AN ABSTRACT OF THE THESIS OF

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Title: Topics in Applied Microeconomics: Estimating the Value of Commercial Land and Testing the Efficiency of the U.S. Motor Carrier Industry.

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Arthur M. O'Sullivan

This thesis consists of two essays on applied microeconomics issues. The first essay presents a hedonic price econometric model of vacant commercial land. The second essay presents cost frontier analysis on the industry and firm's performance of the U.S. Motor Carrier industry.

Our hedonic price econometric model includes two new developments in estimating land values in a multicentric urban area. First, two composite indexes of market accessibility and highway accessibility are developed to account for the impacts of different characteristics of different regional nodes on land value at a particular site. Second, we use nonlinear least squares to estimate the decay parameters of the accessibility indexes within the model. We found that market accessibility is the dominant land value determinant. The estimated market accessibility decay parameter is different in value from the ones that are commonly assumed in hedonic models. The effect of access to highway interchanges is insignificant. Corner lots are of higher value. Finally, under Seattle's zoning policy, zoning classification of neighborhood commercial and community commercial land does not have significant effect on land value.

The second essay uses the stochastic cost frontiers to analyze the performance of the U.S. motor carrier industry in the pre- and post-MCA periods. The average industry

inefficiencies were between 14 and 27 percent during studied period. Our results indicate that the deregulation has no impact on industry efficiency. After a short adjustment period, the average industry inefficiency in the post-MCA years falls back to its pre-MCA level of around 14 to 16 percent. We analyzed the firm-specific inefficiencies by tobit regression. Our result shows that union firms are 1.5 and 4 percent less efficient than non-union firms in the pre- and post-MCA years, respectively. Firms located in the southern region are relatively efficient and the ones in the northern regions are relatively inefficient. Our result supports Stigler's Survivor Principle that survivor firms are relatively efficient.

Topics in Applied Microeconomics:
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Testing the Efficiency of the U.S. Motor Carrier Industry

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APPROVED:

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Major Professor, representing Economics

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Chair of Department of Economics

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Dean of Graduate School

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TABLE OF CONTENTS

Page

1. INTRODUCTION 1

2. ESSAY I: ESTIMATING THE VALUE OF COMMERCIAL LAND 3

2.1 Introduction 3

2.2 A Model of Vacant Commercial Land Value 5

2.3 Data from King County 6

2.3.1 Transactions 6
2.3.2 Chosen Cities 7

2.4 Empirical Model and Estimation Results 10

2.4.1 Site Characteristics 11
2.4.2 Accessibility Indexes 12
2.4.3 Hedonic Commercial Land Price Model 17
2.4.4 Empirical Models 19
2.4.4.1 The Full Model 19
2.4.4.2 The Restricted Model 22

2.5 Implications and In Sample Forecasting 25

2.5.1 Simulation 1 26
2.5.2 Simulation 2 26
2.5.3 Simulation 3 27
2.5.4 Simulation 4 28

2.6 Summary and Extensions 32

2.6.1 Summary 32
2.6.2 Extensions 33

2.7 References 35

3. ESSAY II: TESTING THE EFFICIENCY OF THE U.S. MOTOR CARRIER INDUSTRY 37

3.1 Introduction 37

3.2 Stochastic Frontier Estimation Technique 40

TABLE OF CONTENTS (Continued)

Page

3.3 Data and Model Specification 44

3.3.1 The Data 44
3.3.2 Model Specification 52

3.4 Estimation Results 53

3.4.1 Industry Average Inefficiency 56
3.4.2 Firm Specific Inefficiency 59

3.5 Analysis of Source of Inefficiency 62

3.6 Testing for Heteroskedasticity 67

3.7 Summary and Limitations 70
3.7.1 Summary 70
3.7.2 Limitations 71

3.8 References 73

4. CONCLUSIONS 75

BIBLIOGRAPHY 77

APPENDICES 80
Appendix 1: City Characteristics, Coordinate and Distance 81
Appendix 2: Measuring the Highway/Freeway Inter-change Locations of King County 83

LIST OF FIGURES

Figure		Page
2-1	Spatial Location of the Selected Cities	8
2-2	Observed Land Values and the Cities	9
2-3	The Predicted Value Plot	22
2-4(a)	Simulation 1 (Land Value Profile of Base Lots)	29
2-4(b)	Simulation 1 (Contours Plot)	29
2-5(a)	Simulation 2 (Land Value Profile of Even Population Policy)	30
2-5(b)	Simulation 2 (Contours Plot)	30
3-1	Mean Statistics by Year	49
3-2	The Average Industry Inefficiency by Year	58
3-3	Comparison of Average Inefficiency between "Survivor" Firms and All Firms	61
3-4	Regional Average Inefficiency of "Survivor" Firms: Pre- and Post-MCA era	62

LIST OF TABLES

Table		Page
2-1	Definition of Site Characteristic Variables	12
2-2	The Full Model	21
2-3	The Restricted Model	25
2-4	Per Capita Income Effect: Changes on land value (in dollars p.s.f.) at selected distances for $1,000 dollar change in per capita income	31
2-5	Population Effect: Changes on land value (in dollars p.s.f.) at selected distances for an increase in population of ten thousand	32
3-1	Mean Statistics	48
3-2	Parameter Estimates of frontiers (1976-1987)	54
3-3	Average Industry Inefficiency (1976-1987)	57
3-4	Grouping the Industry Average Inefficiency (Using all individual periods)	58
3-5	Comparison of Average Inefficiency between "Survivor" Firms and All Firms	60
3-6	Regional Average Inefficiency of "Survivor" Firms: Pre- and Post-MCA era	61
3-7	Tobit Regression of Firm Specific Inefficiency	66
3-8(a)	Result of Breusch-Pegan Test	68
3-8(b)	Result of Goldfeld-Quandt Test	70

**Topics in Applied Microeconomics:
Estimating the Value of Commercial Land and
Testing the Efficiency of the U.S. Motor Carrier Industry**

Chapter 1

INTRODUCTION

This thesis consists of two essays on applied microeconomic issues. The first essay presents a hedonic study of vacant commercial land. The second essay tests and analyzes the industry and firm's performance of the U.S. Motor Carrier industry.

The hedonic econometric model we developed in essay I incorporates the multicentric nature of most modern metropolitan areas. This study used 166 vacant commercial land transactions from the King County, Washington, during the period 1990 to 1992, in the regression. Since the model is nonlinear in parameter, we use the Non-linear Least Squares estimation method to estimate the model. It allows decay parameters to be inferred from the data. In this way, we avoid imposing unnecessary restrictions on the parameters.

Our accessibility indexes, using weighted masses of cities, are superior to other indexes suggested in previous studies, such as Downing [6] and Kowalski and Paraskevopoulos [12], which measured accessibility by simple distance. Our indexes also introduce regional heterogeneity and establish relations between the site and markets.

Our study questions the validity of earlier research in four aspects. First, since the metropolitan area is not homogeneous, the market accessibility that captures the heterogeneous nature of the region is the dominant determinant of commercial land value. Second, the decay rate of the market accessibility index should be incurred by the data. Third, zoning on land uses between neighborhood commercial land (classified for the use of smaller business that targets on buyers from the local neighborhood) and community commercial land (classified for the use of larger business that targets on buyers within and among communities) could be statistically insignificant on land value determination because it also depends on the demand of each land use. Fourth, site characteristics such as land shaped and land topography, which are important determinants of industrial land value, may not be important determinants of commercial land value. Essay I provides answer to each of these challenges.

Essay II applies Stochastic Cost Frontier (SCF) models on the U.S. Motor Carrier industry. By using the SCF approach, we are able to estimate the industry level and firm level inefficiencies. We estimated the SCFs using the data from the American Trucking Association between 1976 to 1987 and analyzed the industry performance in the pre- and post-Motor Carrier Act (MCA) era. We also investigated the relationship between firm level inefficiencies and firm characteristics by the Tobit regression method.

Many studies have suggested that the MCA promoted competition in the industry and benefited consumers. Our study contributes more insights on the performance of firms and industry. We achieve the following goals: (1) we use the concept of Stochastic Frontier to estimate stochastic cost frontiers of the U.S. Motor Carrier industry for the period 1976 to 1987; (2) we analyze the difference among average industry inefficiencies for different periods; (3) we identify the relationship between firms' characteristics and their regional inefficiencies; and (4) we compare the efficiency levels of firms and industry prior and post the MCA.

Chapter 2

ESSAY I: ESTIMATING THE VALUE OF COMMERCIAL LAND

2.1 Introduction

This paper presents a hedonic study of vacant commercial land. We computed two accessibility indexes, the market accessibility index and the nearest highway interchange index, for each site. The "markets" of commercial business are the locations of concentrated population -- the economic cities. The market accessibility index measures the locational importance of a site with respect to a regional market by discounting its masses (such as population, income, ... etc) with its distance from the site and a decay parameter. The highway interchange index measures the site's accessibility to the highway using its distance from the site and a decay parameter. Because we employ nonlinear least squares to estimate the model, we can estimate the decay parameters within the model. Our estimated market accessibility decay parameter is different from the assumed values of previous studies, such as Peiser [16], Downing [6], and Kowalski and Paraskevopoulos [12], with a more rapid decay of potential demand from the city center. Therefore, land value declines rapidly away from the city center. However, our estimated nearest highway interchange accessibility parameter and its decay parameter indicate highway interchanges have no significant effect on land value.

This paper improves on earlier studies in three ways. First, the model incorporates the multicentric nature of most modern metropolitan areas. Metropolitan areas normally contain more than one center, so applying a traditional monocentric analysis is inappropriate. Second, the model allows decay parameters to be inferred from the data. In this way, we avoid imposing unnecessary restrictions on the parameters. Third, our accessibility indexes, using weighted masses of cities, are superior to other indexes suggested in previous studies, such as Downing [6] and Kowalski and Paraskevopoulos [12], which measured accessibility by simple distance. Our indexes also introduce regional heterogeneity and establish relations between the site and markets.

Some of our results confirm results of Downing [6] and Peiser [16]. For example, Downing found that corner lots command higher prices for land used by local business, and Peiser found that corner lots of two major streets are of higher prices. We found the similar result in our model. On the other hand, our findings also agree with Peiser's that distance from the freeway does not affect the value of commercial land.

Our study questions the validity of earlier research in four aspects. First, since the metropolitan area is not homogeneous, the market accessibility that captures the heterogeneous nature of the region is the dominant determinant of commercial land value. In contrast, to model a monocentric city, using a simple distance measure from the city center might be sufficient to capture the locational effect of the site. Second, the decay rate of the market accessibility index equals 0.8363, which is higher than Peiser's assumed value of 0.5 and lower than the 1.0 value assumed in previous studies such as Downing [6], Colwell and Sirmans [4], Kowalski and Paraskevopoulous [12], McMillen and McDonald [14] and McMillen [13]. Third, zoning on land uses between neighborhood commercial land (classified for the use of smaller business that targets on buyers from the local neighborhood) and community commercial land (classified for the use of larger business that targets on buyers within and among communities) is statistically insignificant on land value determination. Fourth, site characteristics such as land shaped and land topography, which are important determinants of industrial land value, may not be important determinants of commercial land value.

The plan of the chapter is as follows: The next section presents a hedonic model of commercial land use. Section 2.3 discusses the nature of the data to be used in the study. Section 2.4 develops the empirical model and analyzes the estimated results. Section 2.5

presents some computer simulations and forecasts. Section 2.6 concludes the study and suggests possible extensions.

2.2 A Model of Vacant Commercial Land Value

Consider a commercial firm located on site *i*, described by a vector $z^i \in \Re^M$, whose typical element z^i_m denotes the characteristic *m* of the site. We assume that the firm's production involves land and non-land costs, and define the profit equation π per unit of land as,

$$\pi(z^i) = pq(z^i) - r(z^i) - n(z^i). \tag{2-1}$$

The price for the firm's output is denoted by *p* and is assumed to be independent of *i*. q represents the firm's output, r denotes the unit price of land and n is the non-land cost (improvement costs plus operating costs) per unit of land. Note that we assume that the demand for the firm's product and its non-land cost at site *i* depend on z^i_m, for at least some *m*. For example, let z^i_m represent whether the site is at a street corner and z^i_k indicate whether the site is sloped. z^i_m may increase the demand for the firm's output but not the non-land cost. Conversely, z^i_k may increase the non-land cost but not demand. Note that in our model, market accessibility characteristics, which depend on income, population and distances and the nearest highway interchange accessibility characteristic which depends on distance, are elements of z^i.

Profit maximization behavior implies that,

$$p\left(\frac{\partial q(z^i)}{\partial z^i_m}\right) = \left(\frac{\partial r(z^i)}{\partial z^i_m} + \frac{\partial n(z^i)}{\partial z^i_m}\right) \quad \forall\ m = 1,2,\ldots,M \tag{2-2}$$

where $\bar{z}^i$ is the profit maximizing vector of characteristics. Under the assumption that land is the residual claimant of production, economic profit of the firm will be zero, and in equilibrium,

$$r(\bar{z}^i) = pq(\bar{z}^i) - n(\bar{z}^i). \tag{2-3}$$

Equation (2-3) motivates a regression where land price for differentiated sites are a function of the characteristics z^i associated with each site *i*. The coefficients obtained from the regression are interpreted as the shadow prices of these characteristics.

2.3 Data from King County

2.3.1 Transactions

The data used in this study are actual transactions of parcels of vacant commercial land in King County, central eastern part of the state of Washington, from January 1, 1990 to December 31, 1992. [1,2] A total of 356 million dollars were involved in three hundred and thirty-four commercial land transactions (a total of 2.25 square mile of land). According to the criteria provided by Eco Northwest, a consulting firm, on arm-length sales, 97 records are excluded.[3] We also eliminated another sixty-four records that are

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[1] Seattle and thirteen other cities comprise ninety-two percent of the city population that are included in this study.

[2] The source of data is the Commercial Property Information Services' (CPIS) CallCOMPS database. CPIS obtains information from the County Assessor, verifies the information and obtains additional information that is useful for the appraisers.

[3] I followed the criteria defined by ECO Northwest for non-arm-length transactions and the special site characteristics: (1) transaction was coded "for information", (2) transaction was a part of an exchange, (3) property is involved in litigation, (4) comments indicate that the property is not suitable for development, (5) property is operating as a gravel pit, (6) property is on Maury or Vashon Island and (7) sewer connection is not available. Observations that meet one or more of these criteria are excluded in the study.

zoned for neither "neighborhood intermediate business" nor "community and large business". Seven other records considered as outliers are also excluded from this study.[4] Finally, we use one hundred and sixty-six observations (total 0.4 square mile) to estimate the model. The average observed price (AOP) per square foot (p.s.f.) is $12.15.

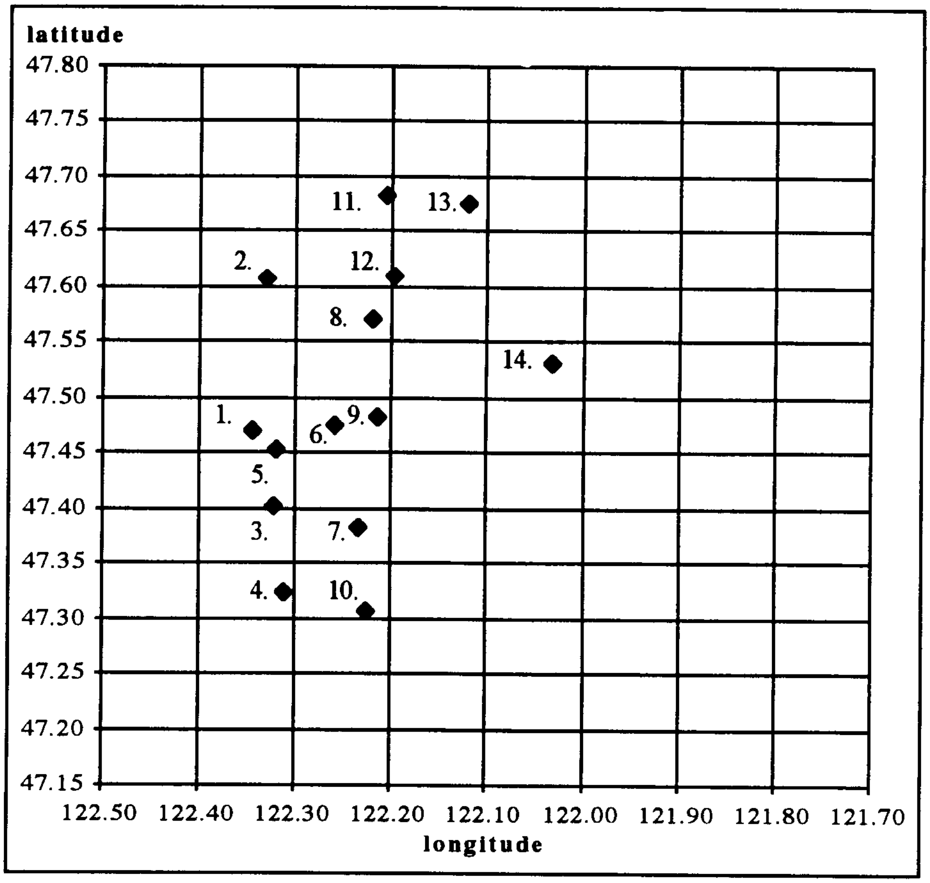
For each of these transactions, we have detailed information on site characteristics. From the data sheets provided by Commercial Property Information Services, we can identify the site's latitude-longitude coordinate, determine whether it is a corner lot and whether it has existing structures. We can also determine its shape, zoning classification, and topographical features.

2.3.2 Chosen Cities

We selected fourteen cities that, based on their population and their locations, represent the source of potential demand of commercial products in the King County. These fourteen economic cities are: Auburn, Bellevue, Burien, Des Moines, Federal Way, Issaquah, Kent, Kirkland, Mercer Island, Redmond, Renton, SeaTac, Seattle and Tukwila. Ten out of the fourteen cities are located next to the major inter-state highways. The rest (Auburn, Burien, Kent and Redmond) are located next to intra-state highways. We took each city's "Populated Area" as the reference point and obtained the coordinate from the US Geographic Name Information System (GNIS). Figure 2-1 shows the spatial location of the selected cities. (See Appendix 1 for information about each city.) Figure 2-2 shows a plot of land values (per square foot) of the observations. We observed that land values around Seattle are much higher than the rest of the region. There is another region of high land values around Bellevue.

[4] Two records contain incomplete information. Four records are located outside the studied region. One record contains extremely high value.

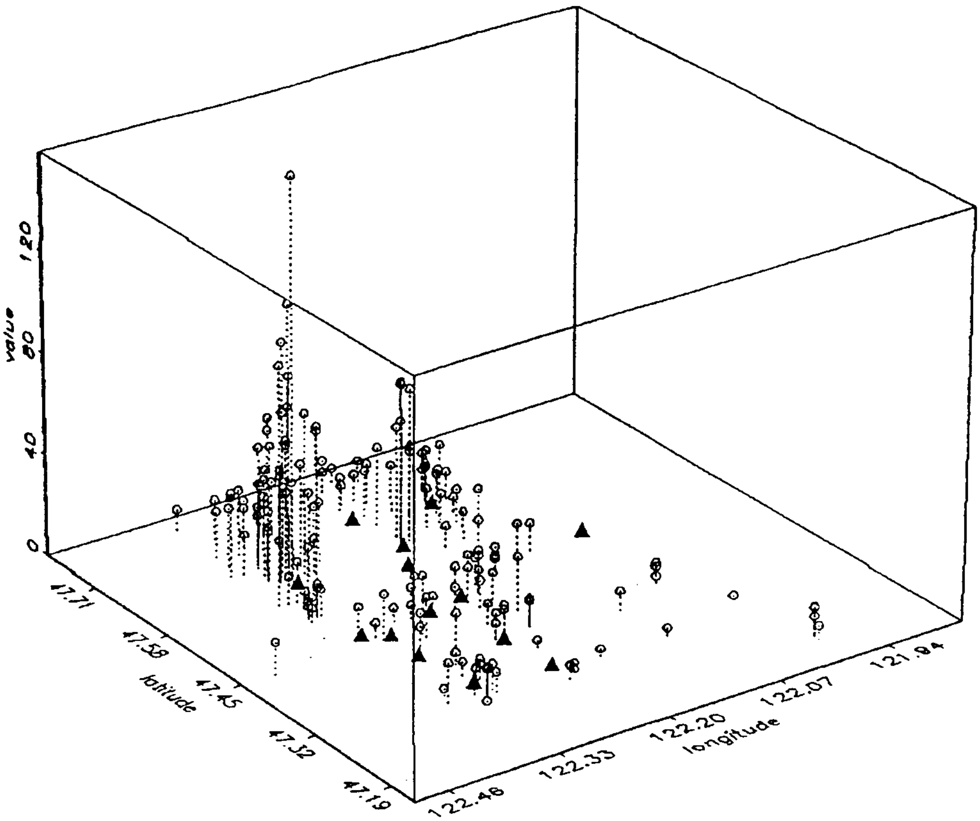
Figure 2-1 Spatial Location of the Selected Cities



Keys:

1 =	Burien	6 =	Tukwila	11 =	Kirkland
2 =	Seattle	7 =	Kent	12 =	Bellevue
3 =	Des Moines	8 =	Mercer Island	13 =	Redmond
4 =	Federal Way	9 =	Renton	14 =	Issaquah
5 =	Sea Tac	10 =	Auburn		

Figure 2-2 Observed Land Values and the Cities



2.4 Empirical Model and Estimation Results

Some earlier studies have provided us useful insights in developing our empirical model. Peiser [16] studied the non-residential land value (for industrial, commercial and office uses) in the Dallas metropolitan area. He used data of vacant land transactions from 1978-82. His study focused on the tendency toward agglomeration by looking at the determinants of land values in the CBD, suburban nodes and other employment centers. He used various types of variables (such as physical site characteristics, macro- and micro-location variables, macroeconomic condition index, development expectation as well as neighborhood characteristics) in his models. Among other results, he reported that commercial land at street corners has higher value.[5]

Downing [6] studied the commercial land values in the city of Milwaukee, Wisconsin, using 1958-62 data. He incorporated site characteristics (including traffic level on the street, corner lot and zone), population density, neighborhood characteristics, and distance to the CBD and to the shopping center in his model. He found that corner location and traffic level increase commercial land values. He also found that zoning has a significant effect on land values. However, we should keep in mind that zoning restricts the supply of land for a particular use, but the observed land values depend on the demand and supply of land for that use, not simply the zoning policy.

Some previous studies reported other important determinants of land values. For example, an industrial land use study by Gandhi and Rahman [7] found that the shape of the land might be an important land value determinant. Kowalski and Colwell [11] used frontage, depth and area as explanatory variables for land value.

Other studies considered the time factor of land values. Kowalski and Paraskevopoulos [12] added a time index (for the period 1975-85, setting 1975=1,

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[5] See Table 1, Commercial land columns, of his paper.

1976=2, and so on) in their model, but they found that it is insignificant.[6] Therefore, our belief is similar to Peiser and Downing that we can pool the observations of different years within a short period and treat them as cross-sectional analysis. In light of these studies and the available data, we decided to use seven variables (five physical site characteristic variables and two accessibility indexes) in our model.

2.4.1 Site Characteristics

The five site characteristics we employed are: corner, level, shape, existing structures and zoning classification. Those are the observable characteristics of the site that are recorded in the transaction data sheet from CallComps. The "corner" characteristic describes whether the site is a corner lot. The "level" characteristic indicates whether the site is leveled or sloped. The "shape" characteristic identifies the lot to be rectangularly or non-rectangularly shaped. The "existing structures" verify whether the site has existing structures or not. The structures are ranged from a seven-story hospital building to a small concrete booth which may or may not be useful to the land buyer. And finally, the "zone" characteristic identifies whether the site is zoned for neighborhood commercial business or community commercial business. (See Table 2-1 for variable definitions.) There are seventy-seven corner lots, fifty-nine lots have existing structures, one hundred and one lots are rectangular, and one hundred and sixteen lots are leveled. Thirty-nine observations are zoned for neighborhood intermediate business.

A corner lot, providing more business knowledge to potential customers seems to increase land price. The estimate of its parameter is expected to be positive. Since land value captures the excess of total revenue over non-land costs, other things being equal, the estimate of parameter of zoning reveals the difference in profitability p.s.f. of land for commercial business from neighborhood business. If the existing structure on the lot is

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[6] Also see Colwell and Sirmans [4] for modeling the land value relation with time and area.

useful (useless) to the buyer, then the buyer may be willing to pay a higher (lower) price for the lot. Therefore, our estimated parameter of "existing structures" can be either positive or negative. A rectangularly shaped or a leveled lot could reduce the waste of land and cost of primary improvements on the site before construction. Therefore, the coefficients of "shape" and "level" of lots are expected to be positive.

Table 2-1 Definition of Site Characteristic Variables

Site Characteristics	Symbol	Variable Definition
Corner	Cor (t = 1)	= 1, if the parcel is a corner lot = 0, otherwise
Existing Structures	Str (t = 2)	= 1, if there is an existing structure = 0, otherwise
Zone[7]	Zon (t = 3)	= 1, if the parcel is zoned for community and large business = 0, otherwise
Shape	Sha (t = 4)	= 1, if the parcel is rectangularly shaped = 0, if non-rectangularly shaped
Level	Lev (t = 5)	= 1, if the parcel is "level" = 0, otherwise

2.4.2 Accessibility Indexes

We use two accessibility indexes to measure the closeness of a site to the regional nodes, such as cities (the demand nodes) and the nearest highway interchange (the transportation node).[8] Each accessibility index consists of three elements: a distance measures, mass(es) of nodes, and a decay parameter.

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[7] According to the King County Department of Assessments - C&I Coding Manual (Appendix E: Zone Codes by Jurisdiction): Community and large business (zone code = 6) and Neighborhood intermediate business (zone code = 5).

[8] See also Richardson *et al.* [18] and Heikkila *et al.* [9] for modeling land value in multicentric metropolitan areas.

To obtain the distance measure for a particular node, we need the latitude-longitude coordinate of each site and node. For each site, we converted the township-range-section-quarter information into latitude-longitude coordinate. For the nodes, we obtained latitude - longitude coordinate of fourteen cities and one hundred and forty-eight major highway interchanges along highways I-5, I-9 and I-405 within the studied region. We used corresponding latitude-longitude coordinates to calculate the straight line distance between site *i* and city *j*, denoted by d_{ij}, where $i = 1, ..., 166$; $j = 1, ..., 14$, and between site *i* and the nearest highway interchange, denoted by d_{ih}.

Recall that the revenue of commercial sales depends on the total demand for product produced at the site. Imagine that each resident who wanted to shop has to travel to the nearby commercial center (site); the longer the traveling distance, the higher the total cost (trip cost plus product cost). If residents are clustered in several cities, then the total demand of commercial products at site *i* will depend on: (1) the distance between the site and the cities, (2) the population in each city and (3) the demand from each resident. We characterize the total demand of commercial products at site *i* from city *j* (Q_{ij}),

$$Q_{ij} = f(\, d_{ij},\, Pop_j,\, q_{ij}\,) \qquad (2\text{-}4)$$

where d_{ij} represents the distance between site *i* and city *j*, Pop_j represents the population of city *j* and q_{ij} represents individual demand of commercial products at site *i* from a resident of city *j*.

If the utility function (consuming commercial and non-commercial products) is homothetic, then the consumption and expenditure of commercial products of an utility maximizing individual will be proportional to his/her income (budget). That means individual demand (or expenses) of commercial product = k times individual income, where k is a constant (i.e., a converting factor between income and demand or expenses of commercial products). In our case, we obtain the potential demand from a city by the total income (per capita income times population) of the city times k. [9] Because of its large population, Seattle generates a huge demand that dominates the demand generated from other cities. The higher the demand, the larger the firm's revenue less costs, and therefore, the higher the land value.

We adopt the gravity-typed model to link the potential demand, from city *j* to the site *i* at a distance of d_{ij}. [10] The accessibility index of city *j* from site *i*, ${}_jD_i$, is expressed as

$$ {}_jD_i = \frac{k \bullet \text{Total Income}_j}{d_{ij}^b} \qquad (2\text{-}5) $$

where *b* is the decay parameter of the potential demand with respect to distance. [11] According to Equation (2-5), the distance between the site and the city is used to discount the potential demand of the city. The larger the distance between site *i* and city *j*, the less accessible (lower demand for given total income) is site *i* to city *j*, therefore, land value of site *i* will be lowered. Similarly, the larger the value of the parameter *b*, the faster the decay of potential demand against distance, and once again, land value of site *i* will be lowered.

Further assume that individual's decisions are independent of one another. Aggregating the accessibility indexes from all cities in the region, the index of accumulated accessibility of site *i* (D_i) is:

$$ D_i = k \bullet \sum_{j=1}^{J} \frac{\text{Total Income}_j}{d_{ij}^b} \quad . \qquad (2\text{-}6) $$

---

[9] Source: Census Report: Summary of Social Characteristics (1990), Tables 1 and 3. Both variables are divided by 10,000. Per Capita Income data are in 1989 dollars.

[10] See Anderson [1]. The general potential formula is: Potential = Mass • Distance $^{-\text{(Decay parameter)}}$.

[11] The magnitude of parameter b should be related to the traveling cost.

Note that parameter k will merge with the slope parameter in the regression. The value of parameter b is essential not only to compute the value of D_i but also to determine the rate of change of the total accessibility at different sites.

There are several ways to incorporate distance variables into the model. For example, Peiser [16] constructed an employment index of the site, and indicated that accessibility to employment centers increases land value. The employment index he used is a weighted sum of employment (in 1980) within 6 miles radius from the site. Using the approach of gravity model, the employment accessibility index of site at coordinate (v, w) from centr at coordinate (g, h): $Empl_{vw} = \sum_g \sum_h E_{gh} e^{-b d_{gh}}$, where E_{gh} represents the employment at grid coordinate (g, h), b is the decay parameter and d_{gh} is the straight line distance from the coordinate (v, w) to (g, h).

Previous studies have assumed values for the decay parameter. In Peiser's model, the decay parameter b is arbitrarily set at 0.5. Downing [6] chose to use a reciprocal of distance, that is, b is set to be one. Kowalski and Paraskevopoulos [12], Colwell and Sirmans [4], McMillen and McDonald [14] used a direct distance measure between a site and regional nodes, that is, b is set to be negative one. In other words, land value is assumed to be linearly related to distance from the node. Interestingly, these values of b are set with no regard to the observations.

Among these studies, only Peiser incorporated the heterogeneity nature of different nodes into his indexes. Without accounting for the mass of each node in the model, the coefficient associated with the distance variable of the node will be a mixture of the weight of the mass and the true coefficient (if the mass is accounted for in the model). The estimated coefficient will not stable if the mass of the node has a tendency to vary. This way of modeling a distance variable allowing no change in the mass of the node is inappropriate unless the node has a stable mass, such as an airport or an ocean (See McMillen and McDonald [14]).

Blackley [2] classified distances into dummy variables.[12] A fundamental question on using a dummy variable is on defining the cut-off point of the variable. In some situations, dummy variable can be easily defined. For example, dummy variables that identify the gender of consumers and different treatments can be easily defined. However, a dummy variable is hard to be well-defined if it is used to represent a continuous variable, such as distance measure, because the cut-off points have to be decided by the researcher. Therefore, researchers using different sets of cut-off points may obtain different regression results. Contrary to previous studies, we make no artibitrary assumption on the value of b. Rather, we estimate its value from the data.

In addition, a multicentric analysis should also take into consideration the spatial allocation of centers. Recall that, in a monocentric area, the accessibility declines monotonically away from the central city. However, in a multicentric situation, the accessibility could change quadratically against distance if a site moves away from one city but, at the same time, moves towards another city.

To formulate the highway accessibility index, we adopt a similar method to the one used to construct the market accessibility index. Assuming that the entire highway provides the same cost of transportation, the mass of the highway is set to be equal to one. Furthermore, we also assume that the access of the highway interchange decays exponentially in distance. So, we transform the distance of site i from the nearest highway interchange (d_{ih}) into ${}_hD_i = d_{ih}^{-b_h}$, where b_h represents the decay parameter of distance from the nearest interchange. b_h will be estimated in the model.[13] This transformation is similar to Downing's distance variable except the assumption on the decay parameter.

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[12] For example, a dummy variable is used to describe whether the site is close to the railroad (equal to 1 if site is near to the railroad; equal to 0, otherwise). Another dummy variable is used to describe how close the site is to the expressway (equal to 1 if within 1/2 mile; equal to 2 if within 2 miles, but not 1/2 mile; equal to 3 if within 5 miles, but not 2 miles; or equal to 4 if more than 5 miles).

[13] See Appendix 2 for the measurement method of the nearest highway interchange.

We expect the estimated parameter of b to be positive because the accessibility of market decreases if a site is located farther away from a city. Therefore, the land value also decreases. If a site has higher accessibility to the market, it should have higher sales as well as revenue, and the excess of revenue over non-land costs.[14] Hence, the parameter relating the market accessibility of a site to its land value should be positive. Next, the highway system provides a means of low cost transportation to and from different locations. Therefore, the closer to the highway interchange the better the accessibility of the site. We expect the estimate of b_h and the coefficient of the discounted distance to the highway interchange to be positive.

2.4.3 Hedonic Commercial Land Price Model

Griliches [8] contains a clear explanation of hedonic prices. To estimate the hedonic prices, previous studies have applied different regression techniques. Mills [15] compared three functional forms of modeling land values and found that the log-log form best fit the data. Kowalski and Cowell [11] applied Box-Cox transformation in their estimation process. Kanemoto and Nakamura [10] improved on Quigley's two-stage econometric method (See Quigley [17j) and suggested using Box-Cox transformation on the data with a new two-stage procedure to estimate a hedonic model. However, Cassel and Mendelsohn [3] used Box-Cox transformation in their model and realized that the method biased the estimator. McMillen and McDonald [14] modeled several land uses with simultaneous equations models.

In our model, using Equations (2-3) and (2-5), we specify the following econometric model (the full model):[15]

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[14] Non-land costs are assumed to be homogeneous degree of one to output.

[15] Subscript notation of j: Burien (j = 1 or Bur), Seattle (j = 2 or Sea), Des Moines (j = 3 or Dsm), Federal Way (j = 4 or Fed), Sea Tac (j = 5 or Set), Tulikwa (j = 6 or Tuk), Kent (j = 7 or Ken), Mercer Island (j = 8 or Mer), Renton (j = 9 or Ren), Auburn (j = 10 or Aub), Kirkland (j = 11 or Kir), Bellevue (j = 12 or Bel), Redmond (j = 13 or Red) and Issaquah (j = 14 or Iss).

$$R_i = \beta_o + \sum_{j=1}^{14} \beta_j \, {}_jD_i + \beta_h \, {}_hD_i + \sum_{t=1}^{5} \tau_t a_{ti} + \varepsilon_i \ , \qquad i = 1, \ldots, 166, \tag{2-7}$$

where R_i is the observed land price of site i, and β_j, β_h, b, b_h and τ_t are parameters to be estimated, the regressors are assumed to be non-random and ε_i denotes the random disturbance term, such that $\varepsilon_i \sim NID(0, \sigma^2)$, $\forall\ i$. [16]

The full model is linear in functional form and in parameters except parameters b and b_h. If we know the values of b and b_h then we can estimate the model by the Ordinary Least Squares (OLS) estimation method. In order to apply the linear estimation technique to estimate their models, making assumptions on b are unavoidable. Both Peiser [16] and Downing [6] reporting relatively low R^2 of 0.6 and 0.44, respectively, it might be due to their assumed values on the decay parameters. Since our model is non-linear in parameters, we use Nonlinear Least Squares (NLS) to perform the estimation. Given the assumptions on the error term ε_i and the regressors, the NLS estimators are asymptotically normal, consistent and efficient. (See Davidson and MacKinnon [5], Ch. 5.)

From the estimation result of Equation (2-7), the implicit marginal price of the market accessibility from city j equals $\hat{\beta}_j$,

$$\frac{\partial R_i}{\partial \, {}_jD_i} = \hat{\beta}_j \ . \tag{2-7a}$$

The implicit marginal price of the site characteristic (a_t) equals $\hat{\tau}_t$,

$$\frac{\partial R_i}{\partial a_t} = \hat{\tau}_t \ . \tag{2-7b}$$

The effect of the income of city j on the value of site i is a composite function of estimates $\hat{\beta}_j$ and $\hat{b}$,

[16] The constant k of Equation (2-7) merges to the full model as β_j ($= k \cdot \beta_j'$) .

$$\frac{\partial R_i}{\partial \text{ Per Capita Income}_j} = \hat{\beta}_j \left(\frac{\text{Population}_j}{d_{ij}^{\hat{b}}} \right) . \qquad (2\text{-}7c)$$

The effect of the population of city *j* on the value of site *i* is also a composite function of estimates $\hat{\beta}_j$ and $\hat{b}$,

$$\frac{\partial R_i}{\partial \text{ Population}_j} = \hat{\beta}_j \left(\frac{\text{Per Capita Income}_j}{d_{ij}^{\hat{b}}} \right) . \qquad (2\text{-}7d)$$

Notice that the income and the population effects from city *j* on the land value are functions of d_{ij}, meaning that these effects vary from site to site. For example, if $\hat{\beta}_j$ and $\hat{b}$ are positive, then the effect on land price due to an increase in population (or per capita income) of city *j* will be larger if the site is location closer to city *j*.

2.4.4 Empirical Models

We estimated a full and a restricted specification models of Equation (2-7) by NLS. We tested the restricted model against the full model and found that the difference between the two models are statistically insignificant at 5% level. In the following, we will briefly present some interesting results of the full model. Then, we will perform a hypothesis testing between the two models and discuss the restricted model.

2.4.4.1 The Full Model

Table 2-2 presents the estimation result of the full model. Five estimates, for parameters β_{Sea}, β_{Bel}, b, τ_{cor} and τ_{tea}, are (asymptotically) significantly different from zero. The estimate of the decaying parameter, $\hat{b}$, equals 0.8733. This indicates a rapid decay of potential demand away from the city. Therefore, a city that is close to a site becomes extremely important in determining its value. Cities located at a long distance from a site may have only little effect.

Since the full model allows different effects of accessibility from each city to a site, we have one parameter of market accessibility, β_j, associated with city *j*. The estimated market accessibility parameters of Seattle, Des Moines, Sea Tac, Kent, Rent, Kirkland, Bellevue, Redmond and Issaquah are positive. Only parameters associated with Seattle and Bellevue are significantly different from zero. The positive coefficient indicates that an increase in the decayed potential demand (due to an increase in population or income, or by a decrease in distance) increases the land value of a site. For example, the estimate of β_{Sea} shows that an additional unit of the accessibility index from Seattle generates an increase in land price of 48 cents p.s.f. (or about 4.0% of our AOP). Although the estimated market accessibility parameters of Burien, Federal Way, Tukilwa, Mercer Island and Auburn are negative, they are insignificant at 5% level.

The effects of site characteristics on land values are also estimated. The estimate of τ_{cor} equals 4.4 meaning that corner lots are, on the average, about $4.4 p.s.f. (or about 36% of our AOP) more expensive than off-corner lots. The estimate of τ_{str} shows that lots with existing structures are of higher price presumably because structures on the site may still be useful to the buyer. The estimate of τ_{zon} shows that lots zoned for large community businesses are relatively cheaper than lots zoned for neighborhood businesses suggesting that the market demand relative to the market supply for community business land is smaller than that of the neighborhood business. The estimates of τ_{sha} and τ_{lev} indicate that rectangularly shaped lots and leveled lots are of higher price. However, the estimates of τ_{zon}, τ_{sha} and τ_{lev} are not significantly different from zero at 5% level.

Table 2-2 The Full Model[17]

Parameter	Estimate	Asymptotic Std. Error	Parameter	Estimate	Asymptotic Std. Error
β_o	-4.6262	62.5351	β_{lss}	7.1964	27.4720
β_{Bur}	-0.1606	0.6449	β_h	10.5267	65.4795
β_{Sea}***	0.4827	0.0787	b ***	0.8733	0.1228
β_{Dsm}	0.0081	0.8273	b_h	0.1390	0.8073
β_{fed}	-0.0035	0.2665	τ_{cor}***	4.4017	2.0476
β_{Set}	1.7102	2.5447	τ_{str}***	4.9142	2.0855
β_{Tuk}	-1.9932	4.7472	τ_{zon}	-0.2537	2.3764
β_{Ken}	0.0227	0.3668	τ_{sha}	1.9971	2.1656
β_{Mer}	-5.4415	5.7265	τ_{lev}	1.0912	2.1023
β_{Ren}	0.1146	0.5069			
β_{Aub}	-3.5723	3.2616	SSR	20053	
β_{Kir}	0.0076	0.5665	d.f.	143	
β_{Bel}***	0.8622	0.2815	$\bar{R}^2$	0.715	
β_{Red}	0.0031	0.3412			

[17] The parameter indexed by "***" represents that the estimate is asymptotically different from zero at 5% significant level. SSR denotes the Sum of Square of Residuals. The notations, d.f. and $\bar{R}^2$, represent the degree of freedom and the adjusted R^2, respectively.

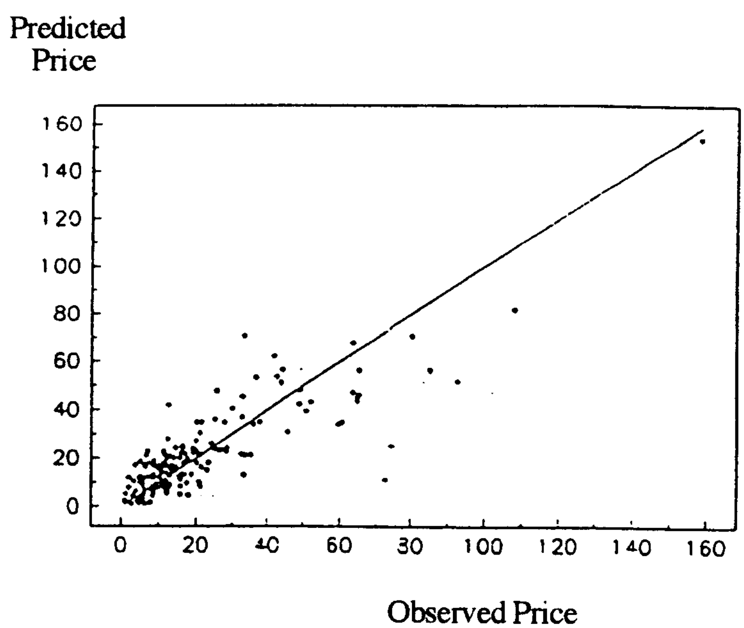
2.4.4.2 The Restricted Model

In the restricted model, we assume that the effects of each unit of the market accessibility index are the same regardless the source of cities. That is, $\beta_1 = \ldots = \beta_{14} = \beta$. The restricted model is of the following form:

$$R_i = \beta_o + \beta \sum_{j=1}^{14} {}_jD_i + \beta_h \, {}_hD_i + \sum_{t=1}^{5} \tau_t a_{ti} + \varepsilon_i \qquad (2\text{-}8)$$

We can test the statistical difference between the full model and the restricted model. The Pseudo-F test statistics equals to 1.66. The critical $F^{13}_{144,\ 0.95} \approx 1.75$ is larger than the computed F value. Therefore, we fail to reject the null hypothesis that $\beta_1, \ldots, \beta_{14}$ are equal at 5% significance level. The $\overline{R}^2$ of our model equals 0.7. Figure 2-3 plots the predicted values of the restricted model against the observed values.

Figure 2-3 The Predicted Value Plot



We checked for heteroscedasticity as a standard practice for cross-sectional model. Using the White test, we obtained the calculated Chi-square statistics as 30.8, which is smaller than the critical statistics for a degree of freedom of 30 at 5% significant level. Therefore, we conclude that the heteroscedasticity is not significant in this model and so results from statistical inferences are reliable.

Regression results of Equation (2-8) are shown in Table 2-3. All estimates are of expected signs. Four estimates, $\hat{\beta}$, $\hat{b}$, $\hat{\tau}_{cor}$ and $\hat{\tau}_{tea}$, are significantly different from zero. The estimate of b, which equals 0.8363, is slightly smaller than that of the full model. The land value elasticity of market accessibility index evaluated at the average observed price and the overall mean of the accessibility index equals $\frac{\partial R}{\partial D_i}\frac{\bar{D}_i}{\bar{R}} = 0.5135\left(\frac{43.83}{12.15}\right) = 1.85$. The estimate of β shows that, regardless of the source of cities, each additional unit of market accessibility index to a site increases its land price by fifty-one cents p.s.f. (or 4.2% of our AOP).

Our estimated result of corner lots are different from earlier studies. In contrast with Peiser [16] and Downing [6] reported that corner locations are insignificant in determining the value for commercial land in Dallas and Milwaukee, respectively, our estimate of τ_{cor} indicates that corner lots are \$5.30 p.s.f. (or 4.4% of our AOP) higher than off-corner lots in the King County. In addition, our estimate in the restricted model is about 0.96 (or 22%) higher than that of the full model. The estimate of τ_{str} indicates that lots with existing structures are about \$5.71 p.s.f. (or 47% of our AOP) higher than lots without them.

Our results question the conclusion of Gandhi and Rahman [7] that land shape is important in determining land value. Our estimates of τ_{sha} and τ_{lev} are equal to 1.93 and 0.59, respectively. By looking at the magnitude of these estimates, they indicate that land shape is more important than topography for commercial land. Rectangularly shaped lots are, \$1.90 p.s.f. (16% of our AOP) more expensive than non-rectangularly shaped lots, while leveled lots are only about \$0.60 p.s.f. more expensive than sloped lots. However, the result of this restricted model, which is similar to that of our full model, indicates that these two estimtates are not significantly different from zero.

We obtained a similar result as Peiser's [16] that the effect of transportation node on commercial land values is statistically insignificant. The estimate of b_h is about half of the estimate of b indicating that the highway interchange effect is less sensitive to distance than the market accessibility effect. It is about twelve times as large as that of the full model. The estimates of β_h and b_h are not significantly different from zero.

Our result on zoning classification does not agree with Downing's [6] that it has no significant impact on commercial land values. The estimate of τ_{zon} is equal -1.05 indicating that lots zoned for community commercial business receives lower land value than lots zoned for neighborhood commercial business. However, once again, it is not significantly different from zero.

Table 2-3 The Restricted Model[18]

Parameter	Estimate	Asymptotic Std. Error	Parameter	Estimate	Asymptotic Std. Error
β_o	-7.8216	7.2516	τ_{zon}	-1.0492	2.4754
β ***	0.5135	0.0548	τ_{sha}	1.9301	2.1312
β_h	1.7330	8.7615	τ_{lev}	0.5925	2.1070
b ***	0.8363	0.0869			
b_h	0.4331	1.5355	SSR	23052	
τ_{cor} ***	5.3580	1.9766	d.f.	156	
τ_{str} ***	5.7075	2.0630	$\bar{R}^2$	0.700	

2.5 Implications and In Sample Forecasting

After obtaining the restricted model, one might naturally pose the following question: How would changes in exogeneous variables, such as the highway system, per-capita income or population, affect land values? To answer this question, we apply the estimates of the restricted model in four computer simulations. Note that all of the following simulations simulate the situation as if all sites have characteristics, a_{it}, equal to zero, for all i and t -- the "base" lots. That is, lots are not in the corner, have no teardown structures, are zoned for neighborhood business, are non-rectangularly shaped, and are not level.

[18] The parameter indexed by "***" represents that the estimate is asymptotically different from zero at 5% significant level. SSR denotes the Sum of Square of Residuals. The notations, d.f. and $\bar{R}^2$, represent the degree of freedom and the adjusted R^2, respectively.

2.5.1 Simulation 1

To visualize the predicted land value profile of the "base" lots of the metropolitan area (the "base" land value profile), we use $\hat{\beta}_o$, $\hat{\beta}$, $\hat{\beta}_h$, $\hat{b}$, and $\hat{b}_h$ from the result of Equation (2-8). The resulting land value profile consists of the market accessibility and the highway interchange accessibility effects. (Note that we can raise the "base" land value profile by $\hat{\tau}_t$ to obtain the profile for lots with site characteristic *t*.) We simulate the "base" land value by the equation:

$$\hat{R}_i = \hat{\beta}_o + \hat{\beta} \sum_{j=1}^{14} {}_jD_i + \hat{\beta}_{hh} D_i$$

$$= -7.8216 + (0.5135) \sum_{j=1}^{14} \frac{\text{Total Income}_j}{d_{ij}^{\,0.8363}} + (1.7330)\,(d_{i,h})^{-0.4331} \quad . \qquad \text{(S-1)}$$

Figure 2-4(a) shows a simulation plot of the land value profile and Figure 2-4(b) shows the land value contours. (Lighter color represents higher value). From Figure 2-4(a), land value at the center of each city is higher than its surrounding area. (A plateau occured at Seattle is due to the fact that land value in the center of Seattle is too high to show on the diagram relative to the rest of the cities; its peak is truncated and shown as a plateau.) The contour plot shows clearly that the triangular region among Des Moines, Federal Way and Kent has the same level of value. This is because the accessibility effects are balanced out in all directions in that part of the multicentric metropolitan area.

2.5.2 Simulation 2

We can also use the restricted model to simulate the land value profile if the regional characteristics were changed. Imagine that the State government has decided to emphasize an even population policy that re-allocates the population of each city to certain target level, say, the average level as in year 1990. Then, the differences in total income (and in market accessibility) between Seattle and other cities will become smaller. Figure 2-5 plots the new land value contours under the policy. We can make two observations. First, Seattle is no longer the dominant city. Instead, the area around Mercer Island and Bellevue has the highest land value because it captures high potential demand from both places. Second, the land value for the rest of the cities have increased.

2.5.3 Simulation 3

The per capita income effect on land value is:

$$\frac{\partial R_i}{\partial \text{ Per Capita Income}_j} = \hat{\beta}\left(\frac{\text{Population}_j}{d_{ij}^{\hat{b}}}\right) = 0.5135\left(\frac{\text{Population}_j}{d_{ij}^{0.8363}}\right) \quad . \qquad \text{(S-2)}$$

Table 2-4 provides simulation result of the change in land value (in dollar p.s.f.) at the selected distance for one thousand dollars change in per capita income. For example, if the per capita income in the city of Seattle increases by one thousand dollars, then land values for sites located at one mile radius away from Seattle will increase by \$2.65 p.s.f. (or 22% of our AOP). Land value for located at two mile radius away from Seattle will increase by only \$1.49 p.s.f. (or 12% of our AOP). If a site is located one mile away from Tukwila and 1.5 away from Renton, and both cities have a one thousand dollar increase in per capita income, then its land value will increase by \$0.21 (equals \$0.06 plus \$0.15) p.s.f. (or 1.7% of our AOP). Seattle is the most influential city because of its relatively large population.

2.5.4 Simulation 4

A change of land value can also be induced by a change in population. Similar to the income effect, the population effect from city *j* depends on the per capita income of city *j*. Therefore, as the city becomes richer, the population effect increases as well. The population effect becomes:

$$\frac{\partial R_i}{\partial \text{ Population}_j} = \hat{\beta}\left(\frac{\text{Per Capita Income}_j}{\text{d}_{ij}^{\hat{\delta}}}\right) = 0.5135\left(\frac{\text{Per Capita Income}_j}{\text{d}_{ij}^{0.8363}}\right). \qquad \text{(S-3)}$$

Table 2-5 provides simulation result of the change in land value (in dollar p.s.f.) at the selected distance for an increase in population of ten thousand. For example, if the population in the city of Seattle increases by ten thousand, then land values for sites located at one mile radius away from Seattle will increase by $0.94 p.s.f. (or 7.7% of our AOP). Land value for located at two mile radius away from Seattle will increase by only $0.53 p.s.f. (or 4.3% of our AOP). If a site is located one mile away from Tukwila and 1.5 away from Renton, and both cities have an increase in population of ten thousand, then its land value will increase by $1.29 (equals $0.82 plus $0.47) p.s.f. (or 10.6% of our AOP). In case of population effect, Seattle is no longer the most influential city; instead, richer cities, such as Mercer Island and Bellevue, are more important.

Figure 2-4(a) Simulation 1 (Land Value Profile of Base Lots)

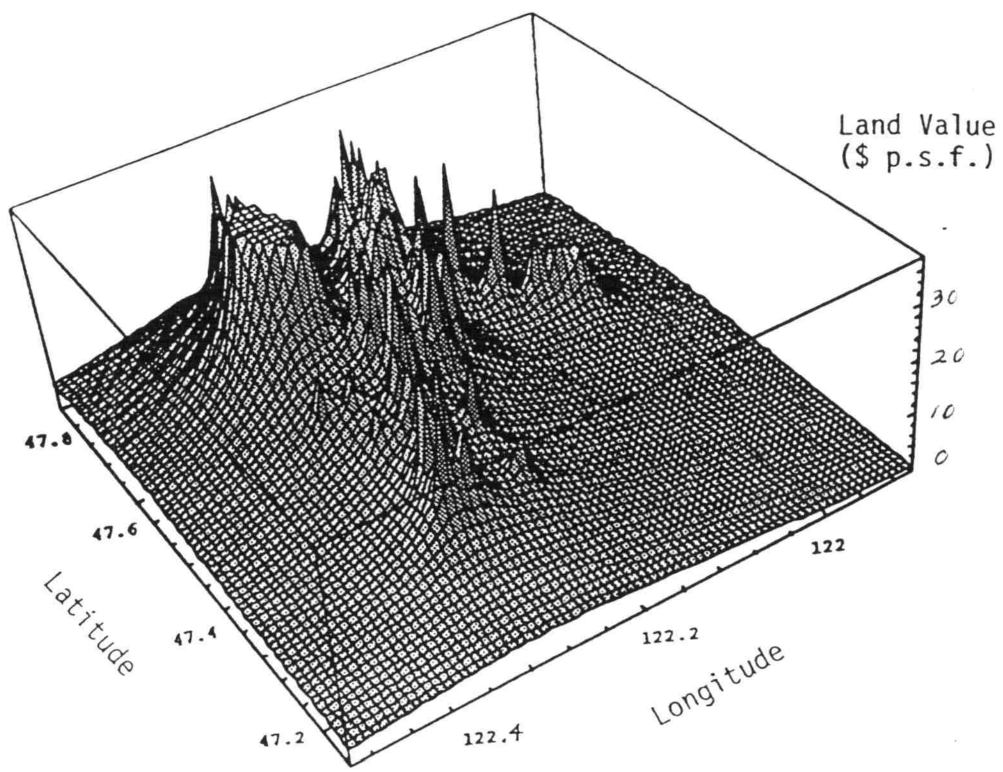


Figure 2-4(b) Simulation 1 (Contours Plot)

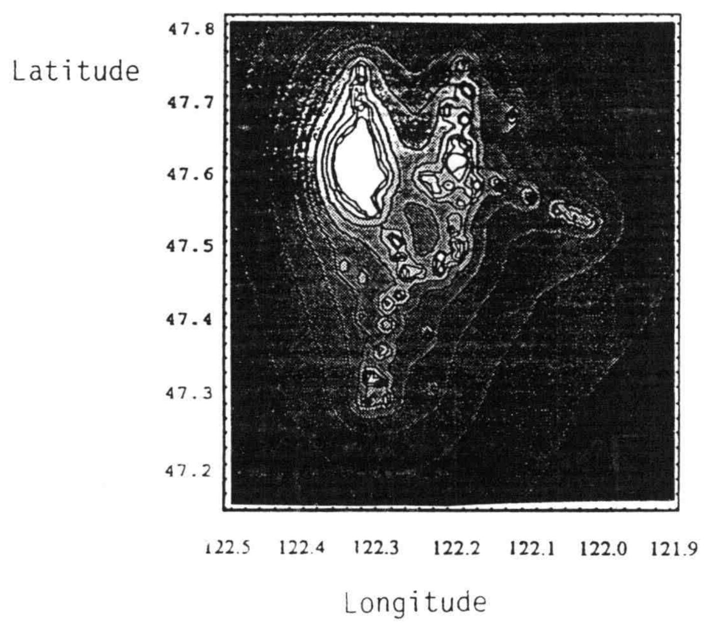


Figure 2-5(a) Simulation 2 (Land Value Profile of Even Population Policy)

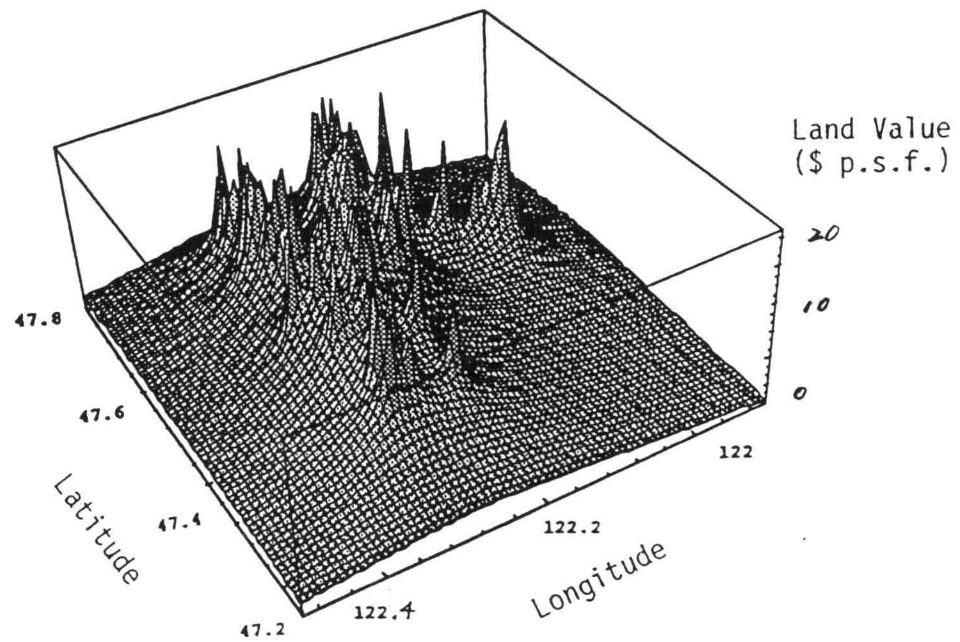


Figure 2-5(b) Simulation 2 (Contours Plot)

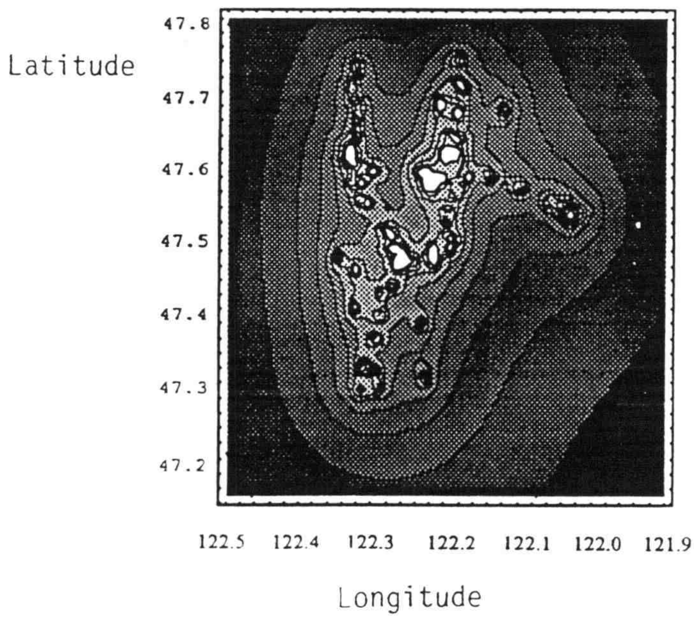


Table 2-4 Per Capita Income Effect: Changes on land value (in dollars p.s.f.) at given distances for $1,000 dollar change in per capita income

City	Population	0.5 mile away	1 mile away	1.5 mile away	2 mile away
Seattle	516259	4.73	2.65	1.89	1.49
Bellevue	86878	0.797	0.446	0.318	0.250
Federal Way	67554	0.619	0.347	0.247	0.194
Renton	41688	0.382	0.214	0.153	0.120
Kirkland	40052	0.367	0.206	0.147	0.115
Kent	37960	0.348	0.195	0.139	0.109
Redmond	35800	0.328	0.184	0.131	0.103
Auburn	33102	0.303	0.170	0.121	0.095
Burien	25089	0.230	0.129	0.092	0.072
SeaTac	22694	0.208	0.117	0.083	0.065
Mercer Island	20816	0.191	0.107	0.076	0.060
Des Moines	17283	0.158	0.089	0.063	0.050
Tukwila	11874	0.109	0.061	0.043	0.034
Issaquah	7712	0.071	0.040	0.028	0.022

Table 2-5 Population Effect: Changes on land value (in dollars p.s.f.) at selected distances for an increase in population of ten thousand

City	Per Capita Income	0.5 mile away	1 mile away	1.5 mile away	2 mile away
Mercer Island	31438	2.88	1.61	1.15	0.90
Bellevue	23816	2.18	1.22	0.87	0.68
Kirkland	21200	1.94	1.09	0.78	0.61
Redmond	20037	1.84	1.03	0.73	0.58
Seattle	18308	1.68	0.94	0.67	0.53
Issaquah	18055	1.66	0.93	0.66	0.52
FederalWay	17126	1.57	0.88	0.63	0.49
Burien	16857	1.55	0.87	0.62	0.48
DesMoines	16778	1.54	0.86	0.61	0.48
Renton	16298	1.49	0.84	0.60	0.47
Kent	15993	1.47	0.82	0.59	0.46
Tukwila	15982	1.47	0.82	0.58	0.46
SeaTac	15579	1.43	0.80	0.57	0.45
Auburn	13866	1.27	0.71	0.51	0.40

2.6 Summary and Extensions

2.6.1 Summary

We used two types of regressors in our model: physical site characteristics and accessibility indexes. Since the indexes consist of distance, mass(es) of nodes, and a decay parameter, the model becomes non-linear in parameters. Therefore, the non-linear least squares estimation method is applied. Our findings are as follow: First, our results indicate market accessibility to be the major factor governing the value of vacant commercial land. Second, our results are consistent with previous studies that highway interchange accessibility is insignificant in determining commercial land values. Third, we found that corner lots and lots with existing structures have higher land values. Fourth, our estimated decay parameter of market accessibility is different in value from the ones that are commonly set arbitrarily. Fifth, we found that, under the zoning policy, neighborhood commercial and community commercial land have no significant difference in value. Sixth, some site characteristics, such as leveled lots and rectangular lots, are insignificant in determining commercial land values.

2.6.2 Extensions

This study proposes a model for estimating vacant commercial land values in a multicentric metropolitan area. Since the use of land for different industries could be different, site characteristics and populated cities might be important in one land use, but not in another. For example, if the study focuses on the land value of land use for high-tech industries, then site characteristics may become less important. Instead, areas concentrated with skilled labor might become more important. However, if the study focuses on the land value of land use for manufacturing industries, then some site characteristics (such as leveled lots and rectangularly shaped lots) and highway accessibility might become important. Therefore, it would be interesting to compare determinants for different land uses.

Second, an extra equation for commercial product demand might be added to the model. Since this paper assumes that each consumer's preference is homothetic between commercial and non-commercial products, the demand and expenditure for commercial products will be proportional to the budget (income level). Therefore, we use total income as a proxy of the demand. An alternative approach is to estimate the commercial demand in each city, then substitute the "Total Income" with their predicted demand.

Third, this study is a cross-sectional analysis assuming land value, income and population are time invariant. We can consider a spatial distribution of population and income, and their changes, to the model -- a time-series analysis. If the data are available, it would be interesting to trace the changes of the land value surfaces for different time periods.

Fourth, the model estimated in this paper assumes an error term with zero mean; therefore, it is an average of estimation that allows positive and negative residuals. We can modify the setup to a one-sided error and estimate a stochastic or a non-stochastic frontier.

2.7 References

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Chapter 3

ESSAY II: TESTING THE EFFICIENCY OF THE U.S. MOTOR CARRIER INDUSTRY

3.1 Introduction

This paper applies Stochastic Cost Frontier (SCF) models to the US Motor Carrier industry. By using the SCF approach, we are able to estimate the industry level and firm level inefficiencies. We estimated the SCFs using data from the American Trucking Association between 1976 and 1987 and analyzed the industry performance in both the pre- and post-Motor Carrier Act (MCA) era. We also used Tobit regression to investigate the relationship between firm level inefficiencies and firm characteristics.

The Motor Carrier Act of 1980 has captured the attention of transportation economists. The general freight section of the industry, consisting mostly of less than truck-load carriers, seems to have suffered the largest impact from this legislation. Many studies have suggested that the MCA promoted the competition in the industry and benefited consumers. For examples, Ying [43] has found that the MCA reduced the production cost of motor carrier services. His simulation results showed that cost savings directly due to the MCA had increased from 1.1 percent in 1981 to 22.8 percent in 1984 (that is 8.7 billions for these four years). Ying and Keeler [44] have found that the MCA reduced prices charged by the industry, so consumers eventually benefited from the MCA.

There have been many changes in the production technology of the Motor Carrier industry. For example, McMullen [35] discussed the development of brokering market, which helped the smaller carriers compete with the larger carriers. Using computer networks, brokers have been able to engage in cobrokerage that helps to refill the empty backhauls or round out shipments. Corsi *et al.* [25] pointed out that the top management teams have increased in size and in functions, and have placed more emphasis on market-oriented functions. There is no doubt that MCA had great impacts on the competitiveness of the business environment. However, significant technological change in production could also be an important factor in lowering the operating costs.

Economists usually measure firm's performance by the cost of production. The larger the gap between the firm's actual cost and its lowest possible production cost (the cost frontier), the more inefficient the firm is. In the presence of new legislation and technological improvement, the firm may be able to produce at a lower cost frontier and actual cost. However, whether a firm becomes more efficient or not, it depends on whether the firm can reduce the gap between the new actual cost and the new frontier. Therefore, the observed cost saving, i.e., the change in actual costs, do not necessarily imply an improvement in efficiency. Measuring cost savings in production alone cannot be correct for describing firm's production efficiency.

The technology of the US Motor Carrier industry has traditionally been measured through the estimation of either a single translog cost model or a system of cost and share equations.[19] These approaches assume that the stochasticity of the cost and share functions capture solely non-systematic factors which are unrelated to the idea that cost functions are the result of firm's cost minimization process (a necessary condition for firm's profit optimization process). In other words, assuming firms are efficient, these models estimate the cost function of the industry at the expected value of its random noise (while expected value = 0). If firms are efficient, then production choices will be located on the cost function. The estimated cost function represents the average performance of the industry. However, if firms are not perfectly efficient, they may systematically depart from the cost function. As a result, tradition models that assuming firms are efficient can only tell

[19] See Ying [43] and McMullen and Stanley [36].

whether the average production cost has become lower but can say nothing about the inefficiency of the industry and the performance of the firm.

To analyze firm's performance, we must assume that firms can be inefficient and implement an estimation technique that allows inefficiency. A new efficiency estimation technique called the Stochastic Frontier Estimation (SFE) was proposed by Aigner, Lovell and Schmidt [19]. The SFE technique assumes that the variation of firm's productivity is due to (i) the random noise (the same assumption as the traditional cost function estimation); and (ii) the firm-specific inefficiency.

The SFE technique has been widely used in studying financial services and other industries. For examples, Ferrier and Lovell [26] compared the stochastic parametric cost frontier and the nonparametric nonstochastic linear programming production frontier using data from the banking industry. Mester [38] also used the SFE technique to investigate the savings and loan industry. Zuckerman *et al.* [46] estimated a multiproduct stochastic cost frontier for hospitals using a sample of 1600 hospitals. Vitaliano and Toren [41] estimated a stochastic cost frontier for nursing homes in New York.

Although the SFE technique has been applied to the estimation of production efficiency for several industries, little work have been done on the motor carrier industry. Bruning [22] estimated a translog stochastic cost frontier and regressed the firm specific inefficiencies on firm attributes by Ordinary Least Squares (OLS). His result showed that 98 percent of firms were producing 10 percent or less excess in cost above their best practices. However, there are several points which are not clear in his paper. First, from the translog cost frontier model, he included only output and input prices as the regressors. This is different from McMullen [35] and Ying [43] and Ying and Keeler [44] who include attributes to capture the difference in output characteristics among firms. They found that attributes are significant regressors. Therefore, Bruning's model might have omitted important variables and his estimates might be biased. Second, he did not impose the regularity restrictions for a well-defined cost function on his model, so we do not know whether his estimated model contains those regular properties. Third, since the estimated inefficiencies are between zero and one, using OLS, that assumes no truncation on the distribution of the dependent variable will generate biased results.

Our paper contributes more insights on the performance of motor carrier firms and the industry. We achieve the following goals: (1) we estimate stochastic cost frontiers for the U.S. Motor Carrier industry for the period 1976 to 1987; (2) we discuss the difference among average industry inefficiencies for different periods; (3) we identify the relationship between firm's characteristics and their regional inefficiencies; and (4) we compare the efficiency levels of firms and industry both prior and post MCA.

This chapter is divided into the following sections. Section 3-2 presents the theoretical SFE model.[20] Section 3-3 explains the data used in the study. Section 3-4 analyzes the estimated results, the average industry inefficiencies, and firm level inefficiencies. Section 3-5 shows a tobit model regressing firm inefficiencies against firm characteristics. Section 3-6 presents tests for heteroskedasticity. Section 3-7 summarizes the results and discusses the limitations and possible extensions of this study.

3.2 Stochastic Frontier Estimation Technique

The single-equation stochastic cost frontier model in this study is specified as follows:

$$\ln C_i = \ln C(y_i\,,\, \boldsymbol{p}_i\,,\, \boldsymbol{a}_i) + u_i + v_i \tag{3-1}$$

where $i = 1, ..., N$ is an index representing N firms, C_i represents observed cost, y_i represents output of firms, $\boldsymbol{p}_i$ represents a vector of input prices, $\boldsymbol{a}_i$ represents a vector of

[20] Discussion of recent developments of the estimation technique can be found in Bauer [21].

firm attributes, u_i represents the one-sided positive disturbance capturing the effects of inefficiency, and v_i represents the two-sided disturbance capturing the effects of random error. Although the stochastic frontier estimation methodology is appealing from an economic theory perspective, there are several critical statistical assumptions that have to be made to implement the procedure. Schmidt [40] pointed out that inefficiency estimates can be very sensitive to assumptions. There are four estimable forms of the one-sided inefficiency distributions, namely, half-normal, truncated normal, exponential and gamma.[21] Since half-normal is the most commonly used distribution in the literature, we use this assumption in this study.[22]

In this study, the sequence $\{v_i : i = 1, 2, ...\}$ is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$ and the sequence $\{u_i : i = 1, 2, ...\}$ is assumed to be half-normally distributed as $|N(0, \sigma_u^2)|$. v_i and u_i are independent for all i. The half-normal distribution of u_i assumes that firms are more likely to be efficient and are less and less likely to be more inefficient.

The stochastic frontier model given by Equation (3-1) has advantages over the typical classical linear model and the deterministic frontier model. The classical linear model of a cost function corresponds to the special case when $u_i = 0$, $\forall i$, i.e., all firms are efficient, which produces an 'average level' that best fits the data. Under this assumption, all the deviations apart from the frontier are measured as random effects. However, since the cost function is the minimum cost associated with a given level of output and input vectors, observations below the cost function are not feasible. Therefore, the fitted cost function is inconsistent with the theoretical concept of cost function. Also from Equation

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[21] Lee [34] suggested a likelihood ratio test researchers can use to compare between different inefficiency distribution assumptions.

[22] Other applications of the SFE technique can be found on the estimation of reservation wages (Hofler and Murphy [29]), on estimation of frictional unemployment (Warren [42]), on estimation of earnings functions (Polachek and Yoon [39]) and on the estimation of the efficiency of life-insurance firms (Yuengert [45]).

(3-1), the stochastic frontier model collapses into a deterministic frontier model when v_i = 0, $\forall i$. Under this assumption, all the deviations apart from the frontier are measured as inefficiency.

The stochastic frontier model, on the other hand, distinguishes inefficiency from the statistical noise. A firm may operate at its best but still above the ideal cost for reasons beyond its control, such as weather or luck. These random disturbances should not be counted as inefficiency. The true inefficiency is the excess of cost above the stochastic frontier which includes the "ideal cost" plus the random disturbance v_i (see Aigner *et al.* [19]). Therefore, the cost inefficiency should be measured by the ratio of the observed costs to the stochastic frontier:

$$\frac{ObservedCost}{C(y,p,a)\,e^{v}} = \frac{C(y,p,a)\,e^{u+v}}{C(y,p,a)\,e^{v}} = e^{u} \tag{3-2}$$

The cost of each firm must lie on or above its cost frontier C(y,**p**,**a**)e^v. Any deviation is the result of factors under the firm's control, such as technical and economic inefficiency. Therefore, the notion of a stochastic frontier is consistent with the underlying economic theory of optimization behavior.

The composite error, ε, has the density function:

$$f_{\varepsilon} = \left(\frac{2}{\sigma}\phi\left(\frac{\varepsilon_i\lambda}{\sigma}\right)\right)\left[1 - \Phi\left(\frac{-\varepsilon_i\lambda}{\sigma}\right)\right]$$

where $\varepsilon_i = u_i + v_i$, $\lambda = \sigma_u/\sigma_v$ and $\sigma = (\sigma_u^2+\sigma_v^2)^{1/2}$, and $\phi(\bullet)$ and $\Phi(\bullet)$ are the probability density function and the cumulative density function of the standard normal distribution, respectively.

Estimates of this model can be obtained by maximizing the following log-likelihood function

$$\ln L = \frac{N}{2}\ln\left(\frac{2}{\pi}\right) - N\ln\sigma - \frac{1}{2\sigma^2}\sum_{i=1}^{N}\varepsilon_i^2 + \sum_{i=1}^{N}\ln\left[\Phi\left(\frac{-\varepsilon_i\lambda}{\sigma}\right)\right] \tag{3-3}$$

where N is the number of observations.

Once the model is estimated, the estimate of the average industry inefficiency level can be expressed by the estimate of the expected value of u (ignoring the subscript *i*) which was shown by Aigner *et al.* [19] to be

$$\hat{E}(\varepsilon) = \hat{E}(u) = \sqrt{\frac{2}{\pi}}\hat{\sigma}_u \quad . \tag{3-4}$$

An estimate of firm-specific inefficiency, u_i, can be obtained by using the distribution of the inefficiency conditional on the estimate of the composite error term, ε_i. Jondrow *et al.* [30] suggested the following decomposition formula:

$$E(u \mid \varepsilon) = \frac{\sigma_u\sigma_v}{\sigma}\left[\frac{\phi\left(\frac{\varepsilon\lambda}{\sigma}\right)}{\Phi\left(\frac{\varepsilon\lambda}{\sigma}\right)} + \frac{\varepsilon\lambda}{\sigma}\right] \tag{3-5}$$

where $E(u|\varepsilon)$ is an unbiased but inconsistent estimator of u_i because its probability does not degenerate asymptotically. Given the invariance property of ML estimators, once we obtained the estimates of λ and σ, we can recover the estimates of σ_u, σ_v, E(u) and $E(u|\varepsilon)$.

Consider an estimated econometric frontier model in the form, $\ln\hat{C} = \boldsymbol{x}\,\hat{b} + \hat{E}(u) + \hat{E}(v)$, where $\hat{E}(v) = 0$, $\hat{b}$ is a vector of parameter estimates and $\boldsymbol{x}$ is a matrix containing vectors of transformed y, $\boldsymbol{p}$ and $\boldsymbol{a}$. The estimated "ideal cost" equals $\boldsymbol{x}\,\hat{b} = \ln\hat{C} - \hat{E}(u)$. The $\hat{\varepsilon}$ can be calculated from the estimated information:[23]

$$\hat{\varepsilon} = \ln C - \ln\hat{C} = \ln C - \boldsymbol{x}\,\hat{b} + \hat{E}(u).$$

3.3 Data and Model Specification

3.3.1 The Data

The data used in this study were collected annually by the American Trucking Association (ATA). We focus on the instruction 27 general freight commodity carriers that were operating during 1976-1987. Following the data definitions of previous studies, such as McMullen and Stanley [36] and McMullen and Tanaka [37] and Ying [43]. we used tonmiles (*TM*) as the measurement of firm's composite output.

Since the major inputs of the motor carrier industry are trucks (owned or rented), fuel and labor, the input price vector $\boldsymbol{p}_i$ in Equation (3-1) contains four elements: price of fuel (*PF*), price of labor (*PL*), price of owned capital (*PK*) and the price of rented capital (*PR*). These input prices are not reported on the ATA data tapes. To calculate each input price, we divide the firm's expenses on the factor by the quantity of factor it consumed. For firms which did not report their purchased transportation or fuel expenses, regional

[23] LIMDEP users using the "Frontier" command should note that the last column of the output is misprinted. The column labeled "y(i) - x(i)b" should be "y(i) - predicted y" instead. The "residual", E(u|e), reported from LIMDEP is calculated based on the decomposition method using the estimated residuals, $\hat{\varepsilon}$, as in Eq. (5).

averages of *PF* and *PR* are used replacing the missing values. Based on the geographical regions designated by the Interstate Commerce Commission (ICC), firms are assigned to regions according to the state in which the firm is located.

To recover the economic cost from the accounting cost reported, a 12% cost of capital is added in the calculation of total cost (C): C = TOE + 0.12 (NOPE+WC), where TOE represents total operating expenses, NOPE represents the real net operating property and equipment, and WC represents net current assets or working capital.

For each year, the real value of the net operating property and equipment is obtained by adjusting to 1988 dollar values using a ten year average of the producer's durable equipment implicit price deflator for trucks.

The price of fuel (*PF*) was calculated by dividing the total fuel and oil expenses by the average number of gallon of fuel consumed. We assumed that the fuel efficiency of trucks is, on average, 5 miles per gallon. The average number of gallons of fuel was calculated by dividing the total number of vehicle miles by 5. The price of labor (*PL*) was calculated by dividing the total employee compensation by the total number of employees. The price of capital (*PK*) was calculated by dividing the residual expenses (total cost minus total labor expenses minus total fuel expenses minus total purchased capital expenses) by the sum of net operating property and equipment and working capital. The price of rented capital (*PR*) was defined as the expenses spent on purchased transportation divided by the total number of rented vehicle miles. All prices are converted to constant 1988 dollars.

In addition to input prices, we added the firm's attribute vector $\boldsymbol{a}_i$ to the model to help capture the heterogeneity of firm's output. The $\boldsymbol{a}_i$ vector in Equation (3-1) contains four elements: average load (*AL*), average length of haul (*ALH*), average shipment size (*AS*) and average insurance (*INS*). Average load is defined as tonmiles divided by miles. This variable describes the average weight of freight. High average load is expected to result in low per unit cost. Average length of haul is defined as tonmiles divided by tons. High average length of haul is expected to result in low per unit cost because the total fixed cost, such as terminal cost, are spread out over more units of output. Average shipment size is defined as tons per shipment. If the shipment size is small, we would expect to have a high unit cost because more transaction and handling charges would have to be incurred. The last attribute is insurance cost per tonmile. This variable describes the average value of the freight shipped. The higher the value, reflecting the higher value of the freight and higher potential loss may result in case of mishandling, so the higher the unit cost due to more handling being required.

Table 3-1 shows the mean statistics for the variables used in this study. One of the important observations is on the number of firms. Each year, there were about twenty more exiting firms than the entering firms. The industry has become more concentrated.[24] Average tonmile per firm grew almost every year (except years 1980, 1982 and 1985), from 156 million tonmiles in 1976 to 257 million tonmiles in 1987 (increased by 65%). Although firm's average production has increased, the bad news of the declining number of firm has pulled down the total industry output.[25] On the other hand, after the MCA, carriers were allowed to ship across regions, so that the average length of haul appears to be higher.

Figure 3-1(a) plots the average cost (in 1988 dollar) per tonmile during the period 1976 to 1987. The average cost remains between 24 cents and 24.5 cents between 1976 and 1978, rises to around 25 cents between 1979 and 1985, and then falls back to 23 cents in 1986 and 1987. We can make two observations. First, average cost falls from 24.3 cents per tonmile in 1976 to 23.1 cents in 1987. Second, average cost rises between 1978 to 1980 (by 5.7%) and falls sharply (by 8.8%) from 1984 to 1986.

We question Ying [43] who concluded that, due to MCA, cost savings were observed between 1981 and 1984. Although there is a trend of decreasing cost after 1980

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[24] See McMullen and Tanaka [37] for the discussion details.

[25] One of the reasons for the decline is the competition from the air-freight industry. The Airline Deregulation Act in 1978 changed the behavior of the airline industry dramatically and slowed down the raising cost of air-freight. As a result, some motor carrier shipments might switch to use the faster air-freight instead.

(except 1984 according to our figures), the decrease in cost occurred after it first rose to a peak in 1980. Ying set a dummy for deregulation that equaled zero before 1980 and one thereafter. In Figure 3-1, simple regressions of average cost against year may generate (i) a flat regression line for the whole 1976-84 period -- the time effect, (ii) a negatively sloped regression line for the post-MCA observations (1980-84) -- the deregulation effect, and (iii) a positively sloped regression line for the pre-MCA observations (1976-80) -- the effect that Ying ignored. Therefore, if we use only the first two regression lines to describe the cost-time-deregulation relationship, we are not able to reveal the whole picture. Ying reported that the estimate of the time parameter equals -0.028 and is statistically insignificant from zero. The estimate of the deregulation dummy parameter equals 0.5608, and is significant from zero. That is different from what we predicted from our observation. Note that his deregulation dummy variable interacts with the time index, so the pre-MCA effects are assumed equal and disappeares (because the dummy variable is set to zero for pre-MCA period) but the post-MCA effect is linearly with time. Since his model focuses on the impact of deregulation but ignores the increased cost between 1978 to 1980 (which is believed to be related to firms' early adjustments to the MCA), it is not appropriate to conclude that the overall cost saving is 16% in 1984.

Table 3-1 Mean Statistics

Year	Number of Firm	Average Cost ($)	Tonmile (in Mil.)	Total Cost (in Mil.)	Average Load	Average Length of Haul
1976	570	0.2431	155.7	37.8	10.246	236.87
1977	511	0.2425	179.7	43.6	10.257	239.71
1978	528	0.2393	196.5	47.0	10.249	238.99
1979	504	0.2447	201.7	49.4	10.343	242.90
1980	433	0.2530	193.8	49.0	11.153	257.23
1981	381	0.2474	206.7	51.1	10.017	257.89
1982	363	0.2497	191.2	47.8	9.759	269.88
1983	334	0.2442	201.0	49.1	9.752	281.02
1984	314	0.2523	208.3	52.6	9.607	272.76
1985	308	0.2467	205.8	50.8	9.521	309.53
1986	292	0.2301	246.9	56.8	9.734	319.77
1987	258	0.2306	256.9	59.2	9.550	307.90

Year	Average Size	Average Insurance	Price of Fuel	Price of Capital	Price of Labor	Price of Rented Capital
1976	2.528	0.014	1.196	2.672	38581	1.709
1977	2.436	0.016	1.133	2.688	40507	1.615
1978	2.605	0.015	1.082	2.286	40642	1.613
1979	2.828	0.040	1.132	2.130	39766	1.448
1980	2.507	0.012	1.015	1.854	38053	1.540
1981	2.505	0.011	0.949	1.618	37599	1.457
1982	2.701	0.011	0.894	1.526	35729	1.266
1983	3.049	0.010	0.878	1.552	35637	1.238
1984	2.794	0.010	0.909	1.474	35587	1.208
1985	3.477	0.012	0.918	1.549	33574	1.232
1986	3.954	0.016	0.935	1.419	34025	1.212
1987	4.232	0.016	0.965	1.558	33450	1.145

Figure 3-1 Mean Statistics by Year

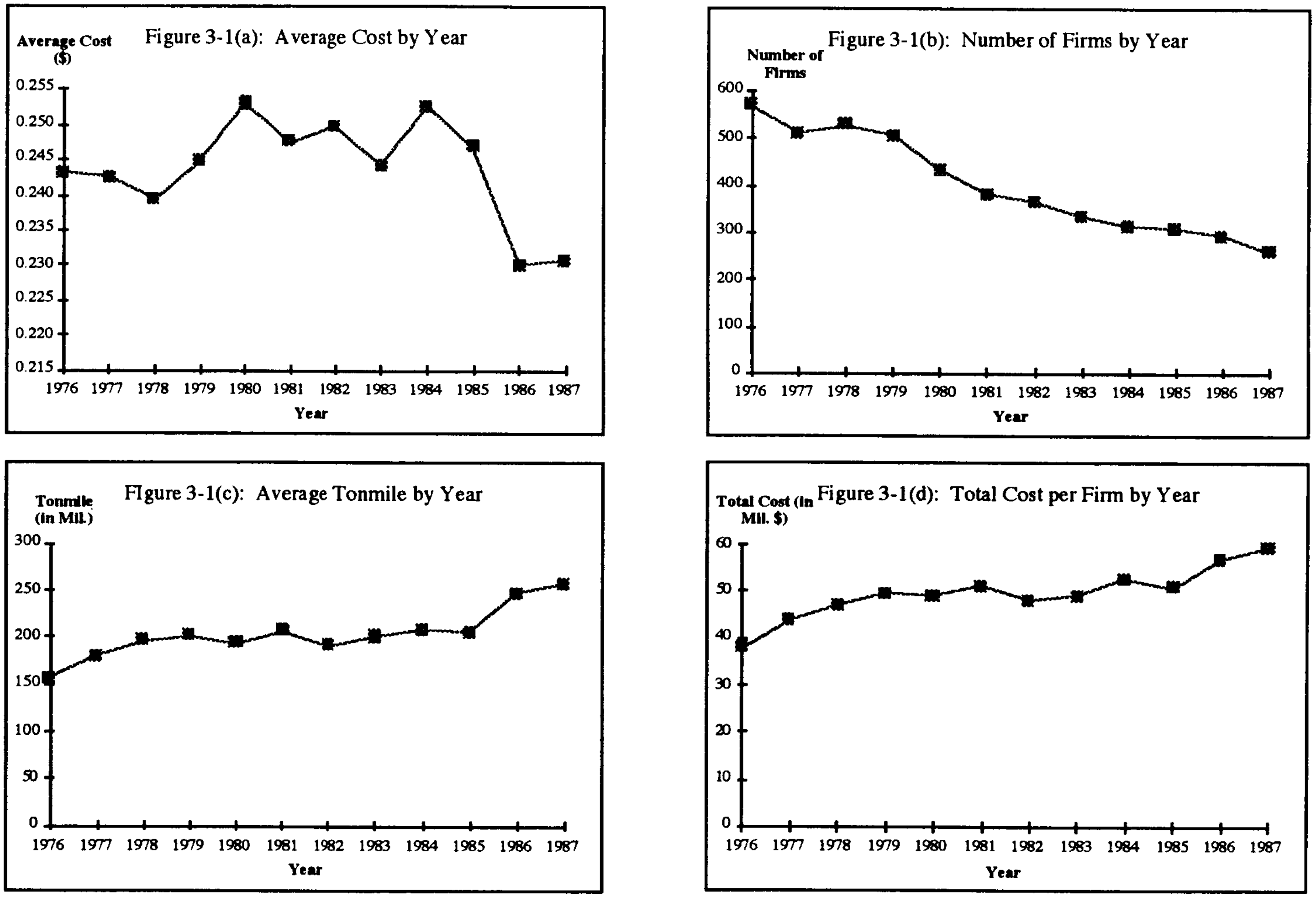

Figure 3-1 (Continued)

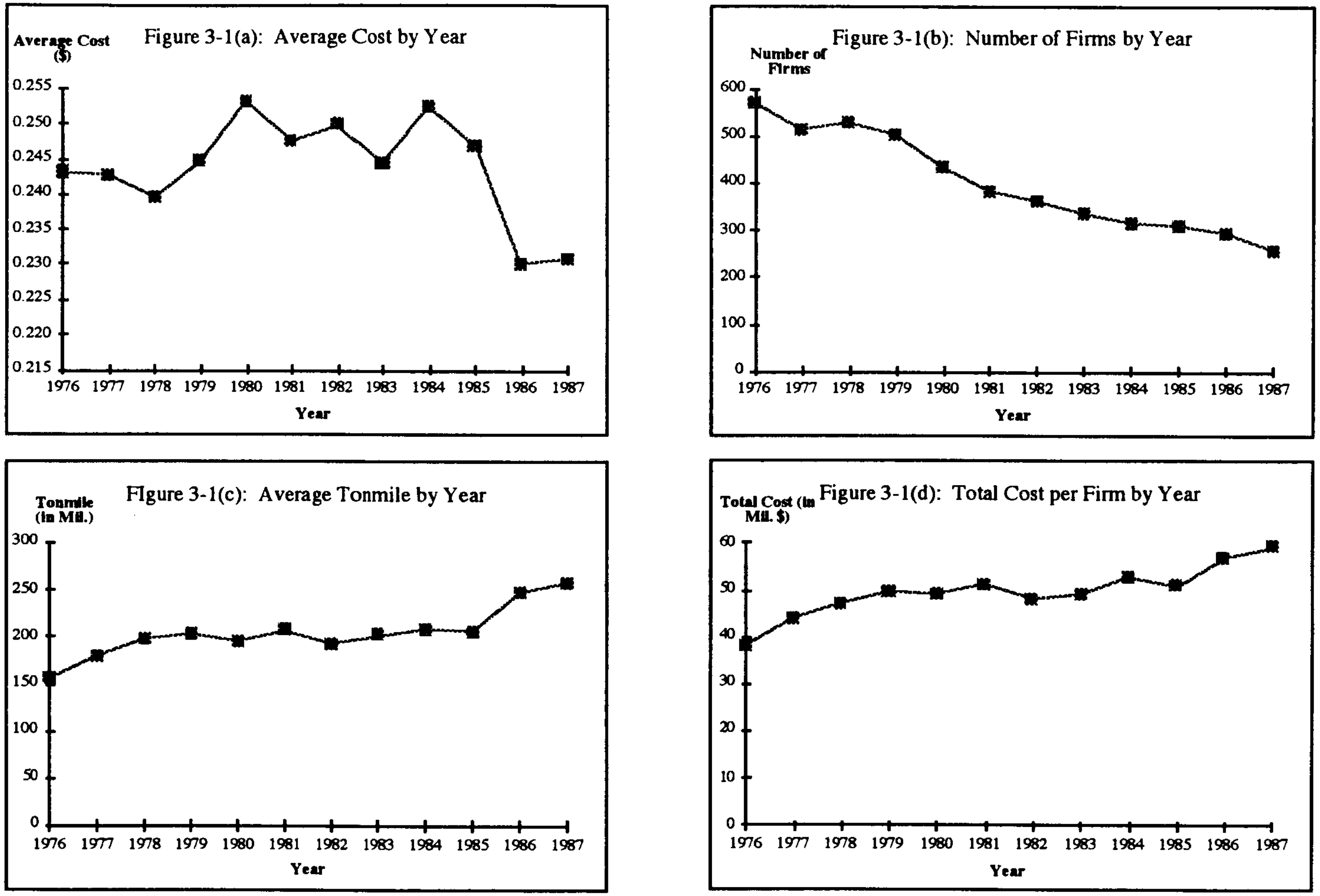

Figure 3-1 (Continued)

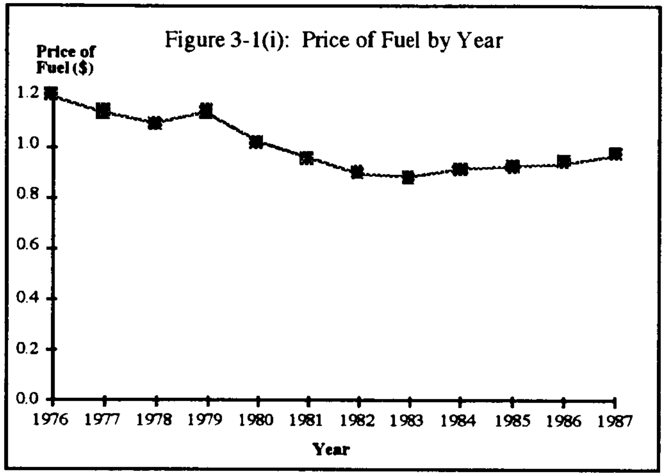

Figure 3-1(i): Price of Fuel by Year

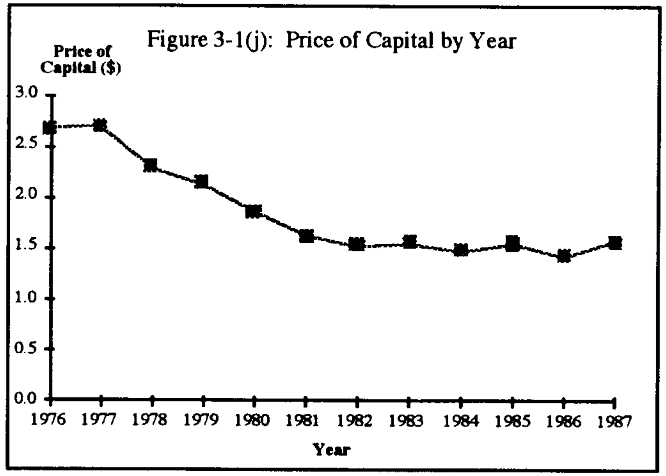

Figure 3-1(j): Price of Capital by Year

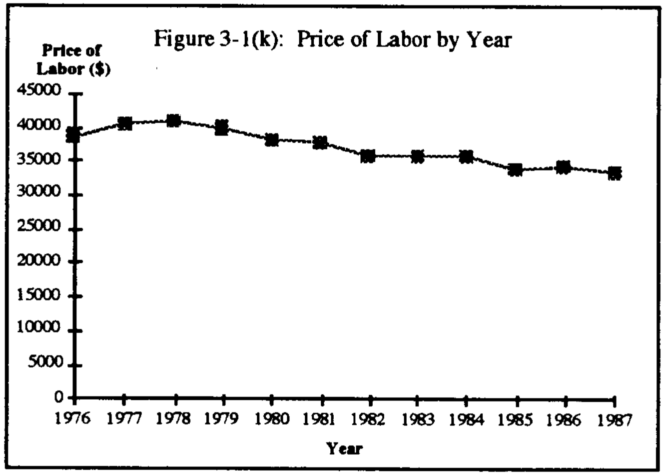

Figure 3-1(k): Price of Labor by Year

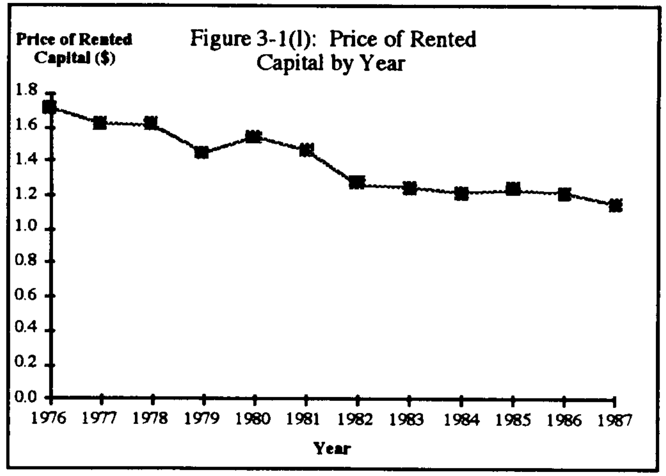

Figure 3-1(l): Price of Rented Capital by Year

3.3.2 Model Specification

Since the inefficiency measure is relative to the estimated frontier, a misspecified functional form of the frontier might bias the estimated parameters and thus, the inefficiency measures. Schmidt [40] suggested that a flexible functional form would generate a better fit of the estimated frontier and thus a more accurate inefficiency measure. Our selection of the model was based on two criteria: (i) the functional form must be flexible enough to permit a wide range of technologies, and (ii) the function needs to be restricted the necessary and sufficient conditions for a cost function. For each firm *i*, the translog specification used in our estimations is given by:

$$\begin{aligned} \ln C = {} & \alpha_o + \alpha_y \ln y + \Sigma_x \alpha_x \ln p_x + \Sigma_j \alpha_j \ln a_j + 1/2 \{ \alpha_{yy}(\ln y)^2 + \Sigma_x \alpha_{xx}(\ln p_x)^2 \\ & + \Sigma_j \alpha_{jj}(\ln a_j)^2 + \Sigma_j \alpha_{yj}(\ln y)(\ln a_j) + \Sigma_x \alpha_{yx}(\ln y)(\ln p_x) \\ & + \Sigma_x \Sigma_j \alpha_{xj}(\ln a_j)(\ln p_x) + \Sigma_x \Sigma_{x^*} \alpha_{xx^*}(\ln p_x)(\ln p_{x^*}) \\ & + \Sigma_j \Sigma_{j^*} \alpha_{jj^*}(\ln a_j)(\ln a_{j^*}) \} + \varepsilon \end{aligned} \quad (3\text{-}6)$$

where a_j represents the *j*th element in the attribute vector, p_x represents the *x*th element in the input price vector and ε represents the composite error of u plus v, $j = x = 1, .., 4$; u and v are defined in Equation (3-1). The α's are the parameters to be estimated. Symmetry in parameters, $\alpha_{kj} = \alpha_{jk}$ for all $j \neq k$, is assumed. Linear homogeneity in input prices requires

$$\Sigma_x \alpha_x = 1; \;\; \Sigma_x \Sigma_j \alpha_{xj} = 0; \;\; \Sigma_x \alpha_{yx} = 0, \text{ and } \Sigma_x \Sigma_{x^*} \alpha_{xx^*} = 0 \text{ for all } x \text{ and } x^*. \quad (3\text{-}7)$$

We impose the above restrictions in our estimation.

3.4 Estimation Results

Using Equation (3-6), we estimate a stochastic frontier independently for each of the twelve years. Table 3-2 lists the parameter estimates for thirteen frontiers, including twelve frontiers for each individual year and one frontier using the pooled data of 1976-78. The pre-MCA frontier is obtained from the pooled data of 1976-78 because we are not able to obtain the pooled frontier for the 1976-79 period due to the "Wrong Skewed" distribution of the residuals. Therefore, we separate the 1979 data from the pool. The maximum likelihood estimates in this study, using the Fletcher-Powell algorithm, have all the usual properties. They are consistent, asymptotically efficient, and asymptotically normal.[26] Since we want to focus on the inefficiency measure, not the technology, we do not discuss the parameter estimates here, except λ and σ^2. By solving the estimates of λ and σ^2, we obtain the estimate of σ_u.[27] Then, using Equation (3-4), we calculate the estimate of the average industry inefficiency, $\hat{E}(u)$.

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[26] See Judge *et al.* [31], p.303.

[27] $\sigma_u = (\sigma^2 \lambda^2/(1+\lambda^2))^{1/2}$.

Table 3-2 Parameter Estimates of frontiers (1976-1987)

Year	76-78	76	77	78	79	80
Constant	-0.1965	-0.2212	-0.2086	-0.2041	-0.1959	-0.2526
TM	1.0283	1.0202	1.0364	1.0432	1.0348	1.0354
AL	-0.4306	-0.4627	-0.4212	-0.4078	-0.4468	-0.3530
ALH	-0.3721	-0.3493	-0.3781	-0.4036	-0.3576	-0.4037
AS	-0.2341	-0.2389	-0.2201	-0.2416	-0.2285	-0.2273
INS	0.1804	0.1616	0.2221	0.1678	0.1829	0.1819
PF	0.3485	0.3346	0.3566	0.3173	0.3384	0.3075
PK	0.0159	0.0242	0.0105	0.0143	0.0509	0.0394
PR	0.0717	0.0475	0.0631	0.0958	0.0990	0.1076
TM*TM	0.0055	0.0146	0.0052	-0.0221	-0.0032	-0.0035
AL*AL	0.0521	0.2030	-0.0719	0.1808	0.2143	0.3415
ALH*ALH	0.0265	0.0909	0.0450	-0.0108	0.0516	-0.0213
AS*AS	0.0266	0.0081	0.0588	0.0228	0.0079	-0.0250
INS*INS	0.1457	0.1923	0.1564	-0.0180	0.1940	0.1701
TM*AL	0.0019	0.0194	-0.0322	0.0053	0.0533	-0.0066
TM*ALH	-0.0235	-0.0531	-0.0165	-0.0002	-0.0257	-0.0174
TM*AS	-0.0353	-0.0330	-0.0347	-0.0483	-0.0385	-0.0197
TM*INS	-0.0315	-0.0227	-0.0506	-0.0716	-0.0264	-0.0502
TM*PF	-0.0175	-0.0362	0.0768	-0.0557	-0.0290	0.0363
TM*PK	0.0012	-0.0126	0.0093	0.0120	-0.0131	-0.0068
TM*PR	-0.0282	-0.0620	-0.0596	0.0158	-0.0134	-0.0391
AL*ALH	0.0667	0.0092	0.1109	-0.0066	-0.0818	0.1319
AL*AS	0.0276	0.0425	0.0067	0.0516	0.0343	-0.0577
AL*INS	0.1479	0.2398	0.0733	0.1212	0.2584	0.3903
AL*PF	-0.0355	-0.0126	0.1946	-0.2841	0.0301	-0.1796
AL*PK	-0.0285	-0.0760	0.0392	-0.0195	-0.0636	-0.0548
AL*PR	-0.0082	0.0825	-0.0546	-0.0495	0.0122	0.1035
ALH*AS	0.0517	0.0319	0.0548	0.0702	0.0455	-0.0022
ALH*INS	0.0384	-0.0061	0.1163	0.0207	-0.0523	-0.0403
ALH*PF	0.0400	0.0120	-0.1648	0.2393	0.1398	-0.0503
ALH*PK	0.0170	0.0500	0.0114	-0.0098	0.0512	0.0492
ALH*PR	0.0762	0.0926	0.1059	0.0345	0.0708	-0.0631
AS*INS	0.0223	0.0240	0.0549	-0.0027	0.0277	-0.0759
AS*PF	-0.0474	-0.0769	0.0263	-0.0811	-0.0191	0.0397
AS*PK	0.0179	0.0343	0.0117	0.0338	-0.0189	0.0536
AS*PR	0.0432	0.0241	0.0648	0.0644	0.0565	0.0137
INS*PF	-0.0613	-0.1450	0.1071	-0.0708	0.0684	-0.1830
INS*PK	0.0335	-0.0056	0.1124	0.0490	-0.0540	0.0359
INS*PR	0.0397	0.0398	0.0192	0.0824	0.0779	-0.0398
PF*PK	-0.0434	0.0303	-0.1228	-0.1294	0.0149	0.0551
PF*PL	-0.0640	-0.1507	0.0420	-0.1416	-0.1644	-0.4032
PF*PR	-0.0144	-0.0052	-0.0628	-0.0122	0.0395	-0.0482
PK*PL	0.0066	-0.0745	0.0814	0.1068	0.0149	0.0384
PK*PR	0.0307	0.0104	0.0630	0.0286	-0.0101	-0.0432
PL*PR	-0.0756	-0.0805	-0.0713	-0.0645	-0.0568	0.0115
λ	1.1134	1.5285	1.1586	1.5680	1.0707	1.3464
σ	0.2343	0.2234	0.2409	0.2468	0.2268	0.2624

Table 3-2 (Continued)

Year	81	82	83	84	85	86	87
Constant	-0.2853	-0.2813	-0.2581	-0.3373	-0.2945	-0.3490	-0.3247
TM	1.0536	1.0215	1.0169	1.0103	1.0256	1.0520	1.0450
AL	-0.2952	-0.2926	-0.2878	-0.2357	-0.3054	-0.4645	-0.4370
ALH	-0.4624	-0.4330	-0.4339	-0.4027	-0.3842	-0.3611	-0.4328
AS	-0.2972	-0.2949	-0.3144	-0.3041	-0.2859	-0.2547	-0.3008
INS	0.1698	0.1577	0.1535	0.2078	0.2388	0.2305	0.1944
PF	0.3442	0.3567	0.3868	0.3102	0.3609	0.3313	0.2835
PK	0.0351	0.0168	0.0397	0.0065	0.0243	0.0479	0.0507
PR	0.0633	0.1234	0.0877	0.1202	0.0968	0.0968	0.1294
TM*TM	-0.0282	0.0121	0.0385	0.0112	0.0118	0.0292	0.0218
AL*AL	0.5400	0.5677	0.3960	0.4065	0.4134	0.2018	0.1922
ALH*ALH	0.0818	0.1831	0.3100	0.0667	0.0032	0.1594	0.0576
AS*AS	0.0581	0.0325	0.0712	0.0659	0.0679	0.0534	0.1581
INS*INS	0.1993	0.1908	0.1125	0.3063	0.2314	0.2208	0.0798
TM*AL	0.0139	-0.0374	0.0026	-0.0191	0.0129	0.0497	0.0017
TM*ALH	-0.0003	0.0055	-0.0657	-0.0293	0.0156	-0.0119	-0.0452
TM*AS	-0.0427	-0.0154	-0.0135	-0.0365	0.0068	-0.0198	-0.0260
TM*INS	-0.0784	-0.0020	-0.0012	-0.0388	0.0794	0.0663	0.0115
TM*PF	-0.1608	-0.0271	-0.0251	-0.0641	-0.0813	-0.0120	0.0061
TM*PK	0.0051	0.0311	0.0236	0.0062	-0.0074	0.0148	-0.0070
TM*PR	-0.0025	-0.0320	-0.0249	0.0110	-0.0192	0.0062	-0.0365
AL*ALH	-0.0168	-0.1854	-0.2531	0.0456	-0.1276	-0.1192	-0.1682
AL*AS	-0.1281	-0.1359	-0.1115	0.0681	-0.0017	-0.1188	-0.1270
AL*INS	0.3224	0.0801	-0.0277	0.3067	0.2192	0.1069	0.0099
AL*PF	-0.1129	-0.0120	0.0194	-0.1672	-0.1520	0.1336	-0.1688
AL*PK	-0.0886	0.0063	-0.0244	-0.0336	-0.0562	-0.1356	-0.1552
AL*PR	0.1690	-0.0208	0.0809	-0.0800	0.0971	0.0496	0.0914
ALH*AS	0.1635	0.1557	0.1486	0.0925	0.0533	0.1367	0.1166
ALH*INS	0.0867	0.0643	0.0630	0.0623	-0.1408	0.0385	-0.1299
ALH*PF	0.2824	0.0919	0.1002	0.1719	0.0377	-0.1153	0.1076
ALH*PK	0.0571	-0.0183	-0.0322	0.0466	0.0382	0.1527	0.0511
ALH*PR	0.0333	0.0971	-0.0314	-0.1342	0.0088	-0.0739	0.0793
AS*INS	0.0079	0.0238	0.0812	0.0940	0.0748	0.0142	0.0735
AS*PF	0.0221	0.0405	0.0686	0.0827	-0.0319	-0.1299	0.0301
AS*PK	0.0423	0.0531	0.0212	-0.0055	-0.0002	0.0717	-0.0002
AS*PR	0.0435	0.0227	0.0057	-0.0631	0.0122	0.0395	0.0676
INS*PF	-0.1060	0.1680	0.0890	-0.1052	-0.1974	-0.1378	-0.0171
INS*PK	0.0111	0.0511	0.0296	0.0046	-0.0017	0.0998	-0.0921
INS*PR	0.1135	-0.0430	0.0279	-0.1372	0.0845	0.0666	0.0904
PF*PK	-0.0656	-0.0487	-0.0184	-0.2124	-0.0371	-0.1086	-0.0208
PF*PL	0.3506	-0.0231	-0.0084	0.1001	-0.3973	-0.1804	-0.0019
PF*PR	0.0046	-0.0163	-0.0289	0.2106	-0.0276	0.0546	-0.0021
PK*PL	-0.0328	0.0515	0.0035	-0.0040	0.0001	0.0377	-0.0609
PK*PR	0.0609	0.0157	0.0063	0.1068	0.0095	0.0590	0.0637
PL*PR	-0.1278	-0.1767	0.0052	-0.5101	-0.0779	-0.1271	-0.0772
λ	2.2638	1.3366	1.2849	1.7184	1.0996	2.5075	1.9645
σ	0.2873	0.2405	0.2305	0.2631	0.2367	0.3149	0.2774

3.4.1 Average Industry Inefficiency

Table 3-3 reports and plots the estimated average industry inefficiencies for the period 1976-1987. In nine out of twelve years, the average inefficiencies are below 20%. There are two periods (1979-1981 and 1985-1986) during which inefficiency increased by about 10%, reaching the peak inefficiencies of the study period. The arithmetic mean of annual average inefficiencies is 18.4 percent. In the pre-MCA period (1976-79), the arithmetic mean of annual average inefficiencies is 16.0 percent, but that of the post-MCA period (1980-87) is 19.6 percent (22.5 percent above the pre-MCA mean).

In Figure 3-2 (numerical values are listed in Table 3-3), inefficiency started to increase in 1979, presumably because firms started to adjust for the impact from the MCA a year before it was implemented in 1980. In 1981, in addition to firms' continuing adjustments for the MCA, the impact of the oil crisis probably helped the industry inefficiency to reach its first peak. Between 1982 and 1985, the inefficiency remained at its pre-MCA level. In 1986, inefficiency rose to its second peak.

Our results indicate that deregulation generated no improvement to the efficiency of the motor carrier industry. The decrease in production cost after deregulation does not contradict the increased inefficiency. Since the cost function results represent an average industry performance and the inefficiency from the stochastic cost frontier shows the deviation from the cost frontier (i.e., the ideal cost plus the random term), a decrease in the estimated cost function does not imply a decrease in inefficiency. Therefore, our results provide new information about the performance of the industry.

We compared the estimated average industry inefficiencies and found that we can separate them into three groups. Table 3-4 reports the group elements and the group average inefficiency. The highest inefficiency group includes only year 1986. The reason for this high inefficiency is still an unkown to me. The group of medium inefficiency includes 1981 and 1987. The group average inefficiency is 22.6 percent. The lowest inefficiency group includes the pre-MCA years and three years after the MCA is implemented. After estimating these average industry inefficiencies, it would be ideal if we are able to test the inefficiencies for the twelve-year period to determine whether they are significantly different from one another. The null hypothesis to be tested is $E(u_s) = E(u_t)$, for s and t = 1976, ..., 1987 and $s \neq t$. Since E(u) equals $(2/\pi)^{1/2}\sigma_u$, testing σ_u is the same as testing E(u). However, the Wald test we tried to use is not straight forward. We will leave the test for future research.

Table 3-3 Average Industry Inefficiency (1976-1987)

Year	Estimate of λ	Estimate of σ	Estimate of σ_u	Estimate of σ_v	Estimate of E(u)	Average Inefficiency
76	1.5285	0.2234	0.1869	0.1223	0.1491	16.1%
77	1.1586	0.2409	0.1824	0.1574	0.1455	15.7%
78	1.5680	0.2468	0.2081	0.1327	0.1660	18.1%
79	1.0707	0.2268	0.1658	0.1548	0.1322	14.1%
80	1.3464	0.2624	0.2106	0.1564	0.1680	18.3%
81	2.2638	0.2873	0.2628	0.1161	0.2096	23.3%
82	1.3366	0.2405	0.1925	0.1441	0.1536	16.6%
83	1.2849	0.2305	0.1819	0.1416	0.1451	15.6%
84	1.7184	0.2631	0.2274	0.1323	0.1814	19.9%
85	1.0996	0.2367	0.1751	0.1592	0.1397	15.0%
86	2.5075	0.3149	0.2925	0.1166	0.2333	26.3%
87	1.9645	0.2774	0.2472	0.1258	0.1972	21.8%
76-78	1.1134	0.2343	0.1743	0.1566	0.1391	14.9%

Figure 3-2 The Average Industry Inefficiency by Year

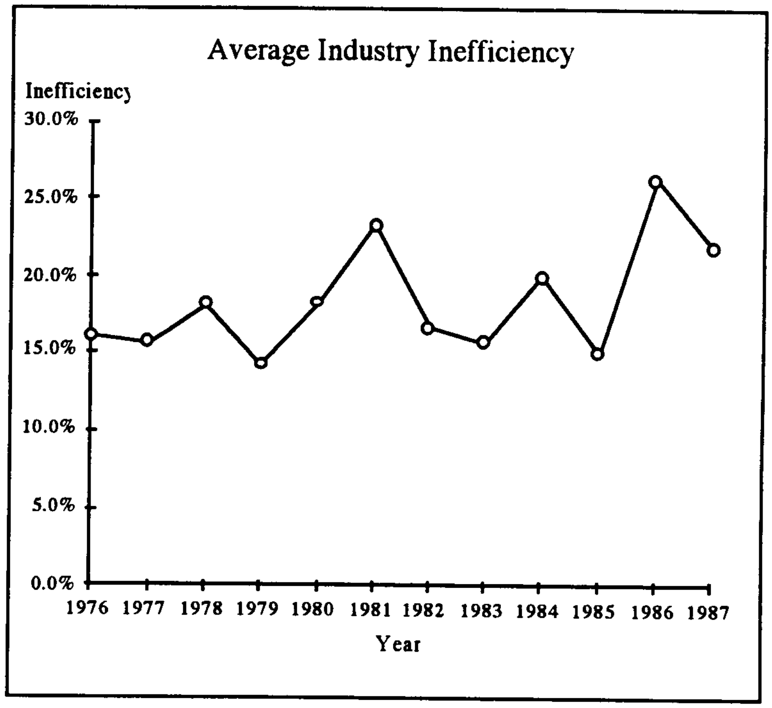


Table 3-4. Grouping the Industry Average Inefficiency (Using all individual periods)

Group	I	II	III
Group Elements	1976 (16.1%) 1977 (15.7%) 1978 (18.1%) 1979 (14.1%) 1980 (18.3%) 1982 (16.6%) 1983 (15.6%) 1984 (19.9%) 1985 (15.0%)	1981 (23.3%) 1987 (21.8%)	1986 (26.3%)
Group Avg. Inefficiency	16.6%	22.6%	26.3%

Notes: Percentage of inefficiencies are in parenthesis.

3.4.2 Firm Specific Inefficiency

Using Equation (3-5), we decomposed firm-specific inefficiencies from the composite residuals of each of the twelve periods. The estimated expected value of the firm-specific inefficiency, $\hat{E}(u|\varepsilon)$, are converted into percentage of expected inefficiency from the frontier of the firm. We are going to focus on 126 "survivor" firms which continued their operations throughout the whole twelve-year period.

Table 3-5 compares the average inefficiencies of the "survivor" firms with the average inefficiencies of all firms. We found that average inefficiencies of "survivor" firms were lower than that of the average for all firms in all twelve years. Figure 3-3 shows that the curve of average inefficiencies of the "survivor" firms is enveloped from above by the curve of average inefficiencies of all firms, meaning that "survivor" firms are relatively efficient. Therefore, this result supports Stigler's Survival Principle.

The next step is to compare the performance of these "survivor" firms by region. We identify each firm by the regional location of its headquarter according to the ICC's definition of geographical regions. [28] The regional average inefficiencies are shown on Figure 3-4. We found that there are large inefficiency difference for these "survivor" firms operating in different territories. Firms in the southern regions (4 and 7) are more efficient than in other regions. The worse performance firms are in the New England States (region 1).

In Figure 3-4, we compared the "survivor" firms' regional difference in the pre- and post-MCA era. (See also Table 3-6 for numerical values comparison.) Surprisingly, we found that, in eight out of nine regions, firms are less efficient after the MCA

[28] The ICC definition of motor carrier operating region: Region 1 includes states: ME, VT, NH, MA, RI and CT; Region 2 includes states: NY, PA, NJ, DE, MD and WV; Region 3 includes states: MI, OH, IN and IL; Region 4 includes states: VA, NC, Sc, GA, FL, KY, TN, AL, and MS; Region 5 includes states: ND, SD, MN and WI; Region 6 includes states: IA, MO, NE and KS; Region 7 includes states: AR, LA, OK and TX; Region 8 includes states: MT, WY, CO, NM, ID and UT; Region 9 includes states: WA, OR, NV, AZ and CA.

deregulation than before. Only the Pacific region (region 9) shows improvement after deregulation. Even the relatively efficient group of firms are producing less efficiently after deregulation.

Table 3-5 Comparison of Average Inefficiency between "Survivor" Firms and All Firms

Year	Survivor Firms	All Firms
1976	15.25%	16.38%
1977	15.51%	15.87%
1978	16.17%	18.44%
1979	13.04%	14.29%
1980	17.00%	18.64%
1981	23.50%	24.15%
1982	16.70%	16.87%
1983	15.16%	15.86%
1984	18.58%	20.39%
1985	15.05%	15.17%
1986	25.07%	27.70%
1987	20.62%	22.49%

Figure 3-3 Comparison of Average Inefficiency between "Survivor" Firms and All Firms

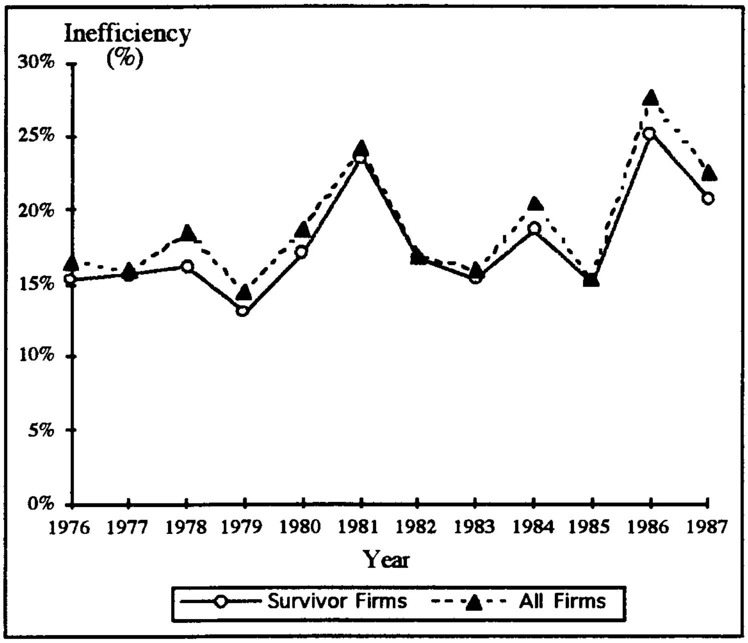
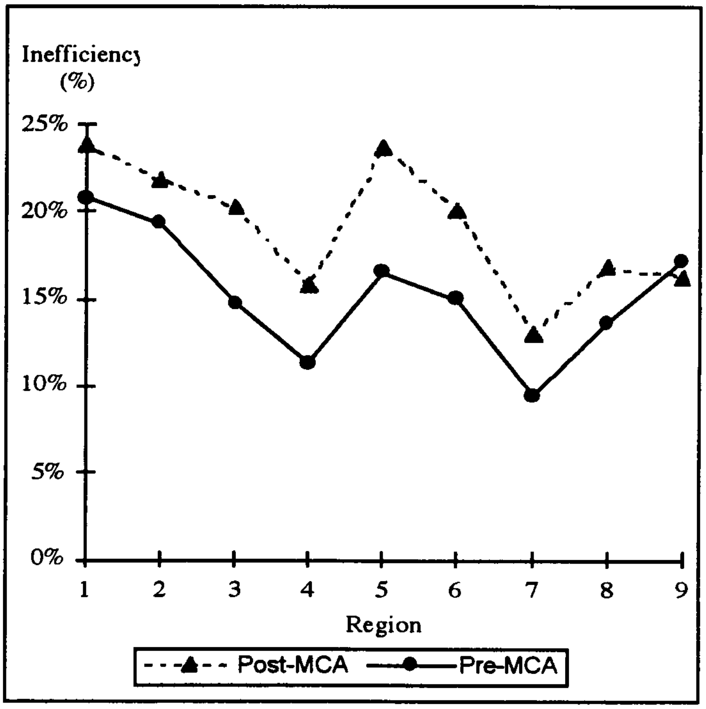


Table 3-6 Regional Average Inefficiency of "Survivor" Firms: Pre- and Post-MCA era

Average Inefficiency by Region

Region	Pre-MCA	Post-MCA
1	20.79%	23.88%
2	19.39%	21.85%
3	14.68%	20.20%
4	11.36%	15.80%
5	16.59%	23.68%
6	15.04%	20.07%
7	9.51%	12.96%
8	13.71%	16.85%
9	17.28%	16.32%
Overall	14.99%	18.96%

Figure 3-4 Regional Average Inefficiency of "Survivor" Firms: Pre- and Post-MCA era



3.5 Analysis the Source of Inefficiency

In this section, we analyze the source of firm specific inefficiency by regressing firm characteristics and regional dummy variables using tobit regression. The firm characteristic variables include percent of less than truck-load shipments to truck-load shipments (LTL), total number of employees (EMP), terminal expenses (TERM), operating revenue to operating expenses ratio (REX), number of standby equipment to number of operating equipment ratio (STO), number of repair and maintenance equipment to number of operating equipment ratio (RTO) and union / nonunion firm dummy variable (UNU).

LTL measures the flexibility in scheduling shipments. The larger the LTL ratio, the more shipments are delivered without a full truck load. It might be beneficial to pick up freight along the route instead of waiting to fill the truck before delivering. LTL results in less idle time of trucks. However, truck-load shipments guarantee full loads for shipments reducing unfilled truck space of each delivering. Therefore, the sign of the LTL parameter is ambiguous. EMP measures the organizational size of the firm. If the employment is large, the firm might experience scale economies in managing labor. The firm might also experience some management problems if it is too large. Therefore, the sign of the EMP parameter is also ambiguous.

TERM measures a firm's investment in terminal facilities for regional network of shipment handling: the larger of these expenses, the more the firm cares about shipment handling. McMullen and Tanaka [37] indicate that larger firms use an extensive network system and hence are able to provide different levels of service quality and lower unit costs by increasing route density. An efficient use of a network system should translate into a lower level of inefficiency. Therefore, the sign of parameter of TERM should be negative. However, over-investing in these terminal facilities increases unit cost reflecting that the firm is inefficient in allocating capital. Therefore, the signs of parameters of TERM could be ambiguous.

REX measures the operating profitability of the firm. The larger the ratio, the more successful the firm is in profit seeking, which in turn, promotes efficiency. Therefore, the sign of the REX parameter is expected to be negative. STO measures the inefficient use of equipment (inputs). For example, if a firm has 4 standby equipment units and 16 operating equipment units, then STO will be equal to 0.25 (=4/16). The larger the ratio, more inputs lie idle. The sign of the STO parameter is expected to be positive. RTO measures the durability and reliability of equipment. Less durable equipment usually requires more repair. However, firms might maintain their equipment more often to keep them in good condition. In the long run, an efficient firm should be able to keep the minimal number of repair equipment. Therefore, the RTO ratio should be low and the sign of the RTO parameter is expected to be positive.

UNU measures whether firm hiring union or non-union worker. Although union workers are said to be more skillful, non-union workers are relative cheap. Therefore, the sign of the UNU parameter would be ambiguous. A recent study by Kerkvliet and McMullen [33] found that the costs of union carriers are higher than the non-union carriers, so we might expect union firms to be less efficient.

In addition, we introduce the region dummy variables to identify where the headquarter of the firm is located based on the definition of ICC geographical region (see footnote 28). If the firm's headquarter is located in the defined region, its score will be one, otherwise zero. Region 9 (the Pacific States) is set as the benchmark. The estimate of the parameter associated with the regional dummy variable reflects the difference of inefficiency between that particular region and region 9.

Since the dependent variable (i.e., the firm specific inefficiencies) is truncated at both sides with observations between zero and one. We use tobit regression technique to regress the model. Table 3-7 reports the estimation results. We have obtained two models for each of the four selected periods: 1976-78 (pooled), 1985, 1986 and 1987. Model 1 regresses inefficiencies against firm characteristic variables and region dummy variables (the full model). Assuming no regional inefficiency difference among all regions, Model 2 regresses inefficiencies against firm characteristic variables only (the restricted model).

Our results show that the explanatory variables explain the variation of inefficiencies in the pre-MCA period better than in the post-MCA periods. Among firm characteristics of the 1976-78 models, parameter estimates of REX, STO, RTO and UNU are significantly different from zero. Only REX and UNU are consistently significant in the pre- and post-MCA models.

Our result confirms Kerkvliet and McMullen [33] that union firms are relative less efficient than non-union firms. On average, union firms are 1.5 percent and 3.9 percent less efficient than non-union firms in the pre- and post-MCA periods, respectively.[29]

[29] I chose the first interpretation of the parameter on Judge *et al.* [32], page 799.

We examine Model 1 of each of the four periods for regional differences in inefficiency difference. Only region 7 is significantly more efficient than region 9 in the pre- and post-MCA periods. Estimates of other regional dummy variables are not significantly different from zero. However, to determine whether the overall regional dummy variable effects are significant, we apply likelihood ratio test to Model 2 against Model 1 for each period. The null hypothesis is that there is no regional inefficiency difference between region 9 and other regions, i.e., all regional dummy parameters are equal to zero. The alternative hypothesis is that there exists at least one region which has different inefficiency from that of region 9. The critical Chi-square test statistics for degree of freedom of eight equal 20.1, 17.5 and 15.5 at 1%, 2.5% and 5% significant levels, respectively. For the 1976-78 model, the computed test statistics equals 81.8 suggesting that there is regional difference in inefficiency (at least one of the regional dummy variables are significantly different from zero).[30] The computed test statistics for 1985, 1986 and 1987 are equal to 2, 16 and 8, respectively. We fail to reject the hypothesis that there is no regional difference from region 9 during these periods.

The test results suggest that, using region 9 as a benchmark, there exists inefficiency difference among regions in the pre-MCA period but the difference is not significant in the post-MCA period. This conclusion makes sense because shipping routes are restricted and other territorial constraints are applied in the pre-MCA era that promotes inefficiency difference for firms located in different regions. The deregulation of 1980 cracks down territorial constraints, relaxes restrictions and promotes competition that eliminates regional inefficiency difference.

[30] By examining the t-ratio, we found that Region 2 is significantly more inefficient and Region 7 is significnatly less inefficient than Region 9.

Table 3-7 Tobit Regression of Firm Specific Inefficiency

Variable definition (Dependent Variable = Inefficiency in percentage) :
LTL = Less than truckload shipment to Truckload shipment ratio
EMP = Total number of employees
TERM = Terminal Expenses
REX = Revenue to total expenditure ratio
STO = Standby to operating equipment ratio
RPO = Repair to operating equipment ratio
UNU = Union index
D_i = Regional Dummy Variable, where i index the region code and i = 1, ..., 8.

	1976-78	1976-78	1985	1985	1986	1986	1987	1987
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Variable	Parameter Estiamte	Parameter Estiamte	Parameter Estiamte	Parameter Estiamte	Parameter Estiamte	Parameter Estiamte	Parameter Estiamte	Parameter Estiamte
Constant	27.088[a]	31.023[a]	31.16[a]	29.606[a]	13.495	12.8990	48.729[a]	47.173[a]
	(8.496)	(9.898)	(4.940)	(4.867)	(1.308)	(1.280)	(3.635)	(3.641)
LTL	0.0023	0.0041[b]	-0.0019	-0.0024	0.0074	0.0045	-0.0093	-0.0127
	(0.945)	(1.685)	(-0.315)	(-0.431)	(0.365)	(0.227)	(-0.725)	(-1.039)
EMP	0.0002	0.0002	0.0003	0.0004	-0.0007	-0.0012	-0.0017	-0.0013
	(0.672)	(0.597)	(0.418)	(0.438)	(-0.372)	(-0.604)	(-1.071)	(-0.826)
TERM	-0.1191	-0.1579	-0.0948	-0.0951	-0.0176	0.0500	0.1905	0.1349
	(-0.966)	(-1.251)	(-0.680)	(-0.691)	(-0.057)	(0.162)	(0.766)	(0.553)
REX	-0.1304[a]	-0.1641[a]	-0.1513[a]	-0.1512[a]	0.0871	0.1062	-0.2777[a]	-0.2560[a]
	(-4.418)	(-5.563)	(-2.577)	(-2.586)	(0.925)	(1.109)	(-2.218)	(-2.040)
STO	0.0064[b]	0.0016	-0.0002	-0.0003	0.0090	0.0031	0.0141	0.0084
	(1.710)	(0.408)	(-0.162)	(-0.260)	(0.376)	(0.127)	(0.806)	(0.481)
RPO	-0.0317[b]	-0.0087	0.0004	-0.0001	-0.0200	-0.0119	-0.0725	-0.0834[b]
	(-1.823)	(-0.494)	(0.105)	(0.020)	(-0.402)	(-0.234)	(-1.514)	(-1.735)
UNU	1.5820[a]	1.801[a]	1.3892	1.4516[b]	3.8979	4336[a]	3.9729[a]	2.8408[b]
	(3.749)	(4.336)	(1.450)	(1.713)	(1.704)	(2.061)	(2.055)	(1.646)
D1	1.5201		-2.4662		-2.8197		-2.9126	
	(1.601)		(-1.240)		(-0.624)		(-0.760)	
D2	3.7021[a]		-1.2457		2.1684		-0.0666	
	(4.401)		(-0.745)		(0.582)		(-0.021)	
D3	-0.2947		-1.9304		0.2140		-2.8461	
	(-0.358)		(-1.146)		(0.053)		(-0.840)	
D4	-0.5148		-1.7564		-2.7681		0.0151	
	(-0.590)		(-1.053)		(-0.714)		(0.005)	
D5	0.0356		-0.8703		5.9954		0.8415	
	(0.034)		(-0.414)		(1.164)		(0.184)	
D6	-0.3882		-2.4188		5.8012		-0.2412	
	(-0.397)		(-1.363)		(1.411)		(-0.070)	
D7	-2.259[a]		-0.7877		3.2195		7.7132[b]	
	(-2.321)		(-0.369)		(0.628)		(1.735)	
D8	1.8856		-1.0478		15.509[a]		4.6614	
	(1.535)		(-0.431)		(2.622)		(0.861)	
Sigma	7.1572	7.3578	6.6347	6.6717	15.9100	16.4300	12.4980	12.7170
	(53.814)	(53.814)	(23.495)	(23.495)	(22.672)	(22.672)	(21.354)	(21.354)
N	1448	1448	276	276	257	257	228	228
Log-Likelihood	-4905	-4945	-914	-915	-1076	-1084	-899	-903

Notes: t-values are in parenthesis, a = significant at 5% level, b = significant at 10% level.

3.6 Testing for Heteroskedasticity

Caudill *et al.* [24] adjusted the heteroskedasticity on the inefficiency measure using the same data set as Ferrier and Lovell [26]. They found that the heteroskedastic frontier parameter estimates were about evenly split between those that were higher than the OLS or regular frontier parameter estimates and those that were smaller. In their study, the average inefficiency estimates were increased by about 50% after the heteroskedasticity is adjusted. In addition, in an early paper Caudill and Ford [23], their Monte Carlo results on the estimated frontier showed that heteroskedasticity in the one-sided inefficiency term caused the intercept to be underestimated and the slope parameters to be overestimated. If the heteroskedasticity is related to the firm size, small firms appear to be less efficient and large firms more efficient if the heteroskedasticity is not adjusted in the estimation.

In this study, we tested the model of Equation (3-6) with Goldfeld-Quandt test and Breusch-Pegan test. Since ε does not have zero mean, we adjusted the $\hat{\varepsilon}$'s with the estimate of its expected value, which equals $\hat{E}(u)$. The results of the Breusch-Pegan test and Goldfeld-Quandt test for four selected periods are shown in Table 3-8(a) and 3-8(b), respectively. Both tests verify that heteroskedasticity exists in the model.

First, we regress the adjusted $\hat{\varepsilon}$ against all suspicious explanatory variables (*TM*, *AL*, *ALH*, *AS* and *INS*). We found that only the parameter estimate of *TM* is consistently significant through out all four periods. The parameter estimate of *AS* is significant only in periods 1976-78 and 1987. We also investigated the relationship between *TM* and the residuals by regressing the residuals against *TM* alone and *TM* and its squared term. The results are also reported in Table 3-8(a). The parameter estimate of the squared term of *TM* is not significant in all four regressions. Therefore, we conclude that the heteroskedasticity is in a linear form of *TM*.

For the Goldfeld-Quandt test, we sorted the data by the suspicious variable (*TM* or *AS*) and then separated them into three groups. We regressed the first and the third groups of the data in the form of Equation (3-6) and then tested the difference between the variances of the two regressions using F-test. The test result suggests that the variance of the model could vary with both *TM* and *AS*. However, the test statistics of *TM* is relatively larger than that of *AS*.

Combining the results from both tests, we conclude that *TM* is the major source of heteroskedasticity in the model. We should keep in mind that the problem of heteroskedasticity in a frontier model is more serious than that in classical linear model because it creates biasedness of variance, and in turn, bias the decomposed inefficiencies. Unfortunately, the correction procedure is not obvious in frontier estimation. Therefore, more effort has to be made in developing correction procedures for this problem.

Table 3-8(a) Result of Breusch-Pegan Test

	(76-78)	85	86	87
Constant	1.0000[a]	0.9888[a]	1.0000[a]	1.0000[a]
	(18.991)	(9.346)	(9.030)	(7.719)
TM	-0.2476[a]	-0.2661[a]	-0.3221[a]	-0.3283[a]
	(-4.787)	(-3.091)	(-3.383)	(-2.923)
AL	0.2232	0.3117	0.4677	0.6520[b]
	(1.483)	(1.145)	(1.544)	(1.801)
ALH	0.4809[a]	0.2425	0.1628	0.4404
	(3.937)	(1.117)	(0.696)	(1.53)
AS	0.2357[a]	0.1984[b]	0.1931[b]	0.3315[a]
	(3.678)	(1.682)	(1.658)	(2.352)
INS	0.3581[a]	0.2260	-0.0212	0.5183
	(2.871)	(0.954)	(-0.085)	(1.577)
R^2	0.0319	0.0504	0.0639	0.0701
Regression S.S.	235.7	54.2	69.9	82.2
LM = (1/2)*Reg.S.S.	117.9	27.1	34.9	41.1

Notes: t-values are in parenthesis.
a = Significant at 5% level (t-statistics = 1.960)
b = Significant at 10% level (t-statistics = 1.645)

Table 3-8(a) (Continued)

Further Analysis:

	(76-78) Model 1	(76-78) Model 2	85 Model 1	85 Model 2	86 Model 1	86 Model 2	87 Model 1	87 Model 2
Constant	1.0012[a]	1.0000[a]	0.9311[a]	0.9845[a]	0.9817[a]	1.0000[a]	0.9627[a]	1.0000[a]
	(14.660)	(18.841)	(7.013)	(9.264)	(7.014)	(8.878)	(5.846)	(7.597)
TM	-0.1321[a]	-0.1322[a]	-0.1716[a]	-0.1648[a]	-0.1392[a]	-0.1370[a]	-0.1830[a]	-0.1782[a]
	(-4.611)	(-4.763)	(-3.054)	(-2.984)	(-2.303)	(-2.302)	(-2.569)	(-2.546)
TM*TM	-0.0003		0.0144		-0.0051		0.0106	
	(-0.027)		(0.671)		(-0.222)		(0.379)	
R^2	0.0139	0.0139	0.0300	0.0286	0.0181	0.0179	0.0253	0.0247
Regression S.S.	102.8	102.8	32.2	30.7	19.8	19.6	29.6	29
LM = (1/2)*Reg.S.S.	51.4	51.4	16.1	15.3	9.9	9.8	14.8	14.5
d.f.	2	1	2	1	2	1	2	1

Notes: t-values are in parenthesis.
a = Significant at 5% level (t-statistics = 1.960)
b = Significant at 10% level (t-statistics = 1.645)
Chi-squares critical statistics for 1 degree of freedom at 5% significant equals 7.88.
Chi-squares critical statistics for 2 degree of freedom at 5% significant equals 10.6.

Table 3-8(b) Result of Goldfeld-Quandt Test

Year		TM (1)	TM (2)	AS (1)	AS (2)
1976-78 d.f. = 495	σ_u	0.2172	0.1833	0.1871	0.1925
	Est. E(u)	0.1732	0.1462	0.1493	0.1535
	F Statistics	1.7		1.09	
1985 d.f. = 65	σ_u	Wrong	0.1814	0.2107	0.2805
	Est. E(u)	Skewed	0.1447	0.1681	0.2238
	F Statistics			1.7	
1986 d.f. = 55	σ_u	0.2525	0.1600	0.1786	0.2767
	Est. E(u)	0.2014	0.1276	0.1425	0.2207
	F Statistics	2.58		2.29	
1987 d.f. = 45	σ_u	0.2827	0.1542	0.1592	0.2433
	Est. E(u)	0.2255	0.1230	0.1270	0.1941
	F Statistics	3.31		2.75	

F Statistics

d.f.	Significant Level 0.95	0.99
45	1.65	2.03
55	1.55	1.90
65	1.53	1.84
Infinity	1.00	1.00

3.7 Summary and Limitations

3.7.1 Summary

This is the first study using the stochastic cost frontiers to analyze the performance of the U.S. motor carrier industry in the pre- and post-MCA periods. We estimated the stochastic cost frontiers, and the industry and firm-specific inefficiencies for twelve consecutive years (1976-1987). The average industry inefficiencies were between 14 and

27 percent during the studied period. Our results indicate that the deregulation had no impact on the industry efficiency. After a short adjustment period, the industry's average inefficiency in the post-MCA years falls back to its pre-MCA level of around 14 to 16 percent. Our tobit regression results on firm-specific inefficiency shows that union firms are 1.5 percent less efficient than non-union firms in the pre-MCA years and are about 4 percent less efficient in the post-MCA years. Firms located in the southern region are relatively efficient and the ones in the northern regions are relatively inefficient. Our result supports Stigler's Survivor Principle that "survivor" firms are relatively efficient. Since the "survivor" firms still have a gap between the actual and best possible practices after the MCA 1980, there is much room to improve the performance of this industry.

3.7.2 Limitations

Although we successfully estimated a series of stochastic frontiers, the estimation results are subjected to several limitations. First, SFE is very sensitive to the functional form used in the model and the assumed functional form of the inefficiency term (u). Schmidt [40] pointed out that flexible functional form models should be used in SFE. Since a more flexible model explains more variations, the estimated frontier would be a better fit to the data. As a result, the inefficiency measures would be more accurate. In this study, we assumed that the inefficiency term followed a half-normal distribution. There is no reason to restrict using other distributions, such as truncated normal, exponential or gamma. Lee [34] tested the relative benefits of using half-normal and truncated normal and Greene [27], [28] illustrated the use of gamma distribution for the distribution of the inefficiency term. It would be interesting to compare the inefficiency measures in the motor carrier industry using different distributions.

Second, SFE recovers the inefficiency conditional on the point of the stochastic frontier. Therefore, it is important to get the best estimate of firm and industry technology. In the context involving time-series and cross-sectional analysis, the timing of structural change should be a major concern in determining the frontier. Traditional CUSUM test of structural change may not work due to the difference between the composite residual and recursive residual. Further effort should be put in developing an appropriate test for structural change in frontier estimation.

Third, the SFE setup assumes that the inefficiency term is identically distributed. If this assumption does not hold, the inefficiency measures will be biased. We have tested that heteroskedasticity results mainly from firm's composite output. However, based on the restrictions of our translog cost function and of the computer software, we cannot correct it through a transformation of variables. Therefore, our SFE results may over-estimate the inefficiencies of the smaller firms but under-estimate the inefficiencies of the larger firms.

Fourth, this study did not account for the quality factor of trucking services as suggested by Allen and Liu [20]. Higher quality services would involve more employees or supervisory personnel. As a result, operating cost frontier would appear to be higher and the inefficiency would be lowered. Without quality adjustment, we would overestimate the cost inefficiency of high quality firms and underestimate that of low quality firms.

Fifth, since firm specific inefficiencies are expected values, it is very unlikely to have zero expected inefficiency even for efficient firms. Therefore, it would be useful to develop a procedure that identifies whether a firm is statistically efficient or not.

3.8 References

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Chapter 4

CONCLUSIONS

In the first essay, we used two types of regressors in our model: site characteristics and accessibility indexes. Since the indexes consist of distance, mass(es) of nodes, and a decay parameter, the model becomes non-linear in parameters. Therefore, the non-linear least square estimation method is applied.

Our findings are as follow: First, our results indicate market accessibility to be the major factor governing the value of vacant commercial land. Second, our results are consistent with those previous studies that highway interchange accessibility is insignificant in determining commercial land values. Third, we found that corner lots and lots with teardown structures have higher land values. Fourth, our estimated decay parameter of market accessibility is different in value from the ones that are commonly set arbitrarily. Fifth, we found that under the zoning policy, land uses between neighborhood commercial and community commercial land have no significant difference in value. Sixth, some of site characteristic parameters, such as leveled lots and rectangular lots, are of expected sign; however, they are statistically insignificant.

The second essay presents the first study using the stochastic cost frontiers to analyze the performance of the U.S. motor carrier industry in the pre- and post-MCA periods. We estimated the stochastic cost frontiers, and the industry and firm-specific inefficiencies for twelve consecutive years (1976-1987).

Our results indicate that the deregulation had no impact on the industry efficiency. The average industry inefficiencies were between 14 and 27 percent during the studied period. After a short adjustment period, the industry's average inefficiency in the post-MCA years falls back to its pre-MCA level of around 14 to 16 percent.

Our tobit regression results on firm-specific inefficiency shows that union firms are 1.5 percent less efficient than non-union firms in the pre-MCA years and are about 4 percent less efficient in the post-MCA years. Firms located in the southern region are relatively efficient and the ones in the northern regions are relatively inefficient. Our result supports Stigler's Survivor Principle that "survivor" firms are relatively efficient. Since the "survivor" firms still have a gap between the actual and best possible practices after the MCA 1980, there is much room to improve the performance of this industry.

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APENDICES

Appendix 1: City Characteristics, Coordinate and Distance

City Characteristics:

Count	Population Center	Population (in 0,000)	Per Capita Income (in 0,000)	Total Income (in 00,000,000)
1	Auburn	3.3102	1.3866	4.5899
2	Bellevue	8.6878	2.3816	20.6909
3	Burien	2.5089	1.6857	4.2293
4	Des Moines	1.7283	1.6778	2.8997
5	Federal Way	6.7554	1.7126	11.5693
6	Issaquah	0.7712	1.8055	1.3924
7	Kent	3.7960	1.5993	6.0709
8	Kirkland	4.0052	2.1200	8.4910
9	Mercer Island	2.0816	3.1438	6.5441
10	Redmond	3.5800	2.0037	7.1732
11	Renton	4.1688	1.6298	6.7943
12	SeaTac	2.2694	1.5579	3.5355
13	Seattle	51.6259	1.8308	94.5167
14	Tukwila	1.1874	1.5982	1.8977

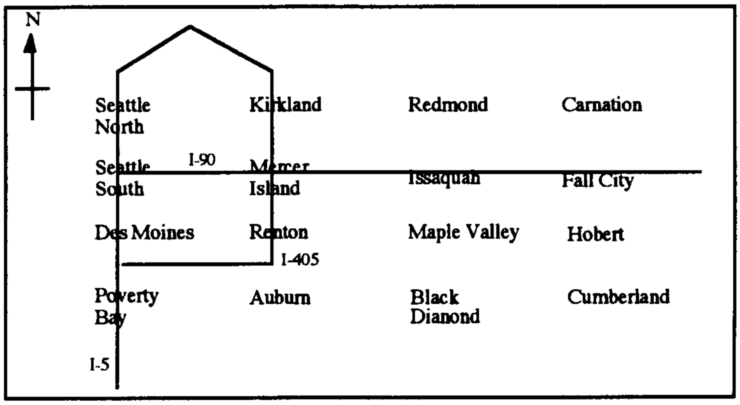
Notes:
(1) Income is in 1989 dollar.
(2) Total population in the 14 centers is 964,761 (64.0% of King County and 92.3% of incorporated city).

Appendix 1: (Continued)

City Distance:

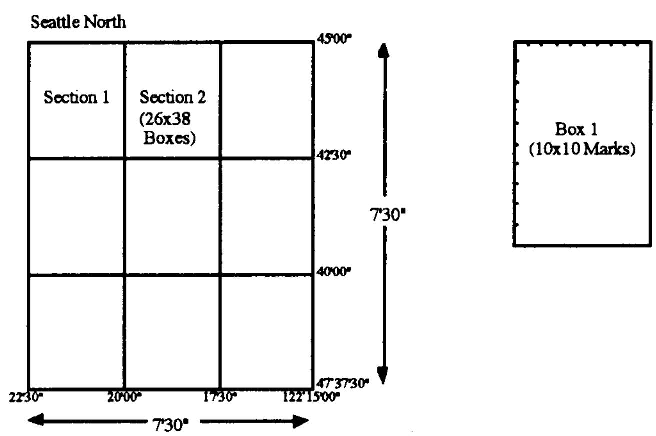
name	longitude	latitude	Burien	Seattle	Des Moines	Federal Way	Sea Tac	Tukwila	Kent	Mercer Island	Renton	Auburn	Kirkland	Bellevue	Redmond	Issaquah
Burien	122.34555556	47.47055556	0.0000	9.4097	4.8577	10.3549	1.6498	4.0642	8.1347	9.0960	6.1913	12.5764	15.9773	11.8839	17.6413	15.4104
Seattle	122.33083333	47.60638889	9.4097	0.0000	14.1286	19.6337	10.5465	9.7331	16.2272	5.7498	10.1062	21.2211	7.8116	6.2162	10.9976	15.0973
Des Moines	122.32305556	47.40194444	4.8577	14.1286	0.0000	5.5160	3.5905	5.8184	4.4655	12.6282	7.5550	7.9425	20.0812	15.5507	21.1073	16.3894
Federal Way	122.31138889	47.32250000	10.3549	19.6337	5.5160	0.0000	9.0872	10.7585	5.4687	17.6816	11.9759	4.1106	25.2938	20.5913	25.9192	19.5232
Sea Tac	122.32055556	47.45388889	1.6498	10.5465	3.5905	9.0872	0.0000	3.1982	6.4933	9.3532	5.3437	11.0332	16.6182	12.2435	17.9212	14.6498
Tukwila	122.25972222	47.47416667	4.0642	9.7331	5.8184	10.7585	3.1982	0.0000	6.5460	6.9264	2.1632	11.6160	14.5458	9.8435	15.3080	11.4664
Kent	122.23361111	47.38111111	8.1347	16.2272	4.4655	5.4687	6.4933	6.5460	0.0000	13.1207	7.0927	5.0943	20.8002	15.9330	20.9420	14.0547
Mercer Island	122.22083333	47.57083333	9.0960	5.7498	12.6282	17.6816	9.3532	6.9264	13.1207	0.0000	6.0686	18.1946	7.6827	2.9244	8.5759	9.3815
Renton	122.21583333	47.48305556	6.1913	10.1062	7.5550	11.9759	5.3437	2.1632	7.0927	6.0686	0.0000	12.1400	13.7265	8.8422	13.9537	9.3075
Auburn	122.22722222	47.30750000	12.5764	21.2211	7.9425	4.1106	11.0332	11.6160	5.0943	18.1946	12.1400	0.0000	25.8657	20.9774	25.8301	17.9590
Kirkland	122.20750000	47.68166667	15.9773	7.8116	20.0812	25.2938	16.6182	14.5458	20.8002	7.6827	13.7265	25.8657	0.0000	4.9274	4.1546	13.3663
Bellevue	122.19944444	47.61055556	11.8839	6.2162	15.5507	20.5913	12.2435	9.8435	15.9330	2.9244	8.8422	20.9774	4.9274	0.0000	5.7715	9.6871
Redmond	122.12027778	47.67416667	17.6413	10.9976	21.1073	25.9192	17.9212	15.3080	20.9420	8.5759	13.9537	25.8301	4.1546	5.7715	0.0000	10.7917
Issaquah	122.03138889	47.53027778	15.4104	15.0973	16.3894	19.5232	14.6498	11.4664	14.0547	9.3815	9.3075	17.9590	13.3663	9.6871	10.7917	0.0000

Appendix 2: Measuring the Highway/Freeway Inter-change Locations of King County



Measuring Method

The locations are measured from 7 1/2 (24000:1) scale official maps produced by the US Geoglocial Information Survey. Some of the revised maps are produced in 1994 and others are produced in 1975. The maps produced in 1975 are compared with the Thomas Guide (1994) to verify for recent changes of the highway system. Only the Highway/Freeway Interchanges of major highways I-5, I-405 and I-90 are measured. The geographical region of King County included in this study can be divided into sixteen sub-regions. The highway system we considered in this study passes through nine out of sixteen sub-regions. (See the diagram above.) Each sub-regional map is further divided into nine (= 3 x 3) sections. Each section represents area of 2'30" in longitude and 2'30" in latitude. Each section is further divided into 26x38 boxes and each box is furhter divided into 10x10 marks. The following diagram illustrates the measuring chart of the "Seattle North" sub-region.



A highway interchange is defined as the entrant or/and the exit of the highway from the city street. The location of an interchange is determined by the first pair of horizontal and vertical "marks" that hits the entrant/exit.