, and the like. This provides an objective yardstick of the importance of various performance characteristics and may improve a public transit system's ability to deploy funds cost-effectively.

o To the extent that land value taxation is implemented, it makes possible enhancing transit-supporting locations for new real estate development. Higher taxes on land in transit-accessible locations will encourage owners to use land more intensively, thereby increasing transit patronage.

Objectives of Land Value/Transit Access Models

Transportation investments play an important role in determining the efficiency and productivity of urban areas. A large part of the benefits created by transport improvements in existing transit systems and in access to transit stations are enjoyed by users of these systems in the form of travel time and travel cost savings, and resultant increases in personal welfare. In economics, such welfare related increases are known as the "consumer surplus" measure.

Additional benefits of transport improvements accrue to owners of real estate which is located in close proximity to improved transit facilities. These benefits take the form of increased rents and sales prices. Land and real estate located at some distance from the improvements can be adversely affected because it is at a relative disadvantage. The net effect is the sum of increases in value in positively affected areas less the sum of decreases in value in negatively affected areas. This net effect can be positive or negative depending on the type of transportation improvement.

To give a historically valid example, let us consider the effect of urban-suburban road building in the nation's cities in the post World War II era. Such roads increased the accessibility of suburbs to people employed in the central cities. Families moved out to the suburbs and chose to commute to their jobs by car, thus being able to purchase larger houses in more attractive suburban settings. Land and housing values in the suburbs rose and, because of the exodus from central cities, land and housing values in the central cities fell.

On balance, the net effect of such value shifts in a metropolitan area is probably a positive one. Families which remained in the central cities benefited from lower rents there and families which moved out to the suburbs benefited from time and cost savings associated with commuting and from the more attractive public goods offered by suburban communities. The changing land and property values also affected revenues of the various municipal governments. Keeping property tax rates the same, suburban governments reaped larger real property revenues while central cities lost revenues as their tax bases declined.

Transit improvements aimed at central cities tend to act as a catalyst for the partial reversal of the effects of urban-suburban road building. Such improvements can increase the attractiveness of city locations for both residential and commercial activity. Hence, if such improvements are substantial, it is natural to expect that values will increase in the city areas which are positively affected and decrease in the suburban areas which are negatively affected. In areas adjacent to the improvements, at transit stations or along transit corridors, value increases will be appreciably greater closer to the improvements, than at further distances serviced by them, all other differences like zoning being explained.

The above discussion, we hope, adequately portrays the complex nature of property value changes in metropolitan regions. On the one hand, there are large shifts in values among the different parts of a region such as cities and suburbs, counties, competing transport corridors, municipalities and neighborhoods as well as among different types of real estate such as housing and commercial. On the other hand, there are changes in values at the parcel level which is the smallest possible geographic unit for which changes can be considered.

It is difficult to deal with both of these scales in the same model. To deal with both of these scales, two models were developed in this study. A regional-scale model (NYREG) which predicts shifts in values within the region and a parcel-scale model (NYSTA) which predicts the structure of parcel-specific property values in relation to transit stations.

<u>NYREG: Regional Equilibrium Model</u>

On the regional scale, the complex effects of transport improvements (whether focused on transit systems or on highway systems) can best be captured by models which simulate the relationships among travel, housing and shopping decisions. Traditional travel demand models examine travel decisions separately from decisions to consume housing and to select shopping destinations. Consequently, such models do not measure how travel decisions affect rents, housing values, vacancies in the housing market, where people live after transport improvements are made, and where people travel for their shopping needs. Operational tools which are designed to simultaneously model these interrelationships are needed in order to properly assess the full impacts and benefits of contemplated transport improvements. Such tools can be designed by adopting an appropriate microeconomic framework which synthesizes the entire bundle of travel and location decisions faced by households and other users of the transport systems.

Major shifts in values among different parts of a region are caused by changes in the transport system which are related to job locations, changes in incomes and changes in costs and travel times among several modes. This is so because, ultimately, changes in values result from the aggregated travel and housing decisions of individuals. A single individual's decision has virtually no effect on the real estate markets, but the decisions of many individuals aggregated together can exert a powerful effect which spreads throughout a region, even though these individuals may be reacting to changes which are locally confined. This spreading of effects is caused by the fact that the different parts of a region are all linked and interconnected through the economic choices available to the affected individuals.

To capture how values shift among different geographic parts of a region as well as among the different types of affected real estate, a model of the real estate markets is needed. Furthermore, since our current focus is how the value shifts are caused by personal transport decisions, such a model must be unified with a model of travel decisions.

The chief objective of such models is to predict the impact of transport improvements on land and property values at the regional scale, in the aggregate, as well as by specific small subregions within a metropolitan area, and for various classes of real estate. These predictions are then used to estimate the potential aggregate revenues that can be raised by taxing the increases and, perhaps, subsidizing the decreases in values. Such taxing (or capturing by alternative means) of net value increases generated by transport improvements is known as value capture financing. (Value capture financing is discussed in more detail in the next major section of this chapter.)

If models of the type discussed are to be useful, they must be of a form which is easy to replicate and operationalize for any major metropolitan area. The ease of such replication should be similar, say, to that of mode choice models, of the UTPS procedure or of transportation network assignment. Hence, it is highly desirable that models use readily available data sources, be easy to calibrate and test, and be relatively easy to operationalize on a mainframe or microcomputer.

When such models are developed, they will close the gap between the needs of the transportation planner, who has traditionally been interested in forecasting physical trips and loads on the transport system, and the needs of the urban economist who is concerned with finding beneficial transport designs and policies that can be implemented in an urban area. Simply stated, transport planners will be equipped with the tools of cost-benefit analysis and will be able to predict not only the physical consequences of their policies and plans, but also the economic impacts of such actions.

One of the models developed in this study, NYREG, is such a regional-scale model. It is important to understand, however, that NYREG is not a "regional economy" model. A regional economy model would divide the region's economy into many sectors and would forecast the output, employment, and trade linkages among the sectors as well as such aggregate quantities as umemployment, regional GDP etc. By contrast, NYREG takes as given the geographic distribution of employment within the region and proceeds from that basis to model the travel and housing related decisions.

A natural way to understand NYREG is to view it as an extension of the Urban Transportation Planning System (UTPS) which has been in use by transportation planners for many years. UTPS models households' travel decisions in an number of sequential steps. These are trip generation, trip distribution, modal split, and, finally, traffic assignment. The sequential nature of the UTPS has been criticized because of the well understood feedback effects among the different steps which are involved. Also, the UTPS does not consider the importance of using economic relationships to model the relationships at every step. Finally, UTPS does not include the working of the real estate markets and, therefore, is not suitable to predicting how real estate values will change in response to the travel decisions of individuals.

NYREG is a response to the above concerns. On the one hand, the sequential steps of the UTPS (trip generation, distribution and modal assignment) are unified into a simultaneous process by means of an economic model. On the other hand, travel decisions are unified with the housing related decisions so that the feedbacks between the two decisions can be captured.

NYREG has been developed and calibrated for the New York Metropolitan Area. It is presented in detail in Chapter 2 of the

Handbook. The model employs a unified treatment whereby housing type, residential location, commuting mode, shopping destination, shopping frequency and shopping mode choices are modeled simultaneously. Travel time improvements are capitalized into consumer and producer surpluses and the producer surplus is divided between the housing and commercial real estate markets.

NYSTA: Station Area Model

While major shifts in values among different parts of the region are important, it is also important to understand how values are likely to vary from parcel to parcel within a small geographic area or within a transport corridor. Changes which occur outside the transit system are admittedly difficult to introduce into such a context. Therefore, the purpose of such a model is to examine how values relate to one another in the proximity of a station under the assumption that outside influences are not causing major shifts in values at the regional scale.

NYSTA, a station area model capable of predicting changes in land value at a radial distance around stations, has been developed as an empirical model from parcel-specific, station-specific and neighborhood data on the area served by the subway system within New York City. It is presented in detail in Chapter 3 of the Handbook. Built by multiple regression analysis, the model contains separate equations for vacant land and land developed in residential and nonresidential uses, as well as for transport related forms of stratification, such as types of transit service. Given changes in various measures of transit accessibility, the model predicts changes in land value while keeping non-transit related factors constant.

Because of the multiplicity of factors affecting land value and the difficulty of assembling explanatory data, empirical models linking land value to particular access characteristics are rare. Since the shape of the Region's transit system has not changed much since 1940, and most areas served by transit stations are extensively developed with land values well capitalized and firm community character, the modeling emphasis is on cross-sectional, rather than time series, analysis. Cross-sectional analysis among station areas allows for determination of the relative importance of transit, land use, density, environmental, socioeconomic and all other major factors in establishing land value differences by location. Once isolated for their relative importance in space, across a spectrum of existing conditions, transit access factors can be varied to predict the increments or decrements in producer surplus or property benefits that will be capitalized into land value.

The station area model should be seen as a natural complement to the regional equilbrium model. With further development, the two models can be statistically linked such that zonal projections of NYREG, solved on a regional equilbrium basis, are further disaggregated to the parcel level by NYSTA, utilizing the set of land use and radial distance equations around specific stations. With such results, the potential revenues raised by value capture means on a zone or regional level can be evaluated and implemented at the appropriate tax administration scale.

Although we are aware of this complementarity we have not, in the current project, made an effort to link the two models. In the future, it might be possible to link the models sequentially so that NYREG predicts shifts in values among small geographic zones, while NYSTA allocates these changes among the parcels.

Some Shortcomings of NYREG and NYSTA

All models are subject to various shortcomings and the models developed here, NYREG and NYSTA, are no exception. The models have shortcomings which are common to both of them as well as individual limitations.

Both models are static in nature, meaning that they are intended to model the relationships between property values and transportation systems at a sinlge point in time. However, there are various techniques by means of which each model can be extended and made dynamic. For NYREG, this would require following the example of CATLAS (the prior dynamic model on which it is partially based) and introducing a multiperiod structure. A dynamic NYREG would not only predict how values changed, but also how the housing and commercial building stocks evolved from one period to the next. This could not be done in the current project due to time limitations. Making NYSTA dynamic would require recognizing the time series nature of property values and reestimating the regression equations with time shifter variables. A dynamic structure would also allow the inclusion of an exogenous inflation parameter in the two models to help isolate real changes in values from inflationary ones. This would allow predictions of value shifts and changes under various assumed scenarios about overall inflation in the economy.

Both models also share the limitation that rent control, while an important factor in New York City's housing market, is not included in the equations as an independent variable or in some other way. While we were aware of this limitation we could not incorporate rent control because we lacked data on the rent control status of individual properties and the proportion of rent controlled apartments in specified zones.

While NYREG includes the effects of important influences on property values, trip making and housing choices, it is not a regional "economy model". Hence, it is not intended to capture the more profound effects of deep structural change in the New York economy on travel patterns, housing choices and values, nor can it model important changes in the national economy and how these might affect the New York City economy. Structural changes in the local and national economies can only be inputed into NYREG exogenously by altering the income and job distribution among the approximately 400 workplaces represented in the model. While the scope of NYREG is limited in this sense, it is still much broader than the more limited scope of the UTPS which models only travel decisions without including important feedback effects. NYREG has solved this problem of the UTPS by modeling the feedbacks between the real estate and multimodal travel markets in an economicly defensible fashion.

NYREG may also be criticized for being highly aggregated. In principle, with adequate data, NYREG's shopping trips component can be disaggregated to include many types of shopping by purpose which would enrich the model's ability to predict the impact of transport changes on various economic activities within the region. However, such disaggregation may not be necessary to get an overall prediction of value shifts which the current model does.

The chief limitation of NYSTA is that it cannot measure the impact of changes in non-transit transport systems on property values. Hence, the model can only be applied under conditions of multimodal stability highly similar to the conditions of the calibration year. In the future, we plan to remedy this shortcoming by linking the regression constants in NYSTA with the predicted zonal values coming out of NYREG.

One other notable limitation pertains to NYSTA's implicit assumption that the real estate market displays a consistently declining gradient from the core, or Central Business District of Manhattan, to New York City's suburban boundary. In reality, the profile of land value per square foot is substantially higher in Manhattan than in the other boroughs and, though suburban stations are not included, commercial subcenters or desireable residential neighborhoods of outer boroughs can achieve land values that peak over nearby areas closer into the Manhattan CBD. To some extent, NYSTA addresses this problem by stratifying equations by land use. In the future, however, we plan to enhance the model with equations for specific boroughs and transit corridors, and with nonlinear regression methods that would yield nonconstant slopes that can vary with other variables in a systematic fashion. Despite these limitations, we feel that NYSTA offers an excellent second stage analysis to follow NYREG, or to be used by itself under conditions of stability.

Objective of Value Capture Financing

Increasingly, local governments face seemingly insurmountable burdens in repairing rapidly decaying infrastructure systems in a time of scarce public resources with mounting deficits, declining tax revenues, and accelerating construction costs. Though cities have imposed infrastructure financing requirements on private development for some time, these mandates have been largely for project-related facilities that did not serve the community at large. There were of course exceptions, such as the special real estate assessments levied in New York in early days to help finance subway construction. By and large, however, capital investment in area wide central facilities and systems was funded out of city wide taxes or user charges.

Since the 1970s, many cities have curtailed provision or expansion of infrastructure systems to new development by growth management programs. Responding to competing demands on scarce capital resources, cities limited or redirected private growth to areas with adequate capacity, thus controling overall development in phase with manageable public financing. It was not until the late 1970s that dramatically different financing alternatives for public infrastructure provision were widely discussed. In a 1979 study published by UMTA, Financing Transit - Alternatives for Local Government, "value capture" financing or benefit-sharing taxation of real estate value increments received prominent attention. Since then, more than one hundred cities have instituted some form of developer fees or exactions, special benefit assessments, tax increment financing, or non-fund contributions, as a value capture approach. Many of these financing mechanisms were put in place without a rational measurement basis or with an inadequate understanding of the market consequences.

The objective of value capture financing, or benefit-sharing of capital investment in public transit systems, is to arrive at an equitable distribution between public and private outlays for new initiatives and normal system rehabilitation that bears a direct relationship to the distribution between diffused public and measureable private benefits, so that capital financing of these systems is placed on a more stable, equitable long term basis. This objective is best achieved by capturing a portion of the surplus (land value) generated for private property owners by the accessibility improvements created by the investment, either as a lump sum or on a recurring basis.

For reasons of equity and efficiency in property markets, value capture financing requires accurate measurement of the surplus value conferred by the capital investment, so as not to create dislocations or disbenefits. In practice, however, numerous forms of value capture or benefit sharing financing have emerged, some of which use strategies or revenue raising mechanisms that are highly interventionist in the development process. The major forms of value capture financing are as follows:

- property taxation: captured from recurring general real estate taxes, or from taxes on value increments (land value only, or on land plus already existing improvements), or from taxes on transfers of real property as lump sum, or by tax increment financing

o special benefit assessments or assessment districts: applied across-the-board, may include linkage programs

o developer fees: imposed as a lump sum or recurring on a phased-in formula basis

o negotiated exactions: monetary, contributions or in-lieu of fees negotiated on a project-specific basis, often with bonuses offered in exchange

Value capture financing is to be distinguished from cost-sharing or cost recovery financing which can take the form of lease arrangements with private developers for operations or maintenance of system facilities, or negotiated agreements to share or recover the initial cost of publicly providing a benefit-generating improvement. These approaches do not necessarily reflect the value or incidence of the surplus benefit created by the transit improvement.

It should be noted, however, that value capture financing need not be limited solely to private property. Publicly owned land adjacent to transit stations or well situated in transit corridors will also benefit from transit improvements. Increases in the sales value or redevelopment potential of such property can be figured into the value capture.

Transport Impact Studies for the Regional Plan Association

When the first Regional Plan for New York and Its Environs was still in its planning stages, Regional Plan Association received a memorandum from Columbia University economist Robert Murray Haig. Haig proposed a most remarkable (and generally forgotten) approach to making an urban plan. He suggested that the plan be drawn on a scientific basis, so as to minimize the total cost of transportation and land rent for the households and businesses located in the Region.

This proposal is remarkable because it called for a global optimization of the costs and benefits of a plan, many years before such an idea was even widely discussed, let alone actively considered. It is also remarkable because Haig apparently had no conception of the difficulty of solving such a problem, even if it could be more accurately formulated. Mathematical programming and the widespread use of computers were still thirty and more years in the future. In the final analysis, Haig's contribution to the plan was a much more modest analysis of locational trends in selected industries.

The modesty of this final contribution should not be allowed to obscure the grand vision which Haig saw of the future of planning. The current report continues his effort to give concrete form to visionary approaches, which has in more than one way been the thrust of much of the work of RPA.

At the time of the preparation of the second Regional Plan, the Association undertook a major survey of the social and economic health of the Region, under the direction of Raymond Vernon, and with outstanding contributions by other associates. In economic terms, this multi-volume study took in the main a "macro" view of the Region and of the interaction of its principal parts. This view omitted any detailed study of many of the mechanisms through which New York City and the Region carry out their social and economic functions. The breadth and power of this approach resided in the comprehensiveness of its overall view of the Region, but perhaps it allowed too much neglect of the detailed interactions which are influenced by planning decisions, and whose understanding may provide the necessary basis for a successful planning effort.

This Handbook reports on the study of land values and transit access undertaken by the Association preparatory to the third Regional Plan. The study represents an effort to relate a macro phenomenon -- the health of the core of the Region in the Manhattan CBD -- to the needs of other parts of the Region, through a micro-analysis of its transport connections. This effort is based on a study of the micro-economic phenomena related to the choice of residence and choice of shopping opportunities, given a pattern of employment, as these are aggregated together into major economic influences.

These detailed phenomena were broadly understood at the time of the first Regional Plan, but their detailed analysis was beyond the grasp of Haig and even of the Vernon study. Their accomplishment at this time provides a measure of the progress of regional analysis over the last sixty years. And a review of these accomplishments also provides a foretaste of the possible extension of these methods into the formulation of the third Regional Plan. At the same time, a candid appraisal of the study serves to underline some of the remaining difficulties which face development in this direction.

The reader's understanding of the present methods and results and their future potential may benefit from a brief review of the recent history of urban analysis. In this review, a particular effort is made to show how history is reflected in the modeling approach reported in this Handbook, and how it influences future developments. This review is brief since the intellectual content and historical relationship of each model is sketched in the following chapters.

The last fifty years have seen an enormous growth of our understanding of residential choice, retail trade location, and transportation demand behavior. This understanding is expressed in economic and behavioral theories, and the theories are implemented for the study of actual situations through the use of computer models. The work reported in this Handbook represents the state of the art with respect to one very important class of theories and models.

At the outset, however, we need to take note of the fact that all of this progress has not solved Haig's original problem of putting planning on a fully scientific basis, and hence perhaps on a basis which would turn the making of plans into an automatic process. Optimization theory has grown at the same time as the theory of urban function and urban models. Optimal solutions are now known for many particular urban functions, as we will describe in connection with this work. But the same development has identified a class of intractable problems for which optimal solutions are unlikely in reasonable time, even with the anticipated enormous increase in computational power. The overall problem identified by Haig suffers from exactly this kind of intractability, given the demonstrated need for many urban activities to form multiple clusters for efficiency and amenity.

Much study suggests that one of the most important outcomes of fifty years of research is a negative result -- a "failure" -- for science, which corresponds with a positive result for the art of planning and public policy making. This result tells us that the largest decisions about the structure and function of the region, and the investment of public and private funds in major improvements, have to be taken with careful exploration and forethought, and with detailed attention to their consequences. Computer models and economic or behavioral theory can provide many instruments for tracing these consequences of alternative decisions, but they cannot be expected to reliably produce the broad outlines of acceptable, affordable, and effective plans.

The use of extensive surveys, behavioral analysis, and computer models of system performance began in the current period with transportation planning studies in the mid-1940s. These studies spent over a decade in learning what governs user choice in transport systems, and how these choices combine to produce congestion or its absence in the use of facilities. These studies did not produce plans by machine: these were handcrafted as before, but their effectiveness could be studied in greater depth. The work described in this Handbook draws on the experience of that early sequence of studies for the work of tracing out paths and costs of travel under alternative assumptions about possible improvements. The same experience uses these costs to calculate the choices which people would make in the future and under changed circumstances between different modes of travel, such as subway, bus and auto.

Transportation studies were originally staffed and planned by engineers, and not by economists. Economic theory did not prove very useful in studying transport behavior, especially since it was widely observed that people in similar situations made dissimilar choices about their mode and distance of travel. At that time economics had no adequate explanation for this, and the engineers operated with ingenious "diversion curves" and "gravity models". (These were found in the 1970s to have anticipated the discovery of the family of "discrete choice models".) At the same time, up until about 1960, transport studies tended to neglect the impact which transport changes would have on the locations of travelers, and hence to underestimate the derived demand which would later swamp many urban vehicular facilities.

The responses to the need for closing the circle of transport demand and supply by taking into account locational effects was not long in coming. One trend, started by Ira S. Lowry, extended the ad hoc approach of the engineers and took account of the variety of human behavior in the land and travel markets. Another approach, independently initiated by Lowdon Wingo and William Alonso, built a new explanation of residential location on neo-classical economic location theory. These investigators showed how the substitution for each other of space costs and benefits on the one hand and travel costs and inconvenience on the other hand would generate competition for land. This competition led to sorting out the occupancy of urban land into concentric rings which were denser and held poorer occupants toward the center. In these theories and their consequent models, people of a given class or income behaved uniformly, partly contrary to experience. And most unrealistically, it was assumed that all employment was at the center.

A critically important feature of these models was that their solution led to a distribution of population into housing which was "Pareto optimal". This means that under the given assumptions about the income distribution and the available jobs, land, housing, and transportation facilities, people would be located so that no one could be moved to make him better off without making someone else worse off. This optimum also corresponded to a market-clearing equilibrium in which everyone was housed at their best achievable levels, and all land was assigned to the highest bidder.

At the same time, progress was being made in understanding the exact mechanisms of retail trade location. The old idea (found in Central Place Theory) that people would shop for a given type of good only at the nearest center offering that good was replaced by a new approach using the gravity model to distribute shopping behavior in a varied fashion. Lowry introduced a simplified model of trade centers which depended on this approach, and which linked trade location with residential location.

The 1960s and 1970s were a period of vigorous experiment with both of these types of model. The Lowry model was extended and improved, and was widely used in many planning offices, especially for structure planning in Great Britain. (This model had never postulated a monocentric city.) Efforts were made to convert the Wingo-Alonso approach to a form of linear programming -- first without employment centers by Herbert and Stevens, and later with multiple centers by the NBER project, centered at Harvard University. Meanwhile McFadden and other economists developed the theory of discrete choice, and thus provided a basis for gravity-like models. The stage was now set for a unification of these two streams of residential theory and models, together with a modern version of retail trade location. This unification proceeded on both a practical and a theoretical level, the practical effort being based on Lowry, and the theoretical on Wingo-Alonso.

The Lowry model tradition reached its peak in the development of an integrated set of models and the addition of an industrial location model in the work of Stephen Putman at the University of Pennsylvania. However, Putnam's model, like Lowery's, did not include rents. At the same time, a Cambridge architect-planner, Marcial Echenique, extended the Lowry model in many directions. He too added a model of industrial location, and he incorporated a full scale transport demand model and used rents (largely fictitious) to arbitrate the competition for space and prevent unrealistic overcrowding. Both of these models have been operational successes, and have been widely applied under their authors' supervision in several metropolitan planning efforts. Echenique's work most closely approximates work deriving from the Wingo-Alonso tradition.

Anas integrated the Wingo-Alonso theory with McFadden's discrete choice theory to allow for diverse choice behaviors and multiple employment centers, while preserving the expression of a true economic theory of land prices as the basis for reaching equilibrium. This equilibrium represents a kind of outer limit of the benefits which can be achieved by a residential plan, assuming that all households ultimately find their best achievable location. The equilibrium depends, however, on all the surrounding decisions about zoning, transport facilities, and industrial (non-population-serving industry) employment. The current formulations of the model, presented as NYREG in this Handbook, have adopted direct measures of the benefits of a transport plan in terms of the economic concepts of consumer and producer surpluses.

There is a significant benefit for planners in the fact that both of these classes of models are readily computable, given their careful formulations and present computer technology. In NYREG's case, this computability depends on the equilibrium nature of the model, and the fact that its formulations are mathematically exact as well as being well-structured for modern super computers or desk-top workstations.

The models developed for this Handbook and by others are not of course completely perfected. The industrial location models presently available are rough approximations of reality, and are especially weak in their portrayal of business services -- activities which are especially important in New York. There is also undoubtedly room for improved behavioral representations of the demand for housing, retail trade facilities, and transport service -- together with more complete representations of the economic and policy behavior of suppliers and regulators of these activities.

All of this background may seem somewhat excessive for an understanding of the relatively simple things which are done in the current modeling effort presented in this Handbook. Basically, NYREG portrays the present system of linkages which determines activity in the Manhattan Central Business District. This system is then perturbed by postulating transport changes. These can be small or large, and as numerous as desired. These changes result in changes in the time and cost of travel from work to home and from home to shop. In response, people rearrange their trips by changing their choices about where to live and where to shop. This results in new competition for land and buildings, and changes their prices and rents, leading to additional changes in behavior, and so on.

The great advantage of the equilibrium formulation in NYREG is that all the interactions in the system -- resulting from changes in location, changes in costs, and competition for space -- are traced out to a final complete readjustment, which would actually result from thousands and millions of small accomodations, perhaps spread out over considerable time. The outcome of the equilibration is a new pattern of rents for land and buildings, new patterns of location, new patterns of transport utilization -- and consequently new patterns of welfare for households and profitability for businesses. These results are available in considerable detail, and in summary form.

These methods, theoretical and abstruse though they might seem at first glance, are in fact intensely practical. They are easily computable, they use data which is in general readily available, and they produce results which are reasonable, plausible, and explainable. The results are at the same time far from being predictable by common-sense methods or classical economics, and require models of this kind for their production. These models are derived from similar efforts which have been used in a number of applications to analyze the possibility of "value capture" for transport improvements in large metropolitan areas.

However, the advantages do not end here. We know from experience with these models that work can be extended to the entire Tri-State Region and disaggregated to reflect both the choice of more types of housing and access to more types of shopping, by more different strata of the population. These changes will increase the volume of computation, but not its intrinsic complexity. In working out these applications, some of the difficulties mentioned above can be corrected. This type of analysis will greatly strengthen the ability of RPA and the Region to trace out the implications of alternative plans and public decisions.

The Regional Context

The regional context for development of models presented in this Handbook represents the central portion of a vast Tri-State Region served by Regional Plan Association. Radiating outward more than one hundred miles from the Manhattan CBD, the Tri-State Region comprises 31 counties in the states of New York, New Jersey and Connecticut. The study area for purposes of this modeling focused primarily on four boroughs of New York City -- Manhattan, Brooklyn, Queens, and the Bronx -- while incorporating four other counties in New York State (including Richmond or the borough of Staten Island in New York City) and one county in New Jersey. As such, the study area approximates the New York Metropolitan Area. (See Figure 1.1)

The 12-county MTA district in New York State, the Metro North Commuter Rail (MNCR) service area in Connecticut, and the commuter rail and bus territory of NJ Transit are enscribed within the Tri-State Region, each system of which delivers commuters to the Manhattan CBD. The 9-county study area contains a majority of the MTA's systems, including the subway and bus systems operated by the New York City Transit Authority and portions of the Hudson, Harlem and New Haven lines operated by MNCR. Excluded from analysis are MTA's Long Island Railroad operations in Nassau and Suffolk counties. Model zones have been disaggregated below the county level in New York City for Manhattan, Brooklyn, Queens, and the Bronx. (See Figure 1.2) The model extension in process will provide disaggregated zones for suburban counties served in the New York State portion of the MNCR system. Future model extensions will expand the study area's geographic boundaries to the Tri-State Region and provide disaggregated zones for Long Island, Connecticut and New Jersey.

In 1990, the 31-county Tri-State Region contained a resident population of 19.8 million persons in 7.3 million households, or 8 percent of the nation's total inhabitants. Nearly three in every five regional inhabitants, or 11.7 million persons in 4.3 million households, resided in the 12-county MTA district of New York State. In 1987, when the Tri-State Region's economy generated one in every nine dollars of national output, or $502.1 billion Gross Regional Product (GRP), the MTA district accounted for $309.3 billion of GRP. Total employment (including self employed) in the 12-county district numbered 6.5 million jobs in 1990, of which 2.6

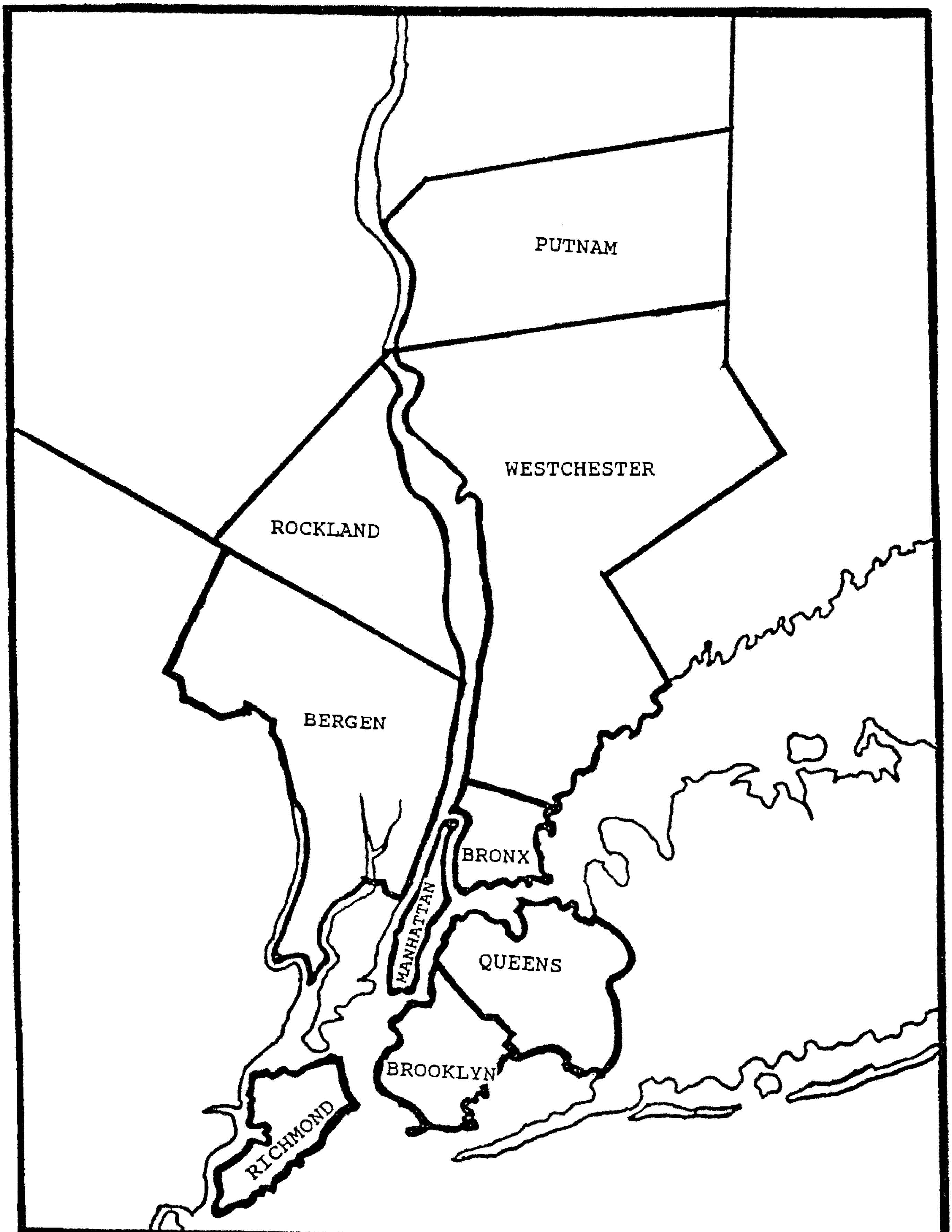
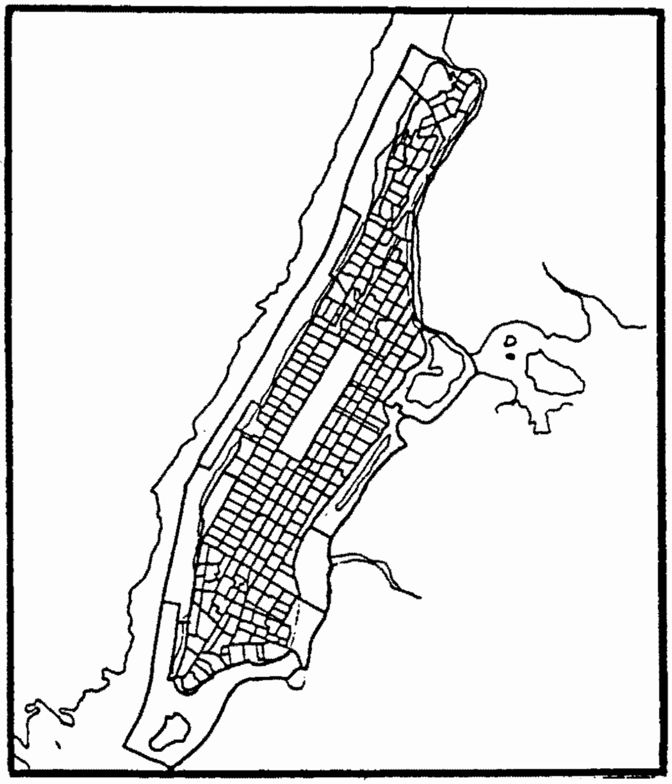
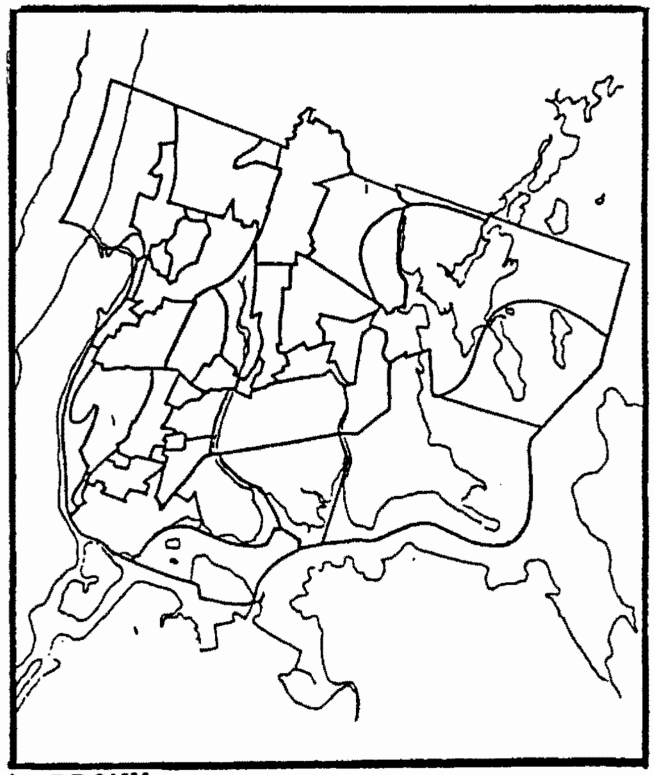


Figure 1.1 The Map of Study Area



a. MANHATTAN



b. BRONX

c. BROOKLYN

d. QUEENS

Figure 1.2

Maps of Model Zones in New York City

million were located in Manhattan, 1.5 million in the rest of New York City, and 2.4 million in the suburban counties of the MTA district. Elsewhere in the Tri-State Region, some 4 million jobs are located in older cities and suburban communities.

Owing to its superior transit accessibility, the nine-square mile Manhattan CBD, which contains more than one fifth of the Region's total employment, supports a unique concentration of over 600 million square feet of nonresidential and over 200 million square feet of residential floorspace. In excess of three million people enter this area on a daily basis, two-thirds of them by public transit. With employment subcenters located elsewhere in New York City, the City has historically provided more employment opportunities than housed resident labor force. According to the 1990 Census, 515,000 more persons worked in New York City in primary jobs (excluding multiple jobs) than resided in the City as employed workers, while 320,000 more workers resided in suburban portions of the MTA district than were employed outside the City.

Over the past decade, the jobs-housing relationship has changed somewhat as worksite employment has grown faster in the suburbs than has the resident labor force, while renewed population growth in New York City has fueled the supply of resident workers. While New York remains the Region's job center, reverse commuting of City residents to suburban jobs and intrasuburban mobility of resident suburban workers have risen. Often destined to dispersed job locations, suburban-bound trips represent challenges to a hub-bound public transit system.

Organization of the Handbook

In the following chapters, this Handbook provides the reader with an exposition of the technical development and configuration of the regional equilibrium and station area models, with Chapter 2 devoted to NYREG and Chapter 3 to NYSTA. In Chapter 4, some issues of value capture are discussed as a framework to regional and station area policy simulations of the models, which are presented in Chapter 5. The final chapter concludes with a description of hardware, software, and training support needs for model implementation. Two appendices contain NYREG methodology in detail.

CHAPTER TWO

DESIGN, ALGORITHM, COMPUTATIONAL REQUIREMENTS, AND APPLICATIONS OF AN OPERATIONAL EQUILIBRIUM MODEL OF URBAN LAND VALUE AND TRANSIT RELATIONSHIPS

A regional model (NYREG) has been designed and calibrated for the New York Metropolitan Area to simulate the equilibrium effects of urban transport improvements on residential and commercial real estate markets. The model has been applied to evaluate the economic benefits of a number of hypothetical improvements in the travel times of the subway, highway, bus and commuter rail modes.

Two kinds of benefits are computed by the model:

o the change in the consumers' surplus measures the approximate improvement in the welfare level of urban households, taking into account the changes in housing and commercial rents induced by the transport improvement, and

o the change in producers' surplus measures the profits which accrue to the owners of residential and commercial real estate, and which are capitalized into land values.

The model is a short run equilibrium model in that building stocks are assumed fixed. The effects of transport improvements on changes in the stocks of residential and commercial real estate are not predicted in the model. However, exogenously predicted changes in building stocks, such as a proposed office development in the Manhattan CBD, can be simulated in the model to generate changes in work trip distributions, travel modes, housing location choices, consumer surpluses, and producer surpluses (or land value increments).

The model is designed in the tradition of urban economics. The equilibrium is driven by decisions of representative households with fixed places of work, but free to choose a place of residence, a mode of commuting from work to home, the type of housing at the place of residence, and a pattern of annual shopping trip frequencies by travel mode from the place of residence to each of a number of shopping zones. The decisions are made simultaneously, taking as given incomes, the rents of housing, and the travel times and costs of each of the travel modes. The rents of housing and commercial floor space respond to the aggregate demands generated by these choices so that demands and supplies are equal in each relevant geographic submarket and for each type of real estate.

How NYREG Relates to the Literature and to Historical Work

The idea that transportation and real estate markets are inextricably linked is not new. There is an old research tradition on the question of how transport improvements affect the magnitude of changes in land or real estate. Many earlier studies are descriptive. These have focused on the impacts of rapid transit [Spengler (1930), Davis (1965)], expressways [Adkins (1959), Lemly (1959), Golden (1968)], interchange development [Ashley (1965)] and interstate highways [Wootan and Haning (1960)] on property values.

More recent studies have utilized statistical analysis. Examples of these are the study of the Philadelphia-Lindenwold High Speed Line by Boyce, Allen, Mudge et. al. (1972), of a rapid transit line in Toronto by Dewees (1976), and of the Washington, D.C., Metro by Lerman et. al. (1978). These studies use multivariate linear or nonlinear regression analysis to isolate the effects of various variables including travel related attributes on property values.

Two criticisms may be made of these regression studies. First, they deal with a single facility in relative isolation, rather than with an improvement with areawide impacts. Second, regression studies cannot simulate equilibrium changes since the regressions are hedonic relationships - that is, the separate shifts in the demand and supply functions cannot be modeled since supply and demand schedules are not identified in the estimation of the regression models.

An appropriate equilibrium model would have to be rooted in the tradition of urban economics while embracing techniques that have proved their worth in modeling travel and related choices. The theoretical literature in urban economics is based on the early studies by Mohring and Harwitz (1962), Alonso (1964), and Mills (1967). The basic argument of this literature is that part of the savings in travel costs are capitalized into land rents. Arnott and Stiglitz (1981) have used such a model to examine the relationship between uniform improvements in unit transportation costs and the aggregate value of urban land in a monocentric city. Even in such simplified cases, it is not possible to obtain simple quantitative rules of thumb about the direction of change: values may increase or decrease in the aggregate.

Because the theoretical models are so ambiguous, the challenge of operationalizing the theory is even greater. The question of what happens to real estate values both in the aggregate as well as at different locations is largely an empirical question requiring elaborate measurement of key behavioral relationships. Partly in response to this challenge, Anas contributed to a research effort to jointly model household choices of travel and residential location by means of multinomial logit analysis [Warner (1962), Domencich and McFadden (1975), Quigley (1976), Lerman (1977), Anas (1981)]. In Anas (1982), and Anas and Duann (1985), it was demonstrated that supply and demand equations derived from logit analysis can be used to construct an equilibrium model of the housing market. The resulting model, the Chicago Area Transportation Land Use Analysis System (CATLAS) was used to study the response of the housing market in the Chicago area to specific proposed new subway lines.

NYREG has a structure which, although similar to CATLAS, is more realistic and has been extended to include choices of shopping travel and housing type together with choices of residential location and travel mode. Although CATLAS was a multiyear dynamic simulation model, its capabilities were narrower in scope than NYREG (which is at present a static equilibrium model) because data limitations and technical constraints did not allow the treatment of non-work travel in CATLAS. Also, limited computing budgets in the mainframe computing environment of the early 1980's did not permit solving large versions of the model. The implemented version of CATLAS consisted of 1690 traffic zones, 2 workplace types (CBD and non-CBD) and 4 commuting modes. All housing was aggregated to a zonal total regardless of type.

Supercomputers are now accessible to planning agencies and academic researchers and the speed of desk-top computing capability is quickly approaching or exceeding that of traditional mainframes. Hence, models which are larger and more complex than CATLAS can be solved very rapidly and at much less cost than was possible a decade ago. In addressing many of the deficiencies of CATLAS, NYREG has also been implemented on both a CRAY supercomputer and a SUN workstation.

What Questions Does NYREG Address ?

It is useful to give a couple of narrative examples which illustrate the way in which the regional equilibrium model can be used to analyze a change, policy or scenario. The reader is encouraged to come up with examples of his or her own making by keeping in mind the list of model inputs and outputs presented below.

Example One: A Station Closing

As one example, suppose there is a station closing in midtown Manhattan. This will affect the travel times on certain subway routes. Using detailed information about the transit network, the user of the model would compute (by means of TRANSCAD software or other comparable procedures) how the travel time by subway from each zone to each other zone would be changed. In the case of the station closing, it will be found that certain zone pairs will experience a reduction in travel time because trains will stop in one less station on their way to and from these zones. However, zones near the closed station may experience increased travel times, because travelers originating from those zones will have to walk to other stations. Hence, some zone-to-zone times might increase while others might decrease, depending upon the net effect of line haul time savings and access time increases.

The recomputed travel time changes for all zone pairs would be entered into the model. The model then simulates three responses of households to the travel time changes. First, some commuters whose travel times have increased may decide to switch to other modes, such as taxi, walking or driving. Second, zones near the closed station may become less attractive and may experience a relocation of households elsewhere, while other zones, of which the travel times decreased, become more attractive and experience an influx of households. Third, shopping trips will be affected because other modes may be used to travel to shopping destinations and because some shoppers may choose to shop at closer destinations.

The netting out of these adjustments will have an effect upon the residential rent of zones affected by the station closing. Rents in those zones which experienced travel time savings will increase, while rents in those zones which experienced higher travel times will decrease. Similarly, zones which receive fewer shopping trips will see their commercial rents go down and zones which become busier with shoppers will see their commercial rents go up. Residential and commercial vacancies will move in opposite directions from rents: as the equilibrium demand for living (or shopping) in a zone falls, the equilibrium residential (or commercial) rent in that zone will decrease, while the equilibrium residential (or commercial) vacancies will increase.

It is clear from the above discussion that the station closing will benefit some travelers while hurting others. The total net effect for travelers is computed by the model as the change in the consumer surplus after all the equilibrating adjustments have taken place. Similarly, while landlords in some zones will enjoy a windfall increase in rental income, others will suffer a loss. The total net effect for landlords is computed by the model as the producer surplus change. An economist doing a cost-benefit analysis of the station closing, would be interested in the sum of the producer surplus and consumer surplus changes less the cost of implementing the change in the transportation system (i.e. the closing of the station). If this criterion yields a positive value, the implication is that the station closing is a socially profitable public sector decision.

Urban planners prefer to make more liberal interpretations of model output and they are rarely interested in aggregative cost-benefit analysis. Hence, a planner may observe that the model indicates where and how much rents change and conclude from this that tax increment financing is called for to "capture" these increases for the public sector in order to offset the public sector's costs associated with the station closing. Planners may also use the model's output to identify which zones are likely to receive more shoppers, concluding from such information that some changes in zoning, such as putting more land into commercial space or into parking, may be justified in those zones where the density of shopping trips per square foot of land increases substantially.

A scenario of station opening would work in the reverse.

Example Two: An Across-the-Board Travel Cost Increase

As another example, we may consider analyzing the effect of an across-the-board increase in the cost of driving sparked by a permanent rise in the price of gasoline. When this happens, some commuters and shoppers will switch from driving to taking the bus, to riding the subway, or to walking, in order to avoid the higher monetary cost of auto-oriented modes. The model will capture all these behavioral changes for the commuters of each workplace zone. In addition, the model will simulate the changes in residential locations induced by increases in the expected cost of commuting and shopping travel.

Clearly, after the auto cost increase, zones which are better served by transit and zones which are within walking distance of shopping destinations, or accessible to such destinations by transit, will become more attractive and thus receive more trips. Housing values and rents in such zones will increase while rents and values in zones which are more auto dependent will decrease.

Compared to the station closing policy, which is expected to have spatially limited impacts on several zones in the immediate vicinity of the station, the across-the-board increase in the cost of auto travel can be expected to have changes in rents and values which are felt throughout the metropolitan area. It is a strength of the model that it is designed to evaluate both micro level and across-the-board type changes, although the relative accuracy of these two types of uses remain to be evaluated with careful empirical implementation of the model in the future.

Data Needs and Outputs of NYREG

We now describe the data needs of the unified regional equilibrium simulation model which is capable of predicting the effects of multimodal transportation improvements on residential and commercial real estate prices. The model is designed so that it can be easily applied to any metropolitan area for which the usual Census and travel data are available for a system of land use zones with sufficient geographic detail.

Three aspects of the model's development are documented in the following section:

o A unified microeconomic formulation of the mode choice, residential location and shopping destination choices of travelers is developed.

o Equilibrium rent determination in the markets for residential and commercial real estate is modeled, allowing for a spatially disaggregated representation of these markets.

o The design of an algorithm for solving the model on the computer is presented.

In this section, it will be useful to describe the model in two different ways. First, we will enumerate the model's input and output capabilities. Second, we will give two examples of how the model may be used to analyze a realistic transportation planning problem.

For purposes of describing the model, we will recall that an urban area is subdivided into a potentially large number of land use zones which are mutually exclusive and collectively exhaust the metropolitan land. A zone may be a Census tract, an aggregation of contiguous Census tracts, a traffic zone or some other geographic delineation. The generic term "zone" will be used for clarity.

On the input side, the model must be provided with the following data:

o A matrix of zone to zone travel times and travel costs for each relevant travel mode and for peak and off-peak travel periods.[1] It is assumed that these zone to zone travel times and costs can be generated outside the model from changes in the transportation networks, using TRANSCAD software or other comparable procedures. Some examples of changes in transportation networks which can create new travel times and travel costs are actions such as the opening or closing of transit stations, bus reroutings, changes in headways of buses and trains, and changes in gasoline prices or changes in transit fares.

o The number of existing housing units by type (i.e. single family houses, apartments in multifamily buildings, and the like) in each zone.

o Recent real estate sales prices for the market value of

[1] Although the model is designed to accept both travel time and travel cost inputs, NYREG is currently calibrated on travel time differences by mode, with travel cost set equal to zero. Although subway travel costs can be assumed to be flat in the New York Metropolitan Area, auto travel cost differerences are considerable and would bias model results if similarly assumed flat. Further model development will focus on calibrating NYREG by travel cost, as well as travel time, differences by mode.

residential property.

o The jobs by number of people who work in each zone, and the resident workers by number of employed persons who reside in each zone.

o The average income of the workers who work in a zone for each zone.

o The quantity of shopping and other commercial floor space in each zone.

o Recent real estate sales prices for the market value of commercial property.

o A vector of housing, neighborhood and socioeconomic attributes which measure the residential attractiveness of each zone. These attributes may include the sizes of houses in each zone, the housing age distribution, the income composition of the zone's residents in recent years, the distance from the zone to key metropolitan facilities and amenities such as waterfronts and parks.

o A set of parameters and coefficients, the values of which are determined in model estimation.

The procedure for compiling data sets, including the computer programs developed to perform data preparation tasks and the form of the model's final geographic disaggregation, are discussed in Appendix A.

On the output side, the model produces the following results:

o The number of commutes from the workplaces in each zone to the residences in each zone (e.g., the work-based origin-to-destination matrix, or the choices of residential location).

o The number of shopping trips from the residences in each zone to the commercial destinations in each zone.

o The number of occupied and vacant housing units in each zone.

o The rent per occupied housing unit in each zone.

o The rent per square foot of commercial floor space in each zone.

o The aggregate value of commercial and residential rent.

o The aggregate value of consumer surplus change in the population (taking into account the imputed changes in travel times and costs and the induced changes in the equilibrium rents reflecting the modal split, residential location, and shopping travel adjustments).

o The aggregate value of the <u>producer surplus change</u> (real estate operating profits from increased sales or rents, fully capitalized as increases in land value) accruing to the owners of residential and commercial real estate.

How NYREG is Designed

The fact that NYREG is a microeconomic model has three specific meanings for its design. First, it means that appropriate attention has been given to the behavior of travelers and households whose income, costs, prices and utility functions are modeled in a way compatible with modern microeconomic analysis. Second, it means that NYREG has a clearly defined demand side as well as a supply side. Finally, the microeconomic nature of the model means that equilibrium adjustments are computed by simulating the action of market prices which are determined so as to balance demands with supplies in the relevant dimensions. This requires more than 800 simultaneous equations which must be solved jointly in order to find the equilibrium prices (such as rents of various housing submarkets). From these equilibrium rents all other needed equilibrium outputs and benefit measures are directly computed.

The demand side of NYREG is designed as a unified model of the joint decision to choose a residence zone, a mode of travel for the daily commute from the fixed work zone to the chosen residence zone, and the number, destinations, and modes of an annual package of shopping trips originating at the chosen residential zone. The model is based on an appropriate view of the household as a decision making unit and allows (by means of an approximating assumption) for the presence of multiple workers in a household. The model follows the discrete choice approach in order to derive a satisfactory probabilistic formulation of household behavior as well as to insure computational feasibility.[2]

The supply side of NYREG is considerably simpler than the demand side primarily because supply side data are more limited. First, supply side adjustments are limited to the behavior of the owners of existing housing and commercial floor space. The possible construction or demolition of housing and commercial space in response to changes in prices and rents is not modeled. Hence, the supply function models the short run response of residential and commercial space generating a utilization rate for existing

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[2] The theoretical, empirical and computational advantages of using discrete choice formulations in the development of urban models has been documented in detail in Anas (1982) and are, therefore, not discussed here.

floor space at equilibrium. In the case of the housing market, the utilization rate takes the form of vacant housing units at equilibrium which is directly measurable by data on vacant units. In the case of the commercial market, the underutilization rate is implicit and an explicit vacancy rate cannot be generated, since vacancy information are not uniformly available for commercial floor space.

The Model Formulation

In the following presentation of the equilibrium set of equations, the basic notation used to define the dimensions of household choices are first described. Lower case letters stand for subscripts, while upper case letters stand for the highest values the subscripts can obtain.

$i = 1 \ldots I$: denotes an employment zone (i.e., a zone in which some employment is located).

$j = 1 \ldots J$: denotes a residential zone (i.e., a zone in which some housing is available).

$k = 1 \ldots K$: denotes the housing types which are available in the residential zone j.

$m = 1 \ldots M$: denotes the modes of travel available for commuting between a zone of residence j and a zone of employment i.

$l = 1 \ldots L$: denotes a shopping zone where commercial real estate provides shopping opportunities.

$n = 1 \ldots N$: denotes the modes of travel available for shopping between every residential zone j and shopping zone l.

It will be convenient to refer more briefly to the triplet (j,k,m) as "a residential choice" and to the pair (l,n) as "a shopping choice".

For clarity in exposition, we will present the model equations by assuming that the household has only one working member. Subsequently, we will make adaptations to deal approximately with the presence of multiple workers per household.

The utility of the household is specified as follows for each jkm;i:

$$U_{jkm;i}=\sum_l\sum_n\alpha_l \ln(X_{ln;ijkm})+\beta w_{jk}+D_{jkm;i}+u_{jkm;i}\ ,\quad \forall\ i,j,k,m \tag{1}$$

where,

$$\alpha_l>0 \text{ for each } l=1,\ldots,L,\ \beta>0 \text{ and } \beta+\sum_l\alpha_l=1. \tag{1'}$$

The $u_{jkm;i}$'s stand for idiosyncratic utilities which vary among households for each residential choice conditional on each employment zone i. The $D_{jkm;i}$'s measure systematic fixed effects for each residential choice for workers employed at i. The w_{jk}'s stand for the subutility function of exogenous attributes of the housing type k and the residential zone j. The $X_{ln;ijkm}$'s are the number of shopping trips per year made to the shopping zone l via mode n, by a household employed at i and choosing (j,k,m).

The above utility function incorporates two crucial assumptions. First, that the utility derived from shopping in a particular destination is a function of the number of shopping trips made to that destination. It would be more appropriate to assume that households do not derive utility from the number of shopping trips per se, but from the quantity of goods and services they purchase on those trips. However, if the demand for the quantity purchased per trip is inelastic, then it is easy to show that the utility derived from shopping at a destination can be measured by the number of trips made to that destination. Second, the fact that shopping trips to different destinations enter the utility separately (instead of being summed together) implies the treatment of alternative shopping destinations as differentiated "goods".

The household's workplace i is given and remains fixed. Given the workplace, the household evaluates each residential choice (j,k,m), and for each such potential choice decides how many shopping trips it will make to each shopping destination and by each of the available modes if that (j,k,m) were actually chosen. To make this nested decision, the household must consider maximizing its utility with respect to the annual shopping trip distribution given by the $X_{ln;ijkm}$'s (of which there are LN), given the annual budget constraint. We specify the household's budget constraint as follows for each ijkm:

$$By_i-R_{jk}-AG_{ijm}-\sum_l\sum_n g_{ijln}X_{ln;ijkm}=0,\quad \forall\ i,j,k,l,m,n \tag{2}$$

Here, By_i is the annual generalized income of the single-worker household employed in zone i, where y_i is monetary income. Generalized income is defined as the sum of monetary income plus the value of the portion of the total discretionary time which can be allocated between commuting, shopping travel, and leisure. B (>1) is the assumed ratio of annual generalized income to annual monetary income. R_{jk} is the annual housing rent (or rent-equivalent owner-occupancy cost) per dwelling unit of type k in zone j. A is two times the given number of work days per year, G_{ijm} is the generalized cost of commuting (money travel cost plus the value of time spent on commuting) per one-way trip, and g_{ijln} is the generalized income expended per shopping trip.

These two generalized cost functions are given by:

$$G_{ijm}=C_{ijm}+\Delta\frac{y_i}{240A}T_{ijm},\quad \forall\ i,j,m \tag{3}$$

and,

$$g_{ijln}=z+2c_{jln}+2\Delta\frac{y_i}{240A}t_{jln},\quad \forall\ i,j,l,n \tag{4}$$

In these equations, c_{ijm} is the money cost of a single commute from workplace i to residence zone j via mode m, and T_{ijm} (or t_{jln}) is the one-way time it takes in minutes to make such a commute (or shopping trip) with Δ, the ratio of the value of time per minute in commuting to the wage rate per minute. To obtain the constant 240, multiply 8 (the assumed number of working hours per day) by 60 minutes per hour and then divide this product by 2. 240A is the total number of minutes spent working annually and $y_i/240A$ is "income per minute of work".

The shopping trip expenditure function, g_{ijln}, is defined to include not only the generalized travel cost of a shopping trip but also the money spent to buy goods and services on that trip. The constant z stands for the shopping purchases per trip, reflecting our assumption that the quantity purchased per trip and the unit price of the composite good are constant.[3] c_{jln} is the monetary cost of a shopping trip and t_{jln} is the travel time.

As is well known, the utility function (1) with the restriction on its coefficients (1') results in demand functions for shopping trips such that each household expends a share

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[3] This assumption can be relaxed by allowing z to vary by l. In the present study we do not have data on shopping expenditures that would allow us to calibrate the value of z_l for each l.

$N\alpha_l/(1-\beta)$ of its net (generalized) income (after rent and commuting), on shopping trips to destination l and a share β of its income on rent and commuting. Because of the restriction (1'), these shares sum to one and exhaust the household's available income. The household's derived demand for the number of shopping trips to zone l via mode n (given workplace i and the residential choice (j,k,m)) is then given by:

$$X^*_{ln;ijkm}=\frac{\alpha_l(By_i-R_{jk}-AG_{ijm})(1-\beta)^{-1}}{g_{ijln}}, \text{ for each } (l,n) \tag{5}$$

As apparent from equation (5), the number of shopping trips (l,n) decreases as each such shopping trip becomes more costly (i.e., as g_{ijln} increases), generating a substitution effect in favor of other (l,n). An income effect occurs as the household becomes poorer due to increases in housing rent or commuting cost which decrease the household's purchasing power available for shopping trips. A problem remains in the specification of the utility function. Note that the expenditure shares (α_l's) are l-specific. Hence, there are too many parameters. To reduce the number of parameters and make their estimation manageable, a well-established notion is adapted from a tradition of retail trade models developed in the 1960s [Lakshmanan and Hansen (1965) and Huff (1964)]. The notion is that purchasing power expended at a particular shopping zone is proportional to a suitable function of that zone's shopping floor space.

For purposes of NYREG, the expenditure shares are specified by the following function:

$$\alpha_l=(1-\beta)N^{-1}\frac{F_l^{\omega}\exp(K_l)}{\sum_x F_x^{\omega}\exp(K_x)}, \quad \forall\, l \tag{6}$$

Here, F_l is the aggregate shopping floor space available in the lth shopping zone and ω is a parameter to be estimated. The exponent K_l measures attributes of the zone other than its floor space which play a role in attracting shopping expenditures. It is reasonable to expect that $\omega > 0$. This reflects an agglomeration (or size) effect in favor of larger shopping zones. An interpretation might be that a shopping concentration confers external benefits of comparison shopping and variety. With $\omega > 0$, the model hypothesizes that shoppers spend more money per square foot of shopping space in larger shopping zones than they do in smaller ones. Seemingly, we have not economized on parameters because we have replaced the α_l's with the new K_l's. However, as we shall see, the K_l's are easy to calibrate, while the ω helps relate the α_l's to the sizes of the shopping zones.

The next step is to plug the optimal trip frequencies given by (5) into the utility function (1), and obtain the indirect (optimized) utility function for each (j,k,m), given each i:

$$V_{jkm;l} = (1-\beta)\ln(By_i - R_{jk} - AG_{ijm}) - \sum_i\sum_n \alpha_l \ln(g_{ijln}) + \beta w_{jk} + D_{jkm;i} + u_{jkm;i}, \tag{7}$$

$$\forall\, j,k,l,m$$

The final step describes the way in which households are distributed among the residential bundles (j,k,m) given their workplaces i by means of a logit model. The logit probabilities are:

$$P_{jkm;i} = (H_{jk})^c \frac{\exp(\delta_i E[V_{jkm;i}])}{\sum_{rxs} (H_{rx})^c \exp(\delta_i E[V_{rxs;i}]) + \exp(\delta_i U_o)}, \quad \forall\, i,j,k,m \tag{8}$$

and,

$$P_{o;i} = \frac{\exp(\delta_i U_o)}{\sum_{rxs} (H_{rx})^c \exp(\delta_i E[V_{rxs;i}) + \exp(\delta_i U_o)}, \quad \forall\, i$$

where U_o is an exogenous utility level for residential choices outside the study area (to be represented by a peripheral superzone o).

The probabilities sum to one over (j,k,m) plus o for each i. H_{jk} is the stock of type k housing units in zone j. The δ_i measure the degree of idiosyncratic taste homogeneity among households employed at i. As δ_i approaches infinity, all households employed at i are identical in idiosyncratic tastes and choose the same residential choice (j,k,m). As δ_i approaches zero, all households are extremely heterogeneous and all alternatives have an equal probability of being chosen. 1-c measures the degree of correlation in the idiosyncratic utilities attributed to the H_{jk} dwellings in the same (j,k,m). If these dwellings are totally uncorrelated in the idiosyncratic utilities households attach to them, then c = 1. Otherwise, if c = 0, dwellings in the same (j,k,m) are identical and function as perfect substitutes.

The logit model given by (8) has the property that alternative residential choices are gross substitutes (i.e., as the rent of choice (j,k,m) increases, keeping all else constant, the probability of choosing (j,k,m) does not increase and the probability of choosing every (r,x,s) not equal to (j,k,m) does not decrease).

The model was set up under the presumption that each household had a single worker. To deal with multiple working members, in order to express the relationship on a per worker basis, the budget constraint is adjusted so that it represents a budget per working member in the household, assuming that working members share equally in income, rent and shopping expenditures. Hence,

$$By_i-\theta_j R_{jk}-AG_{ijm}-\theta_j\sum_l\sum_n g_{ijln}X_{ln;ijkm}=0,\quad \forall\ i,j,k,m \tag{2'}$$

θ_j is the number of household residents of zone j divided by the number of workers resident in zone j. If y_i is measured as the income of the worker, then the function is a budget constraint prorated to each working member in a household. Dividing (2') through by θ_j, it is put in a form similar to (2), except that the values of income and commuting cost in (2) have been divided by θ_j. Hence,

$$By_{ij}-R_{jk}-AG'_{ijm}-\sum_l\sum_n g_{ijln}X_{ln;ijkm}=0,\quad \forall\ i,j,k,m \tag{2''}$$

where $y_{ij} = y_i/\theta_j$ and $G'_{ijm} = G_{ijm}/\theta_j$. Previously stated equations are readusted to reflect these definitions.[4]

We now turn to the formulation of the equilibrium system of equations of the model. Suppose that O_i is the number of workers employed in zone i. Then, at equilibrium, the number of households choosing housing type k in residential zone j should equal the number of occupied dwellings of type k in residential zone j. This is expressed for each (j,k) by

$$\theta_j\sum_i\sum_m O_i P_{jkm;i}-q_{jk}H_{jk}=0,\quad \textit{for each } (j,k) \tag{9}$$

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[4] The data does not allow us to model the travel of <u>each</u> working member in a household. Also, the Census data gives the value of θ by place of residence j, not by place of work i.

where the choice probabilities are given by (8) and where q_{jk} is the share of dwellings that are offered for rental (or sale). As in CATLAS, this share is specified to be an increasing function of rent and given by a binary logit model. Hence,

$$q_{jk}=\frac{\exp\lambda\,(R_{jk}-d_{jk})}{[1+\exp\lambda\,(R_{jk}-d_{jk})]},\quad \textit{for each } (j,k) \tag{10}$$

where $\lambda > 0$ is the coefficient of rent and the d_{jk}'s are fixed effects to be calibrated as proxies for the differential cost of renting versus keeping vacant housing units of type k in residential zone j. The equalities (9) for each (j,k) are held by the equilibrating action of rents. Solving these equations simultaneously for the JK rent vector of R_{jk}^{*}'s determines equilibrium rents.

To ensure equilibrium in the shopping market, the total number of shopping trips arriving at a shopping zone l must be accomodated by a correspondingly intensive use of shopping floor space. Hence, an increase in the demand for shopping in zone l should result in a higher shopping rent, r_l, per square foot of shopping space in that zone l. Letting, $S_l(r_l)$ be the rate of shopping space utilization (an increasing function of r_l), demand and supply equilibrate as follows in each zone l:

$$\sum_{ijkmn}\left[\theta_j O_j P_{jkm;i} X^{*}_{ln;ijkm}\right]-S_l(r_l)\,F_l=0,\quad \forall\ l \tag{11}$$

where F_l is the quantity of floor space in zone l. The summation is the total number of shopping trips arriving at shopping zone l. By specifying the function $S_l(r_l)$ as $B_l r_l^{\rho}$, $\rho > 0$, the equilibrium shopping rents are obtained explicitly as:

$$r_l^{*}=\left(\sum_{ijkmn}\frac{\left[\theta_j O_j P_{jkm;i} X^{*}_{ln;ijkm}\right]}{B_l F_l}\right)^{1/\rho},\quad \forall\ l \tag{12}$$

Once equilibrium is obtained, we can calculate the aggregate consumer surplus of households using the technique discussed in Small and Rosen (1981). In NYREG's case, the consumer surplus will be approximate because the marginal utility of income, μ, is not constant. Calculated at the equilibrium, the weighted average marginal utility of income is as follows for workplace i:

$$\mu_i = (1-\beta) B \sum_{jkm} \frac{P_{jkm;i}}{\theta_j (By_{ij} - R_{jk} - AG'_{ijm})}, \quad \forall\ i. \tag{13}$$

Then, the aggregate consumer surplus measure is:

$$CS = \sum_i \frac{O_i}{\mu_i \delta_i} \ln\Big(\sum_{rxs} (H_{rx})^{c} \exp(\delta_i E[V_{rxs}]) + \exp(\delta_i U_o)\Big) \tag{14}$$

The aggregate producer's surplus (increased land value or profit) accruing to the owners of housing is similarly calculated as:

$$PS_1 = \sum_j \sum_k \frac{H_{jk}}{\lambda} \ln[1 + \exp\lambda (R_{jk} - d_{jk})], \quad \forall\ l \tag{15}$$

The aggregate producer's surplus accruing to the owners of commercial floor space is obtained by integrating over the function $S_l(r_l)$ and summing over each l:

$$PS_2 = \frac{1}{1+\rho} \sum_l F_l B_l (r_l^*)^{\rho+1} \tag{15'}$$

Types of Simulations

Two types of simulations can be conducted with NYREG. The first kind will be referred to as a Base Run and the second kind as a Policy Run. A Base Run determines an equilibrium under a set of calibrated coefficients and input data values. These can be the observed input data values or input data values appropriate to a future point in time or to alternative assumptions about the distribution of jobs, the housing stock, or characteristics of the transport network.

Once a Base Run is established, a Policy Run can be conducted by changing the transport network characteristics (and therefore, the travel times and costs of any one or several of the five modes) and then determining a new equilibrium. Comparison of the Policy Run result with the Base Run result allows computation of the benefits to the users of the transport system (consumer surplus) and of the benefits to property owners in property value increases by land use type (producer surplus). In addition, changes in mode splits, in vacancies, in residential location patterns and in shopping trip patterns are also computed.

Chapter 5 of this Handbook provides illustrative applications of NYREG to eight policy related simulations. The model outputs are presented in extensive detail.

Data Aggregation and Calibration of NYREG's Coefficients

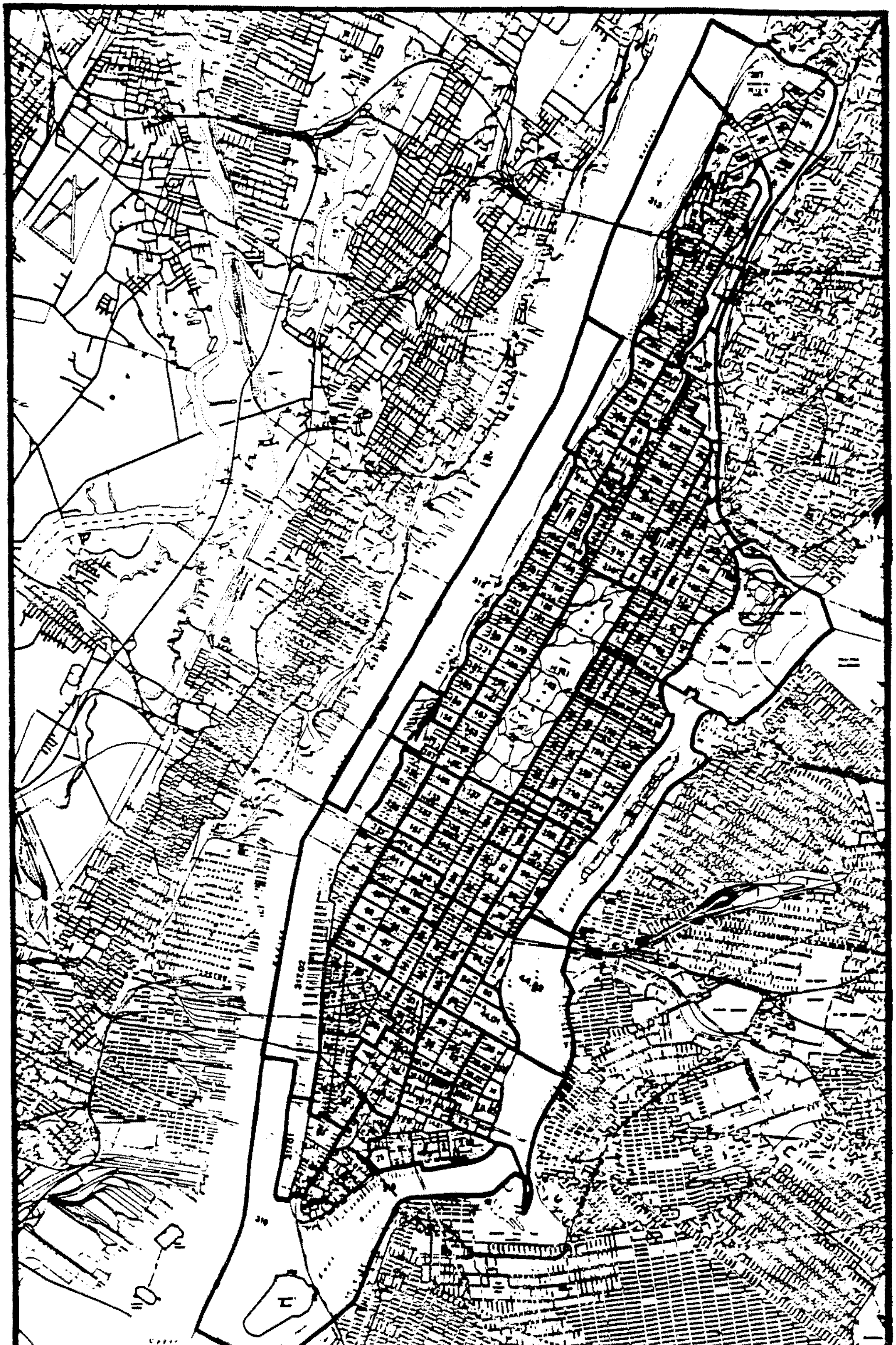
There are many levels of aggregation at which model zones may be defined. Zones may be city blocks, census tracts, groups of census tracts, zip code areas, counties, or even entire states. The definition of NYREG's super zones in New York City and their correspondence with census tracts is presented in a series of maps (Figures 2.1, 2.2, 2.3, and 2.4) and is shown in Table 2.1.

Table 2.1 Aggregation of Zones in NYREG

Area	Tract	SPZN	CTTS	Work	Home	Shop
Manhattan	300	43	25	299	299	25
Queens	671	40	8	40	40	8
Brooklyn	790	67	8	67	67	8
Bronx	356	42	5	42	42	5
Suburbs	-	-	-	5	5	5
Periphery	-	-	-	1	1	1
Total	2117	192	46	454	454	52

Note: Tract: Census Tract; SPZN: Super Zone; CTTS: Comprehensive Telephone Travel Survey Zones.

In Manhattan, zones were defined as census tracts, while in the Bronx, Brooklyn, and Queens, zones were defined as aggregations of contiguous tracts called "super zones". Still larger tract aggregations were used to define the shopping zones in Manhattan, the Bronx, Brooklyn, and Queens. These groupings are based on the geography defined by the MTA's Comprehensive Telephone Travel Survey which provided shopping trip characteristics for NYREG's calibration. Richmond (Staten Island) and four suburban counties (Bergen, Putnam, Rockland and Westchester) were included as whole counties, or giant zones, for jobs, residence and shopping. All remaining areas in New York, including Long Island, in New Jersey and in Connecticut were aggregated into one larger peripheral super zone.

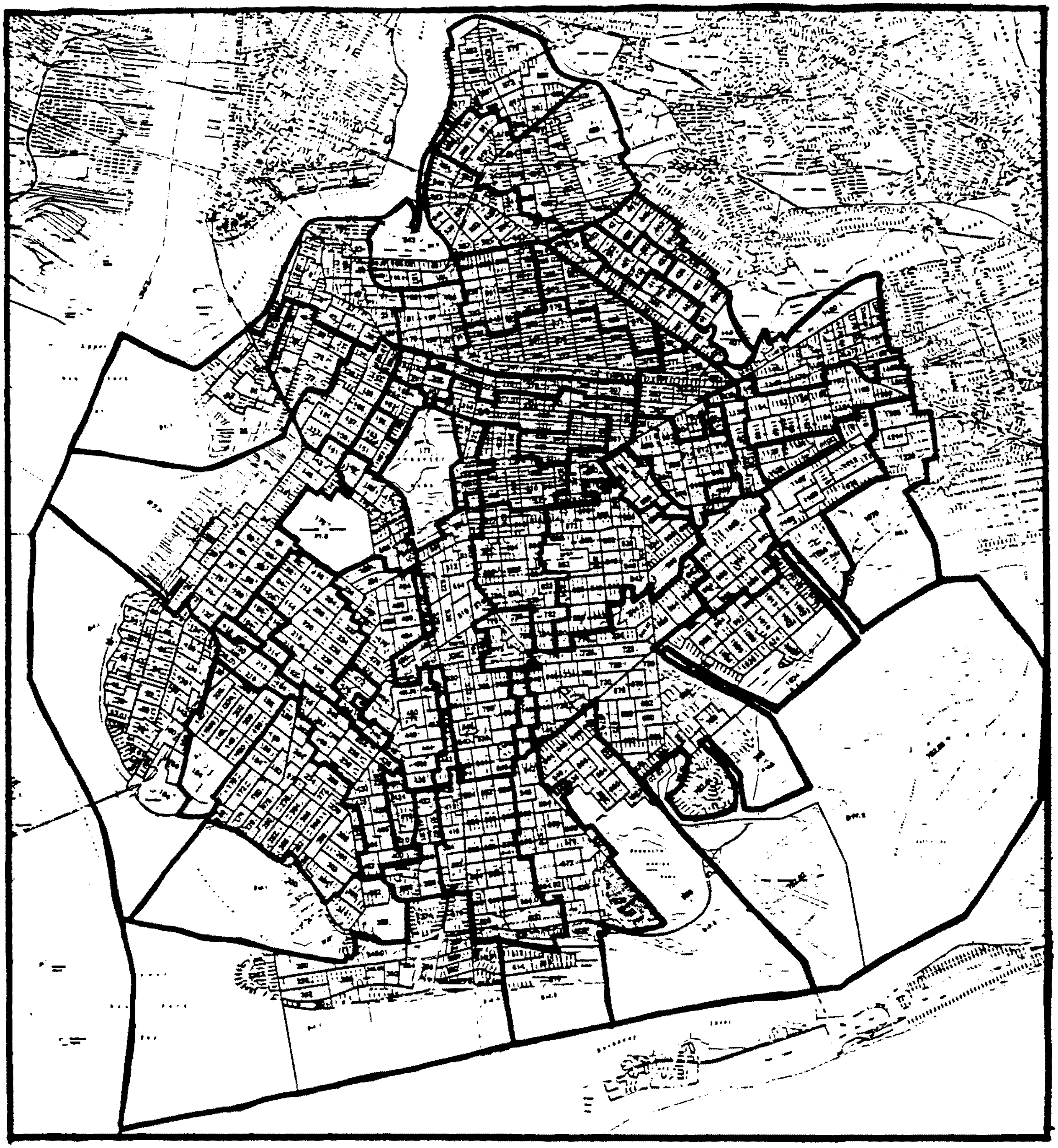


The Manhattan Census Tracts and Super Zones Map
(Each Census Tract is a Model Zone)

Figure 2.1

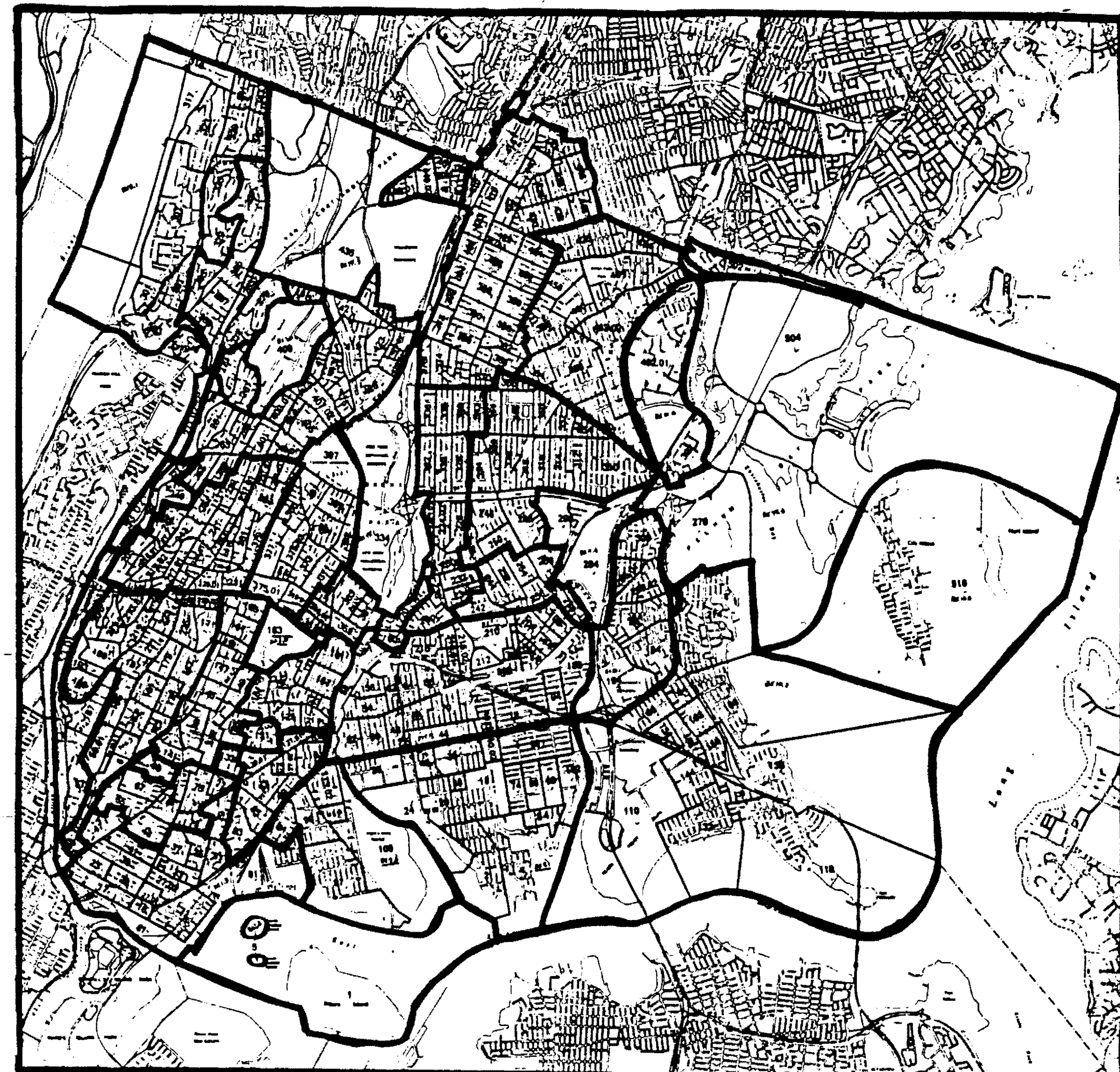
The Queens Census Tracts and Super Zones Map
(Each Super Zone is a Model Zone)

Figure 2.2



The Brooklyn Census Tracts and Super Zones Map
(Each Super Zone is a Model Zone)

Figure 2.3



The Bronx Census Tracts and Super Zones Map
(Each Super Zone is a Model Zone)

Figure 2.4

This aggregation resulted in 454 zones for residence and employment, and in 52 larger zones covering the same area for commerce or shopping. In addition, NYREG has three housing types. Hence:

- o employment zones I = residential zones J = 454,
- o shopping zones L = 52,
- o single family units k = 1,
- o condominiums and cooperatives k = 2, and
- o rental apartments k = 3.

In Manhattan, single family units are less than one percent of stock. Hence, condominiums and cooperatives and single family units were aggregated in Manhattan. Nearly all zones outside of Manhattan contained each of the three housing types. In the five suburban zones, condominiums and cooperatives were aggregated with apartments as multifamily housing.[5] The peripheral super zone was treated as a zone (with a fixed utility level) for which an equilibrium rent is not determined. Households employed within the study area can choose to reside in this zone. Hence, the study area is open with some households working within the four boroughs and the five suburban zones and choosing the peripheral super zone.[6]

Travel mode choices reported for commuters in the <u>1980 Census</u> were aggregated into five modes, as shown in Table 2.2. The zone to zone travel times of the commuting population were calculated as the averages of the reported times from the 1980 Census. These times were assumed to hold in both peak and off-peak periods. For shopping travel, all modes other than auto are aggregated into one mode, called "other".

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[5] The housing stock of each zone was decremented by the stock which is occupied by households working in the peripheral zone. Single family and multifamily housing remaining after this decrementing was assumed to be in the same proportion as the stock of the entire suburban county. The vacancy rate for the included stock was assumed to be the same as the vacancy rate of the county as a whole.

[6] The definition of the peripheral super zone is not entirely satisfactory. It includes areas of Connecticut, New Jersey, and Nassau County, Long Island, which are too close to the centrally located four boroughs to be classified as peripheral. Further model development will address this problem.

Table 2.2 Aggregation of Census Travel Modes into NYREG Modes

- ALL
  - 1. Auto
    - Drive Alone
    - Shared Ride (Car pool)
      - 2 person SR
      - 3 person SR
      - 4 person SR
    - Taxi
  - 2. Bus
  - 3. Rail
  - 4. Subway/Elevated
  - 5. Walk +
    - Walk
    - Bicycle
    - Motor Cycle
    - Other
    - Worked at Home

The model's coefficients were calibrated by means of a sequential procedure. The first step is to estimate a regression which is the log form of the shopping intensity function:

$$\ln(S_l)=\ln(B)+\rho\ln(r_l) \quad (16)$$

The shopping density is observed as $S_l = \Sigma_{jn} (ST_{jln})/F_l$, where ST_{jln} is the matrix of shopping trips from each j to each shopping zone l by each mode n. This estimation gives ρ=0.49866. The slope coefficient is then adjusted for each l so that the observed shopping density in each l is perfectly predicted. This defines the coefficients $B_l = S_l/(r_l^*)^{\rho}$.

In the second step, the rents of housing are estimated. Because census data do not give rents by housing type, sales data obtained from the tax assessor were used. Then, the average sales prices for each (j,k) were used to estimate the housing rent in that zone. For this, it was assumed that rents, R_{jk}, are related to housing values, W_{jk}, as follows: $R_{jk} = a_k(W_{jk})^b$. The value of b was set somewhere between zero and one, and each a_k was calibrated by minimizing a least squares function so that "on average" households spend 25% of their disposable income after commuting on housing. This assumption, in turn, means that the utility coefficient β = 0.25. In doing this, it is also assumed that B = 1.5. This means that workers have an extra time endowment per day of four hours for extra potential income. The minimization is:

$$Minimize_{a_k} \sum_{ijm}[a_k(W_{jk})^{b}-\beta(1.5y_{ij}-AG'_{ijm})]^2 \tag{17}$$

By trial and error, b = 0.3 gives a good result. A = 500, by the assumption that there are 250 working days in a year. Minimizing, we find a_1 = 177.81, a_2 = 144.26, a_3 = 207.17 for single family, condominiums and cooperatives, and rental apartments respectively.

In the third step, the occupancy model given by (10) is calibrated. This is done by using evidence from CATLAS [see Anas and Duann (1985)] where it was estimated that a 1% increase in a zone's average rent resulted in a 0.24% increase in the occupied housing supply of that zone.[7] Thus, the weighted average rent elasticity of housing supply is set at 0.24 and λ is computed as:

$$\lambda=0.24\frac{\sum_{jk}H_{jk}Y_{jk}}{\sum_{jk}R_{jk}(1-Y_{jk})H_{jk}Y_{jk}} \tag{18}$$

where Y_{jk} denotes the observed housing occupancy rate in each housing submarket (j,k) and is calculated by dividing the number of households residing in zone j with the total housing stock in zone j. This gives λ = 0.00118785. Then, the dummy variables d_{jk}, in (5) are calculated as follows:

$$d_{jk}=\lambda R_{jk}-\ln\left(\frac{Y_{jk}}{1-Y_{jk}}\right), \quad for\ each\ (j,k) \tag{19}$$

In the fourth step, the shopping expenditure per trip, z, is calibrated, together with ω, the exponent of floor space in the definition of the α_l's. First, set z = 0 and all K_l = 0, and calibrate ω by means of a least squares procedure. Note that given z and ω, the predicted shopping trips arriving at zone l are:

[7] Although this number was obtained for Chicago, since then the occupancy model has also been estimated for Pittsburgh, Houston and San Diego with highly similar results. Still, it is important to calibrate this model more thoroughly in the future for each of the New York boroughs.

$$STP_l(z,\omega)=\frac{\exp(\omega\ln(F_l)+\mathbf{K}_l)\,Z_l}{N\sum_s \exp(\omega\ln(F_s)+\mathbf{K}_s)}, \tag{20}$$

$$\text{where } Z_l=\sum_{ijkmn}\theta_j O_j P_{jkm;i}\frac{By_{ij}-R_{jk}-AG'_{ijm}}{g_{ijln}}, \quad \forall\ l$$

Hence,

$$Min_{\omega}\ \sum_l [STO_l-STP_l(z,\omega)]^2 \tag{21}$$

where STO_l is the observed shopping trips arriving at l. In the outer stage, κ (in equation (4)) is chosen so that (with all K_l = 0) it satisfies the constraint that the error in the predicted shopping trips is within 2% of the sum of observing trips:

$$\left|\sum_l STO_l-STP_l(\kappa,\omega)\right|<0.02\sum_l STO_l \tag{22}$$

If the above constraint is satisfied, then the desired z and ω have been found. Otherwise, z is adjusted by a Newton-Raphson technique and the procedure goes again to the inner stage for the next iteration, given this new value of z. The calibrated values are: ω = 0.483929 and z = $16.52. Next, the values of the shopping dummies, K_l's, are set for each l in such a way that observed shopping trips to that zone are replicated (one K_L is arbitrary and is set equal to zero). All other K_l's are then computed so that STO_l = STP_l for each l.

$$\mathbf{K}_l=\ln\left(\frac{STO_l Z_L}{STO_L Z_l}\right)-\omega\ln\left(\frac{F_l}{F_L}\right), \quad \forall\ l \tag{23}$$

In the fifth and final step, the utility coefficients are calibrated. First, set $\delta_i = \delta$ for each i. Then, set c = 1. Hence, the problem reduces to estimating δ and the coefficients of the housing subutility w_{jk}. The attributes included in the subutility function are the logarithm of the average floor space per dwelling in j, the percentage of the housing stock built after 1960, the percent black and Hispanic households, and dummy variables for Manhattan, Queens, Brooklyn, and the Bronx. The likelihood function which is maximized is of the form:[8]

$$Maximize_{\{\delta,c,\phi\}} \sum_{ijm} O_{ijm} \frac{H_{jk}}{\sum_s H_{js}} \ln(P_{jkm;i}(\delta,\phi_1,\ldots,\phi_5)) \tag{24}$$

Finally, the values of the alternative specific dummies, $D_{jkm;i}$, are calculated so that predicted choice probabilities equal observed relative frequencies of choice, $Q_{jkm;i}$.[9] This is done for each jkm;i given an arbitrary reference choice rxs;i:

$$D_{jkm;i}=\ln\left(\frac{Q_{jkm;i}}{Q_{rxs;i}}\right)-\delta(E[V_{jkm;i}]-E[V_{rxs;i}])-c\ln\left(\frac{H_{jk}}{H_{rx}}\right), \quad \forall i,j,k,m \tag{25}$$

Selection of the Solution Algorithm and Calibration Results

The main step in solving the model is the determination of the residential rents by housing type k and zone j. This is done by solving simultaneously for the R_{jk}'s the system of nonlinear simultaneous equations given by (11). Then, shopping rents are computed from (12).

To solve (9), two techniques have been developed and experimented with, and one has been adopted. The first technique used the simultaneous equation solver MINPACK which employs a hybrid Newton-Raphson type method based on the computation of the full Jacobian matrix of (11). MINPACK evaluates the Jacobian, not by analytical derivatives but, by numerically approximated

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8 Because the data gives choices by j and m but not by housing type, it will be assumed in the likelihood function that the observed choices O_{ijm} are divided among the housing types in j according to the proportion of that housing type in that zone.

9 The values of the utilities $U_{o;i}$ are calibrated in such a way that the predicted number of commuters working in i and choosing the peripheral super zone is equal to the observed number.

derivatives.[10]

The second technique is a Newton-Raphson procedure utilized in the computational solution of CATLAS and developed by Anas. This technique ignores the off-diagonal elements of the Jacobian in determining the step size at each iteration and evaluates the diagonal elements of the Jacobian matrix using analytical derivatives. It is easy to establish using either technique that the system of simultaneous equations at hand has a unique solution. This is done by starting from many highly different starting points and finding that convergence occurs to the same equilibrium point to within a very tightly defined tolerance.

MINPACK is potentially more accurate in determining the step size at each iteration, as long as the numerical approximation of the derivatives is not too crude. Hence, MINPACK may generally require a relatively small number of iterations. The CATLAS technique is potentially less accurate because it does not utilize the full Jacobian matrix. Hence, it may take a significantly larger number of iterations to find the equilibrium point.

However, it is not clear which technique is more accurate since it is possible that the numerical approximation of the derivatives (in MINPACK) is cruder than the approximation which results from neglecting the off-diagonal elements but accurately evaluating the diagonal elements (in CATLAS). Moreover, the cost of the CATLAS technique at each iteration is lower because the full Jacobian is not evaluated. When the number of simultaneous equations is sufficiently large, the cost saving from not having to evaluate the full Jacobian generally outweighs the cost saving from a potentially smaller number of iterations. As a result of this, the CATLAS technique is more appropriate for larger problems.

For purposes of NYREG, the CATLAS procedure has been adopted. The housing market part of the model has 847 equations which

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[10] The Jacobian matrix is evaluated by perturbing each element of the rent vector one at a time and evaluating the Jacobian matrix at each perturbation. For example, if there are n equations (hence, n rents), the first rent is perturbed by a small amount from its initial value and the effect of this rent perturbation on the elements of the Jacobian are evaluated (recall that the Jacobian is n X n). Following this, the second rent is perturbed etc. Thus, the needed computations are of the order of n-cubed. For example, if there are 400 equations, 64,000,000 computations are needed. With 1800 equations, 5,832,000,000 computations are needed. To avoid excessive computations, MINPACK does not reevaluate the Jacobian matrix at every iteration. This, together with the fact that the Jacobian evaluation is not analytical, contributes to the inaccuracy of the MINPACK search direction.

represent the JK submarkets in which the housing stock is positive.[11] According to the CATLAS procedure for large scale problems, the Jacobian matrix of (9) was obtained and set equal to zero on the off-diagonal elements. Then, using the diagonal elements, a Newton-Raphson procedure was applied to adjust the rent vector iteratively until converge occurred on the equilibrium. Various starting points are used for the housing rent vector. As long as rents are within 30% of the correct equilibrium values, the solution is obtained in seven or fewer iterations for housing market equilibrium.

Policy runs are faster than Base Runs because the starting point for convergence is the pre-policy equilibrium point and most reasonable policies do not deviate greatly from such an equilibrium. The convergence tolerance used in all runs was that the maximum absolute value percent deviation in rents be within 0.1% of the rent of the previous iteration and that demanded and occupied stocks in each (j.k) be within 0.1% of each other.

The estimated model's calibrated results are shown in Table 2.3. Predicted results for housing rents fit fairly well with rents computed from observed values by means of $R_{jk} = a_k(W_{jk})^b$. For single family housing, the average percentage error in average rent by zone (APE) is 16%, for condominiums it is 20.4%, and for rental apartments it is 14.6%. The model predicts, on average, that households spend 15.7% of potential income on commuting, 19.2% on housing rent, and 65.1% on shopping expenditures. The average percentage error in occupancy rates prior to the adjustment of the fixed effects is 4.8%. The average percentage error in shopping trips prior to the adjustment of the K_l's is 38.9%.

The travel time elasticity of housing demand is -0.367 on average, and the rent elasticity of housing demand is -0.363 on average.[12] Table 2.4 shows how these elasticities vary by income levels and with respect to commuting mode. Both elasticities are higher for the lowest income groups.

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[11] The total number of possible equations is 598 for Manhattan (2 housing types by 299 zones), 120 for Queens (3 housing types by 40 zones), 201 for Brooklyn (3 housing types by 67 zones), 126 for the Bronx (3 housing types by 42 zones) and ten for the suburban counties (2 housing types by 5 counties). Although this gives 1,055 possible zones, some zones have no housing of one or more types. Most such zones having only one housing type are in Manhattan.

[12] These elasticities are computed by changing the travel time or rent of a residential choice (j,k,m) by one percent, keeping all else constant, and then taking the weighted average of such elasticities across all the (j,k,m).

Table 2.3 Calibrated Values of NYREG Coefficients
(t-scores in parentheses)

$A = 500$	$B = 1.5$
$\beta = 0.25$	$\Delta = 1.8$
$\rho = 0.49866$	$\lambda = 0.00118785$
$k = \$\ 16.52$	$\omega = 0.483929$
$a_1 = 177.81$, $a_2 = 144.26$, $a_3 = 207.17$, $b=0.3$	
Dispersion Parameter	$\delta = 1.7208$ (1149.75)
Housing Stock	$\eta = 1.000$ (--)
ln(floor space)	0.02125 (6.03)
% Black & Hispanic Population	-0.00012 (-5.28)
% Housing Stock Built after 1960	0.94008 (50.17)
Manhattan	-0.6592 (-288.72)
Queens	0.1694 (103.70)
Brooklyn	0.1438 (82.03)
The Bronx	-0.0785 (-36.03)

Table 2.4 Time & Rent Elasticities of NYREG by Income & Mode

		Income Level			
	Hsg/Mode	<$11,000	$11-15,000	>$25,000	Average
Time	k=1	-0.843	-0.313	-0.479	
Elasticity	k=2	-1.177	-0.383	-0.303	-0.367
	k=3	-0.837	-0.371	-0.416	
Rent	k=1	-0.865	-0.316	-0.323	
Elasticity	k=2	-1.168	-0.420	-0.402	-0.363
	k=3	-0.827	-0.424	-0.398	
Time	Auto				-0.227
Elasticity	Bus				-0.479
	Rail				-0.832
	Transit				-0.591
	Walk/Oth				-0.100

Note: k=1: Single Family Homes; k=2: Condominiums & Cooperatives; k=3: Apartment Units.

CHAPTER THREE

DESIGN, ALGORITHM, COMPUTATIONAL REQUIREMENTS, AND APPLICATIONS OF NYSTA - A LINEAR REGRESSION MODEL OF TRANSIT STATION AREA LAND VALUE GRADIENTS

A station area model (NYSTA) has been designed and calibrated for the area served by the New York City subway system to predict parcel-specific changes in land value with transport improvements based upon a statistical explanation of the relative importance of access among the myriad locational attributes of a site that create its land value. NYSTA differs from NYREG, the regional equilibrium model, in that it utilizes multivariate regression analysis to determine the land value equations that are applied independently, without simultaneous feedback relationships, to solve for changes in property values, assuming an initiating change in transit policy or service affecting the neighborhood or corridor level.

Although the regression technique has acknowledged weaknesses at the regional scale, stemming from its inability to model separate shifts in demand and supply functions, at the local level hedonic regression relationships can confer benefits not available from large scale equilibrium models. For one, NYSTA couples a broader consideration of physical, transport, and socioeconomic variables with a finer grain geographic scale. Measures are computed at the parcel level by distance from a station or a line; not by broad zonal averages. As another benefit, NYSTA solves for changes in market values calibrated by actual real estate transactions, making the model's output more directly applicable to value capture tax administration policy. And then, again, transit inputs to the model that serve as policy or service-related levers are also calibrated on actual operating characteristics of the system, making simulations of transit alternatives for specific stations or corridors a viable management tool.

The model is designed in the tradition of locational studies concerned with access to an array of public services, including transit, highways, neighborhood parks, public beachfront, clean water and sewer services, and other open space. Analysis is focused on the parcel, rather than on the zone, as the basic unit of observation. The approach is cross-sectional, rather than time dimensional. It is more focused on explaining the impact on land value of differences in transit service quality among different transit stations, rather than the mere benefit of proximity to a station. As such, it provides the policy analyst with a tool for predicting the parcel-specific, neighborhoodwide, corridor level, or aggregate systemwide impact of alternative actions.

How NYSTA Relates to Literature and Historical Work

Extant studies of a multiple regression nature concerning the relationship of land value to access of public services, including transit, have varied greatly in complexity. In earlier years, a greater preponderance of studies were performed on property value impacts of interstate highway or urban expressway access. In more recent years, in addition to transit applications, multiple regression models have determined the land value impacts of access to urban parks and recreational areas. Various approaches with respect to transit and open space are summarized as illustrative of related work.

At the simplest level, study of the Philadelphia-Lindenwold High Speed Line by Boyce, Allen, Mudge, et. al. (1972) used statistical techniques to consider only one residential land use and one distance measure for a seven-year period of change in housing property values that occurred prior to, during and after contruction of a new commuter rapid transit line. The analysis, which compared results for the impact corridor with a control corridor, concluded that travel cost and time savings benefits of the Line were reflected in prices of single family houses in the impact corridor once the Line was in use, not in anticipation of its development.

At the intermediate level, the Washington, D.C. Metro study by Lerman, et. al. (1978), conducted over the period of the system's development, used multivariate regression analysis to consider three land use types (single family, multifamily, retail) and two distance variables (to the station and to the CBD), along with appropriate independent variables to explain urban property values. Major conclusions of the analysis were that distance to a station was a determinant of variation in parcel values in the District, although non-transit related variables exerted greater influence over real estate values. With proximity to the opening date of stations, parcel values tended to increase, and the study produced estimates of the impact of new stations on land value in advance of opening.

Subsequent to the Washington, D.C. Metro study, Ferguson (1984) empirically determined the impact of the Advanced Light Rapid Transit (ALRT) system under construction in Vancouver, British Columbia, on pre-service single family property values, using multiple regression analysis on real estate transactions in the corridor and a control area. Results showed that station locations affected housing values as much as three years prior to operation, and that the house-buying market was paying higher prices for homes closer to future stations. Other studies of new transit lines or systems, performed both before and after implementation, include Dewees' (1976) multivariate regression analysis of the impact on property values of replacing an existing streetcar service in Toronto with a subway line. Contrary to expectations, the major impact was determined to be a steepening in the property rent gradient with distance from the subway station, rather than a change in slope with distance along the corridor from the Toronto central business district.

Similar empirically-based, hedonic studies of externalities focus on producer and consumer benefits generated by access to open space. Among them, at the simplest level, Kitchen and Hendon (1967) utilized linear correlation analysis to demonstrate that distance of residential properties from a small neighborhood park in Lubbock, Texas, affected assessed land value inversely. More detailed multiple regression analysis by Weicher and Zerest (1972) analyzed sales prices of residential properties situated around five parks in Columbus, Ohio. Their study measured significant value differences when properties faced open space, but not backed onto parks or overlooked recreational facilities, though these positive externalities were not reflected in tax assessments.

At an intermediate level, Hammer <u>et. al.</u> (1974) computed the declining location rent for sixteen residential property types surrounding a large urban park in Philadelphia. From 40 to 2,500 feet from the park, the producer surplus was shown to decline from 33 percent of land value to less than 5 percent. By applying the value of these external benefits to all dwellings at corresponding distances, the aggregate value of location rent generated by the park was determined. At a somewhat more complex level of analysis, Sexton <u>et. al.</u> (1983) measured the <u>consumer surplus</u> of access to seven beachfront parks on Long Island by decomposing the estimation of consumer demand curves into allocation and generation components which separately valued the benefit of park access and the cost of attaining it. The resulting measure of net benefit was associated with trip origins at distance intervals from the parks to show the declining value of externality, while the economic value of each park was computed by comparing differences between the consumer surplus of all origin zones with the park open versus that with the park closed (based on recomputed travel costs to substitute parks).

What Questions Does NYSTA Address ?

The NYSTA model is concerned with determining the producer surplus or externality conferred on a range of property surrounding transit stations by the benefit of accessibility capitalized into the value of land. The land value benefit will differ by type of land and distance from the station given an array of differences in transit service, all other factors influencing the value of land having been explained.

Three areas of research inquiry relate to the equations that can be modeled using NYSTA methodology. These subject areas can be characterized as issues areas appropriate to the <u>neighborhood</u>

scale, the corridor scale, and to transit finance policy. Concerns at the neighborhood scale focus on the variation in land value with radial distance from a transit station, while concerns at the corridor scale address the variation in land value with travel time or distance from the region's business center, along an established transit corridor. Issues of transit finance policy are both more regional and generic in scale, encompassing as they do systemwide revenue implications from application of land value capture.

Some illustrative questions are posed for each issues area in the context of concerns pertinent to transport improvements in the New York Metropolitan Area. The reader is encouraged to come up with examples of his or her own making by keeping in mind the list of model inputs and outputs.

Neighborhood Scale

How much does proximity to a transit/commuter rail station influence the value of various classes of land? What is the detrimental influence of elevated structures? How far do these influences extend? What would be the benefit of removing the remaining 70 miles of elevated line in New York City and how much of the cost of replacing them could be paid from land-value increments?

Corridor Scale

How much land value will be generated by cutting a train ride, say, 5 minutes on a line with a particular passenger volume? To what extent can line extensions be warranted by increased land value? Do service attributes other than travel time and passenger volume - say, frequency, reliability, lack of crowding, new equipment - have a measurable impact on land value? If so, to what extent could improvements of this type be funded from increased land value?

Transit Finance Policy

What would be some of the consequences of shifting transit subsidies from the present system of general taxes to land value taxes? If all subsidies were funded by property in the service territory, what share of aggregate land value would they comprise? Which geographic areas would lose, which ones would gain, in what ways? Is it realistic to think of self-financing transit improvements from land value taxation? What would be implications for zoning and land development policy? Specifically, would land value capture around transit stations encourage greater density of development to shoulder the added tax burden?

Data Needs and Outputs of NYSTA

Questions posed for NYSTA framed the initial decisions taken regarding the scope of the study area, the appropriate dependent and independent variables, the analytical methodology, and the data sources and sampling adopted. We now describe the characteristics of the study area, and the data inputs and outputs of the model. Because of its geographic scale, range of densities and land use diversity, the study area contains some representation of nearly all development conditions surrounding rapid transit stations in the nation. As such, the model is designed so that it can be applied to any major urban area with a fixed route transit system for which comparable data can be obtained.

Study Area

Unlike predecessor studies, this study is concerned with an entire rapid transit system in full operation, not a particular line or system, before construction or just after implementation. This advantage is coupled with the dominance of the MTA's rapid transit and commuter rail system in the nation. Of some 983 subway stations nationwide, the New York City subway is comprised of 469 stations in four boroughs (Manhattan, Brooklyn, Queens, and the Bronx) and the Staten Island Rapid Transit (SIRT) of 22 stations in the remaining borough. In addition, the Long Island Rail Road and the Metro North Commuter Railroad, which operate 252 commuter rail stations of roughly one thousand in the nation, have 37 stations located in the four major boroughs.

The study area is defined by the four boroughs of New York City (excluding Staten Island) and contains 242 square miles (628 square kilometers) of developed land and park space, served by 506 transit and commuter rail stations. Average population density is 28,700 persons per square mile (11,100 per square kilometer) and average employment density is 16,500 jobs per square mile (6,400 per square kilometer). Peak densities exceed 100,000 residents per square mile on Manhattan's East and West Sides and 200,000 jobs per square mile in Midtown and Downtown. Throughout the Manhattan Central Business District, which contains more than half of all employment in the four boroughs, average walking distance to a subway station is 1,300 feet.

Unlike NYREG, the study area of NYSTA is not subdivided into land use zones. Rather, it is comprised of a large random sample of parcels geographically coded to the nearest transit station, and the stations are located along all fixed rail routes in the four boroughs.

Data Inputs

On the input side, the model has been supplied with a large sample of real estate transactions in the study area to which have been affixed four distinct types of data coded to the parcel level - parcel characteristics, neighborhood characteristics, public access characteristics, and transit access characteristics. The data inputs for determining the universe of property sales are first described, followed by the attribute data.

Universe of Sold Parcels

Two sources of data were utilized in preparation of the universe of sold parcels for selected building classes:

o All real estate transactions in the study area between January, 1985 and July, 1988, were compiled by borough, block and lot identifier, building classification, most recent sales price, sales date, lot dimension, total assessed value, and assessed land value, for the following building codes:

- vacant land
- one family and two family dwellings
- walk-up apartments
- elevator apartments
- office buildings
- store buildings

Over the three and one half years, property sales in the six land use categories comprised 102,400 transactions or individual records for Manhattan, Brooklyn, Queens, and the Bronx, fully 11 percent of all existing tax parcels in the City of New York. The records of 98,800 real estate market sales were obtained from the national data research center of Real Estate Data, Inc., a Sanborn affiliate which compiles primary sales data for major metropolitan areas from municipal and county clerk offices. These records were supplemented by 3,600 auction sales of public property to private ownership, as reported by the New York City Department of General Services.

o All demolition permits and related records of intended change-of-use were assembled for the universe of sold parcels by borough, block and lot identifier, pre-existing use, and vacancy status. Some 4,700 demolition permits were awarded by New York City government to the 102,400 sold parcels, and an additional 340 parcels in Manhattan were purchased by developers for future redevelopment purposes. The demolition records were obtained from the New York City Department of Buildings and the development parcel records were obtained from the Real Estate Board of New York. These records were used to transfer some five thousand parcels, or 4.9% of the sales universe, from the building class identified at date of sale to the vacant land class for which the purchase was intended.

Editing was performed of the real estate transactions file merged with the demolitions file, resulting in the elimination of 12,400 parcels from the universe of 102,400 sales in six building classes. Reasons for elimination included duplication of records, outliers sales (such as "sweetheart" sales of $1), and missing data items. The adjusted transactions file numbered 90,000 parcels.

Parcel Characteristics

Physical and financial characteristics were attributed to the adjusted universe of sales parcels in the study area on a parcel-specific basis, using the block and lot identifiers of sold parcels with the master file of 940,000 parcels of real property on file with New York City tax assessors. The following attributes were matched to each of the sold parcels:

- final actual assessed value of land and improvements
- final actual exemption value of land and improvements
- change in final actual assessed value of land and improvements over previous year
- lot frontage and depth in feet and inches
- building frontage and depth in feet and inches
- number of stories in building
- number of buildings on parcel
- number of units in structure
- year built
- corner lot
- fire damage
- abandonment status
- tax class (implications for assessed-to-market ratio)
- assessment protest
- community district code
- zip zone code
- zoning code

Input data were used to derive the following additional variables by computation or imputation:

- gross square feet of parcel land area
- gross square feet of structure floor area
- permissible floor area (based on zoning)
- land value of sales price (as vacant, or based upon the share of land to total assessed value)
- land value per square foot of parcel land area by building class
- percent annual increase in assessed value

The master file of real property assessments and physical attributes was obtained from the New York City Department of Finance, Real Property Assessment Division (RPAD), for Fiscal Year 1988. The file contains over one hundred fields of parcel-specific data for 26 major building classes and more than two hundred minor classes, of which records were selected for all parcels in the adjusted transactions file. Editing the records for missing RPAD data reduced the size of the adjusted transactions file to 86,300 parcels with complete records.

Neighborhood Characteristics

Neighborhood characteristics were attributed to the adjusted universe of parcel sales in the study area on a parcel-specific basis, using the community district code and the zip zone code assigned to each parcel as the primary neighborhood identifiers. Several sources of data were utilized in acquisition of these areawide characteristics.

o Selected socioeconomic characteristics of the 1980 Census of Population, which are compiled by New York City's community districts approximating neighborhood boundaries, were appended to each parcel record for the following variables:

- median family income, 1979
- percent black and Hispance resident population, 1980
- percent of population in poverty, 1980
- percent total housing units vacant, 1980
- employed labor force per household, 1980
- average number of rooms, 1980
- median housing rent, 1980
- median age of structure, 1980
- mean value of owner occupied dwellings, 1980

The community district data were obtained from MISLAND, a computerized management information system of the New York City Department of City Planning which processes Census data on a community district basis land use review and approval processes.

o Supplemental neighborhood characteristics were obtained from administrative records of New York City and New York State. They were assigned to each parcel by other locational coordinates, such as zip zone codes or correspondence files which transformed the non-Census neighborhood characteristics into aggregates or averages for each community district. The following records of neighborhood characteristics were appended to each parcel record:

- total employment covered by the State Employment Security Program, as reported by zip zones, 1987
- reported crime rates (rape, robbery, assault, burglary) by police precincts, 1987
- elementary reading scores, by school districts, 1987
- traffic counts at major commercial intersection, by air quality zones, 1987
- vacant housing units, as reported by electric utility metering program, 1987

The supplemental neighborhood data were obtained separately from each program administrator.

The adjusted transactions file of 86,300 parcel records with complete physical and neighborhood characteristics was subject to sampling analysis for extraction of a representative sample of smaller size, by building class, before further input data were appended to each sample record. The sample size and composition will be discussed in a subsequent section of this chapter. The description of the following data inputs applies only to the sample of 18,650 parcels.

Public Access Characteristics

For each sample parcel, of the representative sample of 18,650 parcels drawn from the adjusted transaction file, a set of public access characteristics was determined based upon distance measured along public streets and ways, or by airline measure in meters. For this purpose, each sample parcel was first located on tax maps by their respective block and lot identifier. Locations of green parks (not playgrounds), bodies of water, and rapid transit lines and station facilities were similarly noted on the maps. Each transit station was assigned a unique node number. Using the tax maps, the following public access characteristics were determined for each sample parcel:

- walking distance to nearest park with natural ground cover
- walking distance to nearest rapid transit/commuter rail station by shortest path
- nearest rapid transit station coded with node number
- airline distance to nearest elevated transit structure
- airline distance to nearest body of water

The tax maps were obtained from the Sanborn Map Company which maintains a detailed atlas of all property in New York City by borough.

Transit Access Characteristics

Each transit station in the New York City subway system has a unique mix of station characteristics that reflect the density and type of development surrounding the station, its position in a fixed rail corridor oriented toward Manhattan, and the effect of subway system operations and investment practices of the New York City Transit Authority which provides service in the four boroughs for the MTA. The various transit characteristics convey measures of service quantity, quality, frequency, amenity, and performance.

The following transit characteristics were compiled by transit station. Those of the nearest transit station were coded to each sample parcel by their station node number:

- elevated, open cut, or tunnel type of structure
- local, express, interline transfer, or terminal type of service
- year station opened

- average annual passenger entries, 1986, 1987
- inbound trains stopping in peak morning frequency (7:30-8:30 a.m.)
- outbound trains stopping in peak evening frequency
- volume of trains in one direction in 24 hour period
- crowding (square feet per passenger) on trains in peak morning frequency
- percent of new cars in trains, 1986
- percent of rehabilitated cars in trains, 1986
- percent trains on time, 1986, 1987
- percent change in on-time performance, 1986-1987
- miles to Midtown centroid (Sixth Ave. and 42th St.)
- miles to Downtown centroid (Wall and Broadway Sts.)
- transit minutes to Midtown centroid
- transit minutes to Downtown centroid

Transit access characteristics were obtained by station from the MTA.

After all data sets were appended to the representative sample of 18,650 parcels stratified by six building classes, the record for any single parcel recently sold contained over 60 variables, as previously described including its block and lot identifiers.

Data Outputs

On the output side, NYSTA produces the following results:

o As the dependent variable, variation in land value per square foot by distance from a rapid transit station, for the following land use types:

- vacant land
- one and two family dwellings
- walk-up apartments
- elevator apartments
- office buildings
- store buildings

For vacant land parcels, or developed parcels purchased for redevelopment purposes, the land value was taken as the market price. For developed land in residential and commercial use, the land value was derived from the market sales value by applying each parcel's respective portion of assessed land value in total assessed value to the market price. When accuracy of assessment practices regarding land is at issue, an alternative approach would include parcel size with the full market sales value, including land value, as an independent variable in the regression analysis. Differences in value attributable to year of sale were corrected by utilizing the consumer price index for the New York area. Here, again, an alternative approach would introduce a time variable into the regression equation, rather than deflate the sales price.

o As independent variables, the relative importance of transit access characteristics among physical site, neighborhood, and public access characteristics that influence land value.

o As policy levers, variation in land value by distance from a rapid transit station stratified by differences in the following transit characteristics which are independent variables:

- type of transit structure
- type of transit service
- year station opened
- volume of train service
- passenger volume
- on-time performance
- equipment on line
- crowding on trains

How NYSTA is Designed

The appropriate method of determining land value relationships in a built environment, when development has already taken place, is the use of multivariate regression analysis incorporating a wide array of explanatory variables in estimating a land price function. While the choice of the dependent variable in such an analysis is clear, that is, the unit price of land, the choice of independent variables necessitates a process of stepwise regression or factor analysis of all such explanatory factors.

Before this choice is made, a critical decision occurs in the initial identification of independent variables, including dummy variables where appropriate. In this effort, we were guided by theory, prior related research studies, data availability, and tests for colinearity in variation between variables. Chief among omissions of potential independent variables were those quality measures of the built environment that are reflected in the type and condition of building materials used in existing structures. However, since these variables are not likely to covary with the transit access terms, it is doubtful that their effect on land value has been attributed to the measures of transit accessibility.

Given the magnitude of the assembled data base of roughly one hundred thousand parcels recently sold in the study area in vacant, residential and commercial building classes, and the array of some 60 parcel-specific, neighborhood, and access-related factors of potential significance in explaining land value, a sampling method was adopted to extract a representative group of parcels from each building class. Because sampling preceded the measurement of public access variables, it was not possible to stratify the sample based upon a range of distances to transit stations. Rather, considerations of borough and building class representation prevailed.

The frequency distribution of the parcel universe indicated that one- and two-family dwellings comprised two thirds of all recent sales, followed by walk-up dwellings for a cumulative 80 percent. Sales of office buildings and apartment structures were least (collectively 3 percent), and stores and vacant land next most frequent. Nearly half of all parcels were in Queens, three in every eight in Brooklyn, and only 3 percent in Manhattan. Thus, to ensure adequate data points along the spectrum, outward from the CBD, it became necessary to draw disproportionately upon parcels in Manhattan, next most frequently upon parcels in the Bronx and Brooklyn, and least upon parcels in Queens relatively speaking.

All parcels with office buildings and apartment structures were chosen, as were all vacant land parcels. The former two building classes were least represented in the universe, while the latter class reflected the truest measure of land value. For the remaining residential and commercial classes, a random sample selection was performed by computer. For each of these building classes, the total sample size was predetermined, using the following formula for sampling a large universe when the standard deviation is known:

$$n_k = \left(\frac{1.96\sigma}{E}\right)^2$$

where k = 1...6, denotes six building classes, and E is signified at 5% error for a 95% confidence interval. Table 3.1 presents the sample of sales parcels by building class and borough.

Table 3.1 Sample Sales Parcels by Building Class and Borough

	Study Area				
Bldg Class	Manhattan	Bronx	Brooklyn	Queens	Total
Vacant Land	416	1,827	3,396	2,655	8,294
1-2 Family	44	606	2,136	2,848	5,634
Walk-Ups	24	167	717	329	1,237
Apartments	878	483	621	391	2,373
Offices	246	53	90	92	481
Stores	41	54	398	137	630
All Classes	1,649	3,190	7,358	6,452	18,649

The econometric technique of multivariate regression analysis was applied to the sample of sales parcels stratified by building class, utilizing a stepwise least squares method to systematically estimate the best fitting parameters of each equation.[13] Because the method incorporates statistical controls within the model, through use of cross-sectional data and a wide array of site, neighborhood, access and transit related independent variables, the need for a control area is negated. The multivariate regression approach allows us to determine the positive or negative effect of each independent variable, and the significance of these effects on the dependent variable, the unit price of land.

NYSTA is stratified by separate equations specified for each building class and, separately, for vacant land by each transit policy variable. The equations and graphic representations are presented in the next section of this chapter. Statistical tests of modeling results permit an overall assessment of each equation. Because NYSTA is based upon cross-sectional rather than time series data, goodness of fit results as reflected in a high R^2 value are not to be expected. Although this suggests that the model does not fully predict the value of land as a function of the specified independent variables, it does alter its ability to isolate the effect of transit accessibility variables on land value.

Specification of the Equations

In developing separate equations by building class for NYSTA, the specification was guided by various forms of hedonic price models but based, after an iterative process of stepwise regression analysis, upon statistically considerations. The functional form of the basic regression model is:

$$Y = \beta_0 X_0 + \beta_1 X_1 + \ldots + \beta_p X_p + \varepsilon$$

where Y is the vector of dependent variable values, X is the matrix containing the values of the independent variables, β is the vector of parameters, and ϵ is the vector of error components. The specification may be linear, logarithmic, log-linear, or quadratic. Although a wide range of explanatory variables were searched for values that minimized the sum of squared residuals, only some twenty of the sixty available variables were utilized in the model. For those calibrated in the model, Table 3.2 presents the name of each variable, its type, and a brief definition.

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13 Stratification by borough or use of borough dummies might improve explanatory powers since relationships probably differ by borough.

Table 3.2 Type and Definition of NYSTA Variables

Type	Name	Definition
Dependent	RATLSP_A	Land Value per Sq Ft of Land Area, for building classes 1 ... 6
Independent	WDST	Walking Distance to Station (meters)
	WDP	Walking Distance to Park (meters)
	ADW	Airline Distance to Water (meters)
	PSGR87	Passenger Volume of Station in 1987
	TONT87	Trains on Time in Station in 1987
	PONT8687	% of Trains on Time in Station, 1986 & 1987
	MIDTM	Miles to Midtown Manhattan CBD
	DNTM	Miles to Downtown Manhattan CBD
	MIDTMIN	Transit Minutes to Midtown CBD
	DNTMIN	Transit Minutes to Downtown CBD
	TR24H	Train Volume in any 24 Hour Period
	CRWD8T9	Crowding Ratio (V/C) on Trains in Peak Hour, a.m.
	PNEWCAR	% of New Cars
	PRHBCAR	% of Rehabilitated Cars
	YEAR	Year Station Opened
	LEIT	Type of Service - Local, Express, Interline Transfer, Terminal
	EOT	Type of Structure - Elevated, Open Cut, Tunnel
	CONEDVAC	% Vacant Housing Units in 1987
	MTASEQ	Station Node Number, for stations 1 ... 440
	POVERTY	% Households Below Poverty Level in 1979
	EMP	Employment by Work Place
	CRIME	Reported precinct rates, for crimes 1 ... 4

Variation in Land Value by Building Class

The variation in land value explained by NYSTA is stratified by building class, comparing model results for vacant, residential, and commercial land.

Class One: Vacant Land Where land is undeveloped or purchased for redevelopment after demolition of existing structures, the unit price of land is expressed as:[14]

$$
\begin{aligned}
RATLSP\_A_1 = {} & 5.733800 - \underset{(.0001)}{0.150111(WDST)} - \underset{(.0001)}{0.124265(ADW)} \\
& - \underset{(.0570)}{0.061355(WDP)} - \underset{(.0001)}{0.775502(POVERTY)} \\
& + \underset{(.0001)}{0.253251(EMP)} - \underset{(.0001)}{0.470774(MIDTM)} \\
& - \underset{(.0001)}{0.277505(DNTM)} - \underset{(.0301)}{0.082246(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = 0.1411$$[15]

As Figure 3.1 shows, at 200 meters or roughly one eighth of a mile walking distance from a transit station, the value of land is $24 less per square foot than at the station, while at 800 meters or one half mile, the value is $114 less per square foot of land area than at the station. If the mean value of all 6,600 parcels in the vacant land sample was assumed, or $148 per square foot, then one third of a parcel's value would be lost if located one quarter mile away from a transit station measured by the shortest path walking distance. Factors with greater explanatory power in altering land value, than WDST, are poverty and distance from Manhattan.

For purposes of stratifying the vacant land model by transit access variables, other than WDST, it is desireable that these factors are not parameters estimated by the model. A subsequent discussion in this section of the report presents the variation in land value by transit access characteristics.

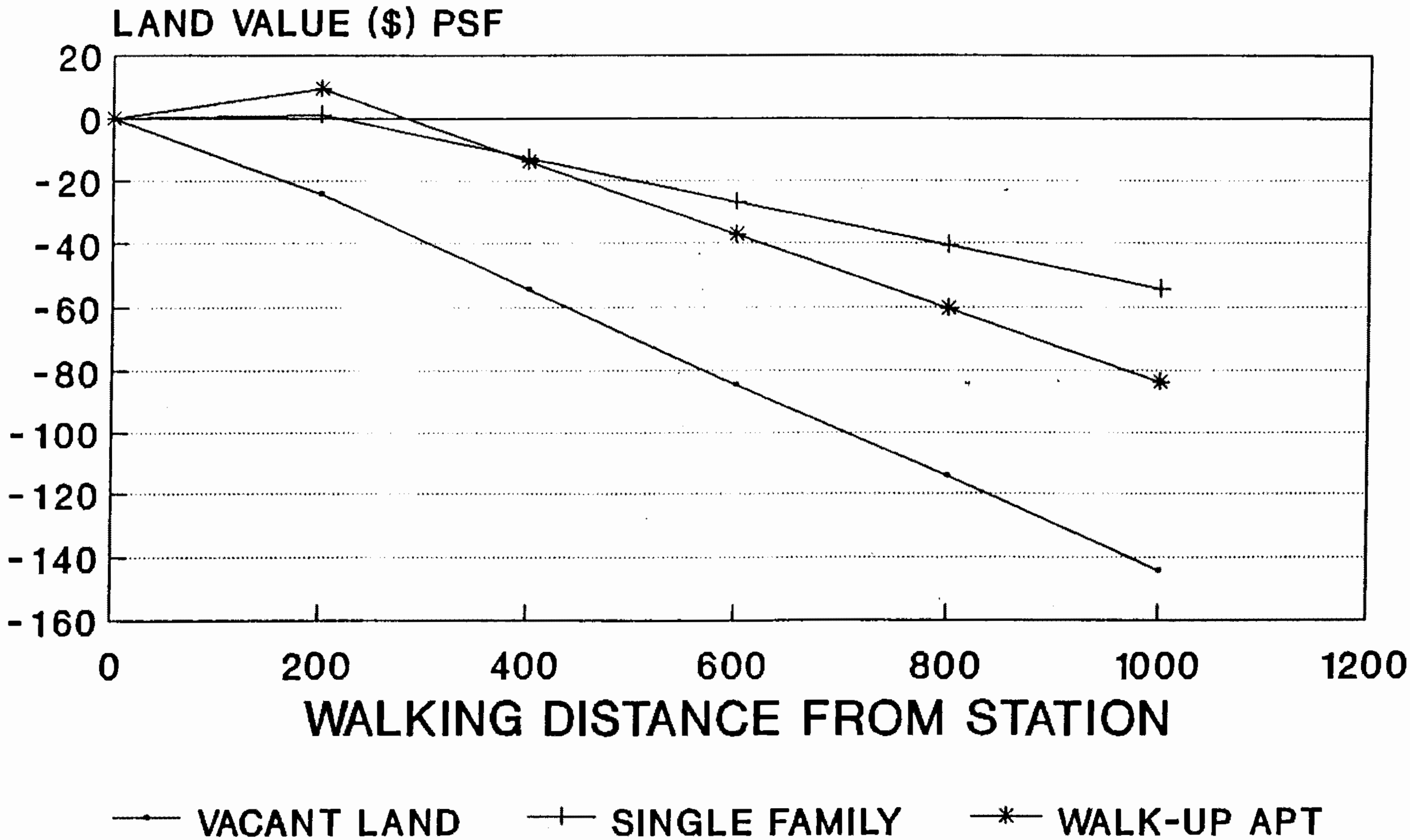
---

[14] Estimated Probability values (Prob > |T|), which are the probability that a type I error will occur, are shown in parentheses below the coefficients.

[15] With cross-sectional data pertaining to transit access characteristics, the value of the R^2 is far less significant than the t-statistics.

Figure 3.1

DECREASE IN LAND VALUE PSF EXPLAINED BY INCREASE IN DISTANCE OF PARCEL FROM SUBWAY STATION



<u>Class Two: One to Two-Family Residential</u> Where land is developed in single and two-family dwellings, the unit price of land is expressed as:

$$\begin{aligned} RATLSP\_A_2 = {} & 15.062852 - \underset{(.0001)}{0.069574(WDST)} - \underset{(.0362)}{0.053908(WDP)} \\ & - \underset{(.0001)}{0.030651(ADW)} - \underset{(.1874)}{0.059848(POVERTY)} + \underset{(.0000)}{0.002587(EMP)} \\ & - \underset{(.0032)}{0.119595(MIDTMIN)} - \underset{(.0001)}{0.174275(DNTMIN)} \end{aligned}$$

$$R^2 = 0.5680$$

Compared to vacant land, land developed in single and two-family residential uses declines less steeply in value with increasing distance from transit stations. At 200 meters, or one eighth of a mile walking distance, the underlying land value of low density housing is virtually the same as at the transit station, owing no doubt to the nuisance effects of residing near a station from traffic congestion and related disbenefits. At 800 meters or one half mile from the station, the value of land in single and two-family dwellings is $40 less per square foot than land value at or within one eighth of a mile of the station.

A slightly larger version of the model, incorporating the crime variable "assault", yields improved t-statistics for POVERTY and WDP, but little positive effect on the coefficient of determination, R^2. It should be noted that transit minutes rather than miles are more important explanatory variables for single family housing.

<u>Class Three: Walk-up Residential</u> Where land is developed in four and five storey walk-up apartments, the unit price of land is expressed as:

$$\begin{aligned} RATLSP\_A_3 = {} & 32.681549 - \underset{(.0031)}{0.116221(WDST)} - \underset{(.0467)}{0.023935(CRIME_{burglary})} \\ & + \underset{(.0001)}{0.000709(EMP)} - \underset{(.0008)}{0.038729(ADW)} + \underset{(.0001)}{0.000003(PSGR87)} \\ & + \underset{(.0073)}{0.199282(TONT87)} - \underset{(.0670)}{0.184592(MIDTMIN)} - \underset{(.0001)}{0.441920(DNTMIN)} \\ & - \underset{(.0003)}{0.433566(POVERTY)} + \underset{(.0241)}{1.960245(CONEDVAC)} \end{aligned}$$

$$R^2 = 0.2383$$

Compared to land used for one and two-family dwellings, land in walk-up apartments commands a relatively greater value per unit of land area. Within several city blocks of a transit station, the land value rises but falls more steeply thereafter, to losses equal to that of single family housing at one quarter mile distance (down $14 per square foot), and to losses exceeding that of single family development at one third of a mile or more from transit stations. If moderate density housing has a steeper land rent gradient than single family housing, as Figure 3.1 shows, it has a more shallow gradient than vacant land. Unlike vacant land, other factors enter into the explanatory relationship, including the prevalence of vacant housing in the neighborhood and transit performance as signified by trains on time and passenger volumes. The positive sign for housing vacancies is contrary to expectations.

Class Four: Elevator Apartments Residential Where land is developed in elevator apartment structures, the unit price of land is expressed as:

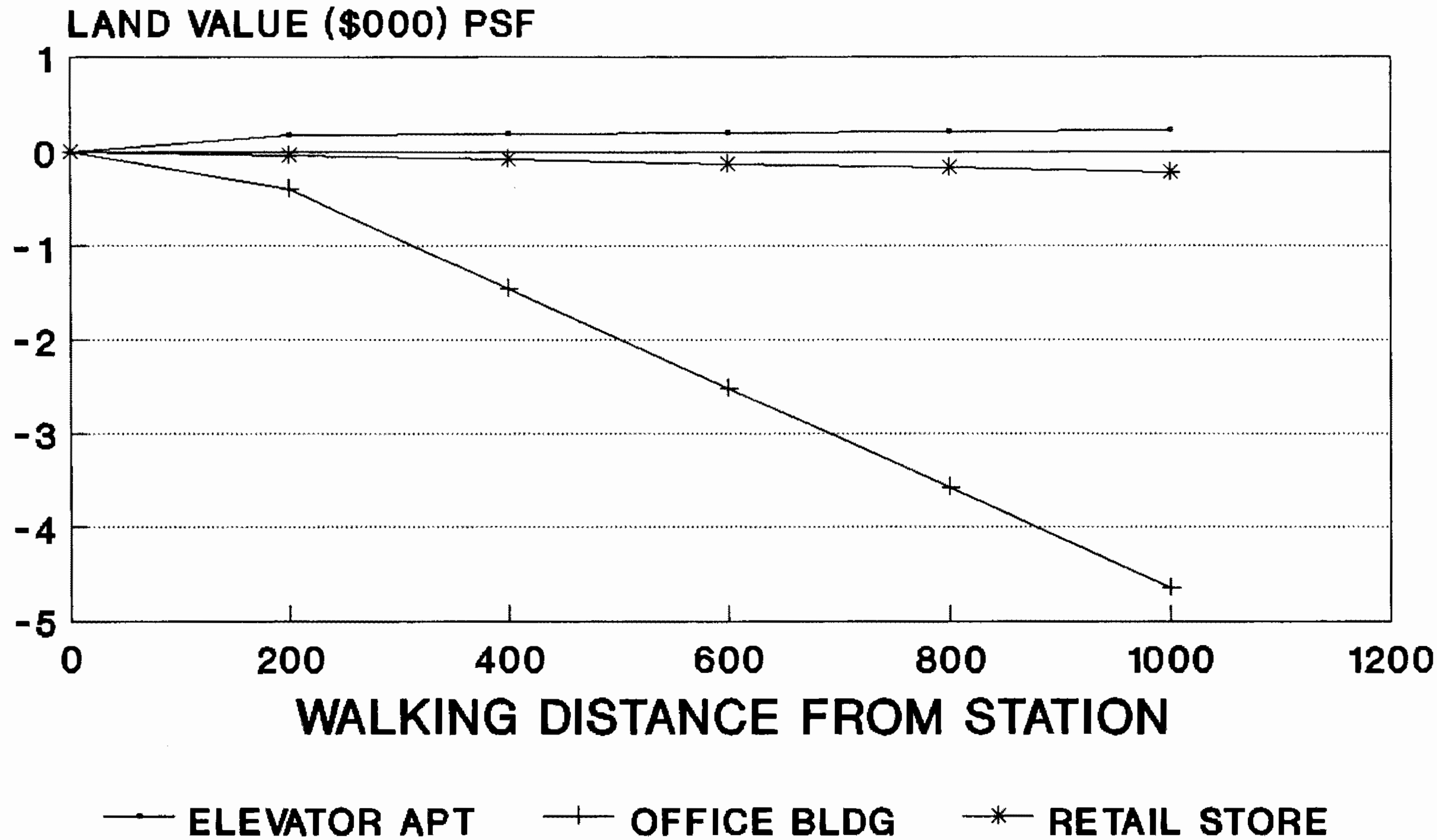
$$\begin{aligned} RATLSP\_A_4 = {} & 159.297136 + \underset{(.0087)}{0.063490(WDST)} + \underset{(.0001)}{0.181794(CRIME_{burglary})} \\ & + \underset{(.0001)}{0.001315(EMP)} - \underset{(.0001)}{0.246635(ADW)} + \underset{(.0129)}{0.000003(PSGR87)} \\ & + \underset{(.0077)}{0.990579(TONT87)} - \underset{(.0001)}{1.914420(MIDTMIN)} \\ & - \underset{(.0008)}{1.265499(DNTMIN)} - \underset{(.0001)}{4.713289(POVERTY)} \\ & + \underset{(.0388)}{6.507916(CONEDVAC)} \end{aligned}$$

$$R^2 = 0.4179$$

Compared to land used for low and moderate density residential development, land used for high density apartment development is more expensively priced and reflects a stable to moderate increase in land value with increasing distance from transit stations. It declines with increasing distance from the Manhattan CBD, and with increasing poverty, and rises with employment density and transit performance measures. Again, a questionable positive relationship with housing vacancy is noted. The relationship of high density residential land is shown with vacant land and land in office development in Figure 3.2.

Figure 3.2

DECREASE IN LAND VALUE PSF EXPLAINED BY INCREASE IN DISTANCE OF PARCEL FROM SUBWAY STATION



Class Five: Office Building Commercial Where land is developed in detached office buildings, the unit price of land is expressed as:

$$RATLSP\_A_5 = 668.473620 - \underset{(.0008)}{5.311914(WDST)} - \underset{(.0064)}{9.018072(POVERTY)} - \underset{(.0096)}{1.480943(ADW)} + \underset{(.0001)}{0.003600(EMP)}$$

$$R^2 = 0.1885$$

Among all land uses studied, the steepest gradient in land value is displayed by land in office development as distance from a transit station increases. At 200 meters, or one eighth of a mile walking distance, land value decreases by nearly $400 per square foot, all other factors remaining unchanged. Increasing rates of poverty and more distant access to water also negatively influence land value, while employment density is a positive factor. Crime rates and walking distance to parks were not significant explanatory factors.

Class Six: Retail Store Commercial Where land is developed in retail stores, the unit price of land is expressed as:

$$RATLSP\_A_6 = 1.458751 - \underset{(.0001)}{0.215260(WDST)} + \underset{(.0001)}{0.565176(EMP)} - \underset{(.0001)}{0.335735(ADW)} - \underset{(.0001)}{0.651557(POVERTY)}$$

$$R^2 = 0.2339$$

Land in retail store development decreases in value at roughly the same rate as vacant land with increasing distance from transit stations. However, its loss in value is somewhat greater. At 200 meters, the value of land is $42 less per square foot than at the station, while at 800 meters or one half mile, the value is $171 less per square foot of land area than at the station. As with vacant land, the surrounding employment density, access to water, and poverty similarly explain land value, while retail land value shows no significant relationship to access to the Manhattan CBD, access to park area, or crime rates.

Variation in Land Value by Transit Characteristics

The variation in land value with access to transit stations can be decomposed with respect to various transit operating and policy characteristics by stratifying the land value model by transit related variables not included in the overall equation. As the baseline, the vacant land value model is utilized for reasons of best fit and overall portrayal of the development gradient. Whereas measures of statistical significance were good for all variables in the generalized vacant land model, with stratification by transit policy variables some t-statistics would not otherwise be acceptable.

Type of Transit Structure Where transit access is provided by elevated, open cut (surface), or tunnel service at the station, the land value gradient measured by walking distance from the station declines most steeply for underground or subway service, and less steeply for elevated transit service. The land value gradient for tunnel service is expressed as:

$$\begin{aligned} RATLSP\_A_{1,T} = 6.505332 &- \underset{(.0001)}{0.193137(WDST)} - \underset{(.2851)}{0.045060(ADW)} \\ &+ \underset{(.2317)}{0.052585(WDP)} - \underset{(.0001)}{0.773082(POVERTY)} \\ &+ \underset{(.0001)}{0.253747(EMP)} - \underset{(.0001)}{1.018307(MIDTM)} \\ &- \underset{(.0025)}{0.223302(DNTM)} - \underset{(.0010)}{0.166260(CRIME_{rape})} \end{aligned}$$

$$R^2 = 0.2641$$

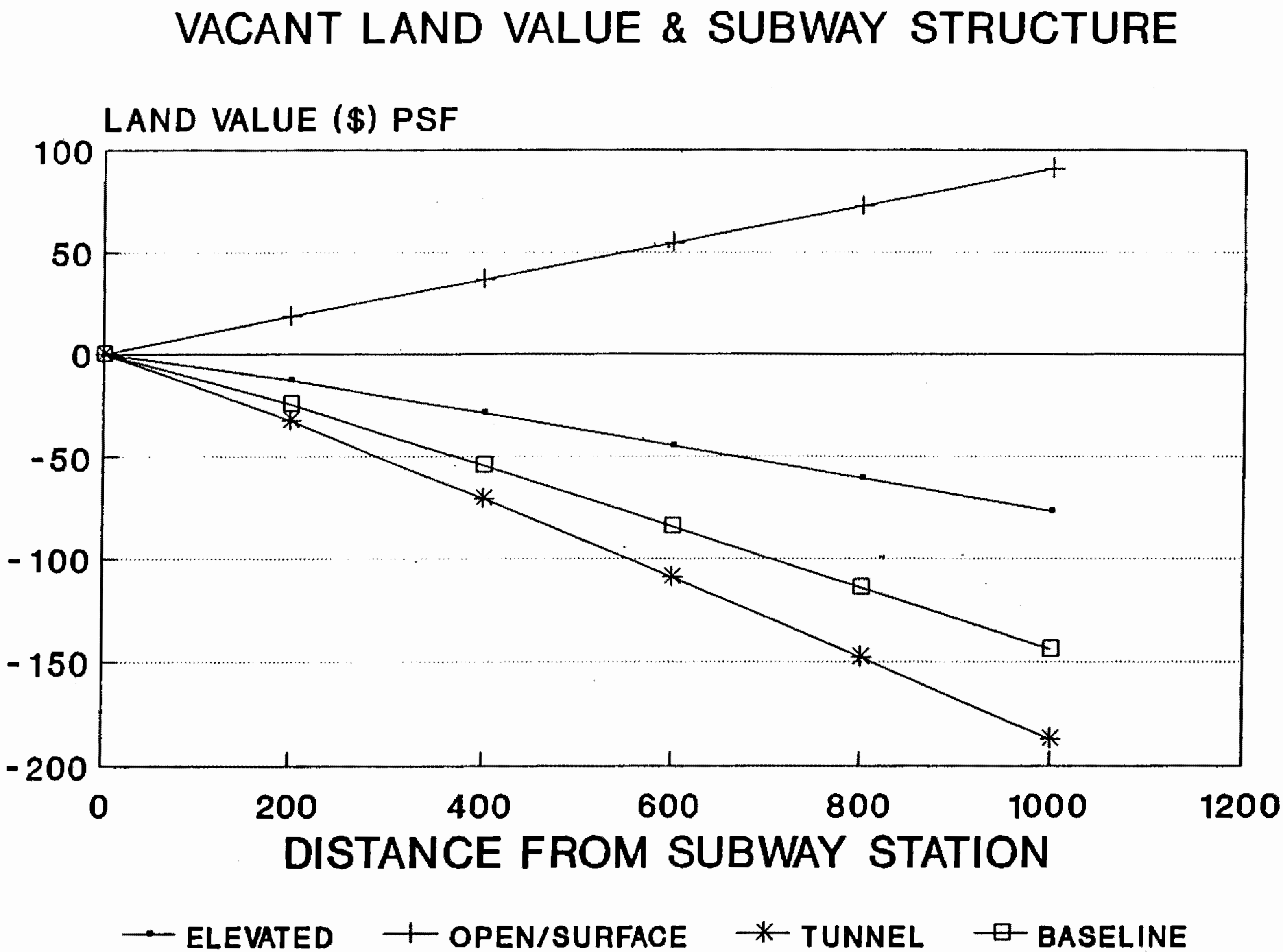
As Figure 3.3 shows, the beneficial effect of subway service confers a steeper rise on land value with access to the station, than does elevated transit service, or all fixed rail service irrespective of structure type (the baseline condition). The land value gradient for elevated service is expressed as:

$$\begin{aligned} RATLSP\_A_{1,E} = 3.463235 &- \underset{(.1267)}{0.080113(WDST)} - \underset{(.0920)}{0.097116(ADW)} \\ &- \underset{(.0003)}{0.184767(WDP)} - \underset{(.0035)}{0.396274(POVERTY)} \\ &+ \underset{(.0062)}{0.192826(EMP)} + \underset{(.0227)}{0.457052(MIDTM)} \\ &- \underset{(.1407)}{0.246268(DNTM)} - \underset{(.0001)}{0.308270(CRIME_{rape})} \end{aligned}$$

$$R^2 = 0.0953$$

The value of land accessible to fixed rail service in an open cut or surface configuration does not have a clear relationship to distance from the station. With an open cut, land value rises as distance increases, but the estimated coefficient for the walking

Figure 3.3


VACANT LAND VALUE & SUBWAY STRUCTURE
LAND VALUE ($) PSF
100
50
0
-50
-100
-150
-200
0
200
400
600
800
1000
1200
DISTANCE FROM SUBWAY STATION
ELEVATED
OPEN/SURFACE
TUNNEL
BASELINE

distance variable (WDST) is extremely insignificant, suggesting that the effect of distance may be zero. The land value gradient for open cut or surface service is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,O} = {} & 0.192084 + \underset{(.4334)}{0.090795(WDST)} + \underset{(.0661)}{0.228779(ADW)} \\
& - \underset{(.2674)}{0.120249(WDP)} - \underset{(.3805)}{0.272916(POVERTY)} \\
& + \underset{(.9940)}{0.001128(EMP)} + \underset{(.0001)}{2.380628(MIDTM)} \\
& - \underset{(.0012)}{1.372995(DNTM)} - \underset{(.1987)}{0.236651(CRIME_{rape})} \\
& R^2 = 0.1110
\end{aligned}
$$

As Figure 3.3 shows, at 400 meters or one quarter mile from a transit station, the value of subway accessible land is \$71 less per square foot than at the station, and the value of elevated accessible land is \$29 less per square foot, while the value of open cut accessible land is as much as \$37 more per square foot of land one quarter mile distant from a transit station.

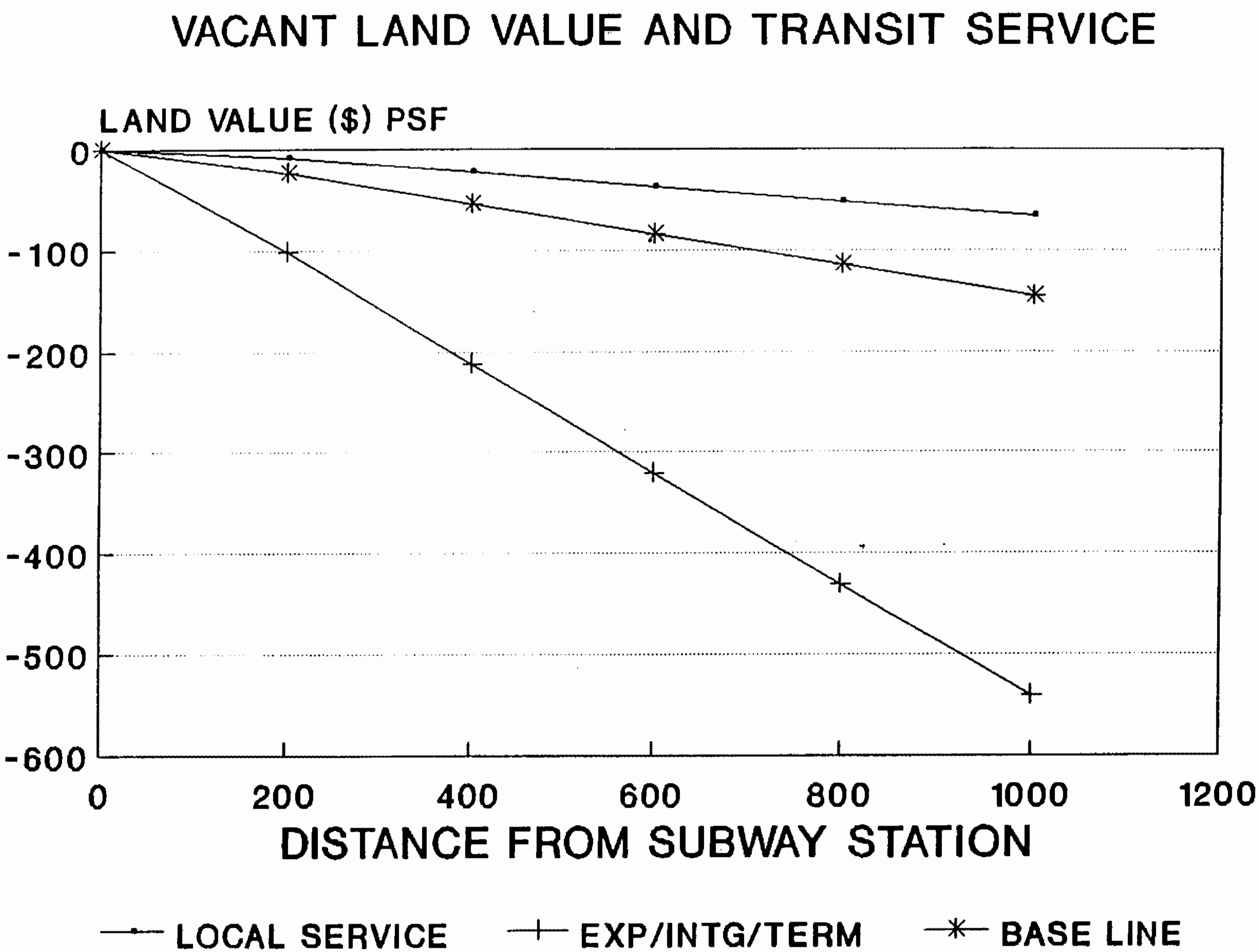
Coefficients of some independent variables in the regression equations stratified by tunnel, elevated and surface structures contain signs contrary to general expectation. In particular, of note, is the positive relationship to distance to parks for tunnel service, and to distance to Midtown Manhattan for elevated and open cut service.

<u>Type of Transit Service</u> Where transit access is provided by local, express, interline transfer, or terminal service at the station, the land value gradient measured by walking distance from the station declines more steeply for the express/transfer/terminal than for the local type of service. The land value gradient for the consolidated express/transfer/terminal type service is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,EIT} = {} & 8.051727 - \underset{(.0001)}{0.548736(WDST)} - \underset{(.0013)}{0.201449(ADW)} \\
& - \underset{(.0889)}{0.109473(WDP)} - \underset{(.0001)}{1.084045(POVERTY)} \\
& + \underset{(.0002)}{0.290291(EMP)} - \underset{(.0032)}{0.462890(MIDTM)} \\
& - \underset{(.2516)}{0.152029(DNTM)} - \underset{(.3737)}{0.079291(CRIME_{rape})} \\
& R^2 = 0.2961
\end{aligned}
$$

As Figure 3.4 shows, the slope of land value over distance from a transit station with local service is flatter than the slope

Figure 3.4



VACANT LAND VALUE AND TRANSIT SERVICE
LAND VALUE ($) PSF
0
-100
-200
-300
-400
-500
-600
0
200
400
600
800
1000
1200
DISTANCE FROM SUBWAY STATION
LOCAL SERVICE
EXP/INTG/TERM
BASE LINE

of decreasing value for all transit service irrespective of type. The land value gradient for local type service is expressed as:

$$\begin{aligned} RATLSP\_A_{1,L} = \; & 5.623145 - \underset{(.0627)}{0.072126(WDST)} - \underset{(.0024)}{0.105354(ADW)} \\ & - \underset{(.0872)}{0.063287(WDP)} - \underset{(.0001)}{0.665849(POVERTY)} \\ & + \underset{(.0002)}{0.195299(EMP)} - \underset{(.0001)}{0.450128(MIDTM)} \\ & - \underset{(.0001)}{0.317349(DNTM)} - \underset{(.0132)}{0.105310(CRIME_{rape})} \end{aligned}$$

$$R^2 = 0.1072$$

As Figure 3.4 shows, at 400 meters or one quarter mile from a transit station, the value of express/transfer/terminal service accessible land is \$211 less per square foot than at the station, while the value of local service accessible land is \$23 less per square foot of land than at the station.

<u>Year Station Opened</u> Where transit access is provided by subway stations that vary in age, and correspondingly in condition (for the period under study), the land value gradient measured by walking distance from the station declines more steeply for newer stations, built between the two world wars, than for older stations built prior to the 1920s. For the newest transit stations, or those built between 1946 and 1956, the estimated coefficients of all independent variables were statistically insignificant.

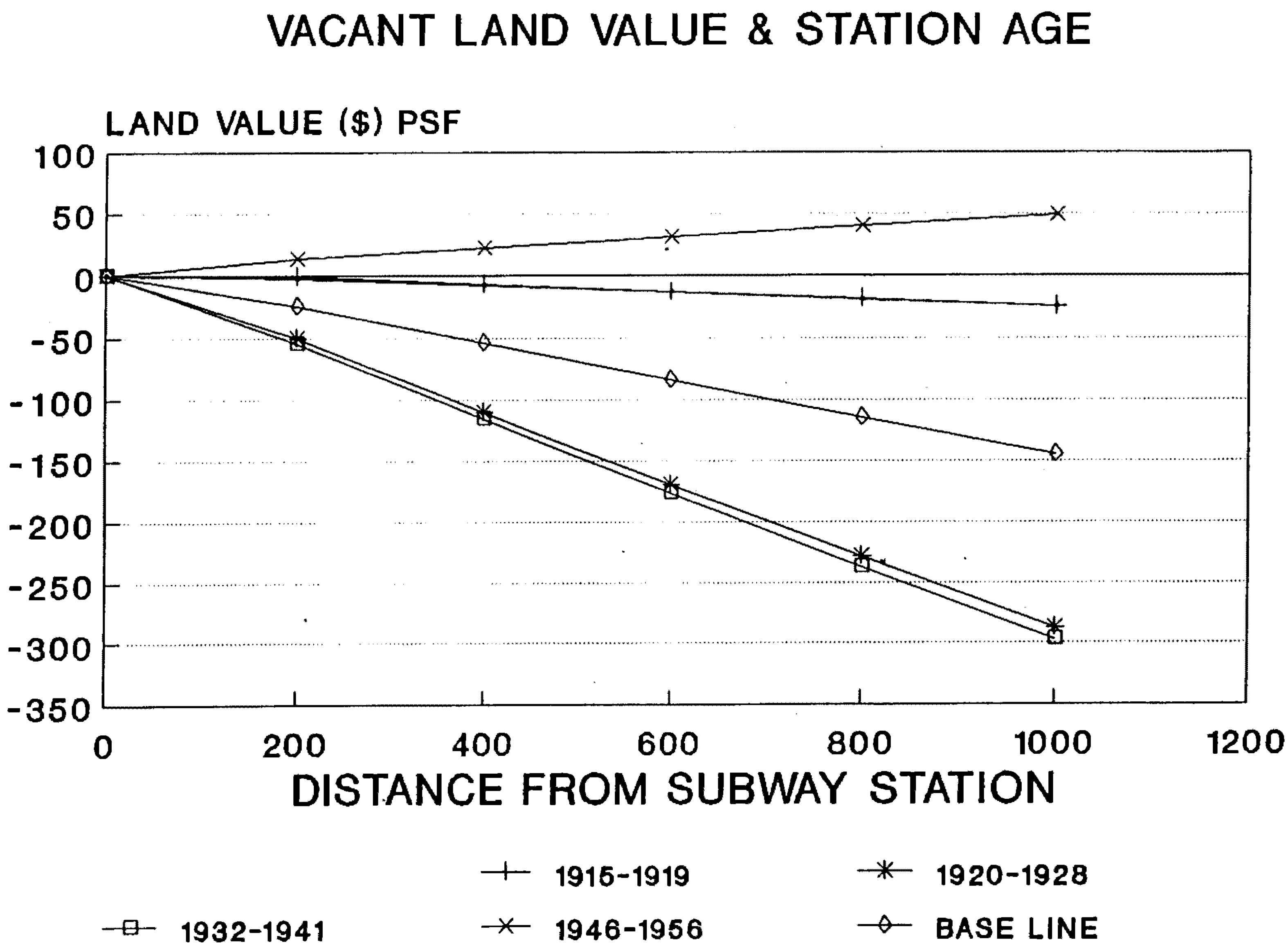
For stations opened between 1920 and 1941, the land value gradient is best expressed as:

$$\begin{aligned} RATLSP\_A_{1,1932} = \; & 5.631298 - \underset{(.0001)}{0.302748(WDST)} - \underset{(.0030)}{0.155254(ADW)} \\ & + \underset{(.0309)}{0.123343(WDP)} - \underset{(.0001)}{0.606747(POVERTY)} \\ & + \underset{(.0001)}{0.268801(EMP)} - \underset{(.0001)}{0.583423(MIDTM)} \\ & - \underset{(.3225)}{0.097450(DNTM)} - \underset{(.0002)}{0.227651(CRIME_{rape})} \end{aligned}$$

$$R^2 = .1820$$

Figure 3.5 compares the declining land value gradients with distance from a station for transit stations stratified by age. It should be noted that the oldest stations are located primarily in Manhattan and the newest stations in the outer boroughs. Because of the low level of statistical significance associated with the regression equations for older and newer stations, caution should

Figure 3.5


VACANT LAND VALUE & STATION AGE
LAND VALUE ($) PSF
100
50
0
-50
-100
-150
-200
-250
-300
-350
0
200
400
600
800
1000
1200
DISTANCE FROM SUBWAY STATION
1915-1919
1920-1928
1932-1941
1946-1956
BASE LINE

be taken in applying these results.

Given the difference in land value gradients by station age, the spread between unit land value losses with declining access can be considerable. At 400 meters or one quarter mile from a transit station, a vacant land parcel served by a station opened in the 1930s will be valued at $115 less per square foot than a comparable parcel at the station, while one served by a station opened at the turn of the century will be $8 less per square foot than at the station. The corresponding relationship for a parcel accessible to a station opened in the 1950s will represent a gain of $22 over the unit land value of a comparable parcel at the station.

Transit Frequency In Any 24 Hour Period Where transit access is provided at stations characterized by frequent around-the-clock service, the land value gradient around the station declines more steeply with distance than is the case with infrequent service. For two in every five parcels in the vacant land model, the nearby transit station provides access to 250 or more trains in any 24 hour period. For one in four parcels, transit access is provided to under 150 trains per day. Unlike age of station or structure type, lack of frequency does not create a condition in which land value rises with distance from the station, but it does lessen the rate of decline in the land value gradient (Figure 3.6). For stations characterized by the most frequent train service, the land value gradient around the station is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,250} = {} & 6.713528 - \underset{(.0001)}{0.209122(WDST)} - \underset{(.0024)}{0.142773(ADW)} \\
& - \underset{(.0943)}{0.083169(WDP)} - \underset{(.0001)}{0.850269(POVERTY)} \\
& + \underset{(.0001)}{0.270850(EMP)} - \underset{(.0001)}{0.642564(MIDTM)} \\
& - \underset{(.0103)}{0.216344(DNTM)} - \underset{(.0029)}{0.171206(CRIME_{rape})} \\
& R^2 = 0.2343
\end{aligned}
$$

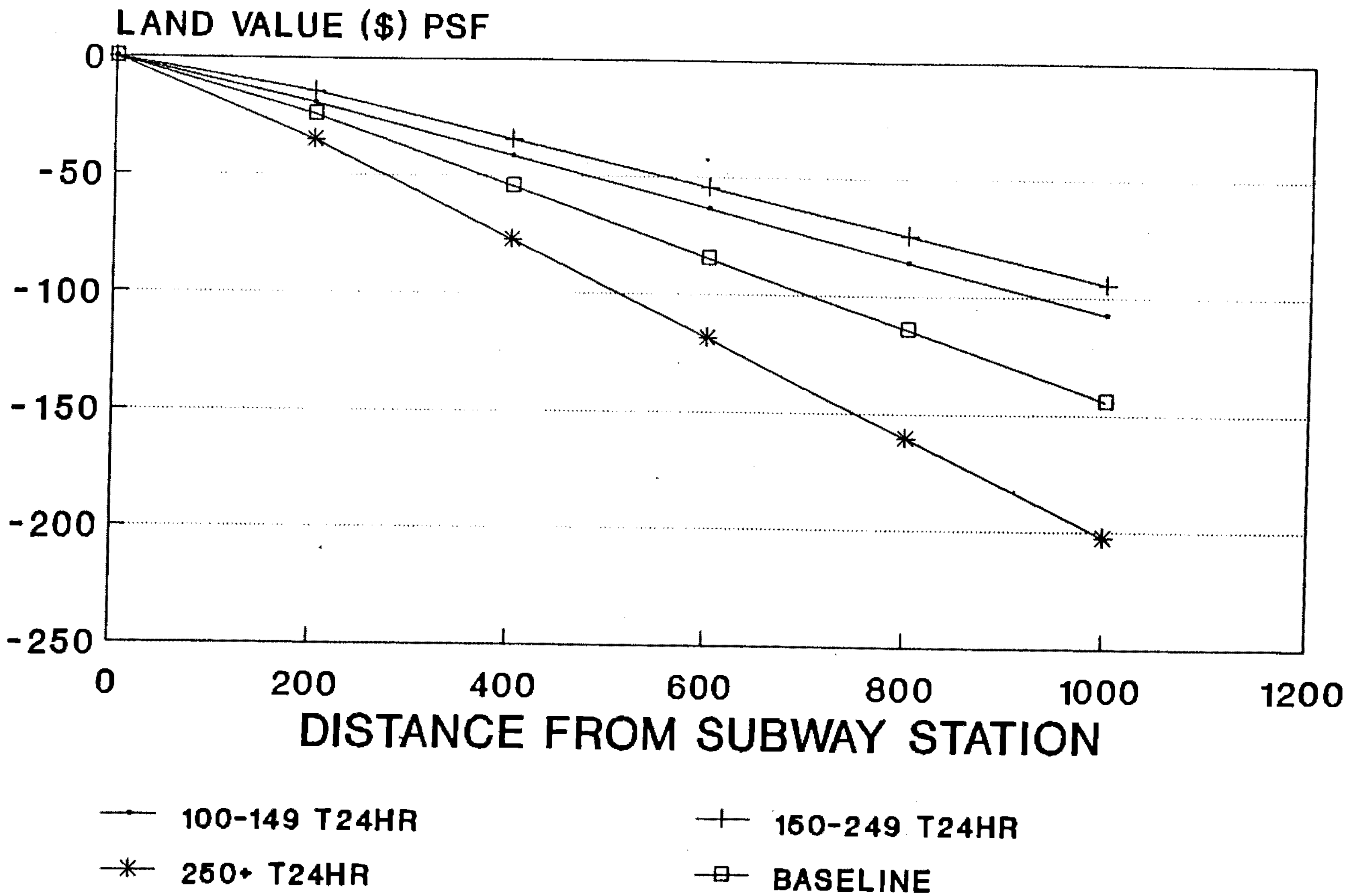
For stations with a moderate volume of train service, or 150 to 249 trains per 24 hour period, the land value gradient around the station is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,150} = {} & 5.258036 - \underset{(.1204)}{0.099426(WDST)} - \underset{(.6893)}{0.024352(ADW)} \\
& + \underset{(.9952)}{0.000364(WDP)} - \underset{(.0004)}{0.599391(POVERTY)} \\
& + \underset{(.1328)}{0.114654(EMP)} - \underset{(.5902)}{0.098691(MIDTM)} \\
& - \underset{(.0011)}{0.462952(DNTM)} - \underset{(.0771)}{0.126885(CRIME_{rape})}
\end{aligned}
$$

$$R_2 = .0728$$

Figure 3.6

VACANT LAND VALUE & SUBWAY FREQUENCY



For station with the least frequest train service, or fewer than 150 trains per 24 hour period, the land value gradient around the station is expressed as:

$$\begin{aligned} RATLSP\_A_{1,100} = {} & 2.374316 - \underset{(.0963)}{0.109804(WDST)} - \underset{(.0002)}{0.256344(ADW)} \\ & - \underset{(.1333)}{0.097869(WDP)} - \underset{(.0004)}{0.667713(POVERTY)} \\ & + \underset{(.0001)}{0.509124(EMP)} - \underset{(.0438)}{0.634130(MIDTM)} \\ & + \underset{(.1030)}{0.383689(DNTM)} + \underset{(.7366)}{0.031707(CRIME_{rape})} \end{aligned}$$

$$R_2 = .1060$$

As Figure 3.6 shows, at 400 meters or one quarter mile from a transit station, the unit land value will have declined by as much as $77 per square foot under conditions of frequent train service, to $42 per square foot under infrequent service. As a policy variable, transit service frequency appears to have a greater impact on land value than structure type, but a lesser effect than express service or newer station age. The equations show that several independent variables are insignificant and/or have questionable signs in the relationships of moderate and infrequent train service, notably: walking distance to parks (WDP) and miles to Downtown Manhattan (DNTM).

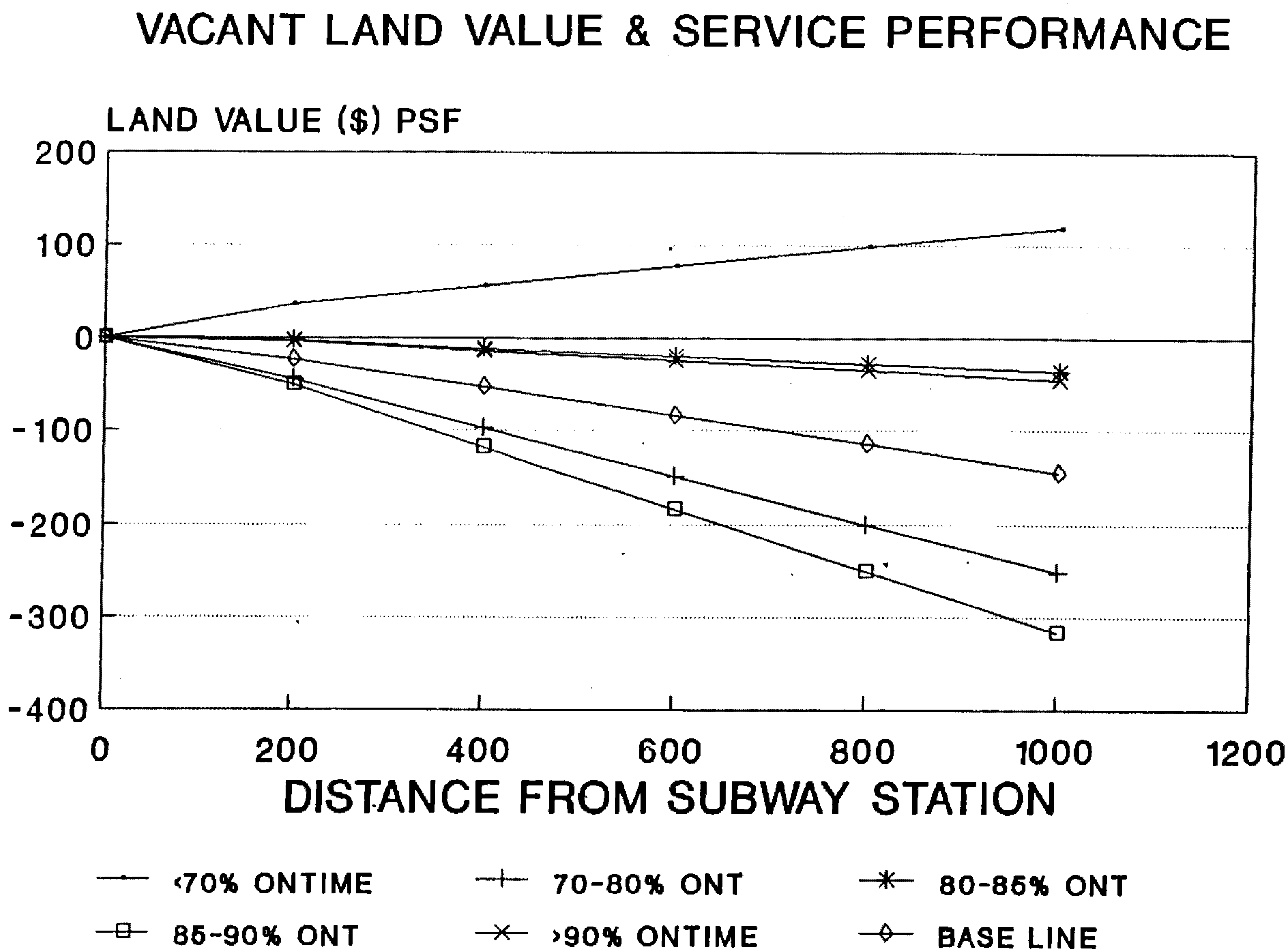
<u>Transit Service Performance</u> Where transit access is provided on subway lines with good on-time performance, the land value gradient around the station declines most steeply if 85% to 90% of trains serving the station are on time. In contrast to infrequency as a poor service measure, the land value gradiant rises with distance when service performance falls below 70% of trains on time. Figure 3.7 displays the relationship for a range of on-time service ratios.

For stations characterized by good performance, or 85% to 90% of trains on time, the declining land value gradient around the stations is expressed as:

$$\begin{aligned} RATLSP\_A_{1,85\%} = {} & 14.273245 - \underset{(.0001)}{0.330308(WDST)} - \underset{(.0118)}{0.194749(ADW)} \\ & - \underset{(.0001)}{0.363665(WDP)} - \underset{(.0001)}{1.688811(POVERTY)} \\ & - \underset{(.4907)}{0.067672(EMP)} - \underset{(.0011)}{0.748352(MIDTM)} \\ & - \underset{(.2577)}{0.236821(DNTM)} - \underset{(.1531)}{0.147939(CRIME_{rape})} \end{aligned}$$

$$R^2 = .2840$$

Figure 3.7


VACANT LAND VALUE & SERVICE PERFORMANCE
LAND VALUE ($) PSF
200
100
0
-100
-200
-300
-400
0
200
400
600
800
1000
1200
DISTANCE FROM SUBWAY STATION
‹70% ONTIME
70-80% ONT
80-85% ONT
85-90% ONT
›90% ONTIME
BASE LINE

For stations characterized by poor performance, or fewer than 70% of trains on time, an inclining land value gradient is expressed around stations, though the variable (WDST) and others in the relationship (ADW, WDP, EMP) are not statistically significant:

$$
\begin{aligned}
RATLSP\_A_{1,<70\%} = {} & 14.964496 + \underset{(.5816)}{0.104326(WDST)} - \underset{(4328)}{0.169014(ADW)} \\
& + \underset{(.2152)}{0.258649(WDP)} - \underset{(.0107)}{2.411789(POVERTY)} \\
& - \underset{(.8816)}{0.035875(EMP)} + \underset{(1226)}{0.853427(MIDTM)} \\
& - \underset{(.0041)}{4.469728(DNTM)} + \underset{(.0001)}{1.562422(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .2639$$

As Figure 3.7 shows at 400 meters, or one quarter mile from a transit station, the unit land values around poor performance stations will have risen by $57 per square foot above station area values, while those around good performance stations will have declined by $118 per square foot of land area. The land value benefit conferred by good on-time performance is greater than that of frequent train service but less than that of express/transfer/ terminal service at the station.

<u>New Versus Rehabilitated Cars on Line</u> Where transit access is provided by stations on subway lines that utilize new cars, or a high proportion of rehabilitated cars, the land value gradient from the station declines steeply with distance. This benefit compares to that of stations with no new cars in service, where land value inclines with distance from the station, and to stations where a lower proportion of the fleet consists of rehabilitated cars in service. In the latter case, the land value gradient declines less steeply from the station.

For stations characterized by new car service, the declining land value gradient around the station is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,new} = {} & 5.166884 - \underset{(.0001)}{0.153044(WDST)} - \underset{(.0024)}{0.108769(ADW)} \\
& - \underset{(.2058)}{0.046117(WDP)} - \underset{(.0001)}{0.748346(POVERTY)} \\
& + \underset{(.0001)}{0.251264(EMP)} - \underset{(.0009)}{0.318351(MIDTM)} \\
& - \underset{(.0008)}{0.256777(DNTM)} - \underset{(.0531)}{0.078897(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .1100$$

For stations characterized by no new car service, the inclining land value gradient around the station is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,nonew} = {} & 7.935736 + \underset{(.8205)}{0.017872(WDST)} - \underset{(.1723)}{0.091932(ADW)} \\
& - \underset{(.0422)}{0.134116(WDP)} - \underset{(.0003)}{0.631724(POVERTY)} \\
& + \underset{(.1116)}{0.182023(EMP)} - \underset{(.0001)}{1.177214(MIDTM)} \\
& - \underset{(.0025)}{0.493342(DNTM)} - \underset{(.0258)}{0.260510(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .3473$$

As Figure 3.8 shows, at 400 meters or one quarter mile from a transit station, the value of land accessible to stations with new car service is $56 less per square foot than at the station, while the value of land accessible to stations without new car service is $15 more per square foot than at the station. Compared to stations with rehabilitated cars in service, the availability of new cars on lines creates little additional benefit capitalized into land value than does a high proportion of rehabilitated stock in service.

For stations served by a high proportion of rehabilitated cars in service, the declining land value gradient around the station (as based upon 25-49% rehabilitated cars) is best expressed as:

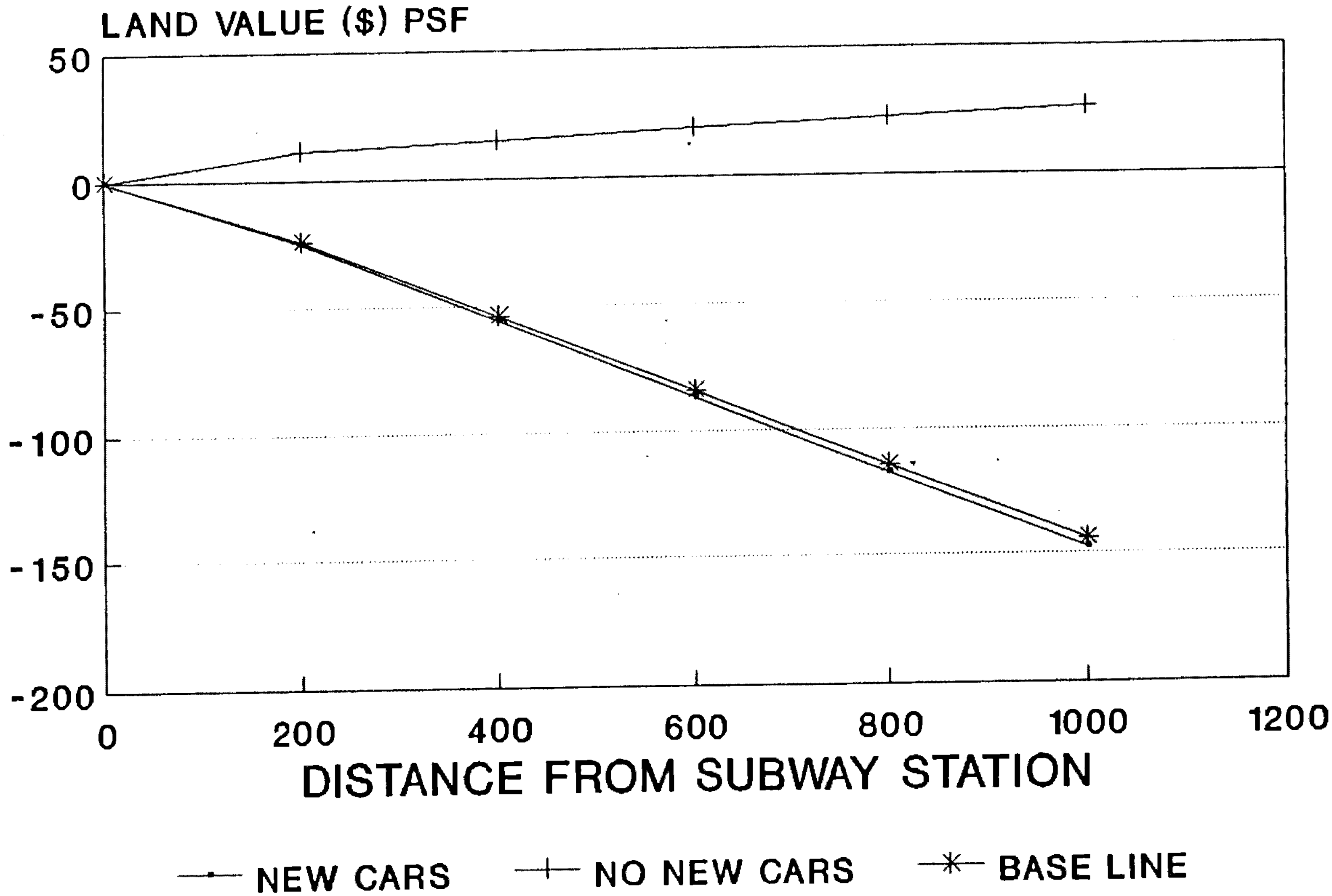
$$
\begin{aligned}
RATLSP\_A_{1,25\%} = {} & 3.441550 - \underset{(.0432)}{0.139301(WDST)} + \underset{(.3382)}{0.061075(ADW)} \\
& - \underset{(.3476)}{0.058836(WDP)} - \underset{(.0001)}{0.837717(POVERTY)} \\
& + \underset{(.0001)}{0.446294(EMP)} - \underset{(.0001)}{0.668640(MIDTM)} \\
& - \underset{(.8679)}{0.021563(DNTM)} - \underset{(.0130)}{0.149987(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .2457$$

For stations served by a low proportion of rehabilitated cars in service, the less steeply declining land value gradient around the station (as based upon 1-24% rehabilitated cars) is best expressed as:

Figure 3.8

VACANT LAND VALUE AND NEW CAR SERVICE



$$
\begin{aligned}
RATLSP\_A_{1,1\%} = {} & 9.371033 - \underset{(.1982)}{0.080614(WDST)} - \underset{(.1490)}{0.082027(ADW)} \\
& - \underset{(.0979)}{0.092555(WDP)} - \underset{(.0001)}{0.789820(POVERTY)} \\
& + \underset{(.2775)}{0.091216(EMP)} - \underset{(.0001)}{1.318767(MIDTM)} \\
& - \underset{(.0443)}{0.342058(DNTM)} - \underset{(.0088)}{0.253277(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .3116$$

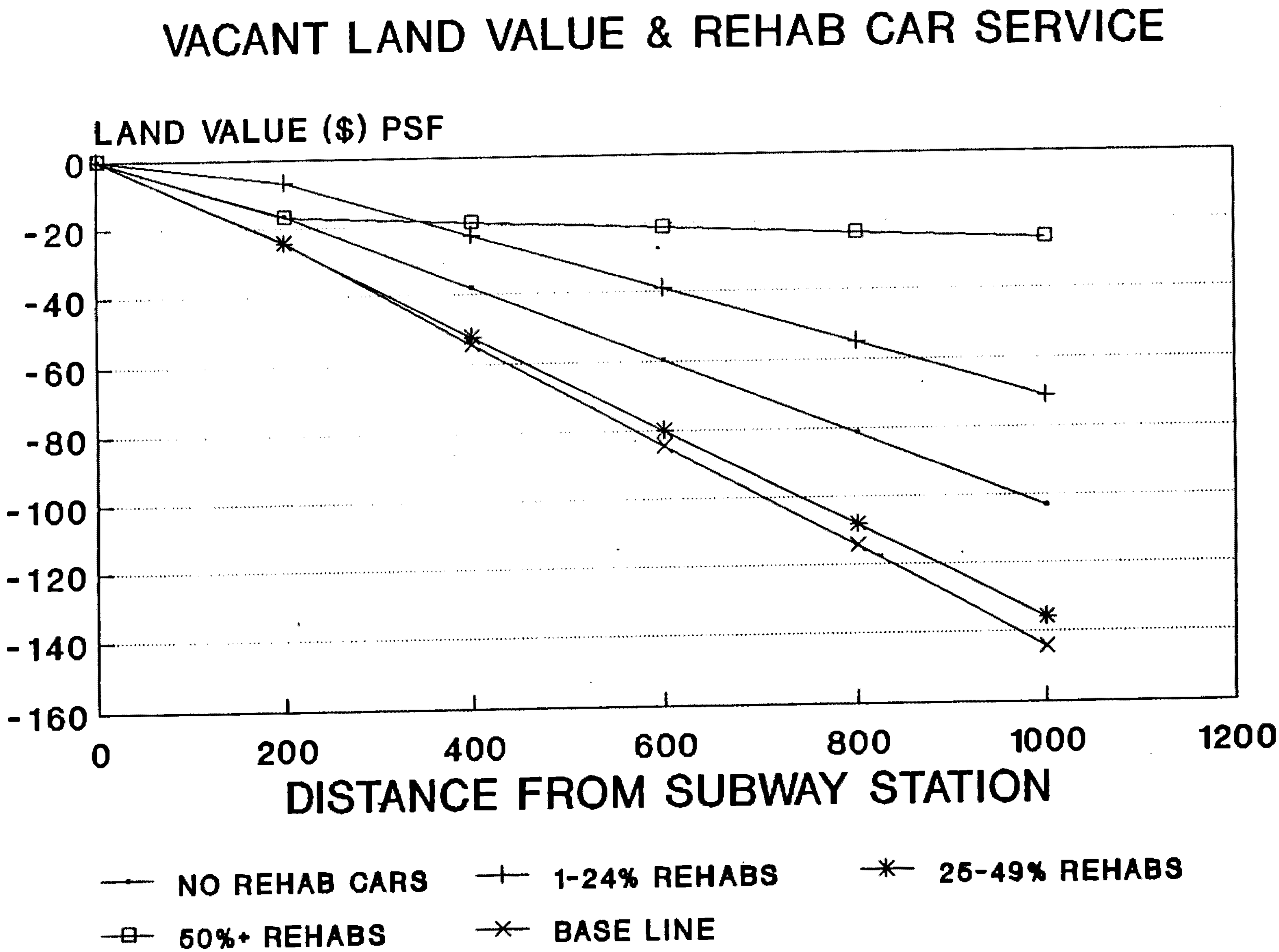
As Figure 3.9 shows, for a range of rehabilitated car ratios, at 400 meters or one quarter mile from the station, the unit value of land will have declined by $52 per square foot with a high proportion of rehabilitated cars in service, compared to $23 per square foot with a low proportion, all other conditions unchanged. The land value equation for stations with more than half of all cars rehabilitated is based upon a small sample of parcels with very low statistical significance for most independent variables.

<u>Passenger Volume at Stations</u> Where transit access is provided by stations with a heavy volume of passengers on an annual basis, the land value benefit for parcels radiating outward from the station increases in direct relation to the passenger load. For stations with more than 3 million annual passengers, as measured in 1987, the land value gradient declines more precipitously than for any other transit operating variable except express, transfer or terminal service. For these stations, the declining land value gradient is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,3M} = {} & 4.256561 - \underset{(.0001)}{0.518521(WDST)} - \underset{(.6238)}{0.042246(ADW)} \\
& - \underset{(.2658)}{0.100036(WDP)} - \underset{(.0023)}{0.733083(POVERTY)} \\
& + \underset{(.0001)}{0.487188(EMP)} - \underset{(.0649)}{0.333377(MIDTM)} \\
& - \underset{(.0244)}{0.369624(DNTM)} + \underset{(.4281)}{0.070307(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .3372$$

Figure 3.9


VACANT LAND VALUE & REHAB CAR SERVICE
LAND VALUE ($) PSF
0
-20
-40
-60
-80
-100
-120
-140
-160
0
200
400
600
800
1000
1200
DISTANCE FROM SUBWAY STATION
NO REHAB CARS
1-24% REHABS
25-49% REHABS
50%+ REHABS
BASE LINE

For stations with half that volume of riders, or 1.5 to 2 million annual passengers in 1987, the land value gradient declines in a manner comparable to the rate for stations with the highest frequency transit service. For these stations, the declining land value gradient is expressed as:

$$\begin{aligned} RATLSP\_A_{1,1.5M} = {} & 9.395395 - \underset{(.0243)}{0.248132(WDST)} - \underset{(.4230)}{0.079391(ADW)} \\ & + \underset{(.1007)}{0.158562(WDP)} - \underset{(.2705)}{0.256933(POVERTY)} \\ & - \underset{(.0482)}{0.277773(EMP)} - \underset{(.1110)}{0.529244(MIDTM)} \\ & - \underset{(.0676)}{0.311163(DNTM)} - \underset{(.0001)}{0.413986(CRIME_{rape})} \end{aligned}$$

$$R^2 = .0966$$

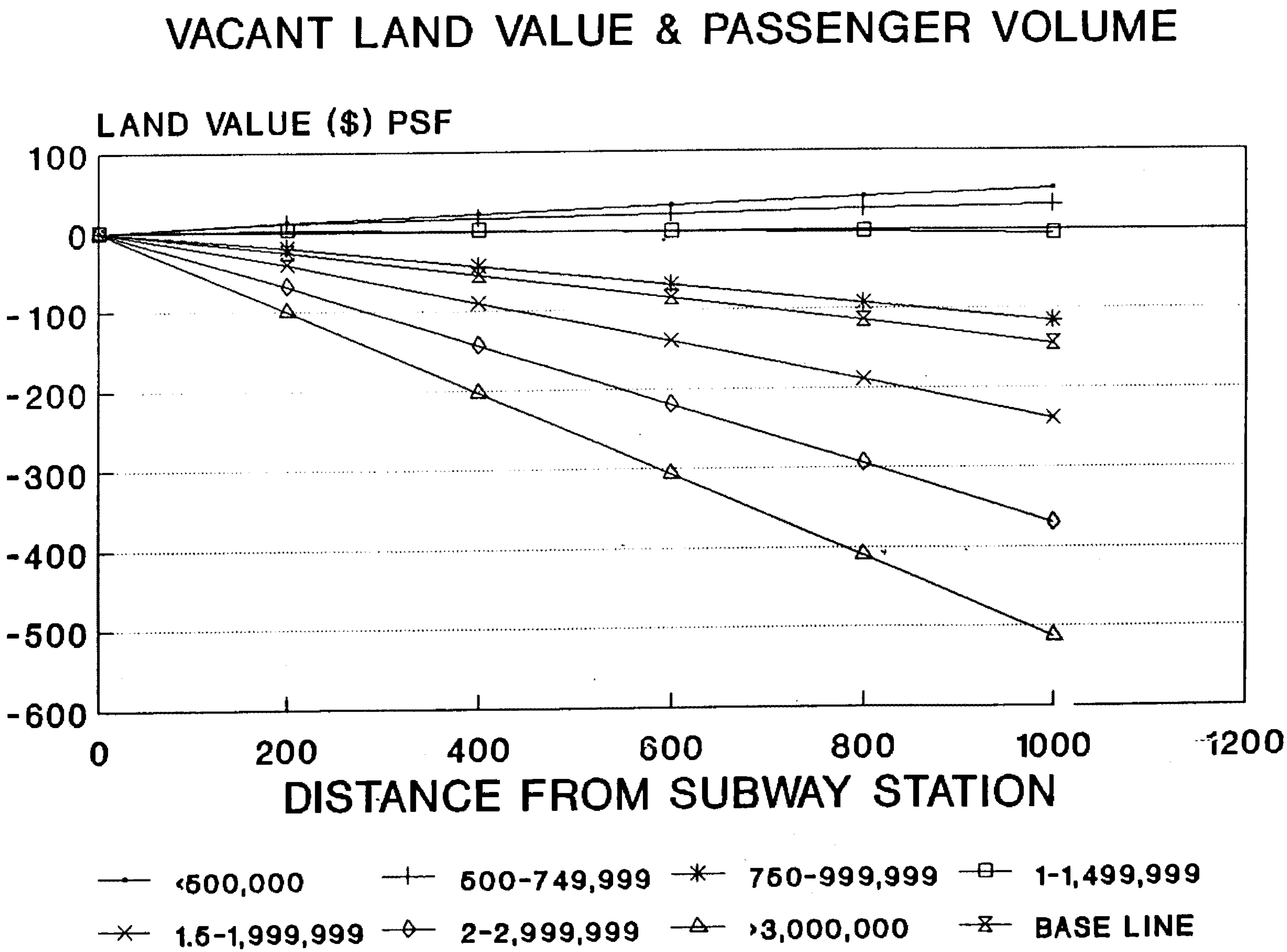
For stations with the lowest passenger volume, or less than three quarters of a million annual riders, land value is shown to rise with increasing distance from the station though the variable (WDST) is not statistically significant. The loss of benefit for surrounding parcels is roughly comparable to that incurred by access to the newest (open cut) stations or to stations without new cars in service. For these low volume stations, the inclining land value gradient is best expressed as:

$$\begin{aligned} RATLSP\_A_{1,.5M} = {} & 2.812042 + \underset{(.5351)}{0.047616(WDST)} - \underset{(.4869)}{0.050258(ADW)} \\ & - \underset{(.3670)}{0.060645(WDP)} - \underset{(.0001)}{0.918253(POVERTY)} \\ & + \underset{(.0110)}{0.249858(EMP)} + \underset{(.0725)}{0.500790(MIDTM)} \\ & - \underset{(.2311)}{0.279736(DNTM)} + \underset{(.4309)}{0.095927(CRIME_{rape})} \end{aligned}$$

$$R^2 = .1347$$

As Figure 3.10 shows, at 400 meters or one quarter mile from a transit station, parcels accessible to high volume stations (3 million or more passengers annually) are valued at $203 less per square foot than parcels at the station, while parcels accessible to moderate volume stations (1.5 to 2 million passengers annually) are valued at $90 less per square foot than parcels at the station, all other conditions unchanged. For parcels 400 meters distant from a low volume station (less than 500,000 passengers annually), the unit value of land is $22 greater than at the station.

Figure 3.10



VACANT LAND VALUE & PASSENGER VOLUME
LAND VALUE ($) PSF
100
0
-100
-200
-300
-400
-500
-600
0
200
400
600
800
1000
1200
DISTANCE FROM SUBWAY STATION
<500,000
500-749,999
750-999,999
1-1,499,999
1.5-1,999,999
2-2,999,999
>3,000,000
BASE LINE

<u>Crowding Conditions at the Station</u> As measured for stations by station-to-station segments, crowding on trains in the morning rush hour between 8:00 and 9:00 a.m. is an indicator of service quality or level of comfort. It pertains to conditions at the station and does not reflect the quality of the rest of the transit trip. Three levels considered were determined by volume/capacity ratios: High crowding prevails when standees are in physical contact (V/C > 1.00); moderate crowding when some passengers remain standing (V/C .35 - 1.00); and low crowding when seats are available (V/C < .35).

Where transit access is provided by stations that have high crowding ratios, the land value gradient declines rapidly with distance from the station. High crowding, which correlates strongly with moderate to heavy passenger volume, confers a higher relative benefit level than good on-time performance. For stations with high crowding ratios, the land value gradient is expressed as:

$$\begin{aligned} RATLSP\_A_{1,HC} = {} & 6.1252657 - \underset{(.0003)}{0.343086(WDST)} - \underset{(.0173)}{0.223225(ADW)} \\ & + \underset{(.1832)}{0.136292(WDP)} - \underset{(.1201)}{0.431209(POVERTY)} \\ & + \underset{(.1846)}{0.156470(EMP)} - \underset{(.0146)}{0.523280(MIDTM)} \\ & - \underset{(.0001)}{0.786779(DNTM)} + \underset{(.2871)}{0.142285(CRIME_{rape})} \end{aligned}$$

$$R^2 = .1977$$

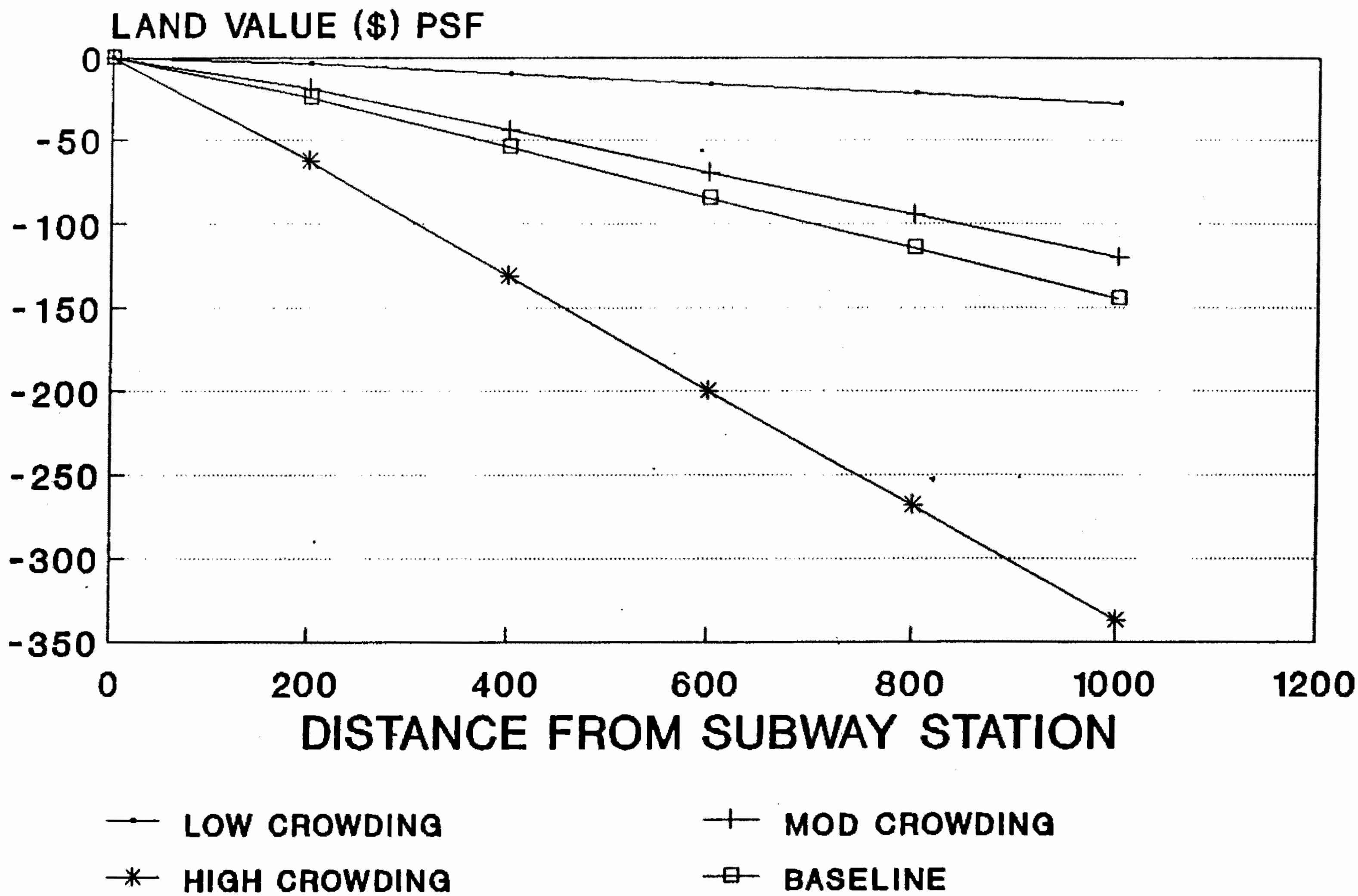
For stations with moderate crowding ratios, the lower order of benefit conferred by access to the station is in keeping with the vacant land baseline or the sloping land value relationship around stations of low to moderate service frequency. For these stations, the declining land value gradients are expressed as:

$$\begin{aligned} RATLSP\_A_{1,MC} = {} & 6.148581 - \underset{(.0061)}{0.125631(WDST)} + \underset{(.5500)}{0.026026(ADW)} \\ & - \underset{(.0099)}{0.109934(WDP)} - \underset{(.0001)}{0.619193(POVERTY)} \\ & + \underset{(.0013)}{0.191274(EMP)} - \underset{(.0001)}{1.148254(MIDTM)} \\ & + \underset{(.7964)}{0.028467(DNTM)} - \underset{(.0001)}{0.182289(CRIME_{rape})} \end{aligned}$$

$$R^2 = .1532$$

Figure 3.11

VACANT LAND VALUE & SUBWAY CONDITIONS



For stations with low crowding ratios, a shallow declining land value gradient is shown around stations -- comparable to that surrounding the system's oldest transit stations -- though the relationship is not statistically significant. Other independent variables have coefficients with questionable signs in the equation. The relationship is expressed as:

$$
\begin{aligned}
RATLSP\_A_{1,LC} = {} & 1.901604 - \underset{(.6476)}{0.029632(WDST)} - \underset{(.1814)}{0.080571(ADW)} \\
& + \underset{(.8979)}{0.007595(WDP)} - \underset{(.0001)}{0.700934(POVERTY)} \\
& + \underset{(.0001)}{0.431639(EMP)} - \underset{(.8027)}{0.054255(MIDTM)} \\
& - \underset{(.6783)}{0.068809(DNTM)} - \underset{(.2669)}{0.109566(CRIME_{rape})}
\end{aligned}
$$

$$R^2 = .0962$$

As Figure 3.11 shows, at 400 meters or one quarter mile from a station, the loss in land value with declining access to transit characterized by high crowding ratios, or low levels of comfort, is $131 per square foot of land area. By comparison, stations with moderate crowding ratios or some standees on the train service are associated with a $44 loss in land value at the distance of one quarter mile from the station, while a low crowding ratio (or a high level of comfort) explains relatively little change in land value around the stations, or $10 per square foot at one quarter mile from the station.

Types of Simulation

NYSTA can be utilized independently, or in conjunction with NYREG which would serve as a driver or predictor of change in transit ridership or land use demand. Used independently, NYSTA can be applied to conditions around specific transit stations, or to the entire landscape of land value and development patterns within walking distance of stations in the transit service territory. The applications can be either to existing conditions, to determine the underlying land value attributable to existing transit access, or to proposed changes in transit operating characteristics or site conditions, to determine the incremental or decremental value added. Despite the fact that NYSTA equations and graphs present citywide averages in property values, and that divergent values exist for each site simulated, the slope of equations can be superimposed upon site conditions to adjust for underlying value differences. In the future, equations calibrated for boroughs and corridors will improve this fit.

The first type of application would calibrate the sloping value/distance relationships of NYSTA to existing site-specific land uses or transit station characteristics to determine the aggregate producers surplus or capitalized value of land attributable to transit access, separate from land value attributable to other features of the location. The existing conditions application of NYSTA may be considered a Base Run. Its usefulness is most apparent in establishing the transit-related land value of a particular site, say, for calculating a developer assessment or negotiating a bonus, or for determining the areawide potential yield of a land value tax given alternative rates of taxation.

The second type of application would change transit operating or policy characteristics for individual stations or for the system as a whole in order to determine the station area land value implications or to measure the aggregate service area benefits of a particular systemwide action. These changes may include the removal of elevated structures, the introduction of new cars on certain transit lines, the elimination of service or reduction of service frequencies at certain stations, and the opening of new routes. In applying NYSTA to issues of this nature, the simulation may be considered a Policy Run. Its applicability is greatest in transportation planning analysis when value capture methods of financing new service changes or proposed investments are of interest and the cost-benefit worthiness of the approach is under consideration.

**Table 3.3 Vacant Land Model Comparisons:
Land Value Impacts of Distance from Transit Stations**

Vacant Land Model Equation	Regress Coeffic	Stat Signif: Prob > T	Chge in $/psf of Land Value with distance from transit station	
			200 meters	400 meters
Base Model	-0.1501	0.0001	($24.29)	($54.31)
Tunnel Structure	-0.1931	0.0001	($32.12)	($70.75)
Exprss/Itchg/Term	-0.5487	0.0001	($101.70)	($211.44)
Built 1920-1928	-0.2970	0.0008	($50.17)	($109.56)
Built 1932-1941	-0.3027	0.0001	($54.92)	($115.47)
250+ Trains/24Hr	-0.2091	0.0001	($35.11)	($76.94)
70-80% On Time	-0.2572	0.0004	($45.73)	($97.18)
85-90% On Time	-0.3303	0.0001	($51.79)	($117.85)
New Cars	-0.1530	0.0001	($25.44)	($56.05)
No Rehab Cars	-0.1079	0.0462	($16.55)	($38.13)
25-49% Rehab Cars	-0.1393	0.0432	($24.42)	($52.28)
Mod Crowding am	-0.1256	0.0061	($18.98)	($44.10)
High Crowding am	-0.3431	0.0003	($62.49)	($131.11)
1.5-2 Mil Psgrs	-0.2481	0.0243	($40.23)	($89.86)
2-3 Mil Psgrs	-0.3775	0.0050	($67.97)	($143.48)
3 Mil + Psgrs	-0.5185	0.0001	($99.45)	($203.15)

Note: Shown only for equations with statistically significant estimated values for WDST.

CHAPTER FOUR

ILLUSTRATIVE APPLICATIONS OF NYREG AND VALUE CAPTURE IMPLICATIONS

We now report the results of seven equilibrium simulations performed by means of the calibrated NYREG model. Simulations 1 through 5 are based on travel times between model zones derived from the reported 1980 Census times. Simulations 6 and 7 are based on network travel times between model zones. The results of several variants of the major simulations are also shown.

In each of these simulations, the base travel times are changed in some assumed manner and NYREG is run to determine the impact of the change on mode splits for commuting and shopping trips, on changes in housing rents by housing type and model zone, on changes in commercial rent per square foot by shopping zone, and on the benefits (consumer surplus, producer surplus in the housing market, and producer surplus in the commercial floor space market). Each simulation is presented in three sets of tables (Set 1 for modal splits, Set 2 for rents, Set 3 for benefit changes). Variants of a simulation are presented only for benefit changes.

The most important of these simulations are now discussed in detail.

Equilibrium Simulation 1: A Decrease in Subway Commuting Times

In this simulation subway commuting times are reduced by 5% for all origin destination pairs on which subway travel is feasible. It can be seen from the table on modal splits, that subway ridership increases by nearly 1.5% while the competing modes lose some ridership. Because of the savings in commuting time, shopping trips by both modes increase as households allocate some of the time saved in commuting to shopping travel.

Because most subway commuting is oriented to Manhattan, the reduced subway travel times allow some households to relocate to the surrounding boroughs. Hence, rents in Queens, the Bronx and Brooklyn increase while rents in Manhattan decrease. Relatedly, vacancies in Manhattan increase while those in the other boroughs decrease. Because of the increased shopping demand, commercial rents increase in each borough.

From the benefits table, we can see that the benefits are significant. The producer surplus in the housing market increases by a little over $50 million dollars per year and that in the commercial market by close to $9 million per year. This occurs despite the fact that 97% of the benefits are in the form of higher utility levels captured by the travelers.

From the value capture standpoint, only the producer surplus changes can possibly be taxed to raise revenues. Such a tax would amount to an average of $13 per dwelling unit and an average of 5 cents per commercial square foot. The overall benefit (including consumer surplus) is $661 per commuter per year.

Table 4.1 A 5% Decrease in All Subway Commuting Times: Mode Splits, Change in Housing Rents, Change in Commercial Rents, and Change in Benefits

Mode Splits

Commuting Trips (One Way, Daily)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	1,629,217	1,621,425 (-0.48)	43.22	43.02 (-0.48)
Bus	436,434	432,057 (-1.00)	11.58	11.46 (-1.00)
Rail	109,845	108,357 (-1.35)	2.91	2.87 (-1.35)
Subway	1,122,626	1,139,291 (1.48)	29.78	30.22 (1.48)
Walk & Other	471,410	468,378 (-0.64)	12.51	12.43 (-0.64)

Shopping Trips (One Way, Annual)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	768,414,784	771,414,784 (0.39)	51.11	51.11 (-0.01)
Transit & Other	734,915,840	737,894,784 (0.41)	48.89	48.89 (0.01)

Table 4.1 (Continued)

Change in Housing Rents

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	-	-	-	-	-	-
Queens	4,345	4,376 (0.71)	311,488	312,053 (0.18)	4.61	4.44 (-3.75)
Brooklyn	4,348	4,393 (1.04)	240,020	240,576 (0.23)	5.20	4.98 (-4.22)
Bronx	4,378	4,416 (0.86)	69,669	69,799 (0.19)	5.97	5.79 (-2.96)
Outside	5,049	5,049* (0.00)	565,519	563,984 (-0.28)	2.69	2.77 (3.19)

Housing Type: Condo (k=2)*

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	5,167	5,121 (-0.89)	34,264	34,163 (-0.29)	7.78	8.05 (3.49)
Queens	4,197	4,226 (0.69)	14,091	14,110 (0.14)	3.82	3.69 (-3.49)
Brooklyn	3,957	3,987 (0.75)	2,737	2,742 (0.16)	5.99	5.83 (-2.56)
Bronx	2,746	2,767 (0.75)	12,542	12,570 (0.22)	8.59	8.38 (-2.37)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.
** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Table 4.1 (Continued)

Housing Type: Apartment (k=3)

	Rent Before	Rent After (%change)	Housing Demand Before	Housing Demand After (%change)	Vacancy Rate Before	Vacancy Rate After (%change)
Manhattan	4,563	4,538 (-0.55)	667,109	666,301 (-0.12)	6.77	6.88 (1.67)
Queens	4,335	4,367 (0.73)	386,992	387,673 (0.18)	4.40	4.24 (-3.82)
Brooklyn	3,652	3,687 (0.97)	588,273	589,565 (0.22)	6.57	6.37 (-3.21)
Bronx	3,517	3,547 (0.86)	347,027	347,709 (0.20)	5.93	5.74 (-3.21)
Outside	5,520	5,520* (0.00)	259,277	258,630 (-0.25)	2.60	2.67 (2.62)

* Housing rents outside the four boroughs are fixed.

<u>Change in Commercial Rents</u>

	Rent* Before	Rent* After (%change)	Shopping Demand** Before	Shopping Demand** After (%change)
Manhattan	23.96	24.15 (0.82)	566,932	569,268 (0.41)
Queens	6.49	6.55 (0.83)	268,671	269,785 (0.42)
Brooklyn	4.40	4.44 (0.83)	311,128	312,426 (0.42)
Bronx	3.62	3.65 (0.73)	151,715	152,272 (0.37)
Outside	-	-	209,164	209,904 (0.35)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Table 4.1 (Continued)

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$2,434,011,000/year = $645/worker/year	0.22	97.62
Producer Surplus	$50,366,576/year = $13/house/year	0.53	2.02
Total Rent	$49,146,882/year = $13/house/year	0.32	
Commercial			
Producer Surplus	$8,925,007 $/year = $0.05/sq ft/year	0.82	0.36
Total Rent	$13,407,232/year = $0.08/sq ft/year	0.82	

Total Benefit = $2,493,302,583/year
= $661/worker/year
= $675/house/year

By decreasing subway times by 10%, rather than 5%, bigger impacts are produced with the result that benefits increase roughly by a factor of two.[16] In this case, the value capture tax would be $28 per dwelling unit and 10 cents per commercial square foot. By adjusting the values of two key parameters to obtain somewhat different travel time and housing rent elasticities of location demand, the results are also shown to vary somewhat in terms of taxable (aggregate producer surplus) and non-taxable (aggregate consumer surplus) benefits, but they are within a reasonable band of the result of the first simulation. For these alternatives, Table 4.2 shows only the change in benefits; first for a doubling of the decrease in subway commuting times, and then for different travel time and housing rent elasticities.

[16] This rough doubling happens because, in the model, the effects of travel time changes are roughly linear for relatively small increments.

Table 4.2 A 10% Decrease in All Subway Commuting Times: Change in Benefits

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$4,878,515,000/year = $1,294/worker/year	0.44	97.50
Producer Surplus	$107,053,346/year = $29/house/year	1.12	2.14
Total Rent	$103,348,220/year = $28/house/year	0.67	
Commercial			
Producer Surplus	$18,196,905/year = $0.10/sq ft/year	1.67	0.36
Total Rent	$27,275,776/year = $0.16/sq ft/year	1.67	

Total Benefit = $5,003,765,251/year
= $1,327/worker/year
= $1,356/house/year
= $1.48/trip

Table 4.3 A 5% Decrease in All Subway Commuting Times And A Change in Time and Rent Elasticities: Change in Benefits for Two Elasticity Alternatives

Change in Benefits

Δ =2.5 (from Δ = 1.8 in simulation 1)
Time Elasticity = - 0.61 (up from -0.383)
Rent Elasticity = - 0.47 (up from -0.380)

	Change of Level	%change	Benefit Share(%)
Housing Consumer Surplus	$4,593,904,000/year = $1,219/worker/year	0.45	99.10
Producer Surplus	$32,794,276/year = $8.9/house/year	0.32	0.71
Total Rent	$29,347,863/year = $7.9/house/year	0.18	
Commercial Producer Surplus	$8,858,332/year = $0.05/sq ft/year	1.14	0.19
Total Rent	$13,275,665 $/year = 0.076/sq ft/year	1.14	

Total Benefit = $4,635,556,608/year
= $1,229/worker/year
= $1,257/house/year
= $1.46/trip

Table 4.3 (Continued)

Change in Benefits

ß=0.05 (from ß=0.25 in simulation 1)
Time Elasticity = - 0.48 (up from -0.383)
Rent Elasticity = - 0.57 (up from -0.380)

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$1,758,283,000/year = $466/worker/year	0.19	96.01
Producer Surplus	$65,358,090/year = $17.7/house/year	0.60	3.57
Total Rent	$61,081,082/year = $16.5/house/year	0.36	
Commercial			
Producer Surplus	$7,604,550/year = $0.04/sq ft/year	0.72	0.42
Total Rent	$11,396,669/year = $0.066/sq ft/year	0.72	

Total Benefit = $1,831,245,640/year
= $486/worker/year
= $496/house/year
= $0.54/trip

Equilibrium Simulation 2: A Decrease in Transit and Shopping Times

In this simulation, the 5% decrease in travel times is applied to the subway commuting times as well as to all non-auto modes of shopping travel. Aggregate benefits are, of course, higher. The sum of the two producer surpluses is approximately the same as in the first simulation, except that the share of the commercial producer surplus is larger than before. All results are shown for mode splits, change in housing rents, change in commercial rents, and change in benefits.

Table 4.4 A 5% Decrease in All Subway Commuting Times And a 5% Decrease in All Transit and Other Shopping Times

Mode Splits

Commuting Trips (One Way, Daily)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	1,629,217	1,621,638 (-0.47)	43.22	43.02 (-0.47)
Bus	436,434	432,046 (-1.01)	11.58	11.46 (-1.01)
Rail	109,845	108,545 (-1.18)	2.91	2.88 (-1.18)
Subway	1,122,626	1,139,220 (1.48)	29.78	30.22 (1.48)
Walk & Other	471,410	468,075 (-0.71)	12.51	12.42 (-0.71)

Shopping Trips (One Way, Annual)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	768,414,784	771,598,848 (0.41)	51.11	50.82 (-0.58)
Transit & Other	734,915,840	746,737,344 (1.61)	48.89	49.18 (0.60)

Table 4.4 (Continued)

Change in Housing Rents

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	-	-	-	-	-	-
Queens	4,345	4,381 (0.83)	311,488	312,052 (0.21)	4.61	4.40 (-4.42)
Brooklyn	4,348	4,393 (1.03)	240,020	240,578 (0.23)	5.20	4.98 (-4.23)
Bronx	4,378	4,412 (0.77)	69,669	69,786 (0.17)	5.97	5.81 (-2.65)
Outside	5,049	5,049* (0.00)	565,519	564,320 (-0.21)	2.69	2.78 (3.49)

Housing Type: Condo (k=2)*

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	5,167	5,096 (-1.38)	34,264	34,103 (-0.47)	7.78	8.21 (5.58)
Queens	4,197	4,230 (0.80)	14,091	14,113 (0.16)	3.82	3.67 (-4.06)
Brooklyn	3,957	3,984 (0.68)	2,737	2,741 (0.14)	5.99	5.86 (-2.14)
Bronx	2,746	2,772 (0.96)	12,542	12,578 (0.29)	8.59	8.32 (-3.06)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.

** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Table 4.4 (Continued)

Housing Type: Apartment (k=3)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	4,563	4,515 (-1.04)	667,109	665,371 (-0.26)	6.77	7.01 (3.59)
Queens	4,335	4,370 (0.80)	386,992	387,755 (0.20)	4.40	4.22 (-4.28)
Brooklyn	3,652	3,686 (0.94)	588,273	589,527 (0.21)	6.57	6.37 (-3.03)
Bronx	3,517	3,546 (0.83)	347,027	347,700 (0.19)	5.93	5.74 (-3.08)
Outside	5,520	5,520* (0.00)	259,277	258,873 (-0.16)	2.60	2.65 (1.75)

* Housing rents outside the four boroughs are fixed.

<u>Change in Commercial Rents</u>

	Rent*		Shopping Demand**	
	Before	After (%change)	Before	After (%change)
Manhattan	23.96	24.48 (2.17)	566,932	573,109 (1.09)
Queens	6.49	6.61 (1.86)	268,671	271,199 (0.94)
Brooklyn	4.40	4.49 (2.00)	311,128	314,178 (0.98)
Bronx	3.62	3.68 (1.72)	151,715	153,039 (0.87)
Outside	-	-	209,164	211,184 (0.97)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Table 4.4 (Continued)

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing Consumer Surplus	$3,090,894,000/year = $820/worker/year	0.28	98.15
Producer Surplus	$35,920,597/year = $9.7/house/year	0.38	1.14
Total Rent	$34,026,343/year = $9.2/house/year	0.22	
Commercial Producer Surplus	$22,446,885/year = $0.13/sq ft/year	2.06	0.71
Total Rent	$33,640,346/year = $0.19/sq ft/year	2.06	

Total Benefit = $3,149,261,482/year
= $835/worker/year
= $853/house/year
= $0.92/trip

Equilibrium Simulation 3: A Decrease in Rail Commuting Times

Simulation 3 shows that a 5% decrease in the travel times of suburban rail is not as beneficial as a 5% decrease in subway travel times. In fact, the effect of this scenario is to reduce rents in each of the four boroughs as households find it less time-consuming to locate in the suburbs and commute into the City by rail. However, the benefits accruing to the suburban areas are underestimated, since the rents in the suburban model zones were fixed because suburban housing stock data was not available.

As Table 4.5 shows, the effects on the taxable (aggregate producer surplus) portion of benefits is negative. These effects are exacerbated in an alternative scenario which decreases commuter rail travel times by 10%. In this instance, land value benefits for commercial property owners increase, but not sufficiently to offset the worsening of producer surpluses in housing. For this alternative, only the change in benefits is shown by land use type (Table 4.6).

Table 4.5 A 5 % Decrease in All Rail Commuting Times: Mode Splits, Change in Housing Rents, Change in Commercial Rents, and Change in Benefits

<u>Mode Splits</u>

Commuting Trips (One Way, Daily)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	1,629,217	1,627,891 (-0.08)	43.22	43.19 (-0.08)
Bus	436,434	435,800 (-0.15)	11.58	11.56 (-0.15)
Rail	109,845	114,225 (4.17)	2.91	3.04 (4.17)
Subway	1,122,626	1,120,427 (-0.20)	29.78	29.72 (-0.20)
Walk & Other	471,410	470,991 (-0.09)	12.51	12.50 (-0.09)

Shopping Trips (One Way, Annual)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	768,414,784	769,191,296 (0.10)	51.11	51.11 (0.00)
Transit & Other	734,915,840	735,635,264 (0.10)	48.89	48.89 (0.00)

Table 4.5 (Continued)

<u>Change in Housing Rents</u>

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	-	-	-	-	-	-
Queens	4,345	4,337	311,488	311,275	4.61	4.67
		(-0.17)		(-0.07)		(1.41)
Brooklyn	4,348	4,341	240,020	239,847	5.20	5.27
		(-0.18)		(-0.07)		(1.32)
Bronx	4,378	4,372	69,669	69,623	5.97	6.03
		(-0.13)		(-0.07)		(1.03)
Outside	5,049	5,049*	565,519	566,455	2.69	2.53
		(0.00)		(0.16)		(-5.94)

Housing Type: Condo. (k=2)*

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	5,167	5,155	34,264	34,226	7.78	7.88
		(-0.23)		(-0.11)		(1.31)
Queens	4,197	4,186	14,091	14,080	3.82	3.89
		(-0.25)		(-0.08)		(1.91)
Brooklyn	3,957	3,948	2,737	2,735	5.99	6.07
		(-0.22)		(-0.09)		(1.35)
Bronx	2,746	2,739	12,542	12,531	8.59	8.67
		(-0.24)		(-0.09)		(0.99)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.
** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Table 4.5 (Continued)

Housing Type: Apartment (k=3)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	4,563	4,552 (-0.25)	667,109	666,431 (-0.10)	6.77	6.86 (1.40)
Queens	4,335	4,324 (-0.24)	386,992	386,695 (-0.08)	4.40	4.48 (1.67)
Brooklyn	3,652	3,645 (-0.19)	588,273	587,835 (-0.07)	6.57	6.64 (1.06)
Bronx	3,517	3,511 (-0.17)	347,027	346,791 (-0.07)	5.93	5.99 (1.08)
Outside	5,520	5,520* (0.00)	259,277	259,944 (0.26)	2.60	2.31 (-11.15)

* Housing rents outside the four boroughs are fixed.

<u>Change in Commercial Rents</u>

	Rent*		Shopping Demand**	
	Before	After (%change)	Before	After (%change)
Manhattan	23.96	24.00 (0.17)	566,932	567,442 (0.09)
Queens	6.49	6.51 (0.21)	268,671	268,949 (0.10)
Brooklyn	4.40	4.41 (0.19)	311,128	311,437 (0.10)
Bronx	3.62	3.63 (0.23)	151,715	151,888 (0.11)
Outside	-	-	209,164	209,410 (0.12)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Table 4.5 (Continued)

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$1,025,507,328/year = $272/worker/year	0.09	99.82
Producer Surplus	-$23,277,568/year = -$6.3/house/year	-0.25	-
Total Rent	-$23,164,348/year = -$6.28/house/year	-0.15	
Commercial			
Producer Surplus	$1,997,696/year = $0.01/sq ft/year	0.18	0.18
Total Rent	$2,948,797/year = $0.02/sq ft/year	0.18	

Total Benefit = $1,004,227,456/year
= $266/worker/year
= $272/house/year
= $0.66/trip

Table 4.6 A 10% Decrease in All Rail Commuting Times: Changes in Benefits

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$2,073,296,896/year = $550/worker/year	0.19	99.82
Producer Surplus	-$46,990,336/year = -$12.74/house/year	-0.50	-
Total Rent	-$47,798,496/year = -$12.96/house/year	-0.31	
Commercial			
Producer Surplus	$4,159,488/year = $0.02/sq ft/year	0.38	0.18
Total Rent	$6,229,103/year = 0.036/sq ft/year	0.38	

Total Benefit = $2,030,466,048/year
= $538/worker/year
= $550/house/year
= $1.34/trip

Equilibrium Simulation 4: A Decrease in Bus Commuting Times

Simulation 4 demonstrates that a similar effect occurs when a 10% decrease is applied to bus commuting times. The only positive source of value capture is the commercial floor space, as shown in Table 4.7. On the benefit side, a comparison is also shown with a 5% decrease in bus commuting times in Table 4.8.

Table 4.7 A 10% Decrease in All Bus Commuting Times: Mode Splits, Change in Housing Rents, Change in Commercial Rents, and Change in Benefits

Mode Splits

Commuting Trips (One Way, Daily)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	1,629,217	1,622,533 (-0.41)	43.22	43.05 (-0.41)
Bus	436,434	455,005 (4.26)	11.58	12.07 (4.26)
Rail	109,845	108,913 (-0.85)	2.91	2.89 (-0.85)
Subway	1,122,626	1,114,178 (-0.75)	29.78	29.56 (-0.75)
Walk & Other	471,410	468,875 (-0.54)	12.51	12.44 (-0.54)

Shopping Trips (One Way, Annual)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	768,414,784	771,256,768 (0.37)	51.11	51.12 (0.00)
Transit & Other	734,915,840	737,588,160 (0.36)	48.89	48.88 (0.00)

Table 4.7 (Continued)

Change in Housing Rents

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	-	-	-	-	-	-
Queens	4,345	4,334 (-0.24)	311,488	311,327 (-0.05)	4.61	4.66 (1.07)
Brooklyn	4,348	4,332 (-0.38)	240,020	239,793 (-0.09)	5.20	5.29 (1.72)
Bronx	4,378	4,383 (-0.12)	69,669	69,703 (-0.05)	5.97	5.92 (-0.78)
Outside	5,049	5,049* (0.00)	565,519	566,937 (0.25)	2.69	2.45 (-9.11)

Housing Type: Condo. (k=2)*

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	5,167	5,152 (-0.30)	34,264	34,217 (-0.14)	7.78	7.91 (1.62)
Queens	4,197	4,179 (-0.41)	14,091	14,080 (-0.08)	3.82	3.90 (1.98)
Brooklyn	3,957	3,934 (-0.58)	2,737	2,732 (-0.18)	5.99	6.16 (2.80)
Bronx	2,746	2,744 (-0.04)	12,542	12,539 (-0.03)	8.59	8.61 (0.33)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.
** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Table 4.7 (Continued)

Housing Type: Apartment (k=3)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	4,563	4,551 (-0.26)	667,109	666,543 (-0.08)	6.77	6.85 (1.17)
Queens	4,335	4,313 (-0.49)	386,992	386,625 (-0.09)	4.40	4.49 (2.06)
Brooklyn	3,652	3,633 (-0.51)	588,273	587,564 (-0.12)	6.57	6.69 (1.71)
Bronx	3,517	3,522 (0.13)	347,027	347,016 (0.00)	5.93	5.93 (0.05)
Outside	5,520	5,520* (0.00)	259,277	259,534 (0.10)	2.60	2.50 (-3.85)

* Housing rents outside the four boroughs are fixed.

<u>Change in Commercial Rents</u>

	Rent*		Shopping Demand**	
	Before	After (%change)	Before	After (%change)
Manhattan	23.96	24.13 (0.73)	566,932	569,038 (0.37)
Queens	6.49	6.54 (0.73)	268,671	269,635 (0.36)
Brooklyn	4.40	4.43 (0.74)	311,128	312,271 (0.37)
Bronx	3.62	3.65 (0.75)	151,715	152,281 (0.37)
Outside	-	-	209,164	209,907 (0.35)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Table 4.7 (Continued)

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	\$3,060,662,272/year = \$811/worker/year	0.28	99.74
Producer Surplus	-\$33,848,320/year = -\$9.18/house/year	-0.36	-
Total Rent	-\$33,950,581/year = -\$9.20/house/year	-0.22	
Commercial			
Producer Surplus	\$8,012,416/year = \$0.05/sq ft/year	0.74	0.26
Total Rent	\$12,173,091/year = \$0.07 \$/sq ft/year	0.74	

Total Benefit = \$3,034,826,240/year
= \$805/worker/year
= \$822/house/year
= \$2.00/trip

Table 4.8 A 5% Decrease in All Bus Commuting Times: Change in Benefits

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$1,486,356,480/year = $394/worker/year	0.13	99.74
Producer Surplus	-$15,372,288/year = -$4.17/house/year	-0.16	-
Total Rent	-$15,450,828/year = -$4.19/house/year	-0.10	
Commercial			
Producer Surplus	$3,817,472/year = $0.02/sq ft/year	0.35	0.26
Total Rent	$5,735,538/year = $0.03/sq ft/year	0.35	

Total Benefit = $1,474,801,664/year
= $391/worker/year
= $399/house/year
= $0.97/trip

Equilibrium Simulation 5: A Decrease in Auto Commuting and Shopping Times

Simulation 5 confirms a similar result when auto commuting is affected. In this scenario, which simulates the effect of a 5% decrease in all auto commuting and shopping times, the commercial floor space sector represents the only positive source of value capture, as shown in Table 4.9.. This continues to be true when auto shopping times are decreased to 10% along with auto commuting times, as shown for benefits only in Table 4.10.

Table 4.9 A 5% Decrease in All Auto Commuting and Shopping Times: Mode Splits, Change in Housing Rents, Change in Commercial Rents, and Change in Benefits

Mode Splits

Commuting Trips (One Way, Daily)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	1,629,217	1,639,813 (0.65)	43.22	43.50 (0.65)
Bus	436,434	434,178 (-0.52)	11.58	11.52 (-0.52)
Rail	109,845	109,485 (-0.33)	2.91	2.90 (-0.33)
Subway	1,122,626	1,117,120 (-0.49)	29.78	29.64 (-0.49)
Walk & Other	471,410	468,923 (-0.53)	12.51	12.47 (-0.53)

Shopping Trips (One Way, Annual)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	768,414,784	779,404,672 (1.43)	51.11	51.37 (0.50)
Transit & Other	734,915,840	737,774,656 (0.39)	48.89	48.63 (-0.53)

Table 4.9 (Continued)

Change in Housing Rents

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	-	-	-	-	-	-
Queens	4,345	4,362 (0.40)	311,488	311,699 (0.07)	4.61	4.54 (-1.40)
Brooklyn	4,348	4,349 (0.02)	240,020	239,914 (-0.04)	5.20	5.25 (0.80)
Bronx	4,378	4,373 (-0.12)	69,669	69,640 (-0.04)	5.97	6.00 (0.65)
Outside	5,049	5,049* (0.00)	565,519	566,859 (0.23)	2.69	2.46 (-8.55)

Housing Type: Condo (k=2)*

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	5,167	5,124 (-0.84)	34,264	34,165 (-0.29)	7.78	8.05 (3.44)
Queens	4,197	4,206 (0.24)	14,091	14,095 (0.03)	3.82	3.79 (-0.84)
Brooklyn	3,957	3,950 (-0.18)	2,737	2,734 (-0.12)	5.99	6.10 (1.88)
Bronx	2,746	2,747 (0.05)	12,542	12,543 (0.00)	8.59	8.58 (-0.03)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.
** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Table 4.9 (Continued)

Housing Type: Apartment (k=3)

	Rent Before	Rent After (%change)	Housing Demand Before	Housing Demand After (%change)	Vacancy Rate Before	Vacancy Rate After (%change)
Manhattan	4,563	4,521 (-0.91)	667,109	665,324 (-0.27)	6.77	7.02 (3.68)
Queens	4,335	4,337 (0.05)	386,992	387,036 (0.01)	4.40	4.39 (-0.24)
Brooklyn	3,652	3,641 (-0.29)	588,273	587,580 (-0.12)	6.57	6.68 (1.67)
Bronx	3,517	3,504 (-0.37)	347,027	346,668 (-0.10)	5.93	6.02 (1.64)
Outside	5,520	5,520* (0.00)	259,277	259,755 (0.18)	2.60	2.42 (-6.92)

* Housing rents outside the four boroughs are fixed.

Change in Commercial Rents

	Rent* Before	Rent* After (%change)	Shopping Demand** Before	Shopping Demand** After (%change)
Manhattan	23.96	24.36 (1.70)	566,932	571,814 (0.86)
Queens	6.49	6.62 (1.90)	268,671	271,249 (0.96)
Brooklyn	4.40	4.48 (1.82)	311,128	313,926 (0.90)
Bronx	3.62	3.68 (1.77)	151,715	153,056 (0.88)
Outside	-	-	209,164	211,466 (1.10)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Table 4.9 (Continued)

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing Consumer Surplus	$3,115,974,656/year = $826/worker/year	0.28	99.39
Producer Surplus	-$34,036,736/year = -$9.23/house/year	-0.36	-
Total Rent	-$35,490,388/year = -$9.62/house/year	-0.23	
Commercial Producer Surplus	$19,132,800/year = $0.11/sq ft/year	1.76	0.61
Total Rent	$29,245,538/year = $0.17 $/sq ft/year	1.76	

Total Benefit = $3,101,070,848/year
= $822/worker/year
= $840/house/year
= $2.03/trip

Table 4.10 A 10 % Decrease in All Auto Commuting and Shopping Times: Change in Benefits

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$6,305,611,776/year = $1,672/worker/year	0.57	99.39
Producer Surplus	-$70,658,048/year = -$19.16/house/year	-0.75	-
Total Rent	-$73,882,828/year = -$20.03/house/year	-0.48	
Commercial			
Producer Surplus	$39,202,048/year = $0.23/sq ft/year	3.60	0.61
Total Rent	$70,623,180/year = $0.41 $/sq ft/year	3.60	

Total Benefit = $6,274,155,520/year
= $1,664/worker/year
= $1,700/house/year
= $4.07/trip

Equilibrium Simulation 6: The Effect of Network Based Travel Times on Equilibrium

Simulations 6 through 8 were performed after the subway travel times measured as the average reported times from the 1980 Census were replaced by travel times computed from the network. Travel times for the other modes remain to be the Census travel times. The calibrated coefficients were not readjusted for the presence of the network based travel times. Because network based travel times differ from reported travel times, simulation 6 measures the effect of this difference.

The results show that using the network-based subway travel times produces higher levels of benefit and that taxable producer surpluses, as well as non-taxable consumer surpluses, are generated.

Table 4.11 The Effect of Network Based Travel Times on the Equilibrium: Mode Splits, Change in Housing Rents, Change in Commercial Rents, and Change in Benefits

Mode Splits

Commuting Trips (One Way, Daily)

Mode	Trips Reported*	Trips Network** (% change)	Market Share Reported	Market Share Network (% change)
Auto	1,629,217	1,598,786 (-1.87)	43.22	42.42 (-1.87)
Bus	436,434	424,396 (-2.76)	11.58	11.26 (-2.76)
Rail	109,845	105,664 (-3.81)	2.91	2.80 (-3.81)
Subway	1,122,626	1,179,311 (5.05)	29.78	31.29 (5.05)
Walk & Other	471,410	461,368 (-2.13)	12.51	12.24 (-2.13)

Shopping Trips (One Way, Annual)

Mode	Trips Reported	Trips Network (% change)	Market Share Reported	Market Share Network (% change)
Auto	768,414,784	781,409,408 (1.69)	51.11	51.09 (-0.04)
Transit & Other	734,915,840	747,984,576 (1.78)	48.89	48.91 (0.04)

* Based on reported travel times from the 1980 Census data for all modes.

** Based on travel times calculated from network data for the subway mode and on travel times from the 1980 Census data for all other modes.

Table 4.11 (Continued)

Change in Housing Rents

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Reported	Network (%change)	Reported	Network (%change)	Reported	Network (%change)
Manhattan	-	-	-	-	-	-
Queens	4,345	4,269 (-1.75)	311,488	310,402 (-0.35)	4.61	4.94 (7.22)
Brooklyn	4,348	4,469 (2.78)	240,020	241,982 (0.82)	5.20	4.43 (-14.89)
Bronx	4,378	4,400 (0.51)	69,669	69,669 (0.00)	5.97	5.97 (0.00)
Outside	5,049	5,049* (0.00)	565,519	563,674 (-0.32)	2.69	2.77 (3.00)

* Housing rents outside the four boroughs are fixed.

Housing Type: Condo. (k=2)*

	Rent		Housing Demand		Vacancy Rate	
	Reported	Network (%change)	Reported	Network (%change)	Reported	Network (%change)
Manhattan	5,167	5,034 (-2.58)	34,264	33,945 (-0.93)	7.78	8.64 (11.02)
Queens	4,197	4,113 (-1.98)	14,091	14,044 (-0.33)	3.82	4.14 (8.38)
Brooklyn	3,957	4,038 (2.05)	2,737	2,757 (0.72)	5.99	5.31 (-11.24)
Bronx	2,746	2,674 (-2.59)	12,542	12,450 (-0.74)	8.59	9.26 (7.82)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.
** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Table 4.11 (Continued)

Housing Type: Apartment (k=3)

	Rent		Housing Demand		Vacancy Rate	
	Reported	Network (%change)	Reported	Network (%change)	Reported	Network (%change)
Manhattan	4,563	4,511 (-1.14)	667,109	665,734 (-0.21)	6.77	6.96 (2.84)
Queens	4,335	4,292 (-0.98)	386,992	386,494 (-0.13)	4.40	4.53 (2.80)
Brooklyn	3,652	3,761 (2.99)	588,273	593,565 (0.90)	6.57	5.73 (-12.79)
Bronx	3,517	3,584 (1.89)	347,027	348,905 (0.54)	5.93	5.42 (-8.59)
Outside	5,520	5,520* (0.00)	259,277	259,049 (-0.09)	2.60	2.67 (2.70)

* Housing rents outside the four boroughs are fixed.

<u>Change in Commercial Rents</u>

	Rent*		Shopping Demand**	
	Reported	Network (%change)	Reported	Network (%change)
Manhattan	23.96	24.80 (3.52)	566,932	576,714 (1.73)
Queens	6.49	6.72 (3.56)	268,671	273,417 (1.77)
Brooklyn	4.40	4.56 (3.64)	311,128	316,859 (1.84)
Bronx	3.62	3.74 (3.40)	151,715	154,301 (1.70)
Outside	-	-	209,164	212,593 (1.64)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Table 4.11 (Continued)

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing Consumer Surplus	$10,734,796,800/year = $2,847/worker/year	0.97	99.31
Producer Surplus	$35,588,096/year = $9.65/house/year	0.38	0.33
Total Rent	$37,208,941/year = $11/house/year	0.24	
Commercial Producer Surplus	$38,635,008/year = $0.22/sq ft/year	3.55	0.36
Total Rent	$60,027,131/year = $0.35/sq ft/year	3.55	

Total Benefit = $10,809,020,416/year
= $2,867/worker/year
= $2,930/house/year
= $7.02/trip

Equilibrium Simulation 7: A Reduction in Subway Waiting Times

Using the network times for transit, it was assumed that trains could be doubled on the system so that average waiting times per trip would be halved from five minutes to two and a half minutes throughout the subway system.[17] Such an improvement attracts households from the suburbs into the four boroughs since a more central location allows households to use the transit system and take part in the benefits of the reduced travel time.

Indeed, with the simulation, it was observed that commuters switched to the subway from all other modes, increasing subway ridership by 1.33%. Housing demands and rents in the boroughs increased for 0.89% to 1.25% for single family housing. For

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[17] It may not be necessary to double the number of trains to halve rush hour travel times nor does doubling the number guarantee that times can be halved. The assumption is meant to be a rough, illustrative one.

condominiums, cooperatives and apartments, Manhattan residents found it feasible to move to Queens, Brooklyn and the Bronx, increasing rents there by about 1.05% to 1.35%, while rents in Manhattan decreased by 0.03% for condominiums and cooperatives, and by 0.43% for apartments.

As a result of lower waiting times, shopping trips increased from 0.39% to 0.51%. This triggered an increase in shopping rents in Manhattan by 1.04%, in the other boroughs by about 1.0%, and in the suburbs by 0.8%. The aggregate consumer surplus increased by 0.02% amounting to a benefit of $953 percommuter per year. The producer surplus in housing increased by some $89 million, amounting to about $24 per dwelling per year. On the shopping side, there is a producer surplus of $0.06 per square foot of shopping floor space corresponding to $11.5 million per year.

The total benefits of reducing waiting times on transit are equal to $3.7 billion, amounting to a benefit of $1.57 per trip (all annual round-trip commutes plus shopping round-trips). Since, on the average each commuter saves 2.5 minutes per one way trip, the implied value of commuting time for the service area is $18.84 per hour. Most of the benefits (97.3%) are increases in consumer surplus with only 2.39% representing an increase in housing producer surplus and 0.31% an increase in commercial producer surplus. Taxing the producer surplus increases by means of a lump sum tax would raise $100 million annually which could go toward funding the policy of doubling the number of trains. Because the actual costs of this policy are not known, a cost-benefit ratio cannot be calculated.

Table 4.12 A Reduction in Subway Waiting Times from 5 to 2.5 Minutes (Network Based Travel Times): Mode Splits, Change in Housing Rents, Change in Commercial Rents, and Change in Benefits

Mode Splits

Commuting Trips (One Way, Daily)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	1,618,819	1,613,904 (-0.30)	42.69	42.51 (-0.41)
Bus	423,713	420,458 (-0.77)	11.17	11.08 (-0.88)
Rail	105,722	104,855 (-0.82)	2.79	2.762 (-0.93)
Subway	1,181,193	1,196,927 (1.33)	31.15	31.53 (1.22)
Walk & Other	462,634	460,173 (-0.53)	12.20	12.12 (-0.64)

Table 4.12 (Continued)

Shopping Trips (One Way, Annual)

Mode	Trips Before	Trips After (% change)	Market Share Before	Market Share After (% change)
Auto	741,352,380	744,953,190 (0.49)	52.33	52.33 (-0.01)
Transit & Other	675,398,310	678,749,120 (0.50)	47.67	47.67 (0.01)

<u>Change in Housing Rents</u>

Housing Type: Single Family (k=1)

	Rent		Housing Demand		Vacancy Rate	
	Before	After (%change)	Before	After (%change)	Before	After (%change)
Manhattan	-	-	-	-	-	-
Queens	4,201	4,238 (0.89)	308,302	308,915 (0.20)	5.58	5.40 (-3.36)
Brooklyn	4,634	4,692 (1.25)	243,368	243,900 (0.22)	3.88	3.67 (-5.42)
Bronx	4,522	4,563 (0.91)	70,045	70,166 (0.17)	5.46	5.29 (-2.98)
Outside	5,476	5,450 (-0.47)	570,756	570,437 (-0.06)	1.79	1.84 (2.79)

Table 4.12 (Continued)

Housing Type: Condo (k=2)*

	Rent Before	Rent After (%change)	Housing Demand Before	Housing Demand After (%change)	Vacancy Rate Before	Vacancy Rate After (%change)
Manhattan	5,212	5,213 (0.03)	34,295	34,283 (-0.03)	7.70	7.73 (0.40)
Queens	4,125	4,171 (1.13)	14,019	14,045 (0.19)	4.31	4.13 (-4.11)
Brooklyn	4,215	4,266 (1.19)	2,781	2,788 (0.23)	4.47	4.24 (-5.01)
Bronx	2,784	2,814 (1.05)	12,583	12,619 (0.29)	8.29	8.03 (-3.16)
Outside**	-	-	-	-	-	-

* "Condo." includes "Single Family" in Manhattan.
** For model zones outside the four boroughs, "Condo" is included in "Apartment".

Housing Type: Apartment (k=3)

	Rent Before	Rent After (%change)	Housing Demand Before	Housing Demand After (%change)	Vacancy Rate Before	Vacancy Rate After (%change)
Manhattan	4,688	4,708 (0.43)	671,780	672,386 (0.09)	6.12	6.03 (-1.38)
Queens	4,307	4,359 (1.22)	385,622	386,491 (0.23)	4.74	4.53 (-4.52)
Brooklyn	3,909	3,962 (1.35)	597,602	599,130 (0.26)	5.09	4.85 (-4.77)
Bronx	3,694	3,737 (1.14)	350,721	351,464 (0.21)	4.93	4.72 (-4.09)
Outside	5,898	5,872* (-0.44)	261,463	261,314 (-0.06)	1.78	1.83 (2.81)

* Housing rents outside the four boroughs are fixed.

Table 4.12 (Continued)

Change in Commercial Rents

	Rent*		Shopping Demand**	
	Before	After (%change)	Before	After (%change)
Manhattan	24.38	24.63 (1.04)	576,810	579,740 (0.51)
Queens	6.59	6.66 (0.98)	271,080	272,409 (0.49)
Brooklyn	4.47	4.52 (1.01)	314,150	315,723 (0.50)
Bronx	3.67	3.71 (0.94)	152,909	153,630 (0.47)
Outside	5.04	5.08 (0.79)	101,799	102,198 (0.39)

* Commercial rent in $/Sq ft of floor space
** Shopping trips in 1,000 trips/year

Change in Benefits

	Change of Level	%change	Benefit Share(%)
Housing			
Consumer Surplus	$3,619,684,352/year = $953/worker/year	0.02	97.30
Producer Surplus	$89,038,848/year = $24.14/house/year	0.89	2.39
Total Rent	$106,550,272/year = $28.9/house/year	0.66	
Commercial			
Producer Surplus	$11,556,608/year = $0.06/sq ft/year	1.01	0.31
Total Rent	$17,319,424/year = $0.09/sq ft/year	1.01	

Total Benefit = $3,720,279,808/year
= $980/worker/year
= $1009/house/year
= $1.57/trip

CHAPTER FIVE

SOFTWARE AND HARDWARE REQUIREMENTS AND SOLUTION OF THE MODELS ON COMPUTER

NYREG Regional Equilibrium Model

There are many aspects of a particular modeling problem that affect the cost of its solution. We have studied three of these in detail. The first is the choice of the computing environment, which is a subject of this chapter.

It is clear that a supercomputer should be more efficient than a conventional IBM mainframe or a SUN workstation by an order of about two to eight times depending on whether the program is vectorized or not. Because, supercomputers are actually becoming more accessible than mainframes and workstations, and seem to be less affected by budget constraints, some of the NYREG computations were performed on the CRAY YMP-1 and on the CRAY-2. This hardware was accessible through the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign, via modem from Northwestern University.

The code (software) which operationalizes the algorithm is written in FORTRAN which is one of the most widely used codes for mathematical computation. While the program has been solved on the CRAY-2 at the NCSA, the final version of the model has also been run on an IBM mainframe and on a SUN workstation. Hence, the code can easily be adapted to any of these computational hardware environments. Computational costs on an IBM mainframe and SUN workstation are similar.

Other factors that affect costs of modeling include the starting point from which model convergence begins. This is very important in determining the speed with which the solution reaches equilibrium. In formulating NYREG, we have found that starting points in which rents are set to low values give much faster results. In addition, the modeler should consider the aggregate vacancy rate of the housing market. It strongly affects the speed of convergence. "Tight" housing markets with a low vacancy rate such as 3% or less will take longer to converge than "loose" markets with 20% or higher vacancy rates. The combined affect of these factors on costs are discussed using several illustrative problems.

Initial Computational Experiments on the CRAY

For comparative purposes, we present the computational results of problems of various sizes and with alternative starting points and aggregate vacancy rates in the following tables. The data in these problems was artificially generated but is fairly realistic. Table 5.1 explores the use of MINPACK to solve four problems. The first two problems have 400 equations (obtained as the product of 100 residential zones and 4 housing types). The second two problems have 1800 equations (1800 residential zones and a single housing type). The vacancy rate for the first three problems is set at 40% and then dropped to a much more realistic 4.5% for the last problem. Each problem is solved using three different starting points:

o the equilibrium rents (hence only one iteration is required to confirm that the starting point is the solution and the computational time is the time needed to do one evaluation of the Jacobian matrix);

o a randomly determined set of rents which are low relative to the equilibrium rents;

o the assumption that rents are zero for each residential zone.

Table 5.1 Solutions of Various Size Problems Using MINPACK with Different Starting Points and Vacancy Rates on the CRAY-YMP

Dimensions	Jacobian	Vacancy		Starting Point		
i,j,k ℓ,m,n	JK X JK	%		Equilibrium Rents(1)	Low Random Rents(2)	Uniformly Zero Rents
1,100,4 100,2,2	400 X 400	40	n CPU	1 19.251	4 19.466	12 20.074
3,100,4 100,2,2	400 X 400	40	n CPU	1 52.371	4 52.632	12 53.896
3,1800,1 6,2,2	1800 X 1800	40	n CPU	1 377.120	4 380.133	12 386.401
3,1800,1 6,2,2	1800 X 1800	4.5	n CPU	1 378.510	? > 900 (3)	? ?

(1) Average equilibrium rent is about $ 4,500.
(2) The starting rent of each zone is a random number generated from the range ($0 - $1,000).
(3) 900 second CPU time was exceeded.
n : the number of iterations needed to converge.
CPU : the computational time includes input-output time.

By comparing the first two runs, it is seen that increasing the number of work zones from one to three does not change the number of iterations but increases computational time by a factor of 2.5 because of the larger number of terms involved in each equation. With only one workplace, it takes 19 seconds to evaluate the Jacobian matrix. When two more workplaces are added, the time it takes to evaluate the Jacobian matrix goes up to 52 seconds. When the number of equations goes from 400 to 1800, the time needed to evaluate the much bigger Jacobian goes to 377 seconds.

Netting out the time it takes to evaluate the Jacobian, we find that one iteration takes a bit more than 5 one hundredths of a second. We also see that the problem with 1800 equations is difficult to solve by means of MINPACK when the vacancy rate is low: the CPU time limit of 900 seconds was exceeded. This experience suggested that MINPACK would be too slow for large realistic problems. The slowness is due to the time it takes to evaluate the Jacobian matrix and due to the fact that the direction-finding is inaccurate because the Jacobian is not reevalauated at each iteration. Hence, it is imperative to ask whether alternative techniques which do not rely on a full Jacobian evaluation would be faster.

Table 5.2 Comparison of MINPACK and CATLAS on the CRAY-YMP (Dimensions: i=3, j=1800, k=1, m=2, l=6, n=2)

Vacancy Rate	Method		Equilibrium Rents	0.7 X (Equil. Rents)	Low Random Rents (1)
		n	1	6	13
45%	MINPACK	CPU	378.51	385.08	389.621
		n	1	4	5
	CATLAS	CPU	0.978	1.394	1.520
		n	1	40	-
4.5%	MINPACK	CPU	378.51	781.13	> 900 (2)
		n	1	10	14
	CATLAS	CPU	0.978	2.078	2.537

(1) The starting rent of each zone is a random number generated from the range ($0 - $1,000).
(2) 900 second CPU time was exceeded.
n : the number of iterations needed to converge.
CPU : the computational time includes input-output time.

Table 5.2 is intended to compare MINPACK with the CATLAS technique. Two problems are solved, one with a high vacancy rate and the other with a low vacancy rate. It is seen that the analytic evaluation of the Jacobian diagonals is 387 times faster than the numerical evaluation of the full Jacobian. The number of iterations needed by MINPACK is higher than the number needed by the CATLAS technique. This means that ignoring the off-diagonals but accurately computing the diagonals is much more accurate than numerically evaluating the whole matrix. Given the bad starting point of the last column, the CATLAS technique converges within about 2.5 seconds, whereas MINPACK takes in excess of 900 seconds.

Table 5.3 Solution of a Problem Using CATLAS with Alternative Starting Points and Vacancy Rates (Dimensions: i=300, j=2200, k=1, m=2, l=60, n=2)

Vacancy Rate		Equilibrium Rents	0.9 X (Equil. Rents)	0.7 X (Equil. Rents)
	n	1	6	7
20%	CPU	12.59	68.65	79.841
	n	1	9	11
5%	CPU	12.59	106.94	130.312
0.5%	n	1	11	14
	CPU	12.59	125.42	159.490

n : the number of iterations needed to converge.
CPU : the computational time does not include input-output time, (19.641 additional seconds were used to input the data).

Table 5.3 shows the computational experience obtained from applying the CATLAS technique to a much larger problem in which there are 2200 residential zones (equations), 300 work zones and 60 shopping zones. The hardest of these problems is solved within 160 seconds and takes only 14 iterations.

To summarize, NYREG appears computationally feasible for fairly large problems using the Newton-Raphson type technique developed and applied in CATLAS. Convergence is rapid and obtainable at reasonable clock times on the CRAY-2 machine of NCSA at the University of Illinois at Urbana-Champaign. As a result of these computational experiments, the CATLAS technique was selected for use with the model and a streamlined and vectorized algorithm was developed.

Table 5.4 Computational Time on the CRAY-2 Supercomputer Using Various Starting Points (in Seconds)

	Equil. point	Rents Within 10% of Eq. (*)	Rents Within 30% of Eq. (*)	Rents Within 50% of Eq. (*)	Rents Uniformly Zero
Reading data and initial comps.	112.83	113.21	112.97	112.85	113.17
Housing equil. (iterations)	3.19 (1)	9.58 (3)	22.10 (7)	315+ (99+)	316+ (99+)
Commercial equil. and output computation	28.29	29.05	28.28	--	--

(*): Rents are randomized within the indicated band around the equilibrium point. Note : Above computations are based on the empirically based New York Model [463 employment zones(i=463);463 residence zones(j=463);
3 housing types (k=3);5 commuting modes(m=5);52 shopping zones(l=52);2 shopping modes(n=2)]. The model's housing market part has 847 equations and the commercial equilibrium part has 46 equations. The convergence tolerance is 0.5% of the equilibrium rents.

Tables 5.4 and 5.5 present the computational performance of the empirically based and vecterized NYREG solved on the NCSA CRAY-2. It is seen from these tables that one iteration in the housing market equilibrium part of the model takes slightly more than 3 seconds. The total time needed to complete all computations is at least 144.31 seconds and depends on how far the starting point of rents is from the equilibrium point of rents. When rents are randomly perturbed within 10% and 30% of the equilibrium point, then 3 to 7 iterations are needed to achieve convergence. Convergence is defined as the state when each rent is calculated to be within 0.5% of the corresponding equilibrium rent value.

Table 5.5 Computational Time on the CRAY-2 Supercomputer for Selected Policy Runs (in Seconds)

	Base run	Policy (1)	Policy (2)	Policy (3)	Policy (4)
Reading data and initial comps.	112.83	113.021	113.14	112.97	1,247.9
Housing equil. (iterations)	3.19 (1)	6.37 (2)	9.77 (3)	6.31 (2)	6.30 (2)
Commercial equil. and output computation	28.29	28.61	28.47	28.77	29.09

Policy (1): 5% decrease in auto commuting and shopping time.
Policy (2): 10% decrease in auto commuting and shopping time.
Policy (3): 5% decrease in reported subway commuting time.
Policy (4): decrease the subway waiting time from 5 minutes to 2.5 minutes (input data is network based times). The convergence tolerance is 0.5 % of the equilibrium rents.

When rents are perturbed within a 50% band of the equilibrium values, then more than 99 iterations are required to achieve convergence. Similarly starting with uniformly zero rents requires a large number of iterations. In practice, it would be very difficult to find conditions under which the equilibrium rents would be that different from the initially known equilibrium rents. Hence it should be relatively easy to keep the overall computational cost of any one run under 456 seconds.

Computational Experience on the SUN Workstation

Because supercomputers are still relatively inaccessible, the empirically calibrated model was also extensively tested on a SUN Sparc Station which is a desktop computer with capabilities equal to or better than many mainframes. A SUN Sparc Station and associated equipment can be purchased for about $12,000.

Table 5.6 Computational Time on the SUN Sparc Station Using Various Starting Points (in Seconds)

	Equil. point	Rents Within 10% of Eq. (*)	Rents Within 30% of Eq. (*)	Rents Within 50% of Eq. (*)	Rents Uniformly Zero
Reading data and initial comps.	230	231	230	230	231
Housing equil. (iterations)	9 (1)	21 (3)	46 (7)	635+ (99+)	639+ (99+)
Commercial equil. and output computation	169	169	170	--	--

(*): Rents are randomized within the indicated band around the equilibrium point.
Note : Above computations are based on the empirically based New York Model [463 employment zones(i=463);463 residence zones(j=463); 3 housing types (k=3);5 commuting modes(m=5);52 shopping zones(l=52);2 shopping modes(n=2)]. The model's housing market part has 847 equations and the commercial equilibrium part has 46 equations. The convergence tolerance is 0.5% of the equilibrium rents.

Tables 5.6 and 5.7 are identical to Tables 5.4 and 5.5 and show the corresponding running times on the SUN. An iteration now takes about 7 seconds or a little more than twice what it takes on the CRAY. Typically, an entire run takes somewhat more than 408 seconds (close to 7 minutes) or 2.8 times the amount of time it takes on the CRAY, provided that a reasonable starting point is used.

Training and Software Requirements

The calibration and simulation procedures rely on the knowledge of the FORTRAN programming language. This, together with some experience in handling computers and computer programs should be sufficient in operating the model. Such operations includes recalibrating the model with updated data, as well as doing simulations with the recalibrated model.

Table 5.7 Computational Time on the SUN Sparc Station for Selected Policy Runs (in Seconds)

	Base run	Policy (1)	Policy (2)	Policy (3)	Policy (4)
Reading data and initial comps.	230	231	232	232	2407
Housing equil. (iterations)	(1)	(2)	(3)	(2)	(2)
Commercial equil.and output computation	169	170	169	169	171

Policy (1): 5% decrease in auto commuting and shopping time.
Policy (2): 10% decrease in auto commuting and shopping time.
Policy (3): 5% decrease in reported subway commuting time.
Policy (4): decrease the subway waiting time from 5 minutes to 2.5 minutes (input data is network based times). The convergence tolerance is 0.5% of the equilibrium rents.

NYSTA Station Area Model

Training and Support Requirements

Software and hardware requirements for developing and running NYSTA are more accessible than those entailed in NYREG. Knowledge of SAS microcomputer programs and 386 or 486 desktop computing capability are sufficient to perform the multivariate regression analysis for a stratified sample as large as 8,000 records for a single land use class. Use was also made of mainframe computers in processing the property tax files and of a transportation planning Geographic Information System (Transcad), which accomodates station and network information of the MTA, in calculating network distances and times.

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