DEMAND FOR FREIGHT TRANSPORTATION
WITH A SPECIAL EMPHASIS ON MODE CHOICE IN CANADA

by

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ABSTRACT

"Demand for Freight Transportation with a Special Emphasis on Mode Choice in Canada"

This thesis derives a freight transportation demand model consistently with neoclassical economic theory: a shipper is assumed to minimize total cost of production and distribution with a given output that has to be delivered to various destination markets. With some further assumptions on the shipper's production technology, it is possible to express the shipper's transportation sectoral unit cost as a function of freight rates and quality attributes of service and length of haul. Four alternative forms of the transportation sectoral unit cost function are hypothesized. These cost functions are specified in the translog form, and corresponding modal revenue share functions are derived.

Each system of the cost and share functions is estimated jointly by a maximum likelihood (ML) method, separately for each of the eight commodity groups selected from the cross-sectional data of Canadian inter-regional freight movements during the year 1970. Results of the hypothesis testing has shown that the quality attributes of service have significant impact on the mode choice of manufactured products but not of bulk commodities and raw materials.

The parameter estimates of the cost and share functions are used to measure the elasticity of substitition and the elasticities of demand with respect to freight rates and quality attributes of service. Both price and quality elasticities of demand vary sub-

stantially from commodity to commodity and from link to link.

For each commodity group, the price elasticities of the rail and truck modes are used to identify the distance range over which an effective rail-truck competition exists. For the relatively high-value commodities, the short-haul traffic is largely dominated by the truck mode, and the significant rail-truck competition exists only in the medium and long-haul markets. On the other hand, for the relatively low-value commodities, the effective rail-truck competition exists only in the short-haul markets leaving the medium and long-haul markets largely rail-dominated.

"DEMAND FOR FREIGHT TRANSPORTATION WITH A SPECIAL EMPHASIS ON MODE CHOICE IN CANADA"

TABLE OF CONTENTS

Chapter		Page

LIST OF TABLES

LIST OF FIGURES

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CHAPTER I

OBJECTIVES AND ORGANIZATION OF THESIS

The study of the demand for freight transportation is an important part of the quantitative analysis of many public and managerial decisions concerning freight transportation. For example, a demand study is essential for economic evaluation of a major investment project on transport infrastructure, a regulatory policy option or a subsidy program. A carrier who wishes to determine the optimal price-service package for a particular class of users, or to examine the feasibility of introducing a new service or opening up a new market for an existing service should also rely heavily on the results obtained from a demand study.

Functionally, there are two major purposes of a demand study. The first is to forecast future demands. The second is to analyze the nature of the demand functions facing various transportation modes. Demand forecasts are necessary for planning future transportation systems and their capacity requirements, as well as for carriers' investment and operational plans. Many public decisions concerning taxes, subsidies and economic regulations, and carriers' decisions on optimal price-quality mix require a precise knowledge of the nature of demand functions as well as demand forecasts. Some demand models are built so as to serve these two purposes simultaneously whereas others serve primarily one or the other of the two purposes.

In an *ex post* sense, except for a few bulk commodities, traffic flow between an origin and a destination depends largely on the geographical distribution of economic activity levels and distance, and less on price and quality of available transportation services. Therefore, macro-economic structural models and gravity-type models turn out to perform reasonably well (in terms of statistical fit) in forecasting demands for planning purposes.

In spite of an obvious need for improving methodologies for studying the nature of demand functions, relatively little effort has been devoted to this area. Furthermore, the information obtained from the limited effort is often radically different among studies,[1] which makes it difficult to believe the results. The following reasons appear to explain this failure:

(i) In most previous studies in this area (such as Mathematica [1967, 1969], Harbeson [1969], Kullman [1973], Tertiev et al. [1975], Turner [1975], Boyer [1977] and Levin [1978]), a demand model of an *ad hoc* nature[2] is used to estimate the parameters of price and quality responsiveness of demand. These *ad hoc* demand models are restrictive for studying the nature of demand functions because, in general, the structure of shippers' distribution technologies that they purport to approximate is not known, nor are the properties of the approximations.

(ii) In most previous demand studies, the demand models were estimated from highly aggregate data primarily because of unavailability of appropriate disaggregate data.

(iii) Cobb-Douglas demand models and logit models which have been used frequently in the past impose severe restrictions on the parameters of price responsiveness of demand and of inter-modal substitution.[3]

Consequently, no one really knows whether the demand for the rail mode by a particular class of users in a particular freight market is elastic or inelastic, whether or not it is responsive to a quality of service variable, and whether the cross elasticity of demand between railway and trucking modes is high or low. However, if regulatory agencies or carriers are going to make rational decisions, it is imperative for them to have accurate knowledge on the nature of demand functions which various modes are facing in various freight markets. To my knowledge, however, no one has systematically investigated the price and quality responsiveness of demands and cross-mode substitution possibilities using a derived demand model which ensures free variation of elasticities of demand and substitution while at the same time employing sufficiently detailed data on shippers' mode choice.[4]

Therefore, the objective of this thesis is to demonstrate a method of measuring price and quality responsiveness of modal demands in a way that is consistent with shipper's mode-choice behavior. This objective will be accomplished through the following procedure:

(i) The duality relation between cost and production functions allows a shipper's distribution cost function to describe his distribution technology completely.

(ii) Since disaggregate data of an individual shipper's distributional and mode-choice data are usually unobtainable, the cost function is aggregated over shippers of a homogeneous commodity group.

(iii) By applying Shephard's lemma [1953] to the cost function, the demand functions for various modes are obtained.

(iv) Several alternative forms of the cost functions and corresponding demand functions are hypothesized and tested empirically. For each commodity group, the model which fits the empirical data best is to be chosen for use in measuring the price and quality responsiveness of demands for rail and truck modes.

(v) Elasticities of demands for railway and trucking modes with respect to price and quality of service variables are computed using the parameter estimates of the cost function.

An attempt is also made, in this thesis, to compare the results with those of previous studies, and to evaluate the extent of inter-modal competition existing in various freight markets in Canada.

The organization of this thesis is as follows: A survey of relevant literature and an outline of the methodology adopted for this thesis are presented in chapter II. In chapter III, the shipper's transportation-sectoral-cost function is derived, and its four alternative forms are hypothesized. These cost functions are specified in translog form and the corresponding modal revenue share functions are derived. Information about the data is presented in chapter IV along with ways of constructing the variables actually used in estimation. Chapter V presents the econometric aspects of estimation and carries out the hypotheses testing.

Chapter VI reports the parameter estimates of the cost functions chosen in chapter V with some explanatory comments. Chapter VII reports and interprets the estimated elasticities of substitution and elasticities of demand with respect to freight rates and quality attributes of service. Chapter VIII closes this thesis with a summary of major findings and suggestions for further research.

Footnotes for Chapter I:

1. The most conspicuous example of radical difference in results among studies can be found in the following U.S. studies concerning the welfare loss due to the traffic misallocation which is claimed to be caused by the I.C.C. (Interstate Commerce Commission) minimum rate regulations.

Comparison of Welfare Loss Estimates

Author	Year	Welfare Loss (current$)	Welfare loss as % of freight revenue
Harbeson	1963	1.1-2.9 billion	12-32
Friedlaender	1964	150 million	1.59
Boyer	1963	125 million	1.37
Levin	1972	53-135 million	0.30-0.77

(Source: Reproduced from Table 11 in Levin [1978]).

Note that differences among the above estimates are primarily due to the differences in assumed or estimated demand elasticities.

2. The term "*ad hoc* model" refers to all demand models that are specified arbitrarily without referring explicitly to the structure of the shippers' distribution technology.

3. (a) The Cobb-Douglas input demand model is consistent only to a Cobb-Douglas production function which is dual to a Cobb-Douglas cost function. Therefore, it restricts the elasticity of substitution between every pair of inputs to unity. The demand model specified in a linear logarithmic form which does not impose the homogeneity condition assumes constant price elasticities.

   (b) The linear logit models have the following inadequacies in measuring price responsiveness of demand (see Oum [1978] for a detailed discussion).

   (1) Linear logit models, specified in terms of a "price-ratio", and other non-price variables:

   (i) The elasticities of substitution and the price elasticities are not invariant to the choice of base mode M.

(ii) A certain choice of base mode amounts to imposing rigid *a priori* restrictions on the relationships between the elasticities of substitution and the corresponding price ratios, and these restrictions are contradictory to the ones that would have been imposed under a different choice of base mode.

(iii) The preference (or technology) structure underlying the multi-nomial logit model of this type is inconsistent and irregular because there are two different measures for the elasticity of substitution between any two non-base modes i and j: one when ith price is held constant and the other when jth price is held constant. Therefore, it is meaningless to measure the price responsiveness of demands using the multi-nomial logit model of this type.

(iv) All cross price elasticities with respect to the price of any given "non-base" mode are restricted to be equal.

(2) Linear logit models, specified in terms of a price-difference and other non-price variables:

(i) The technology (or preference) structure underlying both bi-nomial and mutli-nomial logit models of this type is inconsistent and irregular because of the existence of two different measures for the same elasticity of substitution. Therefore, it is meaningless to try to measure the price responsiveness of demands using the logit models of this type.

(ii) All cross price elasticities with respect to the price of any given mode including the base mode M are restricted to be equal. This is also an extremely unrealistic restriction.

4. As will be mentioned in chapter II, Friedlaender and Spady [1977] have used a demand model that has these desirable properties for studying inter-modal competition. However, their data did not include quality attributes of services and were highly aggregated geographically.

CHAPTER II

LITERATURE REVIEW AND DESCRIPTION OF METHODOLOGY

Section (A) presents a selective review of previous demand studies and the approaches taken in those studies. The methodology adopted for this thesis is described in section (B).

(A) Review of Previous Studies

The study of demand for freight transportation is complicated mainly because of the extreme heterogeneity in quality of service and in types of cargo and shippers. As a result, many studies are not directly comparable because they use different methodologies and types of data. This makes it difficult to compare the results of the previous works. In order to minimize these difficulties, this review of literature is organized according to the approach adopted in the study. On the basis of the author's subjective opinion, past research on freight transport demand can be divided into the following six categories.

Normative Approach:

(1) System optimizing approach

(2) User optimizing approach

Empirical Approach:

(3) Derived demand modelling approach

(4) "Gravity-type" modelling approach

(5) Abstract-mode modelling approach

(6) Mode-choice modelling approach

In a normative approach, the mode-choice for each consignment is done analytically by evaluating an objective function. Therefore, the stochastic nature of shippers' mode-choice behavior is not taken into consideration in the normative approach. On the other hand, in empirical approach, the demand model is imbedded in a stochastic framework and thus estimated from the observed data.

In what follows, each of the above six approaches is described and examples of each approach are cited. Advantages and disadvantages of each approach - in view of the objectives of this thesis - are to be examined as well. Although the discussion will be restricted primarily to freight transport demand studies, some passenger demand studies are to be referred to because their methodologies are applicable to the study of freight transport demand.

(1) Normative approach based on system optimization:

In this approach, the demand for each mode in each freight market is determined such that the total transportation cost over the entire transportation network of a nation or a region is minimized. Geographic distribution of supply and demand for each commodity and the costs of transportation by alternative modes must be identified or forecast ahead of time. Then the demand for each mode in each freight market is estimated by solving a mathematical programming problem which minimizes the total transportation cost over the entire network subject to the supply and demand constraints at various locations for each commodity. Due to the simultaneity between price (or cost) of a mode's service and the volume of flow it handles, the problem becomes an iterative one which normally invites many difficulties concerning convergence and hence calls for a high computational cost. The approaches taken in Tavares [1972], Dye [1972], and Kresge and Roberts [1971] belong to this category.

The flows of commodities predicted by this approach indicate the collectively ideal commodity flow patterns within a region or a nation, and thus provide useful information for strategic planning of future transportation systems. However, this approach is not appropriate for studying the nature of demand functions because of the following shortcomings:

1. The outcome of this approach is the flow predicted over the transportation network rather than the demand functions. The only way to examine the effect of a price change in the ideal flow patterns is to re-solve the entire problem with appropriately changed parameters - a rather expensive option.

2. This approach ignores the effect of quality attributes of service on demand and mode choice primarily due to the difficulties in specifying an appropriate objective function and in obtaining the necessary data. Yet, both total demand and mode choice are likely to depend on the quality attributes of available services as well as on the prices of services.

3. An individual shipper is motivated to minimize the total cost of his given transportation requirements rather than the total transportation costs of an entire region or nation: i.e., shippers are not system-optimizers. As a result, the flows predicted by this approach are not likely to approximate closely the actual flows which are merely an aggregation of the decisions made by individual shippers.

(2) Normative approach based on user optimization:

This is an analytic approach to the shipper's choice of service attributes[1] and thus his choice of mode. In this approach, a shipper with a given transportation requirement is assumed to choose the bundle (or mixture) of service attributes which minimizes the imputed total cost of transportation.

This approach utilizes the notion of a so-called "abstract commodity" introduced formally by Lancaster [1966]. Lancaster observed that users purchase goods or services in order to derive satisfaction from their attributes, and therefore, a good or a service *per se* has no special significance to its users other than as the collection of attributes it possesses. Consequently, he advocated that the user's choice problem can be handled better in the attributes space than in the goods or services space. Therefore, a collection of attributes is called an "abstract commodity". This concept was introduced into the transportation literature as an "abstract mode" through the work of Quandt and Baumol [1966] on passenger transport demand and through a theoretical contribution by Baumol and Vinod [1970] on freight mode selection.

Baumol and Vinod proposed the notion of an abstract freight transport mode characterized by service attributes such as economy, speed, reliability and prevention of loss and damage. Assuming that a shipper minimizes the total cost of transportation and inventory management, the authors used an inventory model to show the shipper's trade-offs between freight rate and service attributes, specifically speed and reliability of speed. The shipper is, therefore, supposed to purchase the bundle of service attributes that yields the highest value to him per dollar spent on a given transportation requirement. The rationale for this conclusion is that both speed and reliability contribute to save inventory management cost by reducing safety stock requirements and the frequency of stockout occasions.

Since inventory costs depend largely on commodity attributes such as the value of the commodity, holding cost, susceptibility of the commodity to loss and damage, cost of a stockout and the nature of the demand for the commodity, so too do the imputed values (or costs) of various quality attributes of service. Using the fact that the values of quality attributes of service are determined mainly by the commodity attributes, Roberts [1970] attempted to operationalize the concept of an abstract freight mode by developing a procedure to compute what he calls a "commodity preference vector". This commodity preference vector essentially measures the shipper's imputed costs of service attributes such as transit time, waiting time, variability of transit time and the probability of loss and damage. Plugging in appropriate values for the inventory-holding cost, the price of commodity, the interest rate, the probability distribution of the demand, and the loss and damage factors, he arrived at the following commodity preference vectors for two commodity groups: bulk commodity and non-bulk commodity groups.

Cost Item	Bulk	General (non-bulk)
Travel time[2] $/ton-hour	.041	.362
Waiting time[2] $/ton-hour	.049	.514
Variability of time $/ton-hour	.003	.035
Out-of-pocket cost $/$	1.0	1.0

(Source: from table 2 in Roberts [1970])

Intuitively, the figures look reasonable in the sense that non-bulk commodity shippers value all the service attributes far more than do bulk commodity shippers. The combined value of monetary cost and the imputed costs of travel time, waiting time and the variability of time for using a particular mode is defined as the product of the commodity preference vector and the modal performance vector for a particular movement of our concern. Then, the idea is to choose the least cost mode in terms of the combined cost. Although Roberts demonstrated this procedure for the two aggregate commodity groups, in principle, the same procedure could be applied to as any disaggregate commodity group as is desired.

Clearly, this approach is an improvement over the system optimizing approach in predicting mode-choice in the senses that the optimizing unit is an individual shipper, and the imputed values (or costs) of quality attributes as well as prices of various modes' services enter explicitly into the shipper's mode choice decision. However, this approach suffers from the following disadvantages:

1. The commodity preference vector is likely to depend not only upon the commodity type but also upon such factors as length of haul, shipment size, total size of shipper's operation, etc. However, it is not readily apparent how this approach could be modified to incorporate these factors, (other than commodity type) and at the same time, maintain the relative simplicity required for practical applications.

2. According to this approach, for a given transportation requirement, all shippers are supposed to choose the same mode, disallowing the stochastic nature of actual mode-choice decisions. Therefore, the demand predicted by this approach may not give a good approximation to the actual demand.

3. The end result of this approach is the mode-choice forecast for a given movement or the modal demand forecasts obtained by aggregating the individual mode-choice results. Therefore, as was the case of the previous approach, the demand functions cannot be identified through this approach.

Although the normative approach based on user optimization is not appropriate for studying the nature of demand functions, many empirical studies, including this thesis, have benefited from this approach because it provides theoretical foundations for the formulation of reasonable hypotheses for empirical research.

(3) Empirical approach with derived demand models:

This approach uses a demand model derived from, or specified consistently with, neoclassical production theory. Consequently, estimation of the demand functions completely identifies the shape of the underlying technology. In this approach, each shipper is assumed to minimize his total transportation cost subject to his transportation-sectoral technology by responding only to changes in freight rates of alternative modes. Although the effect of mean differences in quality attributes of service between modes is reflected in his transportation-sectoral technology (i.e. shapes of isoquants), the effect of variation in relative quality attributes of various modes across observational units is not taken into account in this approach since the demand models do not include quality attributes of service as their independent variables. The demand models used in Sloss [1971], Perle [1964], Oum [1977], and Friedlaender and Spady [1977] may be considered to belong to this approach.

Using time-series data for Canada, Sloss has estimated a highly aggregated demand model in which the total tonnage of intercity freight traffic carried by for-hire trucks is expressed as a 'Cobb-Douglas-like' function[3] of the average rail revenue per ton, the average truck revenue per ton and a variable indicating the general level of economic activity. The data for the model were obtained from annual reports published by the Dominion Bureau of Statistics, Canada. Although Sloss termed his study "a macro-economic analysis", the model used is similar to the demand model one would obtain by aggregating the individual shipper's derived demand model based upon the traditional production (or consumption) theory.

Perle [1964] conducted one of the first major studies of freight demand, and discussed extensively the theory of freight demand based upon the consumption theory. Among other forms of demand models, he estimated "Cobb-Douglas-like" demand functions for rail and truck modes using pooled time-series and cross-sectional U.S. data. The advantages of Perle's study relative to that of Sloss [1971] are: (i) The models were estimated from relatively disaggregate data, (ii) The traffic volumes are measured in ton-miles rather than in tonnage, and (iii) The differences between geographical regions, between years and between commodities were taken into consideration at least partially by either including appropriate dummy variables or by estimating separate equations for each commodity group.

The "Cobb-Douglas-like" demand model used by Sloss [1971] and Perle [1964] has a major disadvantage in measuring elasticities of demand because it restricts the price elasticities of demand to constant values (see footnote 3 in chapter I). Consequently, it is not adequate for studying the nature of demand functions. The three-mode (rail, truck and ship) demand model estimated in Oum [1977] is free from this problem because it was derived from the shipper's "translog" cost function[4] which allows the free variation of price elasticities and elasticities of substitution. Oum also imposed linear homogeneity of the cost function with respect to prices so that the demand functions would be homogeneous of degree zero in prices. Aggregate time series data of Canadian intercity freight transportation, 1945-1974, were used to estimate this derived demand model.

Friedlaender and Spady [1977] estimated the two-mode (rail and truck) demand model derived from a shipper's "trans-log" cost function using a combination of cross-sectional and time-series data for the seven broad commodity types (durable manufactures, nondurable manufactures, field crops, other agricultural commodities, petroleum and petroleum products, coal, and other bulk commodities) and the three U.S. regions (Official Territories, South, and West) for the years 1961-1972. They differ from Oum [1977] in that the additional variables such as truck tons per vehicle, rail tons per car, truck average length of haul, rail average length of haul, and value of commodity are included in the model. However, the inclusion of the first four additional variables which basically represent the characteristics of modal outputs can hardly be justified because the shipper's cost function should reflect the shipper's choice behavior for a given transportation requirement. What is relevant for mode choice is the characteristics of shipments required to be transported instead of the characteristics of shipments carried by various modes.

One advantage of using a derived demand model is that researchers are given full access to the established economic theory for comparative static analysis because the demand functions in combination describe the structure of the shipper's distribution technology. One major disadvantage, however, is that the sensitivity of demand to variation in quality-attributes of service cannot be measured from the derived demand models developed so far. In order to resolve this problem, quality-attributes of service should be included in the model. This is done in the present thesis.

(4) "Gravity-type[5]" modelling approach:

This approach attempts to specify a demand model purely on empirical grounds rather than deriving it from the economic theory of the shipper's mode choice. Thousands of studies on the urban traffic distribution problem have used various forms of gravity models which tell essentially that the volume of traffic between a pair of origin and destination zones is an increasing function of the trip generating factors in the origin and the trip attraction factors in the destination and a decreasing function of the impedance factors. Furthermore, Wilson [1967, 1968, 1969] has improved the gravity model so as to solve simultaneously the entire system of traffic generation, attraction, distribution, mode-split, and route assignment problems. By adapting the logic underlying the passenger gravity models, several studies concerning freight transport demand have used "gravity-type" models for predicting inter-regional commodity flows. In these models, the demand for transport of a particular commodity between a pair of origin and destination regions is usually specified as a function of "push" variables (for example, production of the commodity) at the origin, "pull" variables (for example, the consumption of the commodity) at the destination, and impedance factors such as cost of transportation, distance and travel time. The models used by Black [1971], Chrisholm and O'Sullivan [1973] and the Canadian Transport Commission [1976] are of this general type. The C.T.C. study is different from the other two studies in that its demand model includes separate demand functions for three freight modes (rail, truck and ship). The demand for a mode's service on a link[6] by given commodity shippers was expressed as a "Cobb-Douglas-like" function of excess production of the commodity at the origin, excess consumption of the commodity at the destination, transport cost by the mode and the movements on all links that are complementary to or in competition with the link. Note that the C.T.C. model cannot be used to measure cross-elasticities of demand, elasticities of substitution among modes or elasticities of demand to quality attributes since it does not include the prices of alternative transport modes nor the quality attributes of service. Therefore, the usage of the model is limited only to forecasting modal demands. All gravity-type models possess this disadvantage.

(5) Abstract-mode modelling approach:

The demand model proposed in Quandt and Baumol [1966] may be regarded as a natural extension of the gravity-type model so as to measure sensitivity of demands to price and quality of service variables, at least to a limited extent. This demand model consists essentially of two components: forecasting and mode-split. The forecasting component is a function of "push and pull" variables (populations, mean incomes and industrial character indices of the origin and destination) and impedance factors (travel time by the least time mode, cost by the least cost mode and departure frequency of the most frequent mode). The mode-split component is a function of the number of competing modes on the link, travel time (relative to the least time mode), cost of using the mode (relative to the least cost mode) and departure frequency (relative to the most frequent mode). Clearly the model suggested in Quandt and Baumol [1966] is constructed by combining the concept of abstract-mode[7] with the gravity-type model. Quandt and Young [1969] applied this model directly to an intercity passenger transport demand study while Mathematica [1967] applied this model with a minor change to the Northeast Corridor freight demand study. The model used in the Mathematica study is as follows:

$$V_{ijm} = a_0 \, P_i^{a_1} \, P_j^{a_2} \, Y_i^{a_3} \, Y_j^{a_4} \, M_i^{a_5} \, M_j^{a_6} \, N_{ij}^{a_7} \, (T_{ij}^{b})^{b_0}$$
$$(T_{ijm}^{r})^{b_1} \quad (C_{ij}^{b})^{d_0} \, (C_{ijm}^{r})^{d_1}$$

where

V_{ijm} = volume of freight flow from i to j by mode m,

P_i, P_j = population of the origin and destination,

Y_i, Y_j = gross regional product of the origin and destination,

M_i, M_j = industrial character indices such as the percent of the labor force employed in mining and manufacturing,

T_{ij}^b = travel time from i to j by the least time mode,

T_{imj}^r = travel time of mode m from i to j divided by that of the least time mode,

C_{ij}^b = cost of shipping from i to j by the least cost mode,

C_{ijm}^r = cost of mode m from i to j divided by that of the least cost mode,

N_{ij} = number of modes serving i and j.

Notice that this Mathematica model allows one to compute the elasticities of demand for a mode with respect to own price and travel time. It also allows one to compute the cross elasticities of demand for a mode with respect to the price of the least-cost mode and the travel time of the least-time mode. Although the cross elasticities of demand with respect to price and quality variables of "non-best" modes[8] are implicitly assumed to be zero in this model, this assumption can be relaxed by including price and quality variables of "non-best" modes. However, the major disadvantages of this approach are two-fold. First, this model restricts the elasticities of demand with respect to prices and quality variables to be constant values because of its "Cobb-Douglas-like" functional form. Second, the pattern of shipper's transportation-sectoral technology cannot be identified directly from the estimated demand model because the model is not a derived one: i.e. the model was not derived from shippers' production functions.

(6) Mode-choice modelling approach:

A demand forecasting study is often decomposed into two stages: the first stage is to forecast the total freight demand between two points, and the second is to estimate the mode-split probability model and to apply it to the total demand in order to compute the demand for each mode. Although the total demand and the mode-split may be mutually interdependent, for convenience of modelling and estimation these two stages are often treated separately from one another. If this is the case, a gravity-type model is normally used for forecasting total flows. The mode-split stage normally begins with a careful examination of shipper's mode selection behavior, and then uses discriminant, logit or probit analysis to estimate the conditional mode-choice probability functions. Previous studies on freight mode selection may be grouped into two categories: descriptive studies and mode-choice probability studies. In what follows, an attempt is made to describe the approaches taken in these two categories along with a review of some selected examples.

(i) Descriptive studies:

Many studies have attempted to identify the major factors affecting mode-choice using either published (usually aggregate) or survey (usually disaggregate) data. Although the factors considered differ from study to study, they are usually a sub-set of the following: commodity attributes such as commodity type, value and bulkiness; shipment attributes such as shipment lot size and distance to be shipped; shipper attributes such as regular or occasional user, size of shipper's total operation and location of shipper; service attributes such as rates, travel time, reliability, etc.[9]

Church [1967, 1971] investigated the relationships between truck share and such variables as shipment lot size, distance shipped and commodity type using the 1963 Commodity Transportation Survey data. Buhl [1967] studied the relationships between the truck share and such variables as the number of employees and the SIC (Standard Industrial Classification of Commodities) category. The Economist Intelligence Unit [1967] conducted a survey of shippers in the Canadian Atlantic provinces, and from the data, they identified six important service attributes: speed, completeness of service, regularity, frequency, availability of equipment, size of the unit of service, and safety of shipments. Saleh and LaLonde [1972] presented a detailed process for selecting a motor carrier using the data obtained from interviewing shippers and mail questionnaires. Using waybill samples, Morton [1971] found that considerable variability exists in rates and market shares of truck and rail modes which cannot be explained by weight and mileage blocks alone. Evans and Southard [1974] conducted a motor carrier poll to determine the relative importance of 28 detailed quality attributes of service. They also presented an interesting comparison between the perceptions of buyers and sellers of motor carrier services. These are only a small fraction of the numerous studies which attempted to identify the factors influencing mode selection. Tertiev et al. [1975] presented in a non-empirical paper a detailed list of all service, commodity, market and shipper attributes that may influence mode choice, and subsequently recommended to use multi-nomial logit model which includes all these variables. Although the descriptive research such as those mentioned above is a necessary first step toward a more rigorous study, it provides only partial information on the nature of the demand.

(ii) <u>Mode-Choice probability studies</u>:

Many studies have estimated the models for predicting conditional probabilities of choosing various modes. Discriminant analysis and logit analysis are the two major techniques for estimating the mode-choice probabilities. "Probit" models are also used from time to time. Although the variables included in the model differ from study to study, virtually all previous studies have used a subset of service, shipment and shipper attributes.

Following Warner's application of discriminant analysis to a passenger mode-split problem in Chicago [1962] and the subsequent work by the Traffic Research Corporation of Toronto [1965], discriminant analysis has been increasingly applied to both passenger and freight mode-choice studies. Examples of passenger mode-choice area are Quamby [1967], McGillivary [1970] and the Transportation Development Agency [1976], whereas Miklius [1979], Antle and Haynes [1971], Bayliss [1973], Hartwig and Linton [1974], and Turner [1975] are those of freight mode-choice area.

Charles River Associates [1972] and McFadden [1972] may be considered as among the earliest attempts to apply logit model to passenger mode-choice probability study. Since then, the logit model has become an increasingly popular tool for freight as well as passenger mode-choice studies. For example, Kullman [1973], Hartwig and Linton [1974], Turner [1975], Boyer [1977] and Levin [1978] applied a logit model to predict freight mode-choice.

The "probit" model has been less popular than the other two models because a logit model is far easier and less costly to estimate than a probit model. Note that the logit model approximates quite closely the cumulative normal probability function which a probit model attempts to estimate. (See Berkson [1944, 1951] for more details.) Hartwig and Linton [1974] applied a probit model as well as logit and discriminant analysis models to a freight mode-choice problem.

In what follows several of the studies cited above are selectively described. The emphasis is placed on the form of data used and the variables included in the model rather than on their specific results. Antle and Haynes [1971] used several independent variables in their discriminant function to characterize each mode-choice decision; these variables are annual tonnage shipped, distance, average travel time by the chosen mode, average shipment size, freight rate of the chosen mode, freight rate of the competing mode, and the handling cost of the chosen mode.

As mentioned already, Hartwig and Linton [1974] used logit, probit and discriminant analysis to model the individual shipper's mode-choice between full load truck and full load rail using the information obtained from 1213 waybills for full load truck and rail shipments of consumer durables. Their model used the difference in truck and rail transit times, the difference in truck and rail freight charges, the difference in standard deviation of the transit time distribution between truck and rail and the value of the commodity as the independent variables.

Kullman [1973] estimated a binomial logit model to predict the rail-truck modal split using aggregate data for specific city pairs obtained from the 1967 Census of Transportation and from certain carriers. He used differences in freight rate, transit-time, and reliability of transit time between rail and truck modes, distance, annual volume, and value per ton of commodity as the independent variables in his logit model.

Turner [1975] undertook a major study on freight mode selection which seems the most extensive of its kind among the Canadian studies. It seems worthwhile to describe his models briefly here because basically the same data set that he used is to be used for this thesis. Using the 1970 Canadian inter-regional freight transportation data, which is to be described in chapter IV, he estimated a regression model, a discriminant function and a logit model for each of the selected 13 commodity groups. His regression models of modal shares (rail, truck and ship) were formulated as a linear function[10] of the relative mode attributes (relative to the three-mode average) such as the price ratio, the transit time ratio, the ratio of the standard deviations of transit time distributions, the ratio of skewnesses of transit time distributions, and of shipment attributes such as distance and weight. Although the validity of using some variables (especially using both variability and skewness of the transit time distribution) is questionable, more critical problems with his regression model seem to be the following:

1. The shares of modes were not constrained to add up to one.

2. Although cross-equation covariances are not likely to be zero in most share models, he did not take these into account by using univariate regression. Therefore, the estimated test statistics including t and F statistics are likely to be biased.

3. He also reported the share equations estimated from the pooled share data of all modes. Although, in these cases, he added mode dummy variables, the estimation of a common share equation is hardly justified.

The regression models were estimated from the data corresponding to the shared origin-destination (O-D) pairs, on which at least two modes shared the traffic. From the same shared O-D data, Turner also estimated binomial logit models of rail-truck competition using the same independent variables that were used in his regression models. Using the data corresponding to the monopoly O-D's where all traffic was monopolized by a single mode, Turner estimated discriminant analysis models as functions of distance, weight, and service attributes of the mode used such as freight rate, transit time, and standard deviation and skewness of transit time distribution. Except for the usage of link aggregate data (which he claimed was necessary because of otherwise insurmountable computational cost), the discriminant analysis was well conducted.

Overall, although there were several technical or theoretical flaws in the regression and logit models estimated in his study, Turner achieved a very important step toward a better freight mode selection study by identifying the various mode-choice factors considered by shippers of various commodities.

All mode-choice models such as discriminant analysis, logit and probit models intend to estimate the conditional probabilities of choosing various modes with given values of variables included in the model. Of course, the model can be used for statistical tests of whether or not a specific factor affects the mode choice probabilities significantly. However, several recent studies including Boyer [1977] and Levin [1978] have used the logit model to estimate price sensitivity of modal demands as if it were a demand model. As described in footnote 3 of chapter I, the usage of logit model as a demand model imposes unrealistic restrictions[11] on elasticities of inter-modal substitution and thus elasticities of demand with respect to price and quality of service variables (see Oum [1978] for a detailed derivation of the restrictions imposed by various forms of logit models.) Since the logistic function (the probability function that a logit model tries to estimate) gives a close approximation to the cumulative normal probability function, this restriction also carries over to "probit" model. Furthermore, since Quamby [1967] in his appendix A has derived the binomial logit as a scalar multiple of the score of the discriminant function, this restriction is likely to carry over to discriminant analysis as well. In conclusion, all the mode-choice models which intend to estimate the conditional probabilities of using various modes (logit, probit and discriminant analysis) are not recommended for measuring price and quality responsiveness of demand.

(B) Description of Methodology Adopted for this Thesis

In the preceding section, the approaches taken in previous demand studies were grouped into six categories. For each category, the advantages and disadvantages were explained. None of the six approaches was considered satisfactory for studying the nature of demand functions. All the disadvantages mentioned in the previous section would disappear should a demand model satisfy the following three conditions:

1. The model includes both price and quality variables of all competing modes so that the price and quality responsiveness of demand can be measured,

2. The functional form of the demand model allows for free variation of elasticities of substitution, and

3. The demand model is a derived one so that the structure of the shipper's distribution sectoral technology can be inferred directly from the knowledge of demand functions.

The derived demand models used in Oum [1977] and in Friedlaender and Spady [1977] satisfy conditions 2 and 3 but do not meet condition 1 because of the absence of quality attributes of service in the model. However, the abstract mode approach provides us with some intuitive rationale for including various quality attributes of service in the derived models as well. Therefore, the approach taken in this thesis may be regarded as combining the abstract-mode concept with the derived demand modelling approach. As will be seen later, the resultant demand model includes the quality attributes of service as well as price variables, and is derived from the shipper's distribution technology consistently with the economic theory of mode-choice. The method of deriving the model is sketched as follows.

On each link, a shipper is assumed to purchase physical ton-miles associated with certain quality attributes of service of his choice. It is further assumed that he makes the choices as to the amounts of ton-miles and associated quality attributes of service to purchase so that his total cost of production and distribution is minimized while satisfying the constraints on the required amounts of his products to be delivered to various market places. As is shown in chapter III, this allows a shipper's total cost of production and distribution to be defined as a function of his output level, the freight rates and quality attributes of services of alternative modes on all links, and the prices of other factors of production.

By imposing some restrictions on the shipper's production and distribution technology and by applying the results of duality and separability studies, the shipper's transportation-sectoral-cost function on each link is derived to be a function of freight rates and quality attributes of alternative modes, and the distance of the link. At this stage, it is assumed with some theoretical justification that the transportation-sectoral-cost function is identical across all shippers of the same commodity on a link. This allows the cost function to be estimated from the data aggregated over shippers of the same commodity on each link.

Four alternative forms of the shipper's cost function are hypothesized and tested, including one which is equivalent to the hedonic price hypothesis. The translog function is chosen to specify these cost functions, and the revenue share of each mode is derived as a function of freight rates and the quality attributes of all modes and the distance of the link. Each set of cost and two modal revenue share functions[12] (rail and truck modes) is estimated simultaneously from the data on Canadian inter-regional freight flows during the year 1970, for each of the eight selected commodity groups. For each commodity group, the elasticity of substitution between the two modes and elasticities of the modal demands with respect to freight rates and quality attributes of service (speed and reliability) are computed for some selected links.

Footnotes for Chapter II:

1. Throughout this thesis, the term "service attributes" refers to the freight rate and the "quality attributes" of service such as speed (or transit time), reliability of speed (or variability of transit-time distribution), convenience and flexibility of service, etc.

2. The imputed cost of waiting time is higher than that of travel time mainly because the inventory holding cost is incurred while waiting at the origin of the cargo whereas it does not occur while in transit.

3. Throughout this thesis the term "Cobb-Douglas-like" function refers to the Cobb-Douglas demand model without the condition of homogeneous of degree zero in prices imposed.

4. "Translog" functions belong to a family of "flexible" functions that can be used to give a second order Taylor series approximation to any functional form. For more details on "flexible" functions, see, for example, Diewert [1971], Hall [1973], Christensen et al. [1973] and Denny [1974].

5. The term "gravity-type model" is used here in order to distinguish it from true gravity models which are being widely used in urban passenger transportation studies and which require "attraction balancing" iteration and "calibration" iteration.

6. Throughout this thesis, the term "link" refers to a specific freight market (or route) linking an origin region to a destination region.

7. See the discussion in "normative approach based on user optimization" for an explanation of the concept of abstract-mode.

8. "Non-best" modes are all modes other than the least time mode using travel time criterion but are all modes other than the least time mode using travel cost criterion.

9. See Tertiev et al. [1975] for a detailed list of factors which are likely to influence mode-choice.

10. Turner reported that he also tried to use a Cobb-Douglas-like regression model.

11. This restriction could have introduced some bias in the calculation of welfare loss by Boyer [1977] and Levin [1978] which they claimed is due to the traffic misallocation caused by the I.C.C. minimum rate regulation.

12. Due to the singularity of the two share equations, only one revenue share function is actually estimated together with the cost function.

CHAPTER III

MODEL FORMULATION

The plan for this chapter is as follows: a general form of shipper's transportation-sectoral-cost function that appropriately characterizes the structure of the shipper's transportation-sectoral-technology is derived in relation to a firm's overall optimization of production and distribution activities. Some plausible restrictions are then imposed on the general structure to generate three alternative forms of the transportation-sectoral-cost function. Each form of the cost function is specified in a translog form for the case of two-mode (rail and truck) competition, and the corresponding demand functions of the two modes are derived.

In modelling the demand for freight transportation, it is important to realize that transportation is used as a factor of production. Therefore, the demand model should be derived from the shipper's underlying production or cost function. There are two distinct methods of deriving such an input demand model. One method would be to postulate a functional form for the production function satisfying certain regularity conditions[1] and then solve an output-constrained cost minimization problem for the derived input demands. The other method would be to postulate a differentiable functional form for the shippers' cost function again satisfying the regularity conditions, and obtain the derived input demands by applying Shephard's lemma [Shephard, 1953, p. 11]. The difficulty with the first method is that if the production function is specified in a 'flexible[2] functional form', it is in general impossible to obtain the derived demand functions as explicit functions of the "unknown" parameters of the production function. As will be explained later in this chapter, the usage of a 'flexible' functional form is essential for studying inter-modal competition. Thus, the latter method of deriving demand models will be used in this thesis. The method is based on the duality relation that exists between production and cost functions, a result established originally by Shephard [1953] and Samuelson [1953-4] and refined by Uzawa [1964], McFadden [1966, 1970], Shephard [1970], Diewert [1971, 1974] and Blackorby-Primont-Russell [1978]. Duality theory implies that if producers minimize input costs of producing given outputs, and if competition prevails in factor markets, then the cost function satisfying the usual regularity conditions[3] contains sufficient information to describe completely the corresponding production technology, and vice versa. Thus, rather than specifying a functional form for the production function and deriving the input demand functions therefrom (as in the first method for deriving input demands), one can specify a cost function directly and then apply Shephard's lemma to obtain the input demands.

Since our primary objective is to derive the demand model for freight transportation rather than for all inputs of production and distribution, our interest lies primarily in examining the structure of the shipper's technology for the transportation sector of his total activities (called hereafter as transportation-sectoral-technology).

(A) Derivation of the General Model (Model A)

To derive a demand model for freight transportation, it is essential to look into how shippers value various characteristics of service[4] and how these characteristics serve shippers in achieving their objectives. Since industrial or commercial shippers are major users of freight services, freight transportation services can be considered as an intermediate input to shippers' production and distribution activities. Then it is reasonable to say that a shipper maximizes his profit by using the optimal combination of inputs and at the same time by producing the optimal amount of output. By the same token, a shipper is also motivated to use optimal combinations of various modes of freight services, the characteristics of which differ from one mode to another and from one link to another. Therefore, a shipper's demand for a mode of freight service depends upon the levels of characteristics built into the service and the relative contributions of these characteristics to the shipper's production and distribution activities. A shipper's demand for each mode of freight service can then be derived from the shipper's production and distribution technology by maximizing profit. Alternatively, for a given requirement for shipper's output in various geographical locations, the demands can be derived equally well by minimizing the total cost of production and distribution. Of course, the shipper's total demand for freight service can be obtained by summing the demands of all modes.

To maintain the generality of the discussion, it is assumed throughout this chapter, unless mentioned otherwise, that:

(i) The number of modes competing on each link is M,

(ii) The quality of a service can be completely described by N dimensions, and

(iii) A shipper's distribution network is composed of L links.

In order for a model to be estimated, it should be expressed in terms of only the variables for which data are available. Therefore, it is essential to consider the kinds and form of the available data before formulating the model. As will be explained in chapter IV, only the following data aggregated by each link (directed route) were available for this thesis:

1. Yearly traffic volume (in tons) of each mode for each commodity group,
2. Average freight rate (per ton) of each commodity group charged by each mode,
3. Average transit time and its variability of each mode, and
4. Distance of the link.

Therefore, the objective of this section is to derive a link-specific unit transport cost function for shippers of a particular commodity group, as a function only of freight rates and quality attributes of services of various modes and the distance of the link. Since the demand for freight transportation service is generated as a result of individual shipper's optimization of the production and distribution activities, the primary task here is to identify the set of restrictions (required to be imposed on the shipper's macro production function and/or cost function) which will allow us to express the link-specific unit transport cost function in terms of only the available data mentioned in the above.

The cost function for a shipper's entire production and distribution activities can be defined as:

$$(3,1) \qquad C(Y,P^C,P^T,Z) \equiv \min_{\substack{\text{w.r.t.} \\ X^C, X^T}} \left\{ \sum_{i=1}^{I} P_i^C X_i^C + \sum_{\ell=1}^{L} \left(\sum_{m=1}^{M} P_{m\ell} \cdot X_{m\ell} \right) \right\}$$

subject to the following production technology,

$$(3,2) \qquad f(X^C,X^T,Z) \geq Y$$

where

Y = shipper's total output that needs to be delivered to various destination markets,

P^C = $[P_1^C, P_2^C, \ldots, P_I^C]$ where P_i^C = the price of ith input other than transportation service, $i=1,2,\ldots,I$,

P^T = $[P_{m\ell}]$ a matrix of order MxL representing the freight rates of M modes on L links; i.e.,

$P_{m\ell}$ = mth mode's freight rate per ton-mile on link ℓ, $m=1,2,\ldots,M$, $\ell=1,2,\ldots,L$.

X^C = production factors other than transportation service such as labour (L) and capital (K),

X^T = $[X_{m\ell}]$ a matrix of order MxL representing quantities of M modes used on L links; i.e., $X_{m\ell}$ = ton-miles shipped by mode m on link ℓ, $m=1,2,\ldots,M$, $\ell=1,2,\ldots,L$.

Z = $[Z_1, Z_2, \ldots, Z_\ell, \ldots, Z_L]$ where each element of Z is a matrix of order MxN representing the amounts of N quality attributes of M modes on a particular link; i.e., for link ℓ, $Z_\ell = [z_{mn\ell}]$ and $z_{mn\ell}$ = nth quality attribute of mode m on link ℓ, m=1,2,...,M n=1,2,...,N.

In order to be able to write the link-specific unit transport cost function as a function only of the prices and quality attributes of various modes serving the link, the following restrictions are required to be imposed on the (macro) cost function (3,1).

1. The cost function $C(Y, P^C, P^T, Z)$ is *completely strictly separable* in link-wise partition of the transport-related variables $\{(P_1, Z_1), (P_2, Z_2), \ldots, (P_\ell, Z_\ell), \ldots, (P_L, Z_L)\}$.

2. The cost function C is *positively linearly homogeneous* (PLH) in output Y.

3. The cost function C is differentiable and strictly positively monotonic in (Y, P^C, P^T, Z), and PLH and concave in (P^C, P^T).

Then, Theorem 4.8 (p. 136), Corollary 4.8.4 (p. 142), Theorem 4.9 (p. 143) and Corollary 4.9.4 (p. 156) of Blackorby-Primont-Russell [1978] allow cost function C to be re-written as:

$$(3,3) \qquad C = Y \cdot \overline{C}(P^C, C^T(\sum_{\ell=1}^{L} C^\ell(P_\ell, Z_\ell)))$$

$$= Y \cdot \overline{C}(P^C, (\sum_{\ell=1}^{L} \{\hat{C}^\ell(P_\ell, Z_\ell)\}^\rho)^{\frac{1}{\rho}})$$

$$0 \neq \rho \leq 1$$

where

$\overline{C}$ is an increasing function of its arguments, and each $\hat{C}^\ell(\cdot)$ is differentiable, strictly positively monotonic, PLH and concave in P_ℓ.

Therefore, the link-specific unit transport cost function, say for link $\underline{\ell}$, can be written independently of the output level (Y) and the prices of other inputs (P^C) as the following:

$$(3,4) \qquad UC_\ell = \tilde{C}^\ell(P_\ell, Z_\ell) \qquad \ell=1,2,\ldots,L$$

where

UC_ℓ ; unit transport cost per ton on link $\underline{\ell}$.

In interpreting the meaning of the restrictions, it is sometimes easier to work with a production function rather than cost function. Applying theorem 4.12 of Blackorby-Primont-Russell [1978, p. 157], it is obvious that in order for cost function C to satisfy restrictions 1 and 2 listed above, its dual production function f(·) in equation (3,2) must satisfy the following restrictions: PLH in (X^C, X^T, Z), *complete strict separability* in link-wise partition of transport-related variables $\{(X_1,Z_1),(X_2,Z_2),\ldots,(X_\ell,Z_\ell),\ldots,(X_L,Z_L)\}$, positive monotonicity and quasi-concavity in (X^C,X^T), and differentiability in all variables. By theorem 4.8 of Blackorby-Primont-Russell [1978, p. 152], the production function f(·) can be re-written as follows:

$$(3,5) \qquad f(X^C,X^T,Z) = \bar{f}\ (X^C,\ (\sum_{\ell=1}^{L} f^\ell(X_\ell;Z_\ell)^\rho)^{\frac{1}{\rho}}) \qquad 0 \neq \rho \leq 1$$

where

$\bar{f}$ is an increasing function in its second argument, and each $f^\ell(\cdot)$ is differentiable, positive monotonic, quasi-concave and PLH in X_ℓ.

Among the restrictions imposed on the production function f(·), the following items have empirically important implications that deserve special attention.

1. Positive linear homogeneity of f in (X^C, X^T, Z): This implies that a shipper's production technology is characterized by constant returns to scale in both amounts (X^T) and qualities (Z) of transportation services and in other inputs (X^C) such as labour and capital; i.e., a proportionally identical increase in all inputs (X^C, X^T, Z) will result in an increase in output (Y) by the same proportion. Note that homotheticity of the production function is implied by PLH of f(·).

2. *Complete strict separability* of the transport-related variables (X^T, Z) from other inputs (X^C): This means that every union of link-transport sectors is strictly separable from all variables in the remaining link-transport sectors and non-transport inputs. This implies that each link-specific transportation technology is unaffected by the transportation activity levels of all other links and the amounts of non-transport inputs used in the production. Note that this *complete strict separability* implies strict separability of (X^T, Z) from X^C in the production function f(·).

The two assumptions together imply that a shipper changes the amount of his product transported by each mode on each link in exactly the same proportion as the change in his total output if prices and quality attributes of all modes on all links remain unchanged. This may well be an unrealistic assumption. However, in all the transport demand models estimated to date using data aggregated by each route, exactly the same set of assumptions as made in this thesis have been imposed without mentioning them explicitly. Whether or not these assumptions are valid is an empirical question which cannot be tested here due to lack of necessary data.

Turning our attention to equation (3,4), it should be noticed that the link unit transportation cost function $\tilde{C}^{\ell}(\cdot)$ could be estimated from any time series data of an individual firm's unit cost of transportation (UC_{ℓ}), prices (P_{ℓ}) and quality attributes of service (Z_{ℓ}) of various modes on link $\underline{\ell}$. Since cross-sectional data are to be used in this thesis, it is essential to make the functional form of the unit cost function independent of the link index $\underline{\ell}$. If a shipper's choice criterion in the price-quality attributes space is consistent from link to link, it would be possible to write the unit cost function (3,4) without the subscript $\underline{\ell}$. However, the choice behaviour is likely to depend on the distance of link (D_{ℓ}) because the imputed costs of quality attributes of service, such as transit time and its variability, are likely to depend on distance due to their implications on inventory management cost.[5] The only way to handle this problem is to parameterize the difference in the cost function by including the distance variable (D_{ℓ}) as an argument of the cost function as in (3,6):

$$(3,6) \qquad UC_{\ell} = \hat{C}(P_{\ell}, Z_{\ell}, D_{\ell}) \qquad \ell=1,2,\ldots,L$$

where

UC_{ℓ} = unit cost per *ton* moving on link $\underline{\ell}$.

For convenience of interpretation of empirical results, both sides of equation (3,6) are divided through by distance of the link (D_{ℓ}) so that the image of the new function becomes "unit cost per ton-mile" as follows:

(3,7) $\overline{UC}_\ell = \hat{\hat{C}}(P_\ell, Z_\ell, D_\ell)$

where

$\overline{UC}_\ell$ = unit cost per ton-mile,

P_ℓ = Mx1 vector of prices of M modes on link $\underline{\ell}$,

Z_ℓ = MxN matrix of quality attributes of service of M modes on link $\underline{\ell}$,

D_ℓ = distance of link $\underline{\ell}$ in miles.

This link unit cost model in (3,7) is referred to as the "general model (Model A)" throughout this thesis. Several alternative models will be hypothesized later in this chapter by imposing various restrictions on this general model.

Since the functional form of the link unit cost function (3,7) is independent of the link index $\ell=1,2,\ldots,L$, it can be estimated from cross-sectional data of shipments on $\underline{L}$ different links. Furthermore, the type of analysis presented by Baumol and Vinod [1970] justifies using the same unit cost function for all shippers of a commodity and across all links. Using inventory analysis, they treated quality attributes of freight service, such as transit time and its reliability as the major determinants of safety stock requirements. They concluded that shippers would use a mixture of transport modes whose price-attribute combination renders the minimum total cost of inventory and transportation. Since the key parameters of an inventory model are commodity attributes such as value of the commodity, cost of storage and inventory holding cost, for a given commodity the relative valuation of various service attributes is likely to be similar across shippers on a given link and across cross-sectional links. This implies that the link unit cost function, (3,7), can be estimated from cross-sectional link data, each of which is aggregated over all shippers on that link.

For the purpose of estimation, the cost function (3,7) is postulated in a specific functional form. For the study of inter-modal substitutibility, the functional form should allow for free variation of Allen partial elasticities of substitution (APES) and be sufficiently 'flexible' to provide a valid second order approximation to an arbitrary differentiable function. In recent years, there has been considerable work developing so-called 'flexible' functions which satisfy these properties. The generalized Leontief function[6] [Diewert, 1971], the quadratic mean of order-r function [Denny, 1972 & 1974], the translog function [Christensen et al., 1971 & 1973] and the generalized Cobb-Douglas function [Diewert, 1973] belong to the family of flexible functions. The translog function was chosen to be used throughout this thesis since it generates the system of cost and demand functions that are the most convenient to estimate using the algorithm developed by Berndt-Hall-Hall-Hausman [1974].

To specify the unit cost functions in translog form, it is necessary to decide which modes and what kind of quality variables are to be included in the empirical estimation. As will be seen in chapter IV, data on quality attributes were severely limited and the accuracy of the available data could be disputed in many aspects. Nevertheless, it was possible to obtain the data on link-specific average freight rates per ton-mile, link-specific average transit times in days and link-specific variability of transit times for both railway and highway (truck) modes. It was also possible to obtain link specific total ton-miles carried by each mode and the distance of each link in miles. In order to follow the convention of defining quality attributes such that, *ceteris paribus*, more of an attribute is preferred to less, average transit time and variability of transit time were used to generate 'average speed in miles per day' and 'reliability of transit time' (reciprocal of the coefficient of variation in the transit-time distribution). Due to data limitations, therefore, the empirical implementation is limited to the case of two modes (railway and highway modes) and two quality attributes.

With the Hicks-Samuelson symmetry condition imposed, the translog function corresponding to the link unit cost function (3,7) can be written as:

(3,8) $$\ln C(P_\ell, Z_\ell, D_\ell)$$

$$\equiv \ln\alpha_o + \alpha^t \cdot V + \frac{1}{2} V^t \cdot S \cdot V$$

$$= \ln\alpha_o + [a^t, b^t, c^t, d] \begin{bmatrix} \ln P_\ell \\ \ln Z_{1\ell} \\ \ln Z_{2\ell} \\ \ln D_\ell \end{bmatrix}$$

$$+ \frac{1}{2} [(\ln P_\ell)^t, (\ln Z_{1\ell})^t, (\ln Z_{2\ell})^t, \ln D_\ell] \begin{bmatrix} A & E & F & g \\ E^t & B & G & h \\ F^t & G^t & C & i \\ g^t & h^t & i^t & dd \end{bmatrix} \begin{bmatrix} \ln P_\ell \\ \ln Z_{1\ell} \\ \ln Z_{2\ell} \\ \ln D_\ell \end{bmatrix}$$

where

(i) V = 7x1 vector of variables which is, for convenience, partitioned into four components as follows:

$$V \equiv [\ln P_\ell, \ln Z_{1\ell}, \ln Z_{2\ell}, \ln D_\ell]^t$$

$\ln P_\ell \equiv [\ln P_{r\ell}, \ln P_{h\ell}]^t$; 2x1 vector of logarithms of rail ($P_{r\ell}$) and truck ($P_{h\ell}$) freight rates on link $\underline{\ell}$,

$\ln Z_{1\ell} \equiv [\ln Z_{r1\ell}, \ln Z_{h1\ell}]^t$; 2x1 vector of logarithms of rail ($Z_{r1\ell}$) and truck ($Z_{h1\ell}$) speed on link $\underline{\ell}$,

$\ln Z_{2\ell} \equiv [\ln Z_{r2\ell}, \ln Z_{h2\ell}]^t$; 2x1 vector of logarithms of rail ($Z_{r2\ell}$) and truck ($Z_{h2\ell}$) reliability of speed on link $\underline{\ell}$,

D_ℓ = distance of link $\underline{\ell}$ in miles.

(ii) α = 7x1 vector of first order parameters of translog cost function which is partitioned into four components:

$\alpha \equiv [a,b,c,d]^t$

$a = [a_r, a_h]^t$; 2x1 vector of first order parameters corresponding to price vector (P),

$b = [b_r, b_h]^t$; 2x1 vector of first order parameters corresponding to speed vector (Z_1),

$c = [c_r, c_h]^t$; 2x1 vector of first order parameters corresponding to reliability vector (Z_2),

d = the first order parameter corresponding to distance (D).

(iii) S = 7x7 symmetric matrix of second-order parameters of translog cost function which is partitioned into 16 components as follows:

$$S \equiv \begin{bmatrix} A & E & F & g \\ E^t & B & G & h \\ F^t & G^t & C & i \\ g^t & h^t & i^t & dd \end{bmatrix}$$

$$A \equiv \begin{bmatrix} a_{rr} & a_{rh} \\ a_{rh} & a_{hh} \end{bmatrix}$$; corresponding to the price variables

$B \equiv \begin{bmatrix} b_{rr} & b_{rh} \\ b_{rh} & b_{hh} \end{bmatrix}$; corresponding to the speed variables

$C \equiv \begin{bmatrix} c_{rr} & c_{rh} \\ c_{rh} & c_{hh} \end{bmatrix}$; corresponding to the reliability variables

$E \equiv \begin{bmatrix} ab_{rr} & ab_{rh} \\ ab_{hr} & ab_{hh} \end{bmatrix}$; corresponding to the products of price and speed variables

$F \equiv \begin{bmatrix} ac_{rr} & ac_{rh} \\ ac_{hr} & ac_{hh} \end{bmatrix}$; corresponding to the products of price and reliability variables

$G \equiv \begin{bmatrix} bc_{rr} & bc_{rh} \\ bc_{hr} & bc_{hh} \end{bmatrix}$; corresponding to the products of speed and reliability variables

$g \equiv [ad_r, ad_h]^t$; corresponding to the products of price and distance variables

$h \equiv [bd_r, bd_h]^t$; corresponding to the products of speed and distance variables

$i \equiv [cd_r, cd_h]^t$; corresponding to the products of reliability and distance variables

dd = the second order parameter corresponding to distance variable.

Although the Hick-Samuelson symmetry conditions were already imposed in the translog cost function (3,8), the linear homogeneity conditions of the cost function with respect to freight rates are yet to be imposed. The derivation in Appendix 3A shows that the linear homogeneity conditions impose the following restrictions on the parameters of the translog cost function (3,8):

(3,9) (a) $a_r + a_h = 1$

(b) $a_{rr} + a_{rh} = 0, \ a_{rh} + a_{hh} = 0$

implying $a_{rr} = -a_{rh} = a_{hh}$

(c) $ab_{rr} + ab_{hr} = 0, \ ab_{rh} + ab_{hh} = 0$

(d) $ac_{rr} + ac_{hr} = 0, \ ac_{rh} + ac_{hh} = 0$

(e) $ad_r + ad_h = 0$

The imposition of these linear homogeneity conditions to equations (3,8) gives:

$$(3,10a)\quad \ln C(P_\ell, Z_\ell, D_\ell) = \ln a_o + a_r \ln(\frac{P_{r\ell}}{P_{h\ell}}) + \ln P_{h\ell} + b_r \ln Z_{r1\ell}$$

$$+ b_h \ln Z_{h1\ell} + c_r \ln Z_{r2\ell} + c_h \ln Z_{h2\ell} + d \ln D_\ell$$

$$+ \tfrac{1}{2} a_{rr} [\ln(\frac{P_{r\ell}}{P_{h\ell}})]^2 + \tfrac{1}{2} b_{rr} (\ln Z_{r1\ell})^2 + \tfrac{1}{2} b_{hh} (\ln Z_{h1\ell})^2$$

$$+ b_{rh} \ln Z_{r1\ell} \ln Z_{h1\ell} + \tfrac{1}{2} c_{rr} (\ln Z_{r2\ell})^2 + \tfrac{1}{2} c_{hh} (\ln Z_{h2\ell})^2$$

$$+ c_{rh} \ln Z_{r2\ell} Z_{h2\ell} + \tfrac{1}{2} dd (\ln D_\ell)^2 + ab_{rr} \ln Z_{r1\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}})$$

$$+ ab_{rh} \ln Z_{h1\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}}) + ac_{rr} \ln Z_{r2\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}})$$

$$+ ac_{rh} \ln Z_{h2\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}}) + bc_{rr} \ln Z_{r1\ell} \ln Z_{r2\ell}$$

$$+ bc_{hr} \ln Z_{h1\ell} \ln Z_{r2\ell} + bc_{rh} \ln Z_{r1\ell} \ln Z_{h2\ell} + bc_{hh} \ln Z_{h1\ell} \ln Z_{h2\ell}$$

$$+ ad_r \ln D_\ell \ln(\frac{P_{r\ell}}{P_{h\ell}}) + bd_r \ln Z_{r1\ell} \ln D_\ell + bd_h \ln Z_{h1\ell} \ln D_\ell$$

$$+ cd_r \ln Z_{r2\ell} \ln D_\ell + cd_h \ln Z_{h2\ell} \ln D_\ell$$

The demand functions for the two modes can be derived by applying Shephard's lemma to the cost function (3,10a) as follows:

$$X_{r\ell} = \frac{\partial C(\cdot)}{\partial P_{r\ell}} = \frac{C(\cdot)}{P_{r\ell}} \frac{\partial \ln C(\cdot)}{\partial \ln P_{r\ell}}$$

$$= \frac{C(\cdot)}{P_{r\ell}} [a_r + a_{rr} \ln (\frac{P_{r\ell}}{P_{h\ell}}) + ab_{rr} \ln Z_{r1\ell} + ab_{rh} \ln Z_{h1\ell}$$

$$+ ac_{rr} \ln Z_{r2\ell} + ac_{rh} \ln Z_{h2\ell} + ad_r \ln D_\ell]$$

$$X_{h\ell} = \frac{C(\cdot)}{P_{h\ell}} [(1-a_r) - a_{rr} \ln(\frac{P_{r\ell}}{P_{h\ell}}) - ab_{rr} \ln Z_{r1\ell} - ab_{rh} \ln Z_{h1\ell}$$

$$- ac_{rr} \ln Z_{r2\ell} - ac_{rh} \ln Z_{h2\ell} - ad_r \ln D_\ell] .$$

Therefore, the share of expenditure on rail and truck modes are:

$$\text{(3,10b)} \quad S_{r\ell} = a_r + a_{rr} \ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + ab_{rr} \ln Z_{r1\ell} + ab_{rh} \ln Z_{h1\ell} + ac_{rr} \ln Z_{r2\ell} + ac_{rh} \ln Z_{h2\ell} + ad_r \ln D_\ell$$

$$\text{(3,10c)} \quad S_{h\ell} = (1-a_r) - a_{rr} \ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) - ab_{rr} \ln Z_{r1\ell} - ab_{rh} \ln Z_{h1\ell} - ac_{rr} \ln Z_{r2\ell} - ac_{rh} \ln Z_{h2\ell} - ad_r \ln D_\ell$$

where S_r and S_h are shares of expenditures on rail and truck modes, respectively.

Since the system of these two share equations is singular, only the rail share equation $S_{r\ell}$ in (3,10b) is to be estimated together with the translog cost function (3,10a) using a nonlinear multivariate system estimator.[7] There are 28 unknown parameters to be estimated.

(B) The Model Strictly Independent of Distance (Model B)

It may be of interest to test whether the shipper's link transportation sectoral technology is *strictly independent* of the distance of the link; that is to say, whether shipper's choice behaviour in the price-quality space remains unchanged as the length of haul varies. In the context of production technology, this implies that the rate of technical substitution (or the ratio of marginal productivities) between any pair of elements in the vector $(X_{1\ell}, X_{2\ell}, \ldots, X_{M\ell}, Z_{11\ell}, Z_{12\ell}, \ldots, Z_{1N\ell}, Z_{21\ell}, Z_{22\ell}, \ldots, Z_{2N\ell}, \ldots, Z_{MN\ell})$ is invariant to the distance of link (D_ℓ). In the context of the cost function, this implies that the monetary values of various service attributes do not depend on the length of the link. Thus, the shipper's valuation of service attributes is exactly the same between short and long-haul links. This strict independence holds if and only if the link unit cost function can be written in a multiplicatively-decomposable form as in (3,11) [Theorem 3.15, Blackorby-Primont-Russel, 1978]:

$$(3,11) \qquad C(P_\ell, Z_\ell, D_\ell) \equiv h\,(D_\ell) \cdot \tilde{C}\,(P_\ell, Z_\ell)$$

The cost function (3,11) means that cost per ton-mile can be expressed as a product between a scale factor of distance and a function of prices and service attributes of all modes. If the scale factor $h(D_\ell)$ is specified as an exponential function and the function $\tilde{C}(\cdot)$ is a translog form, then in the two-mode context the link unit cost function can be written as:

$$(3,12) \quad \ln C(P_\ell, Z_\ell, D_\ell) \equiv d \ln D_\ell + \ln \tilde{C}(P_\ell, Z_{1\ell}, Z_{2\ell})$$

where $\ln \tilde{C}(P_\ell, Z_{1\ell}, Z_{2\ell})$ is obtained from equation (3,8) by setting the following parameters to zero:

$$g = [ad_r, ad_h]^t, \; h = [bd_r, bd_h]^t,$$
$$i = [cd_r, cd_h]^t, \; dd$$

Imposition of the linear homogeneity condition listed in (3,9) gives the following cost function and corresponding modal revenue share functions.

$$(3,13a) \quad \ln C(P_\ell, Z_\ell, D_\ell)$$

$$= d\ln D_\ell + \ln a_o + a_r \ln(\frac{P_{r\ell}}{P_{h\ell}}) + \ln P_{h\ell} + b_r \ln Z_{r1\ell} + b_h \ln Z_{h1\ell}$$
$$+ c_r \ln Z_{r2\ell} + c_h \ln Z_{h2\ell} + \tfrac{1}{2} a_{rr} [\ln(\frac{P_{r\ell}}{P_{h\ell}})]^2$$
$$+ \tfrac{1}{2} b_{rr} (\ln Z_{r1\ell})^2 + \tfrac{1}{2} b_{hh} (\ln Z_{h1\ell})^2 + b_{rh} \ln Z_{r1\ell} \ln Z_{h1\ell}$$
$$+ \tfrac{1}{2} c_{rr} (\ln Z_{r2\ell})^2 + \tfrac{1}{2} c_{hh} (\ln Z_{h2\ell})^2 + c_{rh} \ln Z_{r2\ell} \ln Z_{h2\ell}$$
$$+ ab_{rr} \ln Z_{r1\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}}) + ab_{rh} \ln Z_{h1\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}})$$
$$+ ac_{rr} \ln Z_{r2\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}}) + ac_{rh} \ln Z_{h2\ell} \ln(\frac{P_{r\ell}}{P_{h\ell}})$$
$$+ bc_{rr} \ln Z_{r1\ell} \ln Z_{r2\ell} + bc_{hr} \ln Z_{h1\ell} \ln Z_{r2\ell}$$
$$+ bc_{rh} \ln Z_{r1\ell} \ln Z_{h2\ell} + bc_{hh} \ln Z_{h1\ell} \ln Z_{h2\ell}$$

(3,13b) $$S_{r\ell} = a_r + a_{rr}\ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + ab_{rr}\ln Z_{r1\ell} + ab_{rh}\ln Z_{h1\ell} + ac_{rr}\ln Z_{r2\ell} + ac_{rh}\ln Z_{h2\ell}$$

(3,13c) $$S_{h\ell} = (1-a_r) - a_{rr}\ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) - ab_{rr}\ln Z_{r1\ell} - ab_{rh}\ln Z_{h1\ell} - ac_{rr}\ln Z_{r2\ell} - ac_{rh}\ln Z_{h2\ell}$$

The system of equations (3,13) is the same as that obtained from the system (3,10) by setting the parameters ad_r, bd_r, bd_h, cd_r, cd_h and dd to zero, and has 22 parameters to be estimated.

(C) <u>The Model with Mode-Specific Hedonic Aggregators (Model C)</u>

In the two models discussed so far, shippers are assumed to choose the levels of quality attributes of service for each mode as well as the amount of each mode to use: i.e., every quality variable as well as every quantity variable was treated as a choice variable. However, it may be plausible to hypothesize that shippers make decisions only about the quantities of various modes used by valuing each mode as a combined entity of price and quality variables. In this case, quality variables are no longer choice variables, but they still affect mode-choice indirectly through their imputed prices. Under this hypothesis, the link unit cost function can be written as:

$$(3,14)\qquad C(P_\ell, Z_\ell, D_\ell) \equiv \tilde{C}\left[C^1(P_{1\ell}, Z_{11\ell}, \ldots, Z_{1N\ell}, D_\ell), \ldots, C^M(P_{M\ell}, Z_{M1\ell}, \ldots, Z_{MN\ell}, D_\ell)\right]$$

The structure of this cost function is particularly interesting because it has M symmetrically separable modal aggregators, one for each mode, as its arguments. Each modal aggregator is defined as a function of price and the quality attributes of the mode and the distance of the link, which is why it is called here a "hedonic" aggregator.[8] If hedonic aggregators exist, shippers would base their mode-choice decision on prices adjusted for quality variations. Then, the hedonic aggregator of a mode may be regarded as the quality-adjusted price function for the particular mode.

Blackorby-Primont-Russel [1977] have shown that in order for a (macro) translog function to have non-additively separable micro-aggregators, the micro-aggregators nested in the macro translog function are linearly logarithmic. Since, among others, our objective is to study inter-modal competition, an additively separable cost function is of no interest. Therefore, in the two-mode context, the translog specification of cost function (3,14) restricts the two hedonic aggregators $C^r(\cdot)$ and $C^h(\cdot)$ to be of linear logarithmic form as in (3,15). Moreover, the linear homogeneity of each hedonic aggregator with respect to its freight rate restricts the exponent of the price variable to unity. Therefore, the translog specification of the cost function (3,14) becomes:

$$(3,15) \quad ln C[P_\ell, Z_\ell, D_\ell] = ln\tilde{C}[C^r(P_{r\ell}, Z_{r1\ell}, Z_{r2\ell}, D_\ell), \; C^h(P_{h\ell}, Z_{h1\ell}, Z_{h2\ell}, D_\ell)$$

$$= ln a_o + a_r ln(P_{r\ell} Z_{r1\ell}^{\beta_r} Z_{r2\ell}^{\gamma_r} D_\ell^{\delta_r}) + a_h ln(P_{h\ell} Z_{h1\ell}^{\beta_h} Z_{h2\ell}^{\gamma_h} D_\ell^{\delta_h})$$

$$+ \tfrac{1}{2} a_{rr} [ln(P_{r\ell} Z_{r1\ell}^{\beta_r} Z_{r2\ell}^{\gamma_r} D_\ell^{\delta_r})]^2 + \tfrac{1}{2} a_{hh} [ln(P_{h\ell} Z_{h1\ell}^{\beta_h} Z_{h2\ell}^{\gamma_h} D_\ell^{\delta_h})]^2$$

$$+ a_{rh} ln(P_{r\ell} Z_{r1\ell}^{\beta_r} Z_{r2\ell}^{\gamma_r} D_\ell^{\delta_r}) ln(P_{h\ell} Z_{h1\ell}^{\beta_h} Z_{h2\ell}^{\gamma_h} D_\ell^{\delta_h})$$

where

a_o = a constant of proportionality,

$(\beta_r, \gamma_r, \delta_r)$ and $(\beta_h, \gamma_h, \delta_h)$ are parameters of hedonic aggregator functions for railway and highway modes, respectively, and

$(a_r, a_h, a_{rr}, a_{hh}, a_{rh})$ are parameters of macro translog cost function $\tilde{C}$.

The linear homogeneity conditions of translog function $\tilde{C}$ in its arguments $C^r(\cdot)$ and $C^h(\cdot)$ are:

(3,16) (a) $a_r + a_h = 1$

(b) $a_{rr} + a_{rh} = 0$ and $a_{rh} + a_{hh} = 0$

implying $a_{rr} = -a_{rh} = a_{hh}$

Imposition of these restrictions and some straightforward manipulation give the following system of equations:

(3,17a)

$$\ln C\left[(P_{r\ell}Z_{r1\ell}^{\beta_r}\, Z_{r2\ell}^{\gamma_r}\, D_\ell^{\delta_r}),\ (P_{h\ell}Z_{h1\ell}^{\beta_h}\, Z_{h2\ell}^{\gamma_h}\, D_\ell^{\delta_h})\right]$$

$$= \ln a_o + a_r(\ln P_{r\ell} + \beta_r \ln Z_{r1\ell} + \gamma_r \ln Z_{r2\ell} + \delta_r \ln D_\ell)$$

$$+ (1-a_r)(\ln P_{h\ell} + \beta_h \ln Z_{h1\ell} + \gamma_h \ln Z_{h2\ell} + \delta_h \ln D_\ell)$$

$$+ \tfrac{1}{2}\, a_{rr}\left[\ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right)^2 + \beta_r^2(\ln Z_{r1\ell})^2 + \beta_h^2(\ln Z_{h1\ell})^2 + \gamma_r^2(\ln Z_{r2\ell})^2\right.$$

$$\left. + \gamma_h^2(\ln Z_{h1\ell})^2 + (\delta_r-\delta_h)^2(\ln D_\ell)^2\right]$$

$$+ a_{rr}\left[\beta_r \ln P_{r\ell}\ln Z_{r1\ell} + \gamma_r \ln P_{r\ell}\ln Z_{r2\ell} + (\delta_r-\delta_h)\ln P_{r\ell}\ln D_\ell\right.$$

$$+ \beta_r\gamma_r \ln Z_{r1\ell}\ln Z_{r2\ell} + \beta_r(\delta_r-\delta_h)\ln Z_{r1\ell}\ln D_\ell + \gamma_r(\delta_r-\delta_h)\ln Z_{r2\ell}\ln D_\ell$$

$$+ \beta_h \ln P_{h\ell}\ln Z_{h1\ell} + \gamma_h \ln P_{h\ell}\ln Z_{h2\ell} - (\delta_r-\delta_h)\ln P_{h\ell}\ln D_\ell$$

$$- \beta_h\gamma_h \ln Z_{h1\ell}\ln Z_{h2\ell} - \beta_h(\delta_r-\delta_h)\ln Z_{h1\ell}\ln D_\ell - \gamma_h(\delta_r-\delta_h)\ln Z_{h2\ell}\ln D_\ell$$

$$- \beta_r \ln P_{h\ell}\ln Z_{r1\ell} - \gamma_r \ln P_{h\ell}\ln Z_{r2\ell} - \beta_h \ln P_{r\ell}\ln Z_{h1\ell}$$

$$- \beta_r\beta_h \ln Z_{r1\ell}\ln Z_{h1\ell} - \gamma_r\beta_h \ln Z_{r2\ell}\ln Z_{h1\ell} - \gamma_h \ln P_{r\ell}\ln Z_{h2\ell}$$

$$\left. - \beta_r\gamma_h \ln Z_{r1\ell}\ln Z_{h2\ell} - \gamma_r\gamma_h \ln Z_{r2\ell}\ln Z_{h2\ell}\right]$$

(3,17b)

$$S_{r\ell} = a_r + a_{rr}\ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + a_{rr}(\beta_r \ln Z_{r1\ell} - \beta_h \ln Z_{h1\ell})$$

$$+ a_{rr}(\gamma_r \ln Z_{r2\ell} - \gamma_h \ln Z_{h2\ell}) + a_{rr}(\delta_r-\delta_h)\ln D_\ell$$

(3,17c)

$$S_{h\ell} = (1-a_r) - a_{rr}\ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) - a_{rr}(\beta_r \ln Z_{r1\ell} - \beta_h \ln Z_{h1\ell})$$

$$- a_{rr}(\gamma_r \ln Z_{r2\ell} - \gamma_h \ln Z_{h2\ell}) - a_{rr}(\delta_r-\delta_h)\ln D_\ell$$

Note that, alternatively, the system of equations in (3,17) can be obtained by imposing a set of restrictions on the parameters of the general model in (3,10). Therefore, Model C is nested in the general model. It has 9 parameters to be estimated.

In this model, hedonic aggregators are allowed to take different parameter values across the modes although the functional form is constrained to be identical. Since, as mentioned previously, the hedonic aggregator of a mode can be regarded as the quality-adjusted price function, a difference in value of parameters between modes implies that shippers evaluate the imputed values of quality attributes of service differently from mode to mode. This inconsistent evaluation would, of course, contradict the assumption of optimal behaviour postulated in any economic study. However, this could happen for one or more of the following reasons:

(i) Shippers may wrongly perceive the levels of quality attributes of various modes, yet their mode choice decision is made on the basis of perceived quality attributes rather than of the actual levels.

(ii) Since the dimension of quality attributes of service is numerous, and most quality attributes are unmeasurable, the omitted variables could cause the difference in parameter values.

(D) <u>The Model with Identical Hedonic Aggregators (Model D)</u>

Under some restrictive conditions, Rosen [1974] has shown analytically that each consumer who faces a choice among a set of differentiated products defines a well-behaved value (hedonic) function over the quality of product space as a result of utility maximizing behaviour. Then, the product with the highest value per dollar spent is chosen for actual purchase. However, his analysis assumes a perfectly rational consumer whose choice depends not on institutional or psychological barriers, such as brand preference and brand insistence, but only on the true (actual) contents of qualities.

In the context of transport mode choice, this implies that shippers choose a particular mode, not as a physical entity of the mode but as a collection of quality attributes built in the mode, through an inter-modal comparison of the true contents of quality attributes of service. Therefore, in the framework of Rosen's model, the physical entity of a mode has no practical significance to shippers other than as a collection of quality attributes. Consequently, if the model is comprehensive and correct and if there is no deviation between the perceived and the actual levels of quality attributes of various modes, then the hedonic aggregators are expected to have an identical set of parameters. In the context of the link unit cost function (3,14), this means that both the functional form and the parameters of M hedonic aggregators $[C^1(\cdot), C^2(\cdot), \ldots, C^M(\cdot)]$ are identical. Therefore, under Rosen's framework, the cost function can be written as:

$$(3,18) \qquad C_\ell(P_\ell, Z_\ell, D_\ell) \equiv \bar{C}[\hat{C}(P_{1\ell}, Z_{1\ell}, D_\ell), \ldots, \hat{C}(P_{M\ell}, Z_{M\ell}, D_\ell)]$$

Notice that the form of the hedonic aggregator functions, $\hat{C}(\cdot)$, are independent of the modal index.

For the two-mode case, cost function (3,18) can be specified in translog form, and corresponding modal revenue shares can be obtained as follows:

$$(3,19a) \qquad ln C(P_\ell, Z_\ell, D_\ell) = C\left[(P_{r\ell} Z_{r1\ell}^{\beta} Z_{r2\ell}^{\gamma} M_\ell^{\delta_r}), (P_{h\ell} Z_{h1\ell}^{\beta} Z_{h2\ell}^{\gamma} D_\ell^{\delta_h})\right]$$

$$= ln a_o + a_r \left[ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + \beta ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right) + \gamma ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right) + (\delta_r - \delta_h) ln D_\ell\right]$$

$$+ ln P_{h\ell} + \beta ln Z_{h1\ell} + \gamma ln Z_{h2\ell} + \delta_h ln D_\ell$$

$$+ \tfrac{1}{2} a_{rr} \left[ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right)^2 + \beta^2 ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right)^2 + \gamma^2 ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right)^2 + (\delta_r - \delta_h)^2 (ln D_\ell)^2\right]$$

$$+ a_{rr} \left[\beta ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right) + \gamma ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right) + \beta\gamma ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right) ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right)\right.$$

$$+ (\delta_r - \delta_h) ln D_\ell \, ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + \beta ln Z_{r1\ell} \, ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + \beta(\delta_r - \delta_h) ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right) ln D_\ell$$

$$\left. + \gamma(\delta_r - \delta_h) ln D_\ell \, ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right)\right].$$

$$(3,19b) \qquad S_{r\ell} = a_r + a_{rr}\left[ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + \beta ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right) + \gamma ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right) + (\delta_r - \delta_h) ln D_\ell\right]$$

$$(3,19c) \qquad S_{h\ell} = (1 - a_r) - a_{rr}\left[ln\left(\frac{P_{r\ell}}{P_{h\ell}}\right) + \beta ln\left(\frac{Z_{r1\ell}}{Z_{h1\ell}}\right) + \gamma ln\left(\frac{Z_{r2\ell}}{Z_{h2\ell}}\right) + (\delta_r - \delta_h) ln D_\ell\right]$$

The linear homogeneity conditions are already imposed in equations (3,19). This system of equations can also be obtained from (3,17) by imposing two restrictions; $\beta_r = \beta_h = \beta$ and $\gamma_r = \gamma_h = \gamma$. It has 7 parameters to be estimated.

(E) Summary of Alternative Models

In the preceding sections, four alternative forms of the link transport unit cost function were specified in translog form for the case of two-mode (rail and truck) and two-quality attributes (speed and reliability of speed). The corresponding revenue share functions of the two modes were also derived. The following is a summary of the alternative models:

- Model A: general model in (3,10), discussed in section (A),
- Model B: model strictly independent of distance in (3,13), discussed in section (B),
- Model C: model with mode-specific hedonic aggregators in (3,17), discussed in section (C),
- Model D: model with identical hedonic aggregators in (3,19), discussed in section (D).

Note that models B, C and D are nested in model A, and model D is nested also in model C, but there is no nested relation between model B and either model C or model D.

The quality attribute variables (speed and reliability of speed) may or may not play an empirically significant role in mode-choice decisions, depending on the commodity. Consequently, for each commodity group, it is necessary to decide whether speed and/or reliability variables should be included in the model as well as to decide the best model to use. Therefore, each of the above four models is to have the following three sub-models:

Sub-model 1: includes both speed and reliability,

Sub-model 2: includes speed only,

Sub-model 3: does not include any quality variable.

Therefore, for each commodity group, there are eleven different sub-models[9] that need to be estimated.

Footnotes for Chapter III:

1. The regularity conditions required here are that the production function be differentiable, increasing and concave in its arguments.

2. The term 'flexible functional form' will be explained later in this chapter.

3. The regularity conditions that are required to determine uniquely the corresponding production function are that the cost function be increasing, linearly homogeneous and quasi-concave in the input prices.

4. The term 'characteristics' represents both quality attributes of service such as transit time (speed) and reliability of service, and freight rates.

5. In fact, it is to be tested later whether the distance affects shippers' choice behavior in price-quality attributes space.

6. Notice that the generalized Leontief function is a special case of a quadratic mean of order-r function where r = 1.

7. See chapter IV for more details on the singularity of the system and the properties of the estimator.

8. Hedonic Price Theory is originally due to Court [1939], and added and formalized by Stone [1956], Lancaster [1966] and Fisher and Shell [1968]. Hedonic Price Theory has been widely used to construct true price indices of industrial capital goods and household durable goods which are usually subject to quality change. Some typical applications can be found in Cragg and Uhler [1970], Hall [1971], Ohta [1975], Griliches [1971] and Terleckyj [1976].

9. Although three sub-models for each of the four macro models make twelve, model C-3 (sub-model 3 of model C) and model D-3 (sub-model 3 of model D) are in fact identical.

CHAPTER IV

SOURCES OF DATA AND CONSTRUCTION OF THE VARIABLES

In order to estimate the unit cost functions and modal revenue share functions specified in chapter III, it is necessary to construct the following variables:

C_ℓ = weighted average unit cost to shippers in cents per ton-mile on link ℓ, $\ell = 1,2,...,L$.

$S_{r\ell}$ = revenue share of railway mode on link ℓ,

$S_{h\ell}$ = revenue share of highway mode on link ℓ,

$P_{r\ell}$ = average railway freight rate in cents per ton-mile on link ℓ,

$P_{h\ell}$ = average trucking freight rate in cents per ton-mile on link ℓ,

$Z_{r1\ell}$ = average speed of railway services in miles per day on link ℓ,

$Z_{h1\ell}$ = average speed of trucking services in miles per day on link ℓ,

$Z_{r2\ell}$ = reciprocal of coefficient of variation in transit time distribution of railway services on link ℓ (a measure of reliability of transit time),

$Z_{h2\ell}$ = reciprocal of coefficient of variation in transit time distribution of trucking services on link ℓ,

D_ℓ = distance of link ℓ in miles.

Since the empirical implementation has to be done separately for each commodity group, it is necessary to contruct these variables for all commodity groups to be studied. Furthermore, both for railway and for trucking modes the same definitions of commodity groups and of the system of links should be employed in constructing the variables in order to achieve consistency of data between the two modes.

To construct the above variables, it is essential to obtain the following data for each commodity group and for each link:

(1) Distance of the link (D_ℓ),

(2) Total tons moved by railway mode ($V_{r\ell}$),

(3) Total tons moved by trucking mode ($V_{h\ell}$),

(4) Average railway freight rate ($P_{r\ell}$),

(5) Average trucking freight rate ($P_{h\ell}$),

(6) Rail mode's average transit time ($t_{r\ell}$),

(7) Truck mode's average transit time ($t_{h\ell}$),

(8) Standard deviation of the rail mode's transit-time distribution ($K_{r\ell}$),

(9) Standard deviation of the truck mode's transit-time distribution ($K_{h\ell}$).

In the remainder of this chapter, the sources from which these data were obtained and the ways these data were used to construct the variables included in the models are discussed in detail.

(A) Freight Rate and Commodity Flow Data

Waybill records of actual freight shipments are kept in Canada by various government agencies and by certain carrier companies as confidential information. Most of the available data are inappropriate for a multi-modal demand study such as this, primarily due to the inconsistency of the data between modes with respect to the classification of commodities, definitions of links, units of measurements and methods of sampling. For example, both major railways (CN and CP) classify their internal records by the Standard Transportation Commodity Code (STCC) while Statistics Canada uses Standard Commodity Classification (SCC) system for their annual survey of domestic for-hire trucking. Again both major railways use their own systems of station numbers to record origin and destination of cargo whereas Statistics Canada uses Census Divisions defined primarily on the basis of the Standard Geographic Code (SGC). Fortunately, Peterson [1972] has developed the 'Canadian Freight Transportation Model (CFTM) data base' which uses common systems of classifying commodities and of designating geographical regions of origin and destination. The CFTM data base employs 78 commodity groupings (CFTM commodity codes) with cross-references to the STCC and SCC systems and 69 geographic regions (CFTM Canadian regions) with cross-references to the Statistics Canada Census Divisions, SGC and CN/CP station numbers. The CFTM data base has been maintained and updated by the Canadian Institute of

Guided Ground Transport. (See Graham [1975] for more technical details on the data base.)

For each of the eight selected CFTM commodity groups that will be listed later in this chapter, the following information was developed from the CFTM data base using 1970 data.

(1) Total tons carried by railway mode on each link,

(2) Total tons carried by trucking mode on each link,

(3) Average railway freight rate in cents per ton-mile on each link,

(4) Average trucking freight rate in cents per ton-mile on each link.

(B) Distance of Link

A major city was chosen in each CFTM region and was regarded as the centroid of the region. Each of all possible pairs of CFTM regions was treated as a link composing the Canadian freight transport network.[1] Both railway and highway distances were measured between the major cities of each pair of regions from handbook sources.[2]

Shipments within each CFTM region were eliminated from the data set because (i) the measure of distance is meaningless in this case and (ii) the intra-regional flow patterns cannot be represented well by a link. Furthermore, those links having distances significantly different between the two modes were also eliminated from the data set since on these links distance would be the dominant factor determining modal freight rates per ton and transit times and thus mode-choice decision.

For each of the remaining links, the average of the railway and highway distances[3] was used as the distance measure of the link (D_ℓ).

(C) Transit Time and Its Variability

Since transit time information is not available in the CFTM data base, other sources had to be employed. While the proper measure of overall transit time would be the time span between the receipt by the carrier of a request for service and the delivery of the shipment to consignee, no data was available that could provide all this information. The railway's daily car and train movement records show only the time from entry of a loaded car into the origin yard to the exit of the car from the destination yard on its way to delivery. The source for the trucking performance data also lacked information on elapsed time during pickup and delivery and the time between a shipper's request for service and actual pickup. Since this non-transit service time required for railway service is normally longer than that for trucking service, there would have been a downward bias of railway service time if it were omitted. However, as this bias seems more or less constant across the cross-sectional links, on the basis of the information obtained from selected interviews of shippers and railway officials, the rail transit times on all links were increased by two days to account for the potential difference in non-transit service time between the two modes.

The total population of actual car movements recorded during October, 1970 for Canadian National Railways and during March, 1971 for Canadian Pacific Railways were used to calculate the average transit time and standard deviation of transit time for each link.[4] Since it was difficult to classify railway cars by the CFTM commodity groups, these were not computed separately for each commodity group. Rather all commodities were grouped into two categories; 'bulk' and 'non-bulk', and only two sets of average transit time and standard deviation of transit time were computed, one for the 'bulk' group and another for the 'non-bulk' group. Since, for some links, there was no car movement record during the observation periods, the following regression equations estimated from the data were used to generate average transit times and the standard deviation of transit times for those links:[5]

$$(4,1) \qquad ln(t_{r\ell}) = -1.835 + 0.448\ ln(D_{r\ell}) \ ; \ R^2 = 0.5019$$

$$(4,2) \qquad K_{r\ell} = 0.332 + 0.1727\ t_{r\ell} \ ; \ R^2 = 0.3745$$

sample size = 1524 links

where

$t_{r\ell}$ = average rail transit time in days on link ℓ,

$D_{r\ell}$ = railway distance of link ℓ in miles,

$K_{r\ell}$ = standard deviation of rail transit time distribution on link ℓ.

The trucking survey information obtained from Turner [1975] was used to generate the trucking performance data. Turner has obtained the actual transit times of 1274 truck shipments over 12 different links with varying distances from the records of two large trucking companies. Using this information it was possible to estimate the following regression equations:[6]

(4,3) $\ln(t_{h\ell}) = -4.056 + 0.7858 \ln(D_{h\ell})$; $R^2 = 0.9418$

(4,4) $K_{h\ell} = 0.3672 + 0.3617 t_{h\ell}$; $R^2 = 0.7164$

where

$t_{h\ell}$ = average truck transit time in days on link $\underline{\ell}$,

$D_{h\ell}$ = highway distance of link $\underline{\ell}$ in miles,

$K_{h\ell}$ = standard deviation of truck transit time distribution on link $\underline{\ell}$.

These regression equations were used to generate the average transit time and the standard deviation of the transit time distribution for the truck mode, for all links.

(D) Construction of the Variables

Having explained the sources and the ways to obtain necessary data in the preceding sections, this section presents the formulae to compute the variables actually used as arguments of the cost and share functions specified in chapter III.

(1) Distance of link:

$$D_{\ell} = \frac{D_{r\ell} + D_{h\ell}}{2}$$

where $D_{r\ell}$ = railway distance of link ℓ in miles,

$D_{h\ell}$ = highway distance of link ℓ in miles.

(2) Railway average freight rate per ton-mile on link ℓ:

$$P_{r\ell} = \frac{R_{r\ell}}{V_{r\ell} \cdot D_{\ell}}$$

where $R_{r\ell}$ = total revenue of rail mode on link ℓ,

$V_{r\ell}$ = total tons moved by rail mode on link ℓ.

(3) Average trucking freight rate per ton-mile on link ℓ:

$$P_{h\ell} = \frac{R_{h\ell}}{V_{h\ell} \cdot D_{\ell}}$$

where $R_{h\ell}$ = total revenue of truck mode on link ℓ,

$V_{h\ell}$ = total tons moved by truck mode on link ℓ.

(4) Railway share of revenue on link ℓ:

$$S_{r\ell} = \frac{R_{r\ell}}{R_{r\ell}+R_{h\ell}}$$

(5) Trucking share of revenue on link ℓ:

$$S_{h\ell} = 1 - S_{r\ell}$$

(6) Average rail speed in miles per day on link ℓ:

$$Z_{r1\ell} = \frac{D_\ell}{t_{r\ell}}$$

where $t_{r\ell}$ = average rail transit time in days on link ℓ.

(7) Average truck speed in miles per day on link ℓ:

$$Z_{h1\ell} = \frac{D_\ell}{t_{h\ell}}$$

where $t_{h\ell}$ = average truck transit time in days on link ℓ.

(8) Reciprocal of coefficient of variation of rail transit time distribution[7] on link ℓ:

$$Z_{r2\ell} = \frac{t_{r\ell}}{K_{r\ell}}$$

where $K_{r\ell}$ = standard deviation of rail transit time distribution on link ℓ.

(9) Reciprocal of coefficient of variation of truck transit time distribution[7] on link ℓ:

$$Z_{h2\ell} = \frac{t_{h\ell}}{K_{h\ell}}$$

where $K_{h\ell}$ = standard deviation of truck transit time distribution on link ℓ.

So far in this chapter, the sources of data and the methods of computing the variables included in the model have been discussed. Before closing this chapter, it seems worthwhile to summarize the qualifying conditions for an observation. As mentioned previously in various places, a link should satisfy the following conditions to qualify as an observation:

(i) Both railway and trucking modes should actually share the traffic of the particular commodity group on that link.

(ii) Since a common measure of distance (D_ℓ) is to be used, distances by the two modes should be similar to each other.

(iii) Both origin and destination regions of the link should have a single major city so that the major portion of the traffic actually flows between the two cities.

Eight different CFTM commodity groups[8] were chosen for analysis from the 78 CFTM commodity groups such that they represent a wide variety of commodity attributes. The number of links satisfying the above conditions among the total 4692 (i.e., 69 x 68) Canadian inter-regional links was different from commodity to commodity. These are listed in Table (4-1). These observations are used to estimate the cost functions and modal share functions that are to be reported in chapters V and VI.

Table 4-1, Selected CFTM Commodity Groups and Number of Observations

CFTM Commodity Code No.	Name of Commodity Group	Number of Observations
CFTM14	Fruits, vegetables and edible foods	133 links
CFTM52	Lumber including flooring	52 links
CFTM61	Chemicals	86 links
CFTM66	Fuel Oil	65 links
CFTM69	Refined petroleum products	77 links
CFTM71	Steel, irons and alloys	151 links
CFTM75	Metal fabricated basic products	137 links
CFTM78	Non-metallic basic products	156 links

Footnotes for Chapter IV:

1. Due to the definition of link adopted in this study, there is a possible danger that rail and truck traffic may originate at different cities in an origin region and/or go to different cities in a destination region. To avoid this problem as much as possible, links having no major city or else two or more cities of similar size at either end of the link were eliminated from the data.

2. Mileage information listed in CN/CP Regional Time Tables was used to measure railway distances of links. An Official Canadian Highway Map was used to measure highway distances of links.

3. As long as a shipper gets his cargo moved from one location to another, the fact that a certain mode has a longer or shorter distance than the other mode has no direct significance to him other than its impacts on the ton-mile freight rate and quality attributes which are also computed using the common measure of distance (D_ℓ). However, the links whose railway and highway distances are significantly different from one another were eliminated from the data because the mode with a shorter distance would generally dominate traffic due to its favorable impact on freight rates per ton and quality attributes.

4. When the author tried to collect the data for this research, these were the only transit time records available in the CFTM data base. Fortunately, there was no labor dispute during the periods.

5. Several alternative functional forms were estimated from the sample of 1524 observed links and the equations (4,1) and (4,2) were chosen primarily on the basis of goodness of fit.

6. As in the case of the railway mode, several alternative functional forms were tried, and the equations (4,3) and (4,4) were chosen on the basis of goodness of fit.

7. As another indicator of transit-time reliability, the variable called "percentage of shipment that took longer than 3/2 times of mean transit time" was obtained. However, some experiments indicated the superiority of the variable "reciprocal of coefficient of variation of transit time distribution ($Z_{r2\ell}$)" over this variable.

8. A detailed list of commodities included in the eight CFTM commodity groups is available in Appendix 4A with cross-references to the Standard Commodity Classification (SCC) code.

CHAPTER V

ESTIMATION AND HYPOTHESIS TESTING

This chapter is organized as follows. The econometric aspects of estimating the models and the algorithms chosen for the estimation are discussed in section (A). Section (B) lays out the plan for hypothesis testing and discusses a theoretical problem in testing amongst the non-nesting models. A summary table of the models chosen for the eight CFTM commodity groups as a result of the hypothesis testing is presented in section (C). Finally, the tables of test statistics and the detailed reports on hypothesis testing, including the lists of intermediate results are presented in Appendix 5A.

(A) Econometric Aspects of Estimation

The four alternative models derived and specified in chapter III are similar in that each cost function has the natural logarithm of average transportation cost per ton-mile as its dependent variable and each demand function has modal expenditure share (revenue share from the carrier's viewpoint) as the dependent variable. Empirical implementation requires that the cost and share functions be imbedded in a stochastic framework because, in practice, there are errors in adjustment to the cost-minimizing expenditure shares and thus to the cost-minimizing unit transportation cost. For each alternative model, the additive disturbance in the *i*th equation at link ℓ is defined as $E_i(\ell)$. Further, the column vector of disturbances at link ℓ is defined as:

$$(5,1) \qquad E^*(\ell) = [E_c\ (\ell),\ E_r(\ell),\ E_h\ (\ell)], \quad \ell = 1,2,\ldots,L.$$

and the associated disturbance covariance matrix as Ω^*.

Since the two modal shares always sum to one at each link, the sum of the disturbances of the two modal share equations is zero at each observation ℓ. This implies that the disturbance covariance matrix of the full three-equation system, Ω^*, is singular and non-diagonal. If the estimators of parameters are to be efficient, this disturbance covariance matrix must be taken into account. Due to the singularity, the determinant of the disturbance covariance matrix is zero, and consequently the likelihood function is undefined.[1] Therefore, either one of the two modal share equations should be dropped so that the remaining two equations can be estimated. Since the maximum likelihood estimates are invariant to the equation deleted, the disturbance of the trucking revenue share equation, $E_h(\ell)$, is to be dropped from all the alternative models. Define the new disturbance vector as $E(\ell) \equiv [E_c(\ell), E_r(\ell)]$, and assume that the disturbance vector $E(\ell)$ is *independently joint-normally* distributed with a mean vector of zeroes and non-singular covariance matrix Ω, for all $\ell = 1,2,...L$: i.e. NIID. The logarithm of the likelihood function can be written as:[2]

$$(5,2) \qquad ln\mathcal{L} = - L\ [ln(2\pi) + 1] - \frac{L}{2}\ ln\ |\Omega|$$

where L is the number of oberservations (links) used.

The parameters of the four alternative models are estimated using a nonlinear multivariate maximum likelihood procedure. Statistical inference is based on the asymptotic likelihood ratio criterion. Of course, the test results are invariant to the equation deleted. The computation is done by the algorithm developed by Berndt-Hall-Hall-Hausman [1974]. The algorithm used for the nonlinear models is essentially a combination of the iterative Zellner efficient (IZEF) procedure with the Gauss-Newton method of nonlinear least squares, and is equivalent to maximum likelihood (ML) estimation. Since estimation of the nonlinear systems is costly, it was in practice essential to set somewhat loose convergence criteria.

The convergence criteria used are that:

(i) The largest change in parameter estimates from one iteration to another should be no greater than 0.5%, and

(ii) The largest absolute deviation of the the elements of the transformed residual covariance matrix[3] from the identity matrix should be no greater than 0.005.

Convergence was achieved for all alternative models. This convergence criterion is far looser than those normally used in nonlinear programming (NLP) algorithms. Therefore, as a means to check the accuracy of computation, FLETCH[4] and SIMPLX[5] at the University of British Columbia were used to estimate the parameters of the cost functions by the classical equation-by-equation least squares method. The convergence criteria used were 10.E-10 for the FLETCH algorithm and 10.E-6 for the SIMPLX algorithm. Convergence was achieved and the Hessian matrix of second order partial derivatives satisfied positive definiteness for all cases. By this experiment, it was confirmed that at least the signs of parameter estimates were exactly the same between Berndt-Hall-Hall-Hausman algorithm and the NLP algorithms.

(B) The Plan for Hypothesis Testing

Eleven different sub-models are hypothesized in section (E) of chapter III for each commodity group. Recall that (i) models B, C and D are nested[6] in model A, and (ii) model D is nested also in model C, but (iii) there is no nested relation between model B and either model C or model D. Due to the non-nestedness amongst some models, the following complications arise in testing hypotheses:

1. Classical testing procedures cannot be used without a qualification.

2. There is no guarantee that intransitivity amongst the results of inter-related tests does not occur.

Therefore, hypothesis testing is designed such that the occurence of non-nestedness is minimized. Three alternative plans are considered:

1. A complete test requires testing all possible combinations of two sub-models, i.e., 55 separate tests in total.

2. A two-stage test fixing the type of sub-model at the first stage: This would require 12 tests in the first stage, and another 6 tests in the second stage.

3. A two-stage test fixing the type of macro model at the first stage: This would require 12 tests in the first stage, and another 6 tests in the second stage.

The first plan is the worst because it has the largest number of non-nested hypotheses and a high probability of intransitivity of test results. Under the second plan, non-nested cases are present both in the first and in the second stages, whereas under the third plan, non-nested cases are avoided completely in the first stage but some arise in the second stage. There is almost no danger of intransitivity of test results in either the second or third plan.

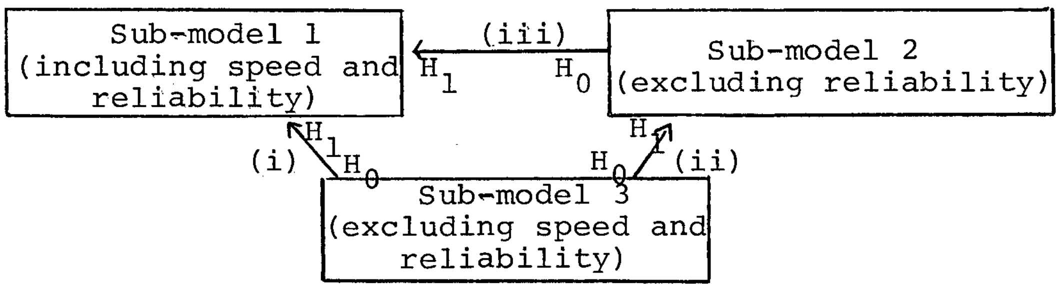
The third plan was chosen for testing hypotheses about the models. The plan is summarized in Figure (5-1). In the first stage, decisions have to be made about which of the three sub-models is most appropriate to represent each (macro) model for the second stage tests. This amounts to determining the independent variables to be included in each (macro) model: For a given (macro) model, test (i) determines whether or not "speed" and "reliability" variables together are statistically significant. If the test result is negative, then test (ii) is conducted to see if "speed" alone is a statistically significant factor. If the result of test (ii) is also negative (or positive) then sub-model 3 (sub-model 2) is chosen to represent the (macro) model in the second-stage tests. Were the result of test (i) positive, then test (iii) is conducted to see if "reliability" is statistically significant even after "speed" is included in the model. If the result of test (iii) is negative (or positive), then sub-model 2 (sub-model 1) is chosen to represent the (macro) model in the second-stage tests. This procedure is repeated for each of the four alternative (macro) models hypothesized in chapter III.

In the second-stage tests, a decision is made about which of the four sub-models chosen in the first-stage tests is the

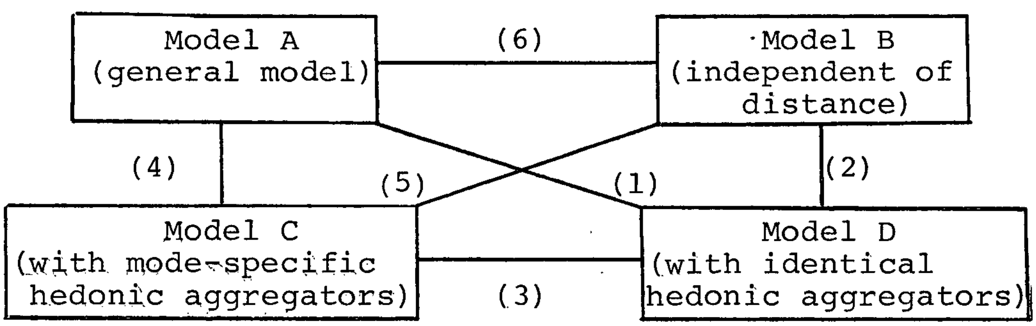
Figure (5-1) Plan for Hypothesis Testing*

First Stage**

For each (macro) model, the following sub-models are to be tested.



Second Stage***



* Note that some of the tests will become redundant as the results of the preceding tests are obtained.

** An arrow links a pair of null hypothesis (at origin) and alternative hypothesis (at destination).

*** In each test, the model with fewer parameters than the other becomes the null hypothesis. Therefore, the null hypothesis depends on which sub-models were chosen in the first stage tests.

most appropriate model to use. Since the number of parameter estimates of each (macro) model depends on the sub-model chosen in the first-stage tests, in each test, the model with fewer parameters becomes the null hypothesis. Therefore, the procedure for conducting the second-stage tests depends largely on the sub-models chosen in the first-stage tests. This is illustrated later in section (C) using the empirical results of CFTM14 (fruits, vegetables and edible foods) as an example. Note that some of the tests in both stages will become redundant depending on the results of the preceding tests.

The asymptotic likelihood ratio criterion is used to discriminate amongst the three sub-models 1, 2, and 3, in the first stage tests. Note that the sub-models 2 and 3 are nested in sub-model 1, and sub-model 3 is again nested in sub-model 2.

It requires a qualification to use the same test method in the second stage tests because of the possible presence of non-nested cases depending on the sub-models chosen in the first stage tests. In the non-nested cases, *a priori*, it is not in general possible to choose one from alternative models on the basis of classical test statistics. However, one can discriminate between the non-nested models *a posteriori* using Bayesian criterion. Let θ_1 and θ_2 denote the parameter vectors corresponding to models (1) and (2), respectively, and let Ω_1 and Ω_2 denote the associated disturbance covariance matrices.

Let P(1) and P(2) denote the prior probabilities that each model holds. Then P $[\Theta_1, \Omega_1 \| \text{model (1)}]$ and P $[\Theta_2, \Omega_2 \| \text{model (2)}]$ are the prior distributions for the parameters of each model. The joint posterior distributions of the models and their parameters, given data X, can be written as:

$$(5,3) \qquad p(\theta_i, \Omega_i, i \mid X) \propto \mathcal{L}(X \mid \theta_i, \Omega_i)\, P(\theta_i, \Omega_i \mid i)\, p(i)$$

$$i = 1,2.$$

Furthermore, Press [1972, p. 167] has shown that a diffuse prior density[7] makes the mode of the posterior distribution correspond to the maximum likelihood estimator. Therefore, if one employs the same diffuse prior distributions for the two models involved in a hypothesis test, then the likelihood ratio test is equivalent to comparing the modes of the two posterior distributions. In addition, when the number of parameters of the two alternative models is the same, the maximum mode of the two posterior distributions can be obtained simply by comparing the values of the likelihood functions evaluated at the maximum likelihood estimates of θ_i and Ω_i. In conclusion, using Bayesian criterion, one can choose *a posteriori* which of the models is most likely to have generated the observed data, through a likelihood ratio test for the case involving different numbers of parameters, and by comparing the values of the likelihood functions for cases involving the same number of parameters.

The values of the logarithm of the likelihood functions obtained by estimating eleven alternative sub-models are reported in Appendix 5A in tables (5A-1) to (5A-8), one for each CFTM commodity group. Theil [1971, p. 396] has shown that, asymptotically, $-2 ln\lambda$ (λ being the likelihood ratio) has a Chi-square distribution with appropriate degrees of freedom. These χ^2- statistics and the results of the hypothesis testing are reported in Appendix 5A in tables (5A-9) to (5A-16). A significance level (probability of type I error) of 0.05 is used for all hypothesis testing.

(C) The Chosen Models

In this section, (i) the testing procedure for choosing the model is illustrated using the fruits, vegetables and edible foods (CFTM14) as an example, and (ii) the list of the finally-chosen models is presented.

For convenience of the discussion, Tables (5A-1) and (5A-9) are reproduced here. Table (5A-1) reports for each of the eleven sub-models estimated from the CFTM14 data, the number of parameters estimated, the logarithm of the likelihood function evaluated at the ML parameter estimates (hereafter called "log of likelihood" or $ln\mathcal{L}$) and R^2 values of the cost and revenue share functions.

The first-stage tests (recall the schematics for the first-stage hypothesis testing outlined in Figure 5-1) are conducted in part (A) of Table (5A-9). This first-stage procedure involves, for each (macro) model, testing amongst the three sub-models, in which different sets of independent variables are included. For a given (macro) model, the first-stage tests are composed of three tests: sub-model 3 vs. sub-model 1, sub-model 3 vs. sub-model 2, and sub-model 3 vs. sub-model 1. For (macro) model A, test (i) compares sub-models (A-3) and (A-1). The test statistic 30.14 ($-2ln\lambda$ where λ is the likelihood ratio) reported in table (5A-9) is computed as:

Table 5A-1, Test Statistics for Commodity Group CFTM14: Fruits, Vegetables and Edible Foods (using 133 link observations)

Model and Sub-model	No. of free Parameters	$ln\mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-635.822	0.8714	0.3754
(A-2)	15	-644.605	0.8596	0.3564
(A-3)	6	-650.892	0.8460	0.3536
Model Strictly Independent of Distance (B)				
(B-1)	22	-641.1	0.8595	0.3590
(B-2)	11	-647.103	0.8552	0.3502
(B-3)	4	-682.177	0.7994	0.0215
Model with Mode-Specific Hedonic Aggregators (C)				
(C-1)	9	-646.74	0.8589	0.3636
(C-2)	7	-658.267	0.8525	0.3007
(C-3)*	5	-670.689	0.8270	0.2722
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-657.646	0.8511	0.3016
(D-2)	6	-658.369	0.8523	0.2999
(D-3)*	5	-670.689	0.8270	0.2722

$ln\mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-9, Hypotheses Testing for CFTM14: Fruits, Vegetables and Edible Foods

(A) Test amongst the three sub-models (First stage tests):

test statistic ($-2\ln\lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	30.140**	82.154	47.898	26.086
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	12.574	70.148	24.844	24.64
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	17.566	12.006	23.054	1.446
Chosen sub-model		(A-3)	(B-2)	(C-1)	(D-2)
No. of free parameters		6	11	9	6
$\ln \mathcal{L}$		-650.892	-647.103	-646.74	-658.369
R^2_c		.8460	.8552	.8589	.8523

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln\lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha = .05$	Test Result
(1) choice between models (D-2) and (A-3)	***			favours (A-3) due to higher $\ln\mathcal{L}$ value.
(2) H_0: model (D-2) H_1: model (B-2)	22.532	5	9.236	favours (B-2)
(3) H_0: model (D-2) H_1: model (C-1)	23.258	3	6.251	favours (C-1)
(4) H_0: model (A-3) H_1: model (C-1)	8.304	3	6.251	favours (C-1)
(5) choice between models (C-1) and (B-2)	***			favours (C-1) because it has higher $\ln\mathcal{L}$ value and smaller number of parameters
(6) H_0: model (A-3) H_1: model (B-2)	6.126	5	9.236	favours (A-3)

Model (C-1) is finally chosen for use.

*** The two models that are compared have the same number of parameters. In this case, the model with a larger value of the likelihood function was chosen.

$$-2 \ln\lambda = 2\ (\ln\mathcal{L} \text{ for alternative hypothesis } (H_1) - \ln\mathcal{L} \text{ for null hypothesis } (H_0))$$
$$= 2\ (\ln\mathcal{L} \text{ for model (A-1)} - \ln\mathcal{L} \text{ for model (A-3)})$$
$$= 2\ (-635.822 - (-650.892))$$
$$= 30.14$$

The test statistic has 22 degrees of freedom because the alternative hypothsis has 22 more parameters to estimate than the null hypothesis. Since the test statistic 30.14 is smaller than the critical value of the χ^2 distribution with 22 degrees of freedom at the 5% level of significance, one cannot reject sub-model (A-3). Exactly the same procedure is used to conduct test (ii), which favours sub-model (A-3) over sub-model (A-2). Since the two test results consistently favoured sub-model (A-3) over sub-models (A-1) and (A-2), the sub-model (A-3) was chosen to represent (macro) model A in the second-stage tests. Note that test (iii) is in fact redundant in this particular case.

The results of the first-stage tests amongst the three sub-models of (macro) model B are as follows:

test (i) : model (B-1) is favoured over model (B-3),
test (ii) : model (B-2) is favoured over model (B-3),
test (iii) : model (B-2) cannot be rejected in favour of model (B-1).

Therefore, sub-model (B-2) was chosen to represent (macro) model B in the second-stage tests. Using a similar procedure, sub-models (C-1) and (D-2) were chosen to represent (macro) models C and D, respectively, in the second-stage tests.

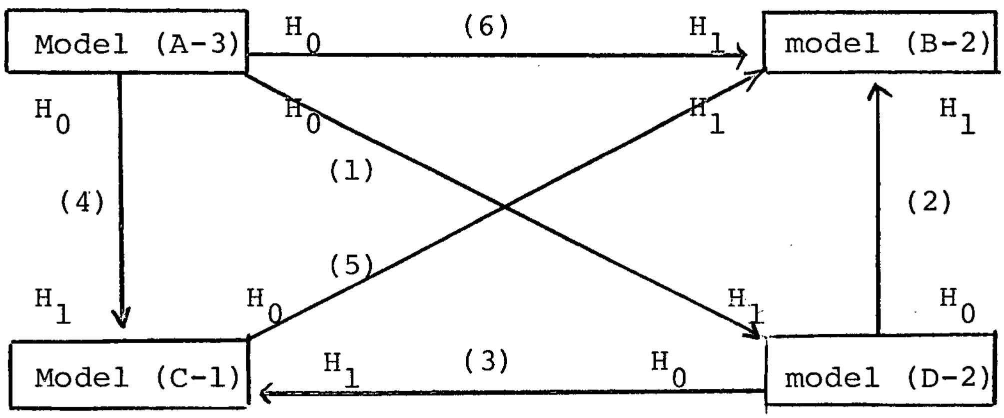
The purpose of the second-stage tests is to choose the most appropriate model to use among the four alternative models chosen in the first-stage tests. According to the schematics for the second-stage hypothesis testing outlined in Figure 5-1, the tests for this particular commodity group (CFTM14), are carried out as in Figure (5-2).

The test statistics ($-2ln\lambda$), degrees of freedom, χ^2-critical values at the 5% level of significance, and the test results for the second-stage tests are presented in part (B) of Table (5A-9). The results of the hypothesis testing are summarized at the bottom of Figure 5-2.

Test (1) favours model (A-3) over model (D-2) because the former has the higher $ln\mathcal{L}$ than the latter, and these two models have the same number of parameters. Tests (2), (3), (4) and (6) are conducted according to the standard procedure for χ^2-test. Test (5) favours model (C-1) over model (B-2) because the former has fewer parameters but attained a higher $ln\mathcal{L}$ than the latter. Since model (C-1) is favoured over all three other models, (D-2), (A-3) and (B-2), the final choice is model (C-1). Model (C-1) is used to obtain various empirical results about CFTM14 (fruits, vegetables and edible foods) in the following chapters.

Essentially the same testing procedure is used to make the choice of the model for each of the remaining commodity groups. The models finally chosen are shown at the bottom of

(Figure (5-2) Second-Stage Testing for CFTM14



Test*	H_0	H_1	Test Result
(1)	(A-3)	(D-2)	favours (A-3)
(2)	(D-2)	(B-2)	favours (B-2)
(3)	(D-2)	(C-1)	favours (C-1)
(4)	(A-4)	(C-1)	favours (C-1)
(5)	(C-1)	(B-2)	favours (C-1)
(6)	(A-3)	(B-2)	favours (A-3)

* Note that some tests are redundant; for this particular commodity, tests (1), (2) and (6) are redundant.

Tables A5-9 to A5-16 in Appendix 5A. Some models are too complicated to see intuitively whether or not the signs of some parameter estimates are reasonable. However, the reasonableness of those models can be judged *a posteriori* after computing the elasticities of demand with respect to price and quality variables which are reported in chapter VII. As will be noticed in chapter VII, all the chosen models other than that for CFTM71 (steel, iron and alloys, etc.) seem to give reasonable estimates for various elasticities. For commodity group CFTM71, model A-2 (the general model with price, speed and distance variables only) was chosen as the result of hypothesis testing. However, the chosen model is found to be unusable because all the speed elasticity estimates computed from the model have the wrong signs. A careful examination of Tables 5A-6 and 5A-14 indicates that model A-3 (the general model with price and distance variables only) is the next best model. Therefore this model is used instead of model A-2. Fortunately, the values of parameter estimates of model A-3 were very close to the corresponding parameters of model A-2, and consequently, the results about the intermodal substitutibility and price responsiveness of demands which are to be discussed in chapter VII do not vary significantly between the two models. (As will be mentioned in chapter VII, eventually the empirical results for this commodity group (CFTM71) will not be used in this thesis because of the counter-intuitively high elasticities of rail-truck substitution predicted by the model.)

The models finally chosen for use in the remaining chapters are summarized in Table 5-1.

Table (5-1), List of the Chosen Models

CFTM14 (fruits, vegetables & edible foods)	Model (C-1):	cost function with mode-specific aggregators as functions of price, speed, reliability and distance.
CFTM52 (lumber including flooring)	Model (C-3):	cost function with modal aggregators as functions of price and distance only.
CFTM61 (chemicals)	Model (C-3):	same as the case of CFTM52.
CFTM66 (fuel oil excluding gasoline)	Model (C-3):	same as the case of CFTM52.
CFTM69 (other refined petroleum products)	Model (A-3):	general model defined in prices and distance only.
CFTM71 (steel, iron & alloys)	Model (A-3):	same as the case of CFTM69. and distance
CFTM75 (metal fabricated basic products)	Model (C-1):	same as the case of CFTM14.
CFTM78 (non-metallic basic products)	Model (C-1):	same as the case of CFTM14.

Footnotes for Chapter V:

1. The likelihood function for the full model is undefined because the inverse of the cross-equation covariance matrix is undefined as is shown below:

$$\Omega^* = \frac{1}{L}\begin{bmatrix} \varepsilon_c^t\varepsilon_c & \varepsilon_c^t\varepsilon_r & \varepsilon_c^t\varepsilon_h \\ \varepsilon_c^t\varepsilon_r & \varepsilon_r^t\varepsilon_r & \varepsilon_r^t\varepsilon_h \\ \varepsilon_c^t\varepsilon_h & \varepsilon_r^t\varepsilon_h & \varepsilon_h^t\varepsilon_h \end{bmatrix} = \frac{1}{L}\begin{bmatrix} \varepsilon_c^t\varepsilon_c & \varepsilon_c^t\varepsilon_r & -\varepsilon_c^t\varepsilon_r \\ \varepsilon_c^t\varepsilon_r & \varepsilon_r^t\varepsilon_r & -\varepsilon_r^t\varepsilon_r \\ -\varepsilon_c^t\varepsilon_r & -\varepsilon_r^t\varepsilon_r & -\varepsilon_r^t\varepsilon_r \end{bmatrix}$$

where $\varepsilon_c' = [\varepsilon_c(1), \varepsilon_c(2), \ldots, \varepsilon_c(L)]$

$\varepsilon_r' = [\varepsilon_r(1), \varepsilon_r(2), \ldots, \varepsilon_r(L)]$

$\varepsilon_h' = [\varepsilon_h(1), \varepsilon_h(2), \ldots, \varepsilon_r(L)]$

and $\varepsilon_h(\ell) = -\varepsilon_r(\ell)$

for all $\ell = 1, 2, \ldots, L$.

$$|\Omega^*| = \frac{1}{L^3}[\varepsilon_c^t\varepsilon_c\{(\varepsilon_r^t\varepsilon_r)^2 - (-\varepsilon_r^t\varepsilon_r)^2\} - \varepsilon_c^t\varepsilon_r\{\varepsilon_c^t\varepsilon_r(\varepsilon_r^t\varepsilon_r) - \varepsilon_c^t\varepsilon_r(\varepsilon_r^t\varepsilon_r)\}$$

$$-\varepsilon_c^t\varepsilon_r\{-\varepsilon_c^t\varepsilon_r(\varepsilon_r^t\varepsilon_r) + \varepsilon_c^t\varepsilon_r(\varepsilon_r^t\varepsilon_r)\}]$$

$$= \frac{1}{L^3}[0] = 0 \qquad \Omega^* \text{ is singular}$$

Therefore, Ω^{*-1} is undefined, and consequently,

$$\mathcal{L} = (2\pi)^{-\frac{1}{2}(3)L}|\Omega^*|^{-\frac{L}{2}}\exp\{-\frac{1}{2}\sum_{\ell=1}^{L}\varepsilon_\ell' \quad \Omega^{*-1} \quad \varepsilon_\ell\}$$

is undefined .

2. The logarithm of the likelihood function in (5,2) is derived below:

For a two-equation model, the likelihood function for L observations can be written as:

$$(1)\quad \mathcal{L} = (2\pi)^{-\frac{1}{2}2L} |\Omega|^{-\frac{L}{2}} \exp\{-\frac{1}{2}\sum_{\ell=1}^{L} \varepsilon(\ell)^t \Omega^{-1} \varepsilon_\ell\}$$

$$\text{where} \quad \varepsilon(\ell)^t \equiv [\varepsilon_1(\ell), \varepsilon_2(\ell)]$$

By taking the natural log of both sides, it can be written as:

$$(2)\quad \ln \mathcal{L} = - L\ln(2\pi) - \frac{L}{2}\ln|\Omega| - \frac{1}{2}\sum_{\ell=1}^{L} \varepsilon(\ell)'\Omega^{-1}\varepsilon(\ell)$$

$$= - L[\ln(2\pi) + 1] - \frac{L}{2}\ln|\Omega|$$

The above equality holds because of the following:

Let $\Omega^{-1} \equiv \begin{bmatrix} w^{11} & w^{12} \\ w^{12} & w^{22} \end{bmatrix}$, then

$$\sum_{\ell=1}^{L} \varepsilon(\ell)^t \Omega^{-1} \varepsilon(\ell) = \sum_{\ell=1}^{L} \{\varepsilon_1(\ell)^2 w^{11} + 2\varepsilon_1(\ell)\varepsilon_2(\ell)w^{12} + \varepsilon_2(\ell)^2 w^{22}\}$$

$$= \varepsilon_1^t\varepsilon_1 w^{11} + 2\varepsilon_1^t\varepsilon_2 w^{12} + \varepsilon_2^t\varepsilon_2 w^{22}$$

Meanwhile, $\Omega = \frac{1}{L}\begin{bmatrix} \varepsilon_1^t\varepsilon_1 & \varepsilon_1^t\varepsilon_2 \\ \varepsilon_1^t\varepsilon_2 & \varepsilon_2^t\varepsilon_2 \end{bmatrix} \quad \therefore \quad \Omega^{-1} = \dfrac{\frac{1}{L}\begin{bmatrix} \varepsilon_2^t\varepsilon_2 & -\varepsilon_1^t\varepsilon_2 \\ -\varepsilon_1^t\varepsilon_2 & \varepsilon_1^t\varepsilon_1 \end{bmatrix}}{\frac{1}{L^2}[(\varepsilon_1^t\varepsilon_1)(\varepsilon_2^t\varepsilon_2) - (\varepsilon_1^t\varepsilon_2)^2]}$

$$\therefore \quad \sum_{\ell=1}^{L} \varepsilon(\ell)^t \Omega^{-1} \varepsilon(\ell) = \frac{L}{(\varepsilon_1^t\varepsilon_1)(\varepsilon_2^t\varepsilon_2) - (\varepsilon_1^t\varepsilon_2)^2} [\varepsilon_1^t\varepsilon_1(\varepsilon_2^t\varepsilon_2) + 2\varepsilon_1^t\varepsilon_2(-\varepsilon_1^t\varepsilon_2) + \varepsilon_2^t\varepsilon_2(\varepsilon_1^t\varepsilon_1)]$$

$$= 2L$$

3. The transformed covariance matrix is the product between the inverse of the covariance matrix from the previous iteration and the covariance matrix from the current iteration.

4. FLETCH is a subroutine for minimizing a function by a quasi-Newton method based on Fletcher's algorithm [1967].

5. SIMPLX is a subroutine for function minimization using a Simplex algorithm developed by Nedler and Meads [1965].

6. For example, the phrase "model B is nested to model A" means that model B is a special or limiting case of Model A.

7. The term "diffuse prior density" means a uniform prior density over the real line. When the analyst does not have any prior information about the parameters of model i, he may assume a uniform prior distribution for $P(\theta_i, \Omega_i | i)P(i)$.

CHAPTER VI

GENERAL RESULTS

This chapter examines the mean values of the important variables, and describes the general results of this study using the chosen models reported in Table 5-1.

Section A reports the mean values of some important variables with explanatory notes. Section B comments on the general implications of the chosen models without specific reference to the parameter estimates. In Section C, the parameter estimates for the models are reported, and the signs and statistical significance of some important parameter estimates are examined as well. And finally, Section D summarizes the discussion in Sections B and C in order to present general findings from the chosen models.

(A) Mean Values of Some Important Variables

It is beneficial to examine the data before any specific results of a model are studied. Although, eventually, the usage of a model is essential because of the joint relations amongst the independent variables, the data themselves are often useful for intuitive interpretations of the conclusions that can be drawn from the model.

Since it is neither necessary nor possible[1] to list the entire data, only the mean values of some important variables such as shares of revenue, shares of tonnage, shares of ton-miles, average freight rates per ton-mile, average lengths of haul and the simple averages of speed and reliability variables are listed in Table 6-1 by each commodity group. In the remainder of this section, the information contained in the table is discussed.

The following observations may be made from the tonnage shares and average lengths of haul of the two modes:

(i) The rail mode carried a relatively small portion of the total tonnages of CFTM14 (fruits, vegetables and edible foods), CFTM69 (refined petroleum products), CFTM75 (metallic basic products) and CFTM78 (non-metallic basic products). Moreover, the rail and truck modes tended to concentrate on long-haul and short-haul traffic, respectively.

(ii) The total tonnages of CFTM61 (chemicals) and CFTM71 (steel, iron and alloys, etc.) were shared almost equally by the two modes, with a heavy concentration of the railway mode on the longer haul movements. As will be mentioned formally in chapter VII, the rail and truck shares of traffic for CFTM71 reported in Table 6-1 misrepresent what has really happened in the freight market.

Table 6-1, Mean Values of Some Important Variables

Variables \ Commodity Group		CFTM14 Fruits, Vegetables & Edible Foods	CFTM52 Lumber, Including Flooring	CFTM61 Chemicals	CFTM66 Fuel Oil Except Gasoline	CFTM69 Refined Petroleum Products	CFTM71 Steel, Iron & Alloys	CFTM75 Basic Metallic Products	CFTM78 Non-Metallic Products
Revenue share	Railway	0.31	0.49	0.60	0.73	0.32	0.44	0.22	0.32
	Trucking	0.69	0.51	0.40	0.27	0.68	0.56	0.78	0.68
Tonnage share	Railway	0.24	0.66	0.56	0.68	0.20	0.47	0.35	0.34
	Trucking	0.76	0.34	0.44	0.32	0.80	0.53	0.65	0.66
Ton-mile share	Railway	0.50	0.62	0.70	0.75	0.32	0.63	0.49	0.51
	Trucking	0.50	0.38	0.30	0.25	0.68	0.37	0.51	0.49
Average freight rate in cents per ton-mile	Railway	2.43	2.16	2.39	1.98	2.17	2.18	2.27	2.30
	Trucking	5.40	3.70	3.86	2.11	2.15	4.70	7.71	5.25
*speed in miles per day	Railway	126.0	77.0	77.0	51.0	92.0	109.0	126.0	107.0
	Trucking	230.0	204.0	202.0	188.0	209.0	219.0	228.0	219.0
*relia-bility	Railway	4.39	4.14	4.14	4.24	4.10	4.25	4.33	4.34
	Trucking	1.90	1.66	1.65	1.45	1.70	1.80	1.89	1.80
average length of haul in miles	Railway	941.0	351.0	389.0	228.0	450.0	546.0	640.0	552.0
	Trucking	296.0	401.0	207.0	165.0	236.0	292.0	351.0	270.0

*These figures may be misleading in some respects since they are the unweighted mean over all links. "Reliability" is measured in terms of "mean transit-time/standard deviation of transit-time distribution."

in terms of inter-modal competition. This was caused by the aggregation of a wide variety of heterogeneous commodities ranging from primary metals to construction hardwares into this commodity group (see Appendix 4A for a detailed list of commodities included in CFTM71). This is a defect of the CFTM data base.

(iii) The rail mode carried a larger proportion of total tonnages of CFTM52 (lumber including flooring) and CFTM66 (fuel oil). Surprisingly, the average length of haul of the railway traffic for CFTM52 was shorter (351 miles) than that of truck traffic (401 miles). A careful examination of the raw data revealed that this may have happened because trucks carried a major portion of medium-/ long-haul "flooring" traffic. Clearly this is also a defect of the data aggregation in the CFTM data base.

Except for the case of CFTM69 (other refined petroleum products), the average freight rate of trucking service was higher than that of railway service. The average trucking rates for CFTM14, CFTM71, CFTM75 and CFTM78 were more than twice as high as the average railway rates. This is probably due to the truck mode's concentration on relatively short-haul traffic. A surprising aspect of the data is that the average rail freight rate per ton-mile for CFTM69 (other refined petroleum products) was marginally higher (¢2.17) than the average trucking rate (¢2.15) although the average length of haul for the rail traffic was longer (450 miles) than the trucking traffic (236 miles). An examination of the raw data showed that the most probable explanation for the higher railway average rate is that railways moved the major portion of lubricating oil and greases, which are normally more expensive than the other commodities belonging to CFTM69. This is another problem of data aggregation in the CFTM data base.

Although the average speed of the rail mode was substantially slower than that of the truck mode, the reliability measure (reciprocal of the coefficient of variation of transit-time distribution, i.e., mean/standard deviation) was higher for the railway mode. Note that, because of the way in which the reliability variables was constructed, the higher reliability for rail mode does not necessarily mean that for a given link, rail transit time distribution is less dispersed from its mean than that of truck mode.

(B) <u>General Observations About the Chosen Models</u>

The following observations may be made about the chosen models reported in Table 5-1:

(1) The models with the quality variables (speed and reliability) are chosen for the relatively high-value (per ton) commodities such as CFTM14 (fruits, vegetables and edible foods), CFTM75 (metal fabricated basic products such as bolts, nuts, nails, screws, etc.) and CFTM78 (non-metallic basic products such as glass products, tiles, gypsum products, etc.) whereas the models without the quality variables are chosen for the relatively low-value (per ton) industrial raw materials such as CFTM52 (lumber), CFTM61 (chemicals)[2], CFTM66 (fuel oil), CFTM69 (other refined petroleum products) and CFTM71 (steel, iron and alloys, etc.). This shows that shippers of the former commodity groups place higher values on the quality attributes of freight service than do shippers of the latter commodity groups.

(2) The model with mode-specific hedonic aggregators (C-1) is chosen for all the above three commodity groups whose model included the speed and reliability variables. As was mentioned in chapter III, this model implies that shippers base their mode-choice decision on prices adjusted for quality

variations. Since this model has mode-specific hedonic aggregators as its arguments, each hedonic aggregator could take different values of the parameters from those of the other hedonic aggregator.[3] The difference between the two aggregators is likely to have been caused by the following factors: (i) shippers' potential mis-perception of the quality attributes of the two modes[4], and (ii) errors in the model specification including the omitted quality variables such as convenience, flexibility and completeness of service, etc.

(3) The revenue share functions in all the models other than model B include the distance (D_{ℓ}^{r}) as an independent variable. In these models, the link unit cost function is not independent of the distance. Since model B was not chosen for any commodity group, it may be generalized that the choice possibility sets in shippers' transport-sectoral-technology space depend on the distance to transport. As can be noticed from chapter VII, this is the reason why the elasticity of substitution between the two modes tends to vary with distance.

(4) The model with an identical hedonic aggregator for the two modes was not chosen for any commodity

group. Therefore, it appears that the conditions for Rosen-like (see Rosen [1974]) joint application of hedonic price theory to a family of differentiated products are not satisfied in the freight mode-choice decision.

(C) Parameter Estimates and Interpretation of Specific Models

The maximum likelihood (ML) estimates of parameters of the chosen models are reported in Table 6-2 for CFTM14, CFTM75 and CFTM78, in Table 6-3 for CFTM52, CFTM61 and CFTM66, and in Table 6-4 for CFTM69 and CFTM71. In what follows, an attempt will be made to interpret the estimated models.

(1) Model C-1 Reported in Table 6-2:

The parameter estimates of model C-1 for commodity groups CFTM14 (fruits, vegetables and edible foods), CFTM75 (metal fabricated basic products) and CFTM78 (non-metallic basic products) are reported in Table 6-2. The model implies that both speed and reliability variables, as well as freight rates, influence the mode selection decision.

In all the three commodity groups, the parameter estimate a_{rh} (the second-order translog parameter) is statistically significant even at the 1% level of significance. This implies that the Cobb-Douglas model is inappropriate to use. As will be noted in chapter VII, the positive value of a_{rh} indicates that the elasticity of substitution between the two modes is larger than one.[5]

In order to examine the parameter estimates of the hedonic aggregators of the two modes, it seems worthwhile to write the quality-adjusted price functions. By looking back to the derivation of model C in chapter III, these functions can be written as (6,1).

Table 6-2 Parameter Estimates for the Chosen Models (C-1)**

(asymptotic t-statistics in parentheses)

Parameter	CFTM14 (fruits, vegetables & edible foods)	CFTM75 (metal fabricated basic products)	CFTM78 (non-metallic basic products)
$ln a_o$	-2.9471 (0.810)	1.5044 (0.823)	-0.3052 (0.091)
a_r	-0.5246 (2.201)	-0.0650 (0.399)	-0.1718 (0.497)
a_h *	1.5246 (6.288)	-0.0650 (6.424)	1.1173 (3.339)
a_{rr}	-0.0981 (4.926)	-0.0872 (3.738)	-0.1173 (6.191)
a_{hh} *	-0.0981 (4.926)	-0.0872 (3.738)	-0.1173 (6.191)
a_{rh} *	0.0981 (4.926)	0.0872 (3.738)	0.1173 (6.191)
β_r	-0.1340 (0.447)	0.0973 (0.318)	-0.2572 (0.883)
β_h	-0.8963 (1.455)	-0.9771 (2.159)	-1.2283 (1.638)
γ_r	-0.0340 (0.302)	-0.1450 (1.281)	-0.0829 (0.772)
γ_h	-2.4209 (3.959)	-0.9740 (2.387)	-2.4212 (3.365)
δ_r	-0.9504 (3.142)	-0.8664 (2.718)	-0.5283 (2.071)
δ_h	1.3408 (4.040)	0.7430 (2.976)	1.4371 (3.858)

* Denotes that the parameter estimates were computed using the linear homogeneity conditions.

** Model with mode-specific hedonic aggregators specified in terms of price, speed, reliability and distance.

$$(6,1) \qquad P_r^* = P_r Z_{r1}^{\beta_r} Z_{r2}^{\gamma_r} D^{\delta_r} \qquad \text{for rail mode}^6$$

$$P_h^* = P_h Z_{h1}^{\beta_h} Z_{r2}^{\gamma_h} D^{\delta_h} \qquad \text{for truck mode}$$

where P_r^* and P_h^* are the quality-adjusted prices of rail and truck modes, respectively, and all other variables are defined as in (3,17).

The signs of parameters $\beta_r, \gamma_r, \beta_h$ and γ_h are expected to be negative because, for a given observed price, the quality-adjusted price should be lower for a service with a higher level of quality variable. The t-statistics reported in Table 6-2 show that all the parameter estimates for the rail hedonic aggregators β_r (corresponding to "speed" variable) and γ_r (corresponding to "reliability" variable) are not statistically different from zero whereas those for the truck hedonic aggregators (β_h and γ_h) are statistically less than zero at the 10% level of significance (one-tail test). This implies that speed and its reliability of the truck mode influence the demands for both modes but those of the rail mode do not affect the demands significantly. Aside from the statistical insignificance of the parameter estimates of the rail hedonic aggregators, the parameter estimates of the truck hedonic aggregators are consistently larger in absolute value than the corresponding parameters of the rail hedonic aggregators.

The assumption of shippers' rational behaviour rules out the possibility that shippers intentionally place a higher value on the trucking service with the same quality attributes as the railway service. The probable explanations for the difference between the two hedonic functions are: (i) The shippers of the three (relatively high-value) commodity groups may have over-perceived the quality attributes of truck mode and/or under-perceived those of rail mode. (ii) The omitted quality variables such as convenience, flexibility, and completeness of service are likely to favour the truck mode.

(2) Model C-3 Reported in Table 6-3:

Table 6-3 reports the parameter estimates of model C-3 for commodity groups CFTM52 (lumber), CFTM61 (chemicals) and CFTM66 (fuel oil). Model C-3 itself implies that neither speed nor reliability of service significantly influences mode selection. The positive values of a_{rh} (the second-order translog parameter) mean that the elasticity of substitution between the two modes is greater than one. The value of a_{rh} for CFTM52 is not statistically different from zero implying that it is possible to use an appropriate constant elasticities of substitution (CES) model in place of the translog cost function. This point will become clearer in chapter VII.

(3) Model A-3 Reported in Table 6-4:

Table 6-4 reports the parameter estimates of model A-3 for commodity groups, CFTM69 (other refined petroleum products) and CFTM71 (steel, iron and alloys). Since model A-3 does not

Table 6-3 Parameter Estimates of the Chosen Models (C-3)**

(asymptotic t-statistics in parentheses)

Parameter	CFTM52 (lumber, inc. flooring)	CFTM61 (chemicals)	CFTM66 (fuel oil other than gasoline)
$\ln a_o$	-1.0222 (1.024)	-0.8298 (1.613)	-1.533 (1.224)
a_r	0.5711 (4.532)	0.0294 (0.202)	-0.0574 (0.288)
a_h *	0.4289 (3.320)	0.9706 (6.566)	1.0574 (5.207)
a_{rr}	-0.0111 (0.790)	-0.1368 (5.813)	-0.0846 (3.176)
a_{hh} *	-0.0111 (0.790)	-0.1368 (5.813)	-0.0846 (3.176)
a_{rh} *	0.0111 (0.790)	0.1368 (5.813)	0.0846 (3.176)
δ_r	1.18636 (2.633)	-0.2991 (2.765)	-0.6499 (2.275)
δ_h	-0.8913 (2.299)	0.2661 (2.479)	0.5190 (1.988)

* Denotes that the parameter estimates were computed using the linear homogeneity conditions.

** Note that model (C-3) is equivalent to model (D-3): model with mode-specific hedonic aggregators specified in terms of price and distance only.

Table 6-4 Parameter Estimates of the Chosen Models (A-3)**

(asymptotic t-statistics in parentheses)

Parameter	Commodity Group			
	CFTM69 (other refined petroleum products)		CFTM71 (steel, iron and alloys, etc.)	
$ln a_o$	-0.0325	(0.027)	-0.0575	(0.115)
a_r	-0.6841	(4.497)	-0.6238	(5.356)
d	0.0559	(0.139)	0.0091	(0.053)
a_{rr}	-0.0883	(3.755)	-0.2740	(16.0)
dd	-0.0209	(0.312)	-0.0054	(0.187)
ad_r	0.1733	(6.869)	0.1626	(8.799)
a_h *	1.6841	(10.852)	1.6238	(7.658)
a_{hh} *	-0.0883	(3.755)	-0.2740	(16.0)
a_{rh} *	0.0883	(3.755)	0.2740	(16.0)
ad_h *	-0.1733	(6.869)	-0.1626	(8.799)

* Denotes that the parameter estimates were computed using the linear homogeneity conditions.

** General model specified in terms of prices and distance only.

include speed and reliability variables, the shippers of these commodities do not seem to place significant values on the quality variables. The positive signs of a_{rh} (the second-order translog parameter) imply that the elasticity of substitution is greater than unity for both of the commodities. Since the value is larger for CFTM71 (a_{rh} = .274) than for CFTM69 (= .0883), *ceteris paribus*, the inter-modal substitutibility is higher for the shipments of CFTM71 than those of CFTM69. The lower inter-modal substitutibility for CFTM69 may be justified intuitively because, normally, special types of rolling stocks and equipment are required to handle it.

(D) Summary of the General Findings

Based on the discussions in sections (B) and (C), the general findings from the chosen models may be summarized as follows:

(i) Speed and reliability variables significantly influence mode selection for the relatively high-value commodities but not for the low-value industrial raw materials. For those commodities whose mode-choice is significantly influenced by the quality variables, the parameter estimates of the truck hedonic aggregators are consistently larger in absolute value than the corresponding parameters of rail hedonic aggregators. Moreover, the parameter estimates of the rail hedonic aggregators are not statistically different from zero.

(ii) For all commodity groups, the choice-possibility sets faced by the shippers depend upon the distance to transport.

(iii) For all the commodity groups, the elasticity of rail-truck substitution is greater than unity because of the positivity of the second-order parameter (a_{rh}).

(iv) Since the second-order translog parameter (a_{rh}) is significantly different from zero, the Cobb-Douglas model is inappropriate for freight demand studies for all the commodity groups other than CFTM52 (lumber including flooring).

Footnotes for Chapter VI:

1. Users of the CFTM data base are not allowed to quote the price and quality variables for specific links.

2. As can be seen from Appendix 4A, commodity group CFTM61 consists of chemicals mainly for industrial use.

3. If (i) the functional form correctly represents the quality-adjusted price function over the entire range of all possible levels of quality attributes, (ii) if shippers are consistent in evaluating the values of quality attributes of the two modes, and (iii) if there is no misperception of the levels of quality attributes of the two modes, then the parameter estimates of the two hedonic aggregators should not be different, at least statistically, as in model D-1.

4. The existence of this misperception does not violate the basic postulate of the optimization models, because shippers still behave optimally but only on the basis of the perceived levels of quality attributes of the two modes, whereas the models are estimated using the actual levels.

5. See the formula for the elasticity of substitution in equation (7,3).

6. Heaver and Oum [1977] reported a slightly different form of hedonic price function estimated from more aggregated Canadian data.

CHAPTER VII

ELASTICITY ESTIMATES AND INTER-MODAL COMPETITION

Having discussed the general findings of this study in the preceding chapter, it is now appropriate to examine some findings concerning specific segments of the Canadian intercity freight market.

For some time, Transport Canada has been preparing for a major revision of the 1967 National Transportation Act (NTA) which would empower the government with the flexibility to apply different sets of regulatory policies to different segments of the transport market depending on the "maturity" of transportation service and the extent of competition in each specific market.[1] Undoubtedly, the correct identification of the extent of competition existing in various segments of the freight market is an essential pre-requisite for implementing such a flexible regulatory policy. Realizing this importance, Heaver and Nelson [1977] have studied the workings of competitive forces under the commercial freedom underlying the 1967 NTA, by examining primarily the process of shipper-carrier negotiations and mutual adaptations to the changing market conditions. Their major conclusion was that, although the extent of visible competition varies from market to market, there is a significant level of "dynamic competition"[2] throughout the Canadian intercity transport market. While their study identifies some descriptive facts about the nature and process of competition, so far no one has attempted to measure systematically the extent of inter-modal competition existing in various segments of the Canadian intercity freight market.

In view of the rising current interest on this issue, therefore, the discussion in this chapter will be focused upon identifying the extent of inter-modal competition existing in various segments of the freight market. To achieve this objective, this chapter is organized as follows: In section A, the formulae for the elasticities of demand with respect to the price and quality variables and for the elasticity of substitution are presented. (The detailed derivations are presented in Appendix 7A.) In addition, the elasticities are evaluated at the mean values of the variables, and compared across the eight CFTM commodity groups. Section B reports the elasticity estimates for each of the major links. These elasticity estimates are used to determine, for each commodity group, the range of distance over which effective inter-modal competition exists.

(A) <u>Elasticity Estimates at the Mean Values of the Variables</u>

Chapter VI showed that shippers of the low-value industrial raw materials (note that these are mainly bulk commodities) make their mode-choice decision primarily on the basis of freight rates, whereas shippers of the high-value commodities (note that these are mainly manufactured commodities) base their mode-choice on both freight rates and quality attributes of service. Carriers' management as well as government regulators are normally interested in seeing what would happen to demands for the two modes if a certain change in freight rate or quality of service is to be introduced. The extent of the effect of such a change can best be measured by the Allen partial elasticities of substitution[3] and elasticities of demand with respect to price and quality variables. In this section, therefore, the formulae for these elasticities are derived, along with an investigation of their properties, and applied to estimate the elasticities evaluated at the mean values of the variables.

Allen [1938] defined the partial elasticity of substitution between two inputs of production, X_i and X_j, as:

$$(7,1) \qquad \sigma_{ij} \equiv \frac{\sum_{k=1}^{M} X_k f_k}{X_i \; X_j} \frac{\tilde{F}_{ij}}{F} \qquad \text{for all } i,j = 1,2,\ldots,M.$$

where

f_k denotes the first partial derivative of the production function $f(X)$ with respect to <u>k</u>th input (X_k),

F denotes the determinant of the bordered Hessian matrix of second-order derivatives of the production function $f(X)$,

$\tilde{F}_{ij}$ denotes the (i,j)th co-factor of F, and

X_i and X_j denote ith and jth inputs, respectively.

Furthermore, Allen [1938] has shown the following additive property of the partial elasticities of substitution:

$$(7,2) \qquad \sum_{j=1}^{M} \sigma_{ij} S_j = 0 \qquad \text{for all } i=1,2,\ldots,M.$$

where

S_j = the share of expenditures (revenue share from carrier's viewpoint) for the jth mode.

Later, Uzawa [1962] derived the following expression for the Allen partial elasticities of substitution in terms of cost function:

$$(7,3a) \qquad \sigma_{ij} = \frac{C\,C_{ij}}{C_i C_j} \qquad \text{for all } i \neq j$$

where

C = the cost function,

C_i = first partial derivative of C with respect to the price of input X_i,

C_{ij} = second partial derivative of C with respect to prices of inputs X_i and X_j.

For a two-mode translog cost function, the Allen elasticity of substitution (AES) can be written as:

(7,3b) $$\sigma_{rh} = \frac{C\,C_{rh}}{C_r C_h} = \frac{S_r S_h + a_{rh}}{S_r \cdot S_h}$$

where

S_i = the revenue share of the ith mode,

a_{rh} = a second-order parameter of the translog cost function.

The additive property (7,2) and equation (7,3b) together allow one to write the following equation:

(7,3c) $$\sigma_{ii} = \frac{-\sigma_{ij} S_j}{S_i} = \frac{a_{ii} + S_i^2 - S_i}{S_i^2} \qquad i,j = r,h$$

where

a_{ii} is a second-order parameter of the translog cost function and is equal to $-a_{rh}$ due to linear homogeneity of the cost function discussed in chapter III.

As is shown in Appendix 7A, the elasticity of Hicksian (compensated) demand for the ith mode with respect to the freight rate of the jth mode and of the ith mode can be written as (7,4a) and (7,4b), respectively.

(7,4a) $$E_{ij} \equiv \frac{\partial X_i}{(\partial P_j)}_{\text{isoquant}} \cdot \frac{P_j}{X_i}$$

$$= \frac{a_{ij} + S_i \cdot S_j}{S_i} = S_j \cdot \sigma_{ij} \text{ using (7,3b) for all } i \neq j$$

$$(7,4b) \qquad E_{ii} = \frac{a_{ii} + S_i^2 - S_i}{S_i} = S_i \sigma_{ii} \text{ using (7,3c)}$$

for all i = r,h

Since the Hicksian (compensated) demand function only takes substitution effects into account, a new measure of price responsiveness of demand is required to include the effect of a change in freight rate on the shippers' output level. Adapting the Allen's formula [Allen,1938] to our sectorally separable structure, the elasticity of Marshallian (ordinary) demand for the ith mode with respect to the price of the jth mode, F_{ij}, can be written as[4]:

$$(7,5) \qquad F_{ij} = S_j(\sigma_{ij} + \lambda_j \eta) \qquad i,j = \begin{cases} r\text{(rail)} \\ h\text{(truck)} \end{cases}$$

where

$\lambda_j = \frac{dP}{dp_j} \frac{p_j}{p}$ is the proportion of change in the commodity's price (p) with respect to a change in the price of the jth mode (p_j).

$\eta = \frac{dY}{dp} \frac{p}{Y}$ is the price elasticity of demand for the commodity (shiper's product).

Note that the price elasticity of ordinary demand for a mode depends, among other things, on the competition in the destination commodity market, which is the so-called "market competition" in transportation literature.

If η and λ_j's for a commodity group are known to us, the formula (7,5) can be used to compute the price elasticities of ordinary demand for each mode. Since these were not readily available, the price elasticities F_{ij}'s reported in this chapter were computed under the rather arbitrary assumptions of $\eta = -1$ and $\lambda_j = 0.1$ for all j's.

was not readily available, the price elasticities of ordinary demands (F_{ij}'s) for rail and truck modes reported in this chapter were computed under a rather arbitrary assumption that the commodity price elasticity η is unity; i.e., $\eta = -1$.

Turning attention to the quality responsiveness of demand, the elasticity of demand for the <u>i</u>th mode with respect to the <u>n</u>th quality attribute of the <u>j</u>th mode may be defined as:

$$(7,6) \qquad E_{ij}^{\ n} \equiv \frac{d\,ln X_i}{d\,ln Z_{jn}} = \frac{\partial X_i}{\partial Z_{jn}} \; \frac{Z_{jn}}{X_i}$$

$$i,j = r,h$$

$$n = 1,2,\ldots,N.$$

As is shown in Appendix 7A, in the context of our translog cost function (3,17a) for model C-1, $E_{ij}^{\ n}$ can be written as:

$$(7,7) \qquad E_{ij}^{\ n} = \begin{cases} \dfrac{B_{jn}\ (a_{ij} + S_i \cdot S_j)}{S_i} = B_{jn}E_{ij} & \text{for all } i \neq j \\[2ex] \dfrac{B_{in}\ (a_{ii} + S_i^{\ 2} - S_i)}{S_i} = B_{in}E_{ii} & \text{for all } i = j \end{cases}$$

where

$$B_{jn} = \begin{cases} \beta_r,\ \beta_h \text{ when } n = 1 \text{ (speed)} \\ \gamma_r,\ \gamma_h \text{ when } n = 2 \text{ (reliability)}. \end{cases}$$

This completes the derivation of the formulae for computing the elasticity of rail-truck substitution and elasticities of demand with respect to freight rates and quality attributes of service.

The formulae in equations (7,3), (7,4) and (7,5) are used here to evaluate various elasticities at the mean values of the variables reported in Table 6-1, and the results are reported in Table 7-1. The estimated elasticity of substitution is the lowest for CFTM52 (lumber including flooring: $\sigma_{rh} = 1.044$) and the highest for CFTM71 (steel, iron and alloys, etc.: $\sigma_{rh} = 2.132$). This implies that as the price ratio of the two modes, P_h/P_r, increases by one percent, the ratio of the demands for the two modes, X_r/X_h, increases by 1.044% for the case of CFTM52 and by 2.132% for the case of CFTM71. Clearly, the highest inter-modal substitutibility obtained for CFTM71 (steel, iron and alloys, etc.) is counter-intuitive. This elasticity of substitution ($\sigma_{rh} = 2.132$) is likely to have been over-estimated[5] because a wide variety of heterogeneous commodities ranging from primary metals to construction hardwares are aggregated into the commodity group CFTM71 (see Appendix 4A for a detailed list of the commodities included in this commodity group). As a result, one cannot rely on the elasticity results estimated from the CFTM71 data. Therefore, the model for this commodity group will not be discussed further in the remainder of this thesis.

Equation (7,3b) implies that the elasticity of substitution, σ_{rh}, is greater than one if the translog parameter a_{rh} is positive. Since, for all the chosen models reported in Tables (6-2), (6-3) and (6-4), the estimate a_{rh} is positive, σ_{rh} is greater than one for all the commodity groups. This implies that the two modes are highly substitutible.

Note an analytical fact that, in the two-mode model, the

Table 7-1, Comparison of Elasticities (Evaluated at Means of Variables)

Commodity Group / Elasticities	*CFTM14 Fruits, Vegetables & Edible Foods	CFTM52 Lumber, Including Flooring	CFTM61 Chemicals	CFTM66 Fuel Oil Except Gasoline	CFTM69 Refined Petroleum Products	CFTM71 Steel, Iron & Alloys	CFTM75 Basic Metallic Products	CFTM78 Non-Metallic Products
σ_{rh}	1.458	1.044	1.57	1.429	1.4	2.132	1.508	1.539
σ_{rr}	-3.2466	-1.087	-1.047	- .5286	-2.987	-2.714	-5.347	-3.271
σ_{hh}	- .6553	-1.003	-2.355	-3.864	- .6615	-1.675	- .4254	- .7243
E_{rr}	-1.006	- .5324	- .6282	- .3858	- .9560	-1.194	-1.176	-1.047
E_{rh}	1.006	.5324	.6282	.3858	.9560	1.194	1.176	1.047
E_{hr}	.4522	.5116	.942	1.043	.4499	.9381	.3318	.4925
E_{hh}	- .4522	- .5116	- .942	-1.043	- .4499	- .9381	- .3318	- .4925
F_{rr}	-1.037	- .5814	- .6882	- .4588	- .988	-1.238	-1.198	-1.079
F_{hh}	- .5212	- .5626	- .982	-1.07	- .5179	- .9941	- .4098	- .5605

σ_{ij} = elasticity of substitution between modes i and j.

E_{ij} = compensated elasticity of demand for ith mode with respect to freight rate of jth mode.

F_{ii} = ordinary elasticity of demand for ith mode with respect to its own freight rate computed assuming unitary elasticity of demand for the commodity and value of 0.1 for all λ_j's.

*"CFTM" stands for Canadian Freight Transportation Model commodity group.

Subscripts "r" and "h" stand for rail and highway (truck) modes, respectively.

cross price elasticity, E_{rh} (or E_{hr}), is the negative of the own-price elasticity, E_{rr} (or E_{hh}) because the compensated price elasticities of a mode sum to zero, i.e., $E_{rr} + E_{rh} = 0$ and $E_{hr} + E_{hh} = 0$. The (Hicksian) compensated demand for the rail mode is price-elastic for CFTM14, CFTM75 and CFTM78, and price-inelastic for the other four commodity groups. The compensated demand for the truck mode is price-elastic only for CFTM66 (fuel oil other than gasoline).

Generally, the ordinary demand for the rail mode is own-price-elastic for the relatively high-value commodities such as CFTM14, CFTM75 and CFTM78, and is own-price-inelastic for the relatively low-value commodities such as CFTM52, CFTM61 and CFTM66. The absolute values of the own-price elasticities for the truck mode are close to unity for the commodity groups CFTM61, CFTM69 and CFTM71, but are between 0.41 and 0.56 for all the other commodities. Of course, one should keep in mind that these estimates are subject to the highly arbitrary assumptions of $\eta=-1$ and $\lambda_j=0.1$ for all j's.

(B) The Elasticity Estimates on Some Selected Links and Inter-modal Competition

In section A, a single set of various elasticities were computed for each commodity group as the aggregate indicators of the competition existing in the particular commodity freight market in general. However, the extent of competition is likely to be different not only from commodity to commodity but also from link to link. In this section, therefore, the elasticities of demand with respect to the price and quality variables and the elasticity of substitution are computed separately for each of the major links. The results are reported in Tables 7-2 to 7-8.

For an effective interpretation of the information in the tables, it is beneficial to know the following relations between each of the elasticity measures and the division of the revenue shares between the two modes:

1. From the formula in equation (7,3b), it is easy to see that the elasticity of substitution, σ_{rh}, increases as the absolute deviation between the two shares $|S_r - S_h|$ is increased because the translog parameter a_{rh} is positive in all the chosen models. As a result, σ_{rh} is minimized when $S_r = S_h = 0.5$.

2. If $|S_r - S_h|$ is large, and $S_r > S_h$ in a particular freight market, then there are two forces acting to increase the compensated elasticity of demand for the trucking service as shown below:

   E_{hr} $(= - E_{hh}) = \sigma_{rh}\ S_r$ gets large because of both the large σ_{rh} caused by the large value of $|S_r - S_h|$ and the large S_r.

   This condition occurs normally on the long-haul links where the rail mode dominates the traffic.

3. If $|S_r - S_h|$ is large and $S_r < S_h$ in a particular freight market, the compensated elasticity of the demand for rail mode, E_{rh} $(= -E_{rr}) = \sigma_{rh} S_h$, becomes large because of both the large σ_{rh} and the large S_h. This condition occurs normally on the short-haul links where the truck mode dominates the traffic.

The above analytical results show that as the distance increases the elasticity of demand for the rail mode decreases and that for the truck mode increases, and vice versa. This can be intuitively justified in terms of the relative cost structures of the two modes because as the length of haul increases, the truck mode becomes increasingly disadvantageous relative to the rail mode, and as the length of haul decreases, the rail mode becomes increasingly disadvantageous relative to the truck mode. On the links where one mode dominates a major portion of the traffic and no significant inter-modal competition exists, the demand for the other mode is likely to be price-elastic. The carriers of the latter mode have to operate on the elastic portion of their demand curve for the following reasons:

1. An increase in price would reduce the traffic proportionally more than the price increase, and thus reduce the revenue.

2. Although a reduction of the price would increase the traffic proportionally more than the price reduction, the pressure of cost eliminates such a possibility because the carriers are presumably offering a freight rate quite close to their marginal cost in the relatively disadvantageous market. Even if it were possible, the reduction of price would invoke a price war with the competitive mode which has a cost advantage.

Although service competition among trucking firms has been fairly high in some corridor routes, the intra-modal price competition has been negligible in the railway industry and marginal in the trucking industry in Canada. Therefore, for a given commodity, the extent of inter-modal competition is the single most important factor which determines the compensated price elasticities of demand in various freight markets. Due to the reasons stated previously, on those links where inter-modal competition is not significant, at least one of the modes should have a price-elastic demand. Since the compensated price-elasticity of rail demand E_{rr} decreases with distance whereas that of truck demand E_{hh} increases with distance, rail and truck modes will dominate the long-haul and short-haul links, respectively, leaving the medium-haul links as the potential markets for the inter-modal competition.

In what follows, for each commodity group, an attempt is made to identify the upper-bound of distance up to which truck mode practically dominates the traffic and the lower-bound of distance beyond which rail mode dominates the traffic. The criterion used for the identification is as follows: a market is regarded *truck-dominated* if $|E_{rr}| > 1$ and $|E_{rr}| > 2 \cdot |E_{hh}|$, and *rail-dominated* if $|E_{hh}| > 1$ and $|E_{hh}| > 2 \cdot |E_{rr}|$.

(1) <u>The Results for CFTM14 (Fruits, Vegetables and edible foods):</u>

Table 7-3 reports the elasticity of substitution and the elasticities of demand with respect to prices, speed and reliability computed for the selected links. The distances of

Table 7-2, Estimated Parameters of Price and Quality Responsiveness of Demands for CFTM14

(Fruits, vegetables and edible foods)

Link			Compensated price elasticities			Speed elasticities				Reliability elasticities			
Origin*	Dest'n.*	Miles	E_{rr}	E_{hh}	σ_{rh}	E_{rr}^{1} **	E_{rh}^{1}	E_{hh}^{1}	E_{hr}^{1} **	E_{rr}^{2}	E_{rh}^{2}	E_{hh}^{2}	E_{hr}^{2} **
11. P.E.I.	53. Toronto	1067	-0.75	-0.64	1.39	0.10	-0.67	0.57	-0.09	0.02	-1.83	1.55	-0.02
33. St. John	46. Montreal	590	-0.91	-0.51	1.42	0.12	-0.82	0.46	-0.07	0.03	-2.21	1.24	-0.02
33. St. John	53. Toronto	925	-0.84	-0.57	1.41	0.11	-0.75	0.51	-0.08	0.03	-2.02	1.38	-0.02
46. Montreal	43. Quebec	173	-1.13	-0.39	1.52	0.15	-1.01	0.35	-0.05	0.04	-2.73	0.94	-0.01
46. Montreal	53. Toronto	335	-1.10	-0.40	1.50	0.15	-0.98	0.36	-0.05	0.04	-2.66	0.97	-0.01
46. Montreal	71. Regina	1783	-0.44	-1.03	1.47	0.06	-0.39	0.92	-0.14	0.01	-1.06	2.49	-0.04
46. Montreal	95. Vancouver	2908	-0.40	-1.11	1.51	0.05	-0.35	1.0	-0.15	0.01	-0.96	2.69	-0.04
53. Toronto	25. Halifax	1113	-0.70	-0.69	1.39	0.09	-0.62	0.62	-0.09	0.02	-1.69	1.67	-0.02
53. Toronto	46. Montreal	335	-0.95	-0.49	1.44	0.13	-0.85	0.43	-0.07	0.03	-2.31	1.17	-0.02
53. Toronto	56. Windsor	229	-1.13	-0.39	1.52	0.15	-1.01	0.35	-0.05	0.04	-2.73	0.93	-0.01
53. Toronto	67. Winnipeg	1256	-0.70	-0.69	1.39	0.09	-0.63	0.62	-0.09	0.02	-1.70	1.66	-0.02
53. Toronto	95. Vancouver	2736	-0.51	-0.92	1.43	0.07	-0.46	0.82	-0.12	0.02	-1.23	2.22	-0.03
54. Hamilton	57. Kitchener	78	-1.70	-0.23	1.93	0.22	-1.53	0.21	-0.03	0.05	-4.12	0.55	-0.01
67 Winnipeg	46. Montreal	1428	-0.65	-0.75	1.40	0.09	-0.58	0.67	-0.10	0.02	-1.56	1.80	-0.03
67. Winnipeg	53. Toronto	1256	-0.84	-0.56	1.40	0.11	-0.75	0.50	-0.07	0.03	-2.04	1.36	-0.02
67. Winnipeg	71. Regina	356	-1.03	-0.44	1.47	0.13	-0.92	0.39	-0.06	0.03	-2.49	1.06	-0.01
67. Winnipeg	95. Vancouver	1480	-0.51	-0.91	1.42	0.06	-0.46	0.81	-0.12	0.01	-1.24	2.20	-0.03
71. Regina	73. Saskatoon	161	-1.67	-0.23	1.90	0.22	-1.50	0.21	-0.03	0.06	-4.05	0.56	-0.01
86. Edmonton	83. Calgary	190	-1.13	-0.38	1.51	0.15	-1.01	0.35	-0.05	0.04	-2.74	0.93	-0.01
95. Vancouver	53. Toronto	2736	-0.40	-1.10	1.50	0.05	-0.36	0.98	-0.15	0.01	-0.97	2.65	-0.03
95. Vancouver	67. Winnipeg	1480	-0.66	-0.74	1.40	0.09	-0.59	0.65	-0.09	0.02	-1.59	1.77	-0.03

* Numbers preceding names of origin and destination are the CFTM region codes.

** These elasticities may be regarded as zero because the parameter estimates β_r and γ_r are not statistically different from zero (see Table 6-2).

the links are also listed in the table. As is expected from the previous discussion on the relationship between the elasticities and the distance, the compensated own-price elasticity of demand for the railway service (E_{rr}) is roughly inversely related to distance of the link while the reverse is true for the trucking service. The links on which $|E_{rr}| > 1$ and $|E_{rr}| > 2 \cdot |E_{hh}|$ are:

Link name	Miles	E_{rr}	E_{hh}
Hamilton-Kitchener	78	-1.70	-0.23
Regina-Saskatoon	161	-1.67	-0.23
Montreal-Quebec	173	-1.13	-0.39
Edmonton-Calgary	190	-1.13	-0.38
Toronto-Windsor	229	-1.13	-0.39
Montreal-Toronto	335	-1.10	-0.40
Winnipeg-Regina	350	-1.03	-0.44

The links on which $|E_{hh}| > 1$ and $|E_{hh}| > 2 \cdot |E_{rr}|$ are:

Link name	Miles	E_{rr}	E_{hh}
Montreal-Regina	1783	-0.44	-1.03
Toronto-Vancouver	2736	-0.51	-1.10
Montreal-Vancouver	2908	-0.40	-1.11

Although there are a few exceptions, a careful examination of the above lists and Table 7-2 allows the following general remarks on the inter-modal competition for this traffic:

(i) The trucking mode tends to dominate the traffic moving up to about 400 miles, whereas the rail mode dominates the traffic moving longer than 1800 miles.

(ii) Therefore, the effective inter-modal competition for this traffic is likely to exist only on those links whose distance is between 400 and 1800 miles.

Table 7-2 shows also that the signs of the elasticities of demand with respect to quality variables conform to our expectation. Generally, the elasticities of demand for railway service with respect to speed and reliability of trucking service, E_{rh}^{1} and E_{rh}^{2}, are in absolute value very high on short-haul traffic but decrease gradually with distance. Elasticities of demand for trucking service with respect to its own speed and reliability, E_{hh}^{1} and E_{hh}^{2}, follow a pattern that is exactly opposite to those of railways. These also show that effective inter-modal competition exists only for medium-haul traffic. The quality elasticity measures, E_{rr}^{1}, E_{hr}^{1}, E_{rr}^{2} and E_{hr}^{2} are very small in absolute value implying that a (small) change in the quality attributes of railway service is not much appreciated by the shippers, and consequently is not an effective means to compete against the trucks. Note that these elasticity estimates may be regarded as zero because the parameter estimates β_r and γ_r are not statistically different from zero as mentioned in chapter VI.

(2) <u>The Results for CFTM52 (Lumber including flooring)</u>:

Table 7-3 reports the compensated price elasticities and elasticity of substitution between the two modes for this commodity group.

Notice from the table that the elasticity of substitution between the two modes is almost same (σ_{rh} = 1.04 or 1.05) on

Table 7-3, Price Elasticities and Elasticity of Substitution for CFTM52 (Lumber including flooring)

Link: Origin*	Dest'n.*	Miles	Compensated price elasticities (1) E_{rr}	(2) E_{hh}	Elasticity of Substitution (3) σ_{rh}
32. Moncton	53. Toronto	949	-0.62	-0.43	1.05
33. St. John	53. Toronto	925	-0.62	-0.43	1.05
43. Quebec City	46. Montreal	173	-0.56	-0.48	1.04
46. Montreal	25. Halifax	778	-0.59	-0.46	1.05
46. Montreal	43. Quebec	173	-0.56	-0.48	1.04
46. Montreal	45. Sherbrook	102	-0.55	-0.49	1.04
53. Toronto	25. Halifax	1113	-0.61	-0.44	1.05
53. Toronto	46. Montreal	335	-0.59	-0.46	1.05
53. Toronto	56. Windsor	229	-0.57	-0.47	1.04
53. Toronto	59. Sudbury	248	-0.57	-0.47	1.04
54. Hamilton	59. Sudbury	289	-0.59	-0.46	1.05
59. Sudbury	46. Montreal	436	-0.56	-0.48	1.04
59. Sudbury	53. Toronto	248	-0.57	-0.47	1.04
59. Sudbury	57. Kitchener	308	-0.59	-0.46	1.05
67. Winnipeg	50. T.-Bay	434	-0.56	-0.48	1.04
86. Edmonton	83. Calgary	190	-0.59	-0.46	1.05
46. Montreal	53. Toronto	335	-0.57	-0.47	1.04

* Numbers preceding names of origin and destination are the CFTM region codes.

all links. The similarity of σ_{rh} across the links is caused by the statistical insignificance of the second-order parameter, a_{rh}, of the translog function mentioned previously in chapter VI. As indicated previously, therefore, an appropriate constant elasticity of substitution (CES) model can be used for this commodity group in place of the translog function.

Notice also from Table 7-1 that the elasticity of substitution for this commodity is the lowest among all the eight commodity groups. Furthermore, even this low elasticity of substitution (σ_{rh} = 1.044) may be considered as an over-estimated figure for the true substitutibility due to the aggregation of two different products: lumber moved primarily by rail mode, and flooring, a major portion of which is moved by truck mode. The reason for the low substitutibility relative to the other commodity groups may be that the lumber shippers who have the access to rail system may not consider the trucking service as an effective alternative.

None of the links listed in Table 7-3 has an elastic demand for either one of the two modes, and the compensated price elasticities are quite stable from link to link; $0.56 \leq |E_{rr}| \leq 0.62$, $0.43 \leq |E_{hh}| \leq 0.49$. These elasticities are not related to the distance of the link unlike the relationships found for other commodity groups. This strange behaviour of the elasticities may be partly due to the low substitutibility, and partly due to the aggregation problem. Therefore, it may be that there is no significant inter-modal competition in this freight market, and shipper's mode-choice is determined largely by the accessibility to rail service.

(3) The Results for CFTM61 (chemicals):

The elasticity estimates for this commodity group are reported in Table 7-4 along with the elasticity of substitution between the two modes. As in the case of CFTM14, the compensated elasticity of demand for the rail mode tends to decrease with the distance of a link whereas that for the truck mode increases with it. Generally on those links whose distance exceeds 500 miles, the compensated demand for truck mode was price-elastic (i.e., $|E_{hh}| > 1$) and $|E_{hh}| > 2 \cdot |E_{rr}|$. This implies that the rail mode generally dominated the traffic moving beyond 500 miles. However, no link had a price-elastic compensated demand for rail mode. Therefore, it can be concluded that the effective inter-modal competition starts at a very short distance (probably 100 miles), and ends at the distance of around 500 miles.

(4) The Results for CFTM66 (fuel oil other than gasoline):

This is the commodity group for which the inter-modal price competition seems to be quite strong. The average revenue per ton-mile was ¢1.98 for the railway mode carrying the average of 228 miles, and ¢2.11 for the truck mode carrying the average distance of 165 miles. With a few exceptions, however, most medium-/long-haul traffic was moved

Table 7-4, Price Elasticities and Elasticity of Substitution for CFTM61 (chemicals)

Link			Compensated price elasticities		Elasticity of Substitution
Origin*	Dest'n.*	Miles	E_{rr}	E_{hh}	σ_{rh}
33. St. John	53. Toronto	925	-.88	- .68	1.55
46. Montreal	25. Halifax	778	-.51	-1.12	1.63
46. Montreal	33. St. John	590	-.55	-1.06	1.61
46. Montreal	43. Quebec	137	-.81	- .74	1.55
46. Montreal	53. Toronto	335	-.68	- .87	1.56
46. Montreal	71. Regina	1783	-.49	-1.17	1.66
53. Toronto	46. Montreal	335	-.69	- .86	1.55
53. Toronto	59. Sudbury	248	-.71	- .84	1.55
53. Toronto	67. Winnipeg	1256	-.45	-1.26	1.71
56. Windsor	46. Montreal	564	-.59	- .99	1.58
56. Windsor	53. Toronto	229	-.71	- .84	1.55
56. Windsor	86. Edmonton	2132	-.56	-1.04	1.60
67. Winnipeg	73. Saskatoon	493	-.20	-3.58	3.77
67. Winnipeg	86. Edmonton	822	-.49	-1.18	1.66
83. Calgary	86. Edmonton	190	-.62	- .95	1.57

* Numbers preceding names of origin and destination are the CFTM region codes.

by railways. The railways moved 68% of the total tonnage of this traffic.

Table 7-5 shows that the demand for railway service is not price-elastic on any of the links listed in the table whereas the demand for truck mode is price-elastic generally on those links, the distance of which exceeds about 400 miles. This implies that the effective inter-modal competition starts from very short distance but ends when the distance reaches 400 miles. Beyond this distance, the rail mode dominates the traffic.

(5) The Results for CFTM69 (Refined petroleum products other than gasoline, fuel oil, coke and gas):

The elasticities of demand and elasticity of substitution for this commodity group are reported in Table 7-6. The demand for railway service is generally price-elastic on short-haul links whose distance is less than 300 miles while the demand for trucking service is price-elastic on long-haul links over 1500 miles. Therefore, the effective inter-modal competition is likely to exist for medium-haul traffic over the distance between 300 and 1500 miles.

(6) The Results for CFTM75 (Metal fabricated basic products):

Shippers of this commodity group demonstrated a strong preference for the truck mode over railways even on many long-haul links. On those links whose distance is less than 400 miles, the two conditions for truck-domination were satisfied (see Table 7-7): i.e., $|E_{rr}| > 1$ and $|E_{rr}| > 2 \cdot |E_{hh}|$. This

Table 7-5, Price Elasticities and Elasticity of Substitution for CFTM66 (Fuel oil other than gasoline)

Link			Compensated price elasticities		Elasticity of Substitution
Origin*	Dest'n.*	Miles	E_{rr}	E_{hh}	σ_{rh}
25. Halifax	32. Moncton	180	-.62	- .72	1.34
46. Montreal	43. Quebec	173	-.76	- .58	1.34
46. Montreal	45. Sherbrooke	102	-.71	- .63	1.34
46. Montreal	53. Toronto	335	-.39	-1.04	1.43
46. Montreal	59. Sudbury	436	-.34	-1.13	1.47
53. Toronto	46. Montreal	335	-.53	- .83	1.36
53. Toronto	56. Windsor	229	-.83	- .53	1.36
53. Toronto	59. Sudbury	248	-.54	- .81	1.35
53. Toronto	67. Winnipeg	1256	-.38	-1.06	1.44
56. Windsor	46. Montreal	564	-.37	-1.07	1.44
56. Windsor	53. Toronto	229	-.58	- .76	1.34
67. Winnipeg	50. T.-Bay	434	-.21	-1.65	1.86
67. Winnipeg	86. Edmonton	822	-.43	- .96	1.40
71. Regina	67. Winnipeg	356	-.91	- .47	1.38
95. Vancouver	83. Calgary	649	-.53	- .83	1.36

* Numbers preceding names of origin and destination are the CFTM region codes.

Table 7-6, Price Elasticities and Elasticity of Substitution for CFTM69 (Other refined petroleum products)

Link			Compensated Price elasticities		Elasticity of Substitution
Origin*	Dest'n.*	Miles	E_{rr}	E_{hh}	σ_{rh}
25. Halifax	21. Sydney	271	-1.00	-0.42	1.42
46. Montreal	25. Halifax	778	-0.69	-0.66	1.35
46. Montreal	33. St. John	590	-0.41	-1.02	1.43
46. Montreal	43. Quebec	173	-1.14	-0.35	1.49
46. Montreal	45. Sherbrooke	102	-1.64	-0.22	1.86
46. Montreal	53. Toronto	335	-0.79	-0.57	1.36
46. Montreal	67. Winnipeg	1428	-0.52	-0.86	1.38
46. Montreal	95. Vancouver	2908	-0.20	-1.78	1.98
53. Toronto	33. St. John	925	-0.59	-0.77	1.36
53. Toronto	46. Montreal	335	-0.85	-0.52	1.37
53. Toronto	56. Windsor	229	-1.28	-0.30	1.58
53. Toronto	59. Sudbury	248	-0.90	-0.49	1.39
53. Toronto	67. Winnipeg	1256	-0.57	-0.79	1.36
53. Toronto	86. Edmonton	2077	-0.40	-1.04	1.44
67. Winnipeg	50. T.-Bay	434	-0.81	-0.56	1.37
83. Calgary	86. Edmonton	190	-1.35	-0.27	1.62
86. Edmonton	67. Winnipeg	882	-0.71	-0.64	1.35
86. Edmonton	73. Saskatoon	329	-0.83	-0.54	1.37
86. Edmonton	95. Vancouver	772	-1.02	-0.41	1.43
95. Vancouver	86. Edmonton	772	-0.85	-0.52	1.37
95. Vancouver	96. Vancouver Island	65	-2.42	-0.15	2.58

*Numbers preceding names of origin and destinations are the CFTM region codes.

Table 7-7, Elasticities of Demand with Respect to Price and Quality Variables for CFTM75

(Metal fabricated basic products)

Link: Origin*	Link: Dest'n.*	Miles	Compensated price elasticities: E_{rr}	Compensated price elasticities: E_{hh}	σ_{rh}	Speed elasticities: E_{rr}^{1} **	Speed elasticities: E_{rh}^{1}	Speed elasticities: E_{hh}^{1}	Speed elasticities: E_{hr}^{1} **	Reliability elasticities: E_{rr}^{2}	Reliability elasticities: E_{rh}^{2}	Reliability elasticities: E_{hh}^{2}	Reliability elasticities: E_{hr}^{2}
25. Halifax	53. Toronto	1113	-0.80	-0.56	1.36	-0.07	-0.78	0.54	0.04	0.12	-0.78	0.55	-0.08
33. St. John	46. Montreal	590	-0.94	-0.45	1.39	-0.09	-0.92	0.44	0.04	0.14	-0.92	0.44	-0.07
46. Montreal	33. St. John	590	-0.90	-0.48	1.38	-0.08	-0.88	0.47	0.04	0.13	-0.88	0.47	-0.07
46. Montreal	43. Quebec	173	-1.15	-0.34	1.49	-0.11	-1.12	0.34	0.03	0.17	-1.12	0.34	-0.05
46. Montreal	53. Toronto	335	-1.02	-0.41	1.43	-0.09	-1.00	0.40	0.03	0.15	-1.00	0.40	-0.06
46. Montreal	67. Winnipeg	1428	-0.80	-0.56	1.36	-0.07	-0.78	0.55	0.05	0.12	-0.78	0.54	-0.08
46. Montreal	95. Vancouver	2908	-0.60	-0.76	1.36	-0.05	-0.58	0.74	0.07	0.09	-0.58	0.74	-0.11
53. Toronto	56. Windsor	229	-1.00	-0.42	1.42	-0.09	-0.98	0.41	0.04	0.15	-0.97	0.41	-0.06
53. Toronto	67. Winnipeg	1256	-0.81	-0.55	1.36	-0.07	-0.80	0.54	0.05	0.12	-0.79	0.53	-0.08
53. Toronto	83. Calgary	2087	-0.74	-0.61	1.35	-0.07	-0.73	0.60	0.05	0.11	-0.72	0.59	-0.09
53. Toronto	95. Vancouver	2736	-0.65	-0.70	1.35	-0.06	-0.64	0.68	0.06	0.09	-0.64	0.68	-0.10
67. Winnipeg	53. Toronto	1256	-0.84	-0.53	1.37	-0.08	-0.82	0.52	0.05	0.12	-0.81	0.52	-0.08
67. Winnipeg	83. Calgary	831	-0.92	-0.47	1.39	-0.08	-0.90	0.46	0.04	0.13	-0.89	0.46	-0.07
67. Winnipeg	95. Vancouver	1480	-0.65	-0.70	1.35	-0.06	-0.64	0.68	0.06	0.09	-0.64	0.68	-0.10
95. Vancouver	53. Toronto	2736	-0.62	-0.74	1.36	-0.06	-0.60	0.72	0.07	0.09	-0.60	0.72	-0.11
95. Vancouver	67. Winnipeg	1480	-0.73	-0.62	1.35	-0.07	-0.71	0.61	0.06	0.11	-0.71	0.61	-0.09
95. Vancouver	86. Edmonton	772	-0.87	-0.51	1.38	-0.08	-0.85	0.50	0.04	0.13	-0.85	0.49	-0.07

* Numbers preceding names of origin and destination are the CFTM region codes.

** These elasticities may be regarded as zero since the parameter estimate β_r is not statistically different from zero (see Table 6-2).

means that the truck mode was dominant on the short-haul links.

On the other hand, there is not any link which satisfies the two conditions for rail-domination. Note that even on extremely long-haul links such as Montreal-Winnipeg and Toronto-Calgary links, the compensated demand for truck mode is price-inelastic. This implies that even the long-haul markets are not dominated by rail mode. For example, more than two-thirds of the total traffic moved from Montreal to Winnipeg was carried by trucking mode even at the high average rate of 3.93 cents per ton-mile as compared to the railways' 2.60 cents per ton-mile. A similar situation occurred on Toronto-Calgary link: more than 60% of the total traffic was moved by trucks at an average rate of 5.04 cents per ton-mile as opposed to railways' average rate of 3.36 cents per ton-mile.

From the above discussion, it is possible to conclude that the trucks dominate the traffic moving up to about 400 miles, and an effective inter-modal competition exists for the traffic moving beyond it. For this commodity group, there seems to be no rail-dominant distance range. This is because of the effect of the difference in quality attributes of service between the two modes.

Among the four different elasticities of demand with respect to speed listed in Table 7-7, E_{rr}^{1} and E_{hr}^{2} have wrong signs. This was caused due to the wrong sign of parameter estimate β_r = 0.0973 reported in Table 6-2. However, since the parameter estimate β_r had asymptotic t-value of only 0.318, the E_{rr}^1 and E_{hr}^2 for this commodity group can be regarded as zero.

The elasticity of demand for railway service with respect to trucking speed (E_{rh}^1) decreases generally as distance increases. On the other hand, the elasticity of demand for trucking service with respect to its own speed (E_{hh}^1) tends to increase with distance of link.

All the estimated elasticities of demand with respect to reliability of service have correct signs. A comparison of E_{rr}^2 and E_{hr}^2 to E_{hh}^2 and E_{rh}^2, respectively, shows that a change in the reliability of trucking transit time has far more influence on demands of both modes than same proportionate change in reliability of railway transit time. This can be explained by comparing the parameter estimates γ_r = -0.1450 and γ_h = -0.8664 reported in Table 6-2. Note also that the parameter γ_r used for computing E_{rr}^2 and E_{hr}^2 has asymptotic t-value of only 1.281. The absolute values of E_{rr}^2 and E_{rh}^2 tend to decrease with distance while those of E_{hh}^2 and E_{hr}^2 tend to increase with distance.

(7) <u>The Results for CFTM78 (Non-metallic basic and fabricated products):</u>

Similar to other commodities, the absolute value of E_{rr} decreases with distance and of E_{hh} increases with distance. An examination of Table 7-8 shows that, with a few exceptions,

Table 7-8, Parameters of Price and Quality Responsiveness of Demand for CFTM78

(Non-metallic basic & fabricated products)

Link			Compensated price elasticities			Speed elasticities				Reliability elasticities			
Origin*	Dest'n.*	Miles	E_{rr}	E_{hh}	σ_{rh}	E_{rr}^{1} **	E_{rh}^{1}	E_{hh}^{1}	E_{hr}^{1} **	E_{rr}^{2} **	E_{rh}^{2}	E_{hh}^{2}	E_{hr}^{2} **
25. Halifax	24. Yarmouth	217	-0.98	-0.53	1.51	0.25	-1.21	0.65	-0.14	-0.08	-2.38	1.29	0.04
43. Quebec city	46. Montreal	173	-1.45	-0.33	1.78	0.37	-1.79	-0.40	-0.08	-0.12	-3.52	0.79	0.03
46. Montreal	25. Halifax	778	-0.54	-0.97	1.51	0.14	-0.67	1.19	-0.25	-0.04	-1.31	2.34	0.08
46. Montreal	43. Quebec	173	-1.29	-0.38	1.67	0.33	-1.58	0.47	-0.10	-0.10	-3.11	0.92	0.03
46. Montreal	53. Toronto	335	-0.83	-0.65	1.48	0.21	-1.02	0.79	-0.17	-0.07	-2.01	1.56	0.05
46. Montreal	67. Winnipeg	1428	-0.52	-1.00	1.52	0.13	-0.64	1.23	-0.26	-0.04	-1.26	2.43	0.08
46. Montreal	83. Calgary	2559	-0.35	-1.38	1.73	0.09	-0.43	1.69	-0.35	-0.02	-0.85	3.33	0.11
46. Montreal	95. Vancouver	2908	-0.29	-1.60	1.89	0.08	0.36	1.97	0.41	-0.02	-0.71	3.88	0.13
53. Toronto	46. Montreal	335	-0.81	-0.67	1.48	0.21	-0.99	0.82	-0.17	-0.06	-1.95	1.61	0.05
53. Toronto	56. Windsor	229	-1.01	-0.52	1.53	0.26	-1.24	0.63	-0.13	-0.08	-2.44	1.25	0.04
53. Toronto	67. Winnipeg	1256	-0.61	-0.87	1.48	0.16	-0.75	1.07	-0.22	-0.05	-1.48	2.11	0.07
53. Toronto	83. Calgary	2087	-0.67	-0.81	1.48	0.17	-0.82	0.99	-0.21	-0.05	-1.62	1.95	0.06
53. Toronto	95. Vancouver	2736	-0.24	-1.93	2.17	0.06	-0.30	2.37	-0.50	-0.02	0.59	4.67	0.16
95. Vancouver	71. Regina	1125	-0.25	-1.88	2.13	0.06	-0.31	2.31	-0.48	-0.02	-0.61	4.55	0.15
95. Vancouver	86. Edmonton	772	-0.66	-0.82	1.48	0.17	-0.80	1.01	-0.21	-0.05	-1.59	1.99	0.06

* Numbers preceding origin and destination are the CFTM region codes.

** These elasticity estimates may be regarded as zero because the parameter estimates β_r and γ_r are not statistically different from zero (see Table 6-2).

the railway demand is price-elastic on the links whose distance is less than 200 miles, and the truck mode has a price-elastic demand on the links longer than 1200 miles. This implies that effective inter-modal competition exists on those links, the distance of which is between 200 and 1200 miles, leaving the traffic moving less than 200 miles and farther than 1200 miles primarily to the truck and rail modes, respectively. One exception is the Toronto-Winnipeg link (1256 miles) on which trucks moved more than 75% of the total tons transported during the year 1970. Unlike the rate on other links, the average rate charged by trucking mode on Toronto-Winnipeg link (2.84 cents per ton-mile) was slightly lower than the average rate charged by railways (2.87 cents per ton-mile). Another exception is that truckers carried more than two-thirds of total traffic on the Montreal-Toronto link (335 miles) whereas railways carried about 80% of the total traffic moving in the opposite direction.

All the estimated elasticities of demand with respect to quality variables had the correct signs. As in CFTM14 and CFTM75,the absolute values of E_{rr}^{1}, E_{hr}^{1}, E_{rr}^{2} and E_{hr}^{2} are far less than the absolute values of E_{rh}^{1}, E_{hh}^{1}, E_{rh}^{2} and E_{hh}^{2}, respectively, meaning that the effects on the demands for the two modes caused by a change in the quality attributes of the rail mode is relatively smaller than those caused by a similar change in the quality attributes of the truck mode. This can be explained by comparing the parameter estimates of quality-adjusted price functions of the two modes reported in Table 6-2.

$\beta_r = -0.2575$ $\beta_h = -1.2283$

$\gamma_r = -0.0829$ $\gamma_h = -2.4212$

Furthermore, the elasticity estimates E_{rr}^1, E_{hr}^1, E_{rr}^2 and E_{hr}^2 may be regarded as zero because the parameter estimates β_r and γ_r are not significantly different from zero (see Table 6-2).

Generally, the absolute values of E_{rr}^1, E_{rh}^1, E_{rr}^2 and E_{rh}^2 decrease with distance whereas those of E_{hh}^1, E_{hr}^1, E_{hh}^2 and E_{hr}^2 increase with distance.

(8) Summary about Inter-modal Competition:

So far in this section, the link-specific elasticity estimates were reported separately for each commodity group, and attempts were made to identify the range of distance over which an effective inter-modal competition appears to exist. Table 7-9 summarizes the previous discussions about the inter-modal competition.

The results roughly conform with expectations in the following sense:

(i) Normally for high-value (per ton) commodities such as CFTM14 (fruits, vegetables and edible foods), CFTM69 (other refined petroleum products), CFTM75 (metal fabricated basic products) and CFTM78 (non-metallic basic products), the truck mode dominates the short-haul traffic, and the rail-truck competition exists for medium-haul and fairly long-haul traffic.

Table 7-9, The Distance Range for Effective Inter-Modal Competition

Commodity Group	Distance Range
CFTM14 (Fruits, vegetables and edible foods)	400 - 1800 miles
CFTM52 (Lumber, including flooring)	There is no significant inter-modal competition
CFTM61 (Chemicals)	Up to 500 miles
CFTM66 (Fuel oil except gasoline)	Up to 400 miles
CFTM69 (Other refined petroleum products)	300 - 1500 miles
CFTM75 (Metal fabricated basic products)	From 400 miles with no upper bound
CFTM78 (Non-metallic basic products)	200 - 1200 miles

(ii) For CFTM61 (chemicals) and CFTM66 (fuel oil), rail-truck competition is active on short-distance links and the rail mode dominates medium- and long-haul traffic. This is because shippers of this commodity group are very sensitive to freight rates.

(iii) Because of the rail mode's efficiency of handling lumber and flooring (CFTM52), accessibility to rail service is the major determinant of shippers' mode-choice. Therefore, effective rail-truck competition does not seem to exist even on short-haul routes.

Since there is no previous study of a similar type, it is not possible to compare these results with those of others.

Footnotes for Chapter VII:

1. For more detail on the proposed revision, see the policy documents, Transport Canada [1975a, 1975b and 1975c].

2. Giving attention to all types of competitive appeals instead of price alone, Clark [1961] found that competition can be dynamic and effective in spite of market imperfection in the modern economy.

3. Diewert [1974] interpreted the elasticity of substitution as a normalization of the corresponding price-elasticity of demand so that a symmetric relationship holds, i.e., $\sigma_{ij} = \sigma_{ji}$ where σ_{ij} is the elasticity of substitution between inputs _i_ and _j_.

4. The term "Marshallian (ordinary) demand", borrowed from consumption theory, refers to the input demand when the level of shippers' output is allowed to vary in response to changes in freight rates; it therefore is distinguished from the input demand along an isoquant.
   Professor J.H.E. Taplin provided some insightful suggestions for modifying the Allen's formula to fit to our situation.

5. Suppose, for example, that the standard commodity code (SCC) No. 476 (wires, iron or steel) is moved mainly by the truck mode, whereas SCC 456 (ferro-alloys) is moved by the rail mode. The aggregation of the two commodities into a commodity group (CFTM72: steel, iron and alloys), would give a false impression as if the traffic is shared between the rail and truck modes, and thus lead to over-estimation of the inter-modal substitutibility.

CHAPTER VIII

SUMMARY OF MAJOR FINDINGS AND SUGGESTIONS FOR FURTHER RESEARCH

This chapter is organized as follows: In Section A, the major findings of this study are summarized on the basis of the discussions in the preceding two chapters. In the process, an attempt is made to compare these findings with those of others wherever it is appropriate to do so.[1] Section B presents several suggestions for further research and future research needs.

(A) Summary of Major Findings

The major findings of this study may be grouped into the following five items.

(1) The appropriate functional form for a freight demand model:

The second-order parameter a_{rh} of the translog cost function was statistically significant in all the chosen models except that for the commodity group CFTM52 (lumber). Consequently, the elasticity of substitution between the two modes varies with the shares of expenditure as indicated by the formula in equation (7,3b). Therefore, CES (constant elasticity of substitution) models including the Cobb-Douglas model are not appropriate to use as a freight demand model.

Logit models, which have been used most frequently in freight demand studies, impose unrealistic *a priori* restrictions both on the elasticity of substitution and on the price elasticities (see footnote 3 in chapter I for the details of the restrictions). Throughout this thesis we have seen that "flexible" functions are appropriate to use to approximate the shippers' cost function and thus the demand functions, because they allow for a free variation of the elasticities of substitution and the price elasticities of demand.

(2) <u>The variables to include in a demand model</u>:

The results of hypothesis testing in chapter V have shown that the mode selection by the shippers of the relatively high-value (per ton) commodities is influenced not only by the freight rates but also by the quality attributes such as speed and reliability of speed, whereas prices are the single major mode-choice factor for the relatively low-value (per ton) commodities. Turner [1975] has obtained more or less similar results in this regard from his logit analysis: i.e., the parameters associated with the transit time and the variability of transit time were statistically significant for most of the manufactured goods but they were statistically insignificant for most industrial raw materials.

Recently, Levin [1978] estimated a logit model as a function only of the differences in freight rates, transit time and variability of transit time between a pair of modes. In order to justify the logit model, which does not include the distance variable, he asserted that shipment mileage affects the mode selection only indirectly through changing the freight rates, transit time and variability of transit time.[2] However, this thesis has shown, by choosing models which depend upon the distance, that the shipper's choice possibility sets in the transportation-sectoral-technology space depend on the distance to transport a specific cargo. The distance affects shipper's transportation-sectoral-technology directly as well as indirectly through its influence on the freight rates, speed and reliability of speed, implying that Levin's assumption postulated in his logit model does not seem to hold empirically. This in turn implies that the distance variable should enter directly in the demand model.

All the eight chosen models reported in chapter VI are different from one another. This implies that the shippers' transportation sectoral technology depends on the commodity type. Therefore, even without a formal statistical test, it may be concluded that the commodity attribute variables such as value and density of the commodity should be included in a demand model if the model is to be estimated from the data which include heterogeneous commodities.

By integrating the discussions so far, it can be said that a demand model should include prices and distance in any case, with an addition of the quality attribute variables for the manufactured or high-valued goods and the commodity attribute variables when it is estimated from the aggregate data over heterogeneous commodities.

(3) Mode-specific hedonic aggregators:

For the relatively high-value (per ton) commodities, the mode-choice of which is significantly influenced by the quality attributes of service, the model with mode-specific hedonic aggregators (model D-3) was chosen as the result of hypothesis testing in chapter V. This implies that shippers perceive a mode as its institutional entity rather than as a mere combination of the characteristics of service it has.

The comparisons of the two hedonic aggregators have shown that the parameter estimates for the truck mode are consistently larger in absolute value than those for the rail mode. The author attributed this to the following factors:

(i) Shippers may have overperceived the quality attributes of trucking service and/or underperceived those of railway service.

(ii) The omitted quality variables such as convenience, flexibility, and completeness of service are likely to favour the truck mode.

(4) Estimates of elasticity of substitution:

The elasticity of substitution between the two modes reported in chapter VII are all greater than one as a result of the positive parameter estimate a_{rh}. This also tells that Cobb-Douglas model should not be used to estimate the freight demand functions. Table 7-1 shows that the elasticity of substitution evaluated at the mean values of the variables varies from 1.044 for CFTM52 (lumber) to 2.132 for CFTM71 (steel, iron and alloys, etc.). As mentioned in chapter VII, an aggregation of two or more commodities of a heterogeneous nature causes an over-estimation of substitutibility. The same holds for the case of an aggregation over heterogeneous geographical regions. Since the data used in this study suffers from aggregation problems, although to a less extent than most other studies, the elasticities of substitution reported in chapter VII may have been over-estimated.

The elasticities of substitution computed from the translog cost function reported in Friedlaender and Spady [1977] are, in general, substantially higher than those of this study.[3] This may be because they estimated their model from the data that is more highly aggregated commodity-wise and region-wise: The entire U.S.A. was divided only into three regions and the non-agricultural products into the four commodity groups.

(5) Inter-modal competition:

In chapter VII it was shown that as the distance increases, the compensated price elasticity for the rail mode decreases whereas that for the truck mode increases. The relative values of price elasticities of the two modes were used to identify the range of distance over which effective inter-modal competition is likely to exist. The results are roughly as follows:

(i) For the relatively low-value commodities such as chemicals (CFTM61) and fuel oil (CFTM66), the inter-modal competition seems to exist only for the short-haul traffic leaving the medium- and long-haul traffic primarily rail-dominated. One exception is lumber and flooring (CFTM52) for which no significant inter-modal competition seems to exist even in short-haul markets.

(ii) For the relatively high-value products such as foods (CFTM14), refined petroleum products (CFTM69), metal fabricated products (CFTM75) and non-metallic basic products (CFTM78), the inter-modal competition is likely to exist over a fairly wide range of medium-distance markets.

(B) Suggestions for Further Research

For any empirical research such as this study, the quality of data and the choice of model are crucially important. In this study, for each (CFTM) commodity group, the shipper's transport unit cost function and the corresponding expenditure share functions were estimated from the data aggregated over the shippers of the commodity group on each link. As explained in chapter III, since the decision making unit for mode selection is an individual shipper, ideally the model should be estimated from the disaggregated data on the individual shipper's production and distribution activities over its entire distribution network. Although this is the ideal way to eliminate the potential aggregation bias, the data are almost impossible to obtain because of the confidentiality of shipper's business information. The only practical way to reduce the aggregation bias is, therefore, to use data that is as disaggregated as possible. The data used in this study, perhaps the least aggregated one among the studies which did not use survey or interview information,[4] still suffers from the following aggregation problems:

1. Some of the CFTM commodity groups include a fairly heterogeneous range of products as can be seen from Appendix 4A. For example, CFTM71 includes a diversity of items ranging from primary steel and iron to the industrial hardwares such as pipes, tubes, wires, etc.

2. The commodity flow data are compiled from region to region rather than from city to city.

The true variability in mode-choice may have been concealed by the data aggregation, and thus the inter-modal substitutibility may have been over-estimated. To reduce aggregation bias, therefore, the true inter-city flow data should be compiled separately for each homogeneous commodity, and each commodity-specific model should be estimated.

In modelling freight demand, a derived demand model should be used in order to treat the freight demand as an intermediate input for production and distribution activities of the firms. More empirical models should be estimated using "flexible" functions which do not impose *a priori* restriction on the elasticity of substitution and can serve as the second order approximation to the arbitrary true function. So far in the freight transport area, only the translog function has been used in Oum [1977] and Friedlaender and Spady [1977] as well as in this thesis. Other forms of flexible function such as generalized Leontief function, generalized Cobb-Douglas function and quadratic mean of order-r functions should also be used in future freight demand studies to compare with the results of this study.

Footnotes for Chapter VIII:

1. Since the results are not comparable between the studies which use both different models and different data, the results of this study are compared only with the following studies:

   (i) Friedlaender and Spady [1977], in which the demand model derived from the translog cost function was estimated,

   (ii) Turner [1975], in which the two-mode (rail, truck) logit model was estimated from data basically the same as those in this thesis, and

   (iii) Levin [1978], in which the three-mode (truck, box car and piggyback) logit model was estimated as a function of differential freight rate, transit time and variability of transit time.

2. Levin [1978] cited the results of the two shipper surveys conducted by Wood and Domencich [1971] and Kullman [1973] for the justification of this assumption. However, the authors of the two surveys did not test whether or not distance influences the mode selection only indirectly.

3. The elasticities of substitution computed by summing the compensated price elasticities reported in their paper across the two modes are:

Durable manufactured:	1.715
Non-durable manufactured:	1.757
Petroleum and related:	1.709
Mineral, chemical and others:	1.935

   Notice that the above figures are substantially higher than those reported in table 7-1 except that of CFTM71 (σ_{rh} = 2.132) which also suffers from aggregation.

4. Note that the information that can be obtained from a shipper survey or interview is only partial information which is not sufficient to estimate the shipper's cost function.

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APPENDIX 3A

Derivation of Linear Homogeneity Condition

The linear homogeneity condition for the translog cost function (3,8) is derived in this appendix.

(1) $\ln C\,[\ln P, \ln Z_1, \ln Z_2, \ln D]$

$$= \ln a_o + a^t \cdot \ln P + b^t \cdot \ln Z_1 + c^t \cdot \ln Z_2 + d \ln D$$

$$+ \tfrac{1}{2}(\ln P)^t \cdot A \cdot \ln P + \tfrac{1}{2}(\ln Z_1)^t \cdot B \cdot \ln Z_1 + \tfrac{1}{2}(\ln Z_2)^t \cdot C \cdot \ln Z_2$$

$$+ \tfrac{1}{2} dd (\ln D)^2 + \tfrac{1}{2}(\ln P)^t \cdot E \cdot \ln Z_1 + \tfrac{1}{2}(\ln Z_1)^t \cdot E^t \cdot \ln P$$

$$+ \tfrac{1}{2}(\ln P)^t \cdot F \cdot \ln Z_2 + \tfrac{1}{2}(\ln Z_2)^t \cdot F^t \cdot \ln P + \tfrac{1}{2}(\ln Z_1)^t \cdot G \cdot \ln Z_2$$

$$+ \tfrac{1}{2}(\ln Z_2)^t \cdot G^t \cdot \ln Z_1 + \ln D (g^t \cdot \ln P) + \ln D (h^t \cdot \ln Z_1) + \ln D (i^t \cdot \ln Z_2)$$

where $a = (a_r, a_h)^t \quad b = (b_r, b_h)^t \quad c = (c_r, c_h)^t$

$$A = \begin{bmatrix} a_{rr} & a_{rh} \\ a_{rh} & a_{hh} \end{bmatrix} \qquad B = \begin{bmatrix} b_{rr} & b_{rh} \\ b_{rh} & b_{hh} \end{bmatrix} \qquad C = \begin{bmatrix} c_{rr} & c_{rh} \\ c_{rh} & c_{hh} \end{bmatrix}$$

$$E = \begin{bmatrix} ab_{rr} & ab_{rh} \\ ab_{hr} & ab_{hh} \end{bmatrix} \qquad F = \begin{bmatrix} ac_{rr} & ac_{rh} \\ ac_{hr} & ac_{hh} \end{bmatrix} \qquad G = \begin{bmatrix} bc_{rr} & bc_{rh} \\ bc_{hr} & bc_{hh} \end{bmatrix}$$

$$g = (ad_r,\ ad_h)^t \quad h = (bd_r,\ bd_h)^t \quad i = (cd_r, cd_h)^t$$

$$P = \begin{pmatrix} P_{r\ell} \\ P_{h\ell} \end{pmatrix} \qquad Z_1 = \begin{pmatrix} Z_{r1\ell} \\ Z_{h1\ell} \end{pmatrix} \qquad Z_2 = \begin{pmatrix} Z_{r2\ell} \\ Z_{h2\ell} \end{pmatrix}$$

Linear homogeneity of the translog function with respect to prices (P) holds only if equality (2) holds for any positive scalar λ.

(2) $\ln C\left[\ln\lambda P,\ \ln Z_1,\ \ln Z_2,\ \ln D\right] = \ln\lambda C_1\left[\ln P,\ \ln Z_1,\ \ln Z_2,\ \ln D\right]$

where

$$\ln C\left[\ln P,\ \ln Z_1,\ \ln Z_2,\ \ln D\right]$$

$$= \ln A_o + a^t\cdot\ln P + A\cdot(\ln\lambda e) + b^t\cdot\ln Z_1 + c^t\cdot\ln Z_2 + d\ln D$$

$$+ \tfrac{1}{2}(\ln P)^t\cdot A\cdot\ln P + \tfrac{1}{2}(\ln\lambda e)^t\cdot A\cdot(\ln\lambda e) + \tfrac{1}{2}(\ln\lambda e)^t\cdot A\cdot\ln P$$

$$+ \tfrac{1}{2}(\ln P)^t\cdot A\cdot(\ln\lambda e) + \tfrac{1}{2}(\ln Z_1)^t\cdot B\cdot\ln Z_1 + \tfrac{1}{2}(\ln Z_2)^t\cdot C\cdot\ln Z_2$$

$$+ \tfrac{1}{2}dd(\ln D)^2 + \tfrac{1}{2}(\ln P)^t\cdot E\cdot\ln Z_1 + \tfrac{1}{2}(\ln\lambda e)^t\cdot E\cdot\ln Z_1$$

$$+ \tfrac{1}{2}(\ln Z_1)^t\cdot E^t\cdot\ln P + \tfrac{1}{2}(\ln Z_1)^t\cdot E^t\cdot(\ln\lambda e) + \tfrac{1}{2}(\ln P)^t\cdot F\cdot\ln Z_2$$

$$+ \tfrac{1}{2}(\ln\lambda e)^t\cdot F\cdot\ln Z_2 + \tfrac{1}{2}(\ln Z_2)^t\cdot F^t\cdot\ln P + \tfrac{1}{2}(\ln Z_2)^t\cdot F^t\cdot(\ln\lambda e)$$

$$+ \tfrac{1}{2}(\ln Z_1)^t\cdot G\cdot\ln Z_2 + \tfrac{1}{2}(\ln Z_2)^t\cdot G^t\cdot\ln Z_1 + \ln D\,(g^t\cdot\ln P)$$

$$+ \ln D\,(g^t\cdot\ln\lambda e) + \ln D\,(h^t\cdot\ln Z_1)\ \ln D\,(i^t\cdot\ln Z_2)$$

where $e = [1,1]^t$

In order for the quality (2) to hold, the following conditions must be met:

(a) $a^t \cdot ln\lambda e = ln\lambda$

(b) $(ln\lambda e)^t \cdot A = \underline{0}$ and $A \cdot ln\lambda e = \underline{0}$

(c) $(ln\lambda e)^t \cdot E = \underline{0}$

(d) $(ln\lambda e)^t \cdot F = \underline{0}$

(e) $g^t \cdot (ln\lambda e) = 0$

where $\underline{0} = (0,0)$ or $= \begin{pmatrix}0\\0\end{pmatrix}$

Therefore, the linear homogeneity condition imposes the following restrictions on the parameters of translog function (3,8):

(3) (a) $a_r + a_h = 1$

(b) $a_{rr} + a_{rh} = 0$, $a_{rh} + a_{hh} = 0$ implying $a_{rr} = -a_{rh} = a_{hh}$,

(c) $ab_{rr} + ab_{hr} = 0$, $a_{rh} + ab_{hh} = 0$

(d) $ac_{rr} + ac_{hr} = 0$, $ac_{rh} + ac_{hh} = 0$

(e) $ad_r + ad_h = 0$

APPENDIX 4A

List of Commodities Included in the Eight CFTM Commodity Groups

CFTM 14 (Fruits, Vegetables and Edible Foods):

SCC code	Description
076	Dried and dehydrated fruits
078	Fruit juices, and fruit juice concentrates, not frozen
080	Fruit juice concentrates, frozen
082	Fruits and fruit preparation, n.e.s.
084	Nuts, except oil nuts
104	Vegetables, dried
106	Vegetables and preparations, n.e.s.
112	Sugar preparations (inc. confectionery), n.e.s.
114	Coffee
116	Cocoa and chocolate, tea, spices and vinegar
118	Margarine and similar products
120	Shortening and lard
122	Soups and infant and junior foods
124	Pre-cooked frozen food preparations
126	Food preparations and materials for food preparations, n.e.s.

CFTM 52 (Lumber including flooring):

SCC code	Description
308	Lumber
310	Flooring

CFTM 61 (Chemicals):

SCC code	Description
378	Carbon blacks
380	Chemical elements
384	Inorganic acids and oxygen compounds of non-metals or metalloids, n.e.s.
386	Sodium hydroxide
388	Inorganic bases and metallic oxides, hydroxides and peroxides, n.e.s.
390	Sodium sulphate
392	Sodium carbonate
394	Metallic salts and peroxy-salts of inorganic acids, n.e.s.
396	Calcium carbide
398	Inorganic chemicals, other, n.e.s.

CFTM 61 (Chemicals) continued:

SCC code	Description
400	Hydrocarbons and their derivatives
402	Alcohols and their derivatives
404	Phenols, ethers, aldehydes, ketones and their derivatives
406	Organic acids, their anhydrides, halides, peroxides, peracids, and derivatives
408	Nitrogen function compounds
410	Organic chemicals, n.e.s.

CFTM 66 (Fuel oil other than gasoline):

SCC code	Description
436	Aviation turbine fuel
438	Diesel fuel
440	Kerosene
442	Fuel oil, n.e.s.

CFTM 69 (Refined petroleum products other than coke and gases):

SCC code	Description
444	Lubricating oils and greases
452	Asphalts and road oils
454	Other petroleum and coal products

CFTM 71 (Steel, iron and alloys, etc.):

SCC code	Description
456	Ferro-alloys
458	Pig iron
460	Ingots, blooms, billets and slabs, iron and steel
461	Primary iron and steel, n.e.s.
462	Castings and forgings, iron or steel
464	Bars and rods, steel
466	Plates, steel, fabricated
468	Sheet and strip, steel
470	Structural shapes and sheet piling, iron or steel
472	Rails and railway track materials
474	Pipes and tubes, iron and steel
476	Wire, iron or steel

CFTM 75 (Metal fabricated basic products):

SCC code	Description
496	Tanks
498	Bolts, nuts, nails, screws and basic hardware
500	Metal fabricated basic products, n.e.s.

CFTM 78 (Non-metallic basic products):

SCC code	Description
502	Natural stone basic products, chiefly structural
504	Bricks and tiles, clay
506	Fire brick and similar shapes
508	Dolomite and magnesite, calcined
510	Refractories, n.e.s.
512	Glass basic products
514	Asbestos and asbestos-cement basic products
518	Concrete pipe
520	Cement and concrete basic products, n.e.s.
522	Plaster
524	Gypsum wallboard and sheathing
526	Gypsum basic products, n.e.s.
528	Lime, hydrated and quick
530	Non-metallic mineral basic products, n.e.s.
532	Bituminous pressed or molded fabricated materials
534	Miscellaneous fabricated materials

APPENDIX 5A

Tables of Test Statistics and the Results of Hypotheses Testing

The values of the logarithm of likelihood functions evaluated at the maximum likelihood estimates and R^2 values for the cost and revenue share functions are reported in tables (5A-1) to (5A-8). Tables (5A-9) to (5A-16) report the detailed results of the first and second stage tests. The following is a list of the tables by commodity group:

Commodity group	Tables
CFTM 14	5A-1, 5A-9
CFTM 52	5A-2, 5A-10
CFTM 61	5A-3, 5A-11
CFTM 66	5A-4, 5A-12
CFTM 69	5A-5, 5A-13
CFTM 71	5A-6, 5A-14
CFTM 75	5A-7, 5A-15
CFTM 78	5A-8, 5A-16

Table 5A-1, Test Statistics for Commodity Group CFTM14: Fruits, Vegetables and Edible Foods (using 133 link observations)

Model and Sub-model	No. of free Parameters	$ln\mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-635.822	0.8714	0.3754
(A-2)	15	-644.605	0.8596	0.3564
(A-3)	6	-650.892	0.8460	0.3536
Model Strictly Independent of Distance (B)				
(B-1)	22	-641.1	0.8595	0.3590
(B-2)	11	-647.103	0.8552	0.3502
(B-3)	4	-682.177	0.7994	0.0215
Model with Mode-Specific Hedonic Aggregators (C)				
(C-1)	9	-646.74	0.8589	0.3636
(C-2)	7	-658.267	0.8525	0.3007
(C-3)*	5	-670.689	0.8270	0.2722
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-657.646	0.8511	0.3016
(D-2)	6	-658.369	0.8523	0.2999
(D-3)*	5	-670.689	0.8270	0.2722

$ln\mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-2, Test Statistics for Commodity Group CFTM52: Lumber Including Flooring (using 52 link observations)

Model and Sub-model	No. of free Parameters	$\ln \mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-236.250	.7007	.0932
(A-2)	15	-242.445	.7396	.0202
(A-3)	6	-249.925	.6609	.0135
Model Strictly Independent of Distance (B)				
(B-1)	22	-237.373	.6980	.0821
(B-2)	11	-244.155	.6527	.1042
(B-3)	4	-252.165	.6546	.0001
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-247.023	.6870	.0305
(C-2)	7	-249.783	.6784	.0312
(C-3)*	5	-249.935	.6621	.0153
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-247.791	.6725	.0072
(D-2)	6	-248.557	.6732	.0190
(D-3)*	5	-249.935	.6621	.0153

$\ln \mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-3, Test Statistics for Commodity Group CFTM61: Chemicals

(using 86 link observations)

Model and Sub-model	No. of free Parameters	$ln\mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-397.607	0.7558	0.2247
(A-2)	15	-401.526	0.7504	0.1947
(A-3)	6	-409.718	0.7008	0.2041
Model Strictly Independent of Distance (B)				
(B-1)	22	-400.357	0.7470	0.2210
(B-2)	11	-405.466	0.7211	0.2115
(B-3)	4	-416.264	0.6718	0.0897
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-408.965	0.7068	0.2038
(C-2)	7	-409.982	0.7060	0.1911
(C-3)*	5	-411.166	0.7002	0.1890
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-410.077	0.7054	0.1920
(D-2)	6	-410.140	0.7049	0.1915
(D-3)*	5	-411.166	0.7002	0.1890

$ln\mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-4, Test Statistics for Commodity Group CFTM66: Fuel Oil

(using 65 link observations)

Model and Sub-model	No. of free Parameters	$\ln\mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-323.210	0.7248	0.1015
(A-2)	15	-326.629	0.7106	0.1012
(A-3)	6	-334.696	0.6721	0.0431
Model Strictly Independent of Distance (B)				
(B-1)	22	-324.928	0.7205	0.0873
(B-2)	11	-333.609	0.7199	0.0834
(B-3)	4	-338.515	0.6312	0.0320
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-332.386	0.6926	0.0546
(C-2)	7	-332.720	0.6827	0.0550
(C-3)*	5	-335.264	0.6623	0.0447
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-334.200	0.6831	0.0537
(D-2)	6	-334.747	0.6755	0.0528
(D-3)*	5	-335.264	0.6623	0.0447

$\ln\mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-5, Test Statistics for Commodity Group CFTM69: Refined Petroleum Products (using 77 link observations)

Model and Sub-model	No. of free Parameters	$\ln \mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-356.286	0.9102	0.2836
(A-2)	15	-358.271	0.9007	0.2838
(A-3)	6	-362.732	0.8859	0.2835
Model Strictly Independent of Distance (B)				
(B-1)	22	-357.542	0.9089	0.2719
(B-2)	11	-361.320	0.8968	0.2572
(B-3)	4	-383.776	0.8389	0.0442
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-360.967	0.8943	0.2691
(C-2)	7	-365.806	0.8701	0.2465
(C-3)*	5	-366.266	0.8802	0.2479
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-364.704	0.8881	0.2422
(D-2)	6	-366.150	0.8804	0.2487
(D-3)*	5	-366.266	0.8802	0.2479

$\ln \mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-6, Test Statistics for Commodity Group CFTM71: Steel, Irons and Alloys (using 151 link observations)

Model and Sub-model	No. of free Parameters	$ln\mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-754.384	0.9230	0.3810
(A-2)	15	-754.919	0.9167	0.3923
(A-3)	6	-770.533	0.9031	0.3560
Model Strictly Independent of Distance (B)				
(B-1)	22	-759.230	0.9189	0.3782
(B-2)	11	-760.100	0.9159	0.3605
(B-3)	4	-803.767	0.8537	0.0981
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-771.330	0.9055	0.3550
(C-2)	7	-774.156	0.9045	0.3322
(C-3)*	5	-774.303	0.9039	0.3334
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-774.104	0.9052	0.3331
(D-2)	6	-774.297	0.9040	0.3326
(D-3)*	5	-774.303	0.9039	0.3334

$ln\mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-7, Test Statistics for Commodity Group CFTM75: Metal Fabricated Basic Products (using 137 link observations)

Model and Sub-model	No. of free Parameters	$\ln \mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-645.499	0.8377	0.2698
(A-2)	15	-656.541	0.8309	0.2742
(A-3)	6	-751.292	0.8060	0.3038
Model Strictly Independent of Distance (B)				
(B-1)	22	-652.478	0.8350	0.2577
(B-2)	11	-662.574	0.8265	0.2491
(B-3)	4	-770.771	0.8178	0.3206
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-658.974	0.8226	0.3111
(C-2)	7	-664.516	0.8215	0.3111
(C-3)*	5	-759.663	0.7980	0.3291
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-662.851	0.8130	0.2920
(D-2)	6	-665.333	0.8178	0.3206
(D-3)*	5	-759.663	0.7980	0.3291

$\ln \mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-8, Test Statistics for Commodity Group CFTM78: Non-metallic Basic Products (using 156 link observations)

Model and Sub-model	No. of free Parameters	$ln\mathcal{L}$	R_c^2	R_s^2
General Model (A)				
(A-1)	28	-844.632	0.7548	0.3702
(A-2)	15	-850.886	0.7258	0.3543
(A-3)	6	-859.013	0.7191	0.3453
Model Strictly Independent of Distance (B)				
(B-1)	22	-845.685	0.7416	0.3584
(B-2)	11	-854.979	0.7124	0.3515
(B-3)	4	-889.667	0.6198	0.1230
Model with Mode-specific Hedonic Aggregators (C)				
(C-1)	9	-853.032	0.7216	0.3498
(C-2)	7	-860.165	0.7052	0.3388
(C-3)*	5	-861.214	0.7018	0.3344
Model with Identical Hedonic Aggregators (D)				
(D-1)	7	-860.135	0.7074	0.3394
(D-2)	6	-860.219	0.7053	0.3384
(D-3)*	5	-861.214	0.7018	0.3344

$ln\mathcal{L}$ = The value of natural logarithm of likelihood function evaluated at the ML parameter estimates.

R_c^2 = R^2 value for the translog cost function.

R_s^2 = R^2 value for the modal share functions.

*Models (C-3) and (D-3) are identical.

Table 5A-9, Hypotheses Testing for CFTM14: Fruits, Vegetables and Edible Foods

(A) Test amongst the three sub-models (First stage tests):
test statistic ($-2 ln \lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	30.140**	82.154	47.898	26.086
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	12.674	70.148	24.844	24.64
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	17.566	12.006	23.054	1.446
Chosen sub-model		(A-3)	(B-2)	(C-1)	(D-2)
No. of free parameters		6	11	9	6
$ln \mathcal{L}$		-650.892	-647.103	-646.74	-658.369
R^2_c		.8460	.8552	.8589	.8523

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln \lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha=.05$	Test Result
(1) choice between models (D-2) and (A-3)	***			favours (A-3) due to higher $\ln \mathcal{L}$ value.
(2) H_0: model (D-2) H_1: model (B-2)	22.532	5	9.236	favours (B-2)
(3) H_0: model (D-2) H_1: model (C-1)	23.258	3	6.251	favours (C-1)
(4) H_0: model (A-3) H_1: model (C-1)	8.304	3	6.251	favours (C-1)
(5) choice between models (C-1) and (B-2)	***			favours (C-1) because it has higher $\ln \mathcal{L}$ value and smaller number of parameters
(6) H_0: model (A-3) H_1: model (B-2)	6.126	5	9.236	favours (A-3)

Model (C-1) is finally chosen for use.

*** The two models that are compared have the same number of parameters. In this case, the model with a larger value of the likelihood function was chosen.

Table 5A-10, Hypotheses Testing for CFTM52: Lumber Including Flooring

(A) Tests amongst the three sub-models (First stage tests): test statistic ($-2 \ln \lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	27.35**	29.584	5.824	4.288
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	14.96	16.02	.304	2.756
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	12.39	13.564	5.52	1.532
Chosen sub-model		(A-3)	(B-3)	(C-3)	(D-3)
No. of free parameters		6	4	5	5
$\ln \mathcal{L}$		-249.925	-252.165	-249.935	same as C-3
R^2_c		.6609	.6546	.6621	

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln\lambda$)	Degrees of Freedom	χ^2 critical value at α=.05	Test Result
(1) H_0: model (D-3) H_1: model (A-3)	.02	1	3.841	favours (D-3)
(2) H_0: model (D-3) H_1: model (B-3)	4.46	1	3.841	favours (D-3)
(3) H_0: model (D-3) H_1: model (C-3)	these are an identical model.			
(4) H_0: model (C-3) H_1: model (A-3)	same result as in (1)			
(5) H_0: model (C-3) H_1: model (B-3)	same result as in (2)			
(6) H_0: model (B-3) H_1: model (A-3)	4.48	2	5.991	favours (B-3)

Model (D-3) = (C-3) is finally chosen for use.

Table 5A-11, <u>Hypotheses Testing for CFTM61: Chemicals</u>

(A) Tests amongst the three sub-models (First stage tests):
test statistic ($-2 \ln \lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	24.222**	31.814	4.402	2.178
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	16.384	21.596	2.368	2.052
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	7.838	10.218	2.034	0.126
Chosen sub-model		(A-3)	(B-2)	(C-3)	(D-3)
No. of free parameters		6	11	5	5
$\ln \mathcal{L}$		-409.718	-405.466	-411.166	-411.166
R^2_c		.7008	.7211	.7002	.7002

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln\lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha = .05$	Test Result
(1) H_0: model (D-3)				
H_1: model (A-3)	2.896	1	3.841	favours (D-3)
(2) H_0: model (D-3)				
H_1: model (B-2)	11.4	6	12.592	favours (D-3)
(3) models (D-3) and (C-3) are identical.				
(4) H_0: model (C-3)				
H_1: model (A-3)	result is exactly same as in (1)			
(5) H_0: model (C-3)				
H_1: model (B-2)	result is exactly same as in (2)			
(6) H_0: model (A-3)				
H_1: model (B-2)	8.504	5	11.071	favours (A-3)

Model (D-3) = model (C-3) is finally chosen for use.

Table 5A-12, <u>Hypotheses Testing for CFTM66: Fuel Oil</u>

(A) Tests amongst the three sub-models (First stage tests):
<u>test statistic ($-2\ln\lambda$) and degrees of freedom</u>

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	22.972**	27.174	5.756	2.128
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	16.134	9.812	5.088	1.034
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	6.838	17.362	.668	1.094
Chosen sub-model		(A-3)	(B-3)	(C-3)	(D-3)
No. of free parameters		6	4	5	same as (C-3)
$\ln\mathcal{L}$		-334.696	-338.515	-335.264	
R^2_c		.6721	.6312	.6623	

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln \lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha = .05$	Test Result
(1) H_0: model (D-3) H_1: model (A-3)	1.136	1	3.841	favours (D-3)
(2) H_0: model (D-3) H_1: model (B-3)	6.502	1	3.841	favours (D-3)
(3) Models (4,11C) and (4,18C) are identical				
(4) H_0: model (C-3) H_1: model (A-3)	same result as in (1)			
(5) H_0: model (B-3) H_1: model (C-3)	same result as in (2)			
(6) H_0: model (B-3) H_1: model (A-3)	7.638	2	5.991	favours (A-3)

Model (D-3) = (C-3) is finally chosen for use.

Table 5A-13, Hypotheses Testing for CFTM69: Refined Petroleum Products

(A) Tests amongst the three sub-models (First stage tests):
test statistic ($-2\ln\lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	12.892**	52.468	10.598	3.124
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	8.922	44.912	0.92	.232
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	3.97	7.556	9.678	2.892
Chosen sub-model		(A-3)	(B-2)	(C-1)	(D-3)
No. of free parameters		6	11	9	5
$\ln\mathcal{L}$		-362.732	-361.320	-360.967	-366.266
R^2_c		.8859	.8968	.8943	.8802

Degrees of freedom	χ^2 critical value at $\alpha=.05$
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln \lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha = .05$	Test Result
(1) H_0: model (D-3) H_1: model (A-3)	7.068	1	3.841	favours (A-3)
(2) H_0: model (D-3) H_1: model (B-2)	9.892	6	12.592	favours (D-3)
(3) H_0: model (D-3) H_1: model (C-1)	10.598	4	9.488	favours (C-1)
(4) H_0: model (A-3) H_1: model (C-1)	7.068	3	7.815	favours (A-3)
(5) H_0: model (C-1) H_1: model (B-2)	.706	2	5.991	favours (C-1)
(6) H_0: model (A-3) H_1: model (B-2)	2.824	5	11.071	favours (A-3)

Model (A-3) is finally chosen for use.

Table 5A-14, Hypotheses Testing for CFTM71: Steel, Irons and Alloy

(A) Tests amongst the three sub-models (First stage tests):
test statistic $(-2 \ln\lambda)$ and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	32.398**	89.074	5.946	.398
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	31.228	87.334	0.294	.012
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	1.07	1.74	5.652	.386
Chosen sub-model		(A-2)	(B-2)	(C-3)	(D-3)
No. of free parameters		15	11	5	5
$\ln\mathcal{L}$		-754.919	-760.1	-774.303	same as (C-3)
R^2_c		.9167	.9159	.9039	

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln \lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha = .05$	Test Result
(1) H_0: model (D-3)				
H_1: model (A-2)	38.768	10	18.307	favours (A-2)
(2) H_0: model (D-3)				
H_1: model (B-2)	28.406	6	12.592	favours (B-2)
(3) Models (4,11C) and (4,18C) are identical				
(4) H_0: model (C-3)				
H_1: model (A-2)	same result as in (1)			
(5) H_0: model (C-3)				
H_1: model (B-2)	same result as in (2)			
(5) H_0: model (B-2)				
H_1: model (A-2)	10.362	4	9.488	favours (A-2)

Model (A-2) is finally chosen for use.

Table 5A-15, Hypotheses Testing for CFTM75: Metal Fabricated Basic Products

(A) Tests amongst the three sub-models (First stage tests):

test statistic ($-2 \ln \lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	211.586**	236.586	201.378	193.694
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	189.502	216.394	190.294	188.73
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	22.084	20.192	11.084	4.964
Chosen sub-model		(A-2)	(B-1)	(C-1)	(D-1)
No. of free parameters		15	22	9	7
$\ln \mathcal{L}$		-656.541	-652.478	-658.974	-662.851
R^2_c		.8309	.8350	.8226	.8130

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln \lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha=.05$	Test Result
(1) H_0: model (D-1) H_1: model (A-2)	12.62	8	15.507	favours (D-1)
(2) H_0: model (D-1) H_1: model (B-1)	20.746	15	24.996	favours (D-1)
(3) H_0: model (D-1) H_1: model (C-1)	7.754	2	5.991	favours (C-1)
(4) H_0: model (C-1) H_1: model (A-2)	4.866	6	12.592	favours (C-1)
(5) H_0: model (C-1) H_1: model (B-1)	12.992	13	22.362	favours (C-1)
(6) H_0: model (A-2) H_1: model (B-1)	8.126	7	14.067	favours (A-2)

Model (C-1) is finally chosen for use.

Table 5A-16, Hypotheses Testing for CFTM78: Non-metallic Basic Products

(A) Tests amongst the three sub-models (First stage tests):

test statistic ($-2\ln\lambda$) and degrees of freedom

Test		Model A	Model B	Model C	Model D
(i)	H_0: sub-model 3	(22)*	(18)	(4)	(2)
	H_1: sub-model 1	28.762	87.964	16.364	2.158
(ii)	H_0: sub-model 3	(9)	(7)	(2)	(1)
	H_1: sub-model 2	16.254	69.376	2.098	1.99
(iii)	H_0: sub-model 2	(13)	(11)	(2)	(1)
	H_1: sub-model 1	12.508	18.588	14.266	0.168
Chosen sub-model		(A-3)	(B-2)	(C-1)	(D-1)
No. of free parameters		6	11	9	5
$\ln\mathcal{L}$		-859.013	-854.979	-853.032	-861.214
R^2_c		.7191	.7124	.7216	.7018

Degrees of freedom	χ^2 critical value at α=.05
1	3.841
2	5.991
4	9.488
7	14.067
9	16.919
11	19.675
13	22.362
18	28.869
22	33.924

* Figures reported in parentheses are the degrees of freedom for the respective tests.

** Figures reported on the same line as H_1 are the test statistics for the respective tests.

(B) Tests amongst the chosen sub-models (Second stage tests):

Test	Test statistic ($-2 \ln\lambda$)	Degrees of Freedom	χ^2 critical value at $\alpha=.05$	Test Result
(1) H_0: model (D-3) H_1: model (A-3)	4.402	1	3.841	favours (A-3)
(2) H_0: model (D-3) H_1: model (B-2)	12.47	6	12.592	favours (D-3)
(3) H_0: model (D-3) H_1: model (C-1)	16.364	4	9.488	favours (C-1)
(4) H_0: model (A-3) H_1: model (C-1)	11.962	3	7.815	favours (C-1)
(5) H_0: model (A-3) H_1: model (B-2)	3.894	2	5.991	favours (C-1)
(6) H_0: model (A-3) H_1: model (B-2)	8.068	5	11.071	favours (A-3)

Model (C-1) is finally chosen for use.

APPENDIX 7A

Derivation of Price and Quality Elasticities

Elasticity of demand for the ith mode with respect to the freight rate of the jth mode can be written as:

(1) $E_{ij} = \frac{\partial X_i}{\partial P_j} \frac{P_j}{X_i}$ for all i=r,h and all j=r,h

Shephard's lemma allows us to write the demand for ith mode as:

(2) $X_i = \frac{\partial C}{\partial P_i} = \frac{\partial \ln C}{\partial \ln P_i} \frac{C}{P_i} = \frac{S_i \cdot C}{P_i}$

where C is the shipper's transportation sectoral total cost function.

Therefore,

(3) $$\frac{\partial X_i}{\partial P_j} = \frac{1}{P_i} \left(\frac{\partial S_i}{\partial P_j} \cdot C + \frac{\partial C}{\partial P_j} \cdot S_i\right)$$

$$= \frac{1}{P_i} \left(\frac{a_{ij} \cdot C}{P_j}\right) + X_j \cdot S_i)$$

$$= \frac{1}{P_i} \left(\frac{a_{ij} \cdot C}{P_j}\right) + \frac{S_j \cdot C}{P_j} \cdot S_i)$$

$$= \frac{C}{P_i P_j} (a_{ij} + S_i S_j) \qquad \text{for all } i \neq j$$

(4) $$\frac{\partial X_i}{\partial P_i} = \frac{\partial}{\partial P_i} \left(\frac{S_i \cdot C}{P_i}\right) = \left(\frac{\partial (S_i \cdot C)}{\partial P_i} - S_i \cdot C\right) \cdot \frac{1}{P_i^2}$$

$$= [P_i \left(\frac{\partial S_i}{\partial P_i} \cdot C + \frac{\partial C}{\partial P_i} S_i\right) - S_i \cdot C] \frac{1}{P_i^2}$$

$$= [P_i \left(\frac{a_{ii} \cdot C}{P_i} + \frac{S_i^2 \cdot C}{P_i}\right) - S_i \cdot C] \frac{1}{P_i^2}$$

$$= \frac{C \cdot (a_{ii} + S_i^2 - S_i)}{P_i^2}$$

Substitution of equations (3) and (4), respectively, into equation (1) gives:

$$(5)\quad E_{ij} = \frac{\partial X_i}{\partial P_j}\frac{P_j}{X_i} = \frac{C}{P_i P_j}\frac{P_j}{X_i}(a_{ij} + S_i S_j)$$

$$= \frac{1}{S_i}(a_{ij} + S_i \cdot S_j)$$

$$= S_j \cdot \sigma_{ij} \quad \text{using equation (7,3)} \qquad \text{for } i \neq j$$

$$E_{ii} = \frac{\partial X_i}{\partial P_i}\frac{P_i}{X_i} = \frac{C}{P_i^{\,2}}(a_{ii} + S_i^{\,2} - S_i)\frac{P_i}{X_i}$$

$$= \frac{1}{S_i}(a_{ii} + S_i^{\,2} - S_i)$$

$$= S_i \cdot \sigma_{ii} \quad \text{using equation (7,3)} \qquad \text{for } i = j$$

Elasticities of demand for ith mode with respect to nth quality attribute of mode j can be written as:

$$(6)\quad E_{ij}^{n} = \frac{d\,ln X_i}{d\,ln Z_{jn}} = \frac{\partial X_i}{\partial Z_{jn}}\frac{Z_{jn}}{X_i} = \frac{\partial}{\partial Z_{jn}}\left(\frac{S_i \cdot C}{P_i}\right)\frac{Z_{jn}}{X_i}$$

For the translog cost function (3,19a) for model C-1,

$$(7)\quad \frac{\partial X_i}{\partial Z_{jn}} = \frac{\partial}{\partial Z_{jn}}\left(\frac{S_i \cdot C}{P_i}\right) = \frac{1}{P_i}\left(\frac{\partial S_i}{\partial Z_{jn}} \cdot C + \frac{\partial C}{\partial Z_{nj}} \cdot S_i\right)$$

$$= \frac{C}{P_i}\frac{\beta_{jn}}{Z_{jn}}(a_{ij} + S_i \cdot S_j)$$

$$\text{for} \quad \frac{\partial S_i}{\partial Z_{jn}} = \frac{a_{ij}\beta_{jn}}{Z_{jn}},$$

and $\frac{\partial C}{\partial Z_{jn}} = \frac{\partial \ln C}{\partial \ln Z_{jn}} \frac{C}{Z_{jn}}$

$$= \beta_{jn}[a_j + a_{ij}(\ln P_i + \sum_{k=1}^{2} \beta_{ik} \ln Z_{ik} + \delta_i \ln D)$$

$$+ A_{jj}(\ln P_j + \sum_{k=1}^{2} \beta_{jk} \ln Z_{jk} + \delta_j \ln D)]$$

$$= \beta_{jn} \cdot S_j$$

Substitution of equation (7) into equation (6) gives:

$$(8)\quad E_{ij}^{n} = \frac{C}{P_i} \frac{\beta_{jn}}{Z_{jn}} \frac{Z_{jn}}{X_i} (a_{ij} + S_i \cdot S_j) = \frac{\beta_{jn}}{S_i} (a_{ij} + S_i \cdot S_j)$$

$$= \beta_{jn} E_{ij} \qquad \text{using equation (5)}$$

for all $i \neq j$.

Similarly,

$$(9)\quad \frac{\partial X_i}{\partial Z_{in}} = \frac{\partial}{\partial Z_{in}} \left(\frac{S_i \cdot C}{P_i}\right)$$

$$= \frac{1}{P_i^2} \left[\frac{\partial (S_i \cdot C)}{\partial Z_{in}} \cdot P_i - \frac{\partial P_i}{\partial Z_{in}} S_i \cdot C\right]$$

$$= \frac{1}{P_i^2} \left[\left(\frac{\partial S_i}{\partial Z_{in}} \cdot C + \frac{\partial C}{\partial Z_{in}} \cdot S_i\right) P_i - \frac{\partial P_i}{\partial Z_{in}} S_i \cdot C\right]$$

$$= \frac{\beta_{in} \cdot C}{P_i \cdot Z_{in}} (a_{ii} + S_i^2 - S_i)$$

for $\frac{\partial S_i}{\partial Z_{in}} = \frac{a_{ii}\beta_{in}}{Z_{in}}$.

$$\frac{\partial C}{\partial Z_{in}} = \frac{\partial \ln C}{\partial \ln Z_{in}} \frac{C}{Z_{in}} = \beta_{in}S_i$$ similarly as before,

and

$$\frac{\partial P_i}{\partial Z_{in}} = \frac{\partial \ln P_i}{\partial \ln Z_{in}} \frac{P_i}{Z_{in}} = \frac{\beta_{in}P_i}{Z_{in}}$$ invoking the hedonic price relation.

Substitution of (9) into (6) gives:

(10) $$E_{ii}^{n} = \frac{\beta_{in}C}{P_i Z_{in}} \frac{Z_{in}}{X_i} (a_{ii} + s_i^2 - S_i)$$

$$= \frac{\beta_{in}}{S_i} (a_{ii} + S_i^2 - S_i)$$

$$= \beta_{in}E_{ii}$$ again using (5).