# A REGIONAL MODEL OF THE FUTURE DEMAND FOR TRANSPORTATION: THE CASE OF BARGE TRANSPORTATION

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U. S. ARMY ENGINEER INSTITUTE FOR WATER RESOURCES
Kingman Building
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This report is not to be construed as necessarily representing the views of the Federal Government or of the U. S. Army Corps of Engineers.

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# PREFACE

The objective of this research was to develop a systematic methodology for projecting the demand for barge transportation. The methodology is based upon a general equilibrium model of the supply and demand for specific commodities, then an analysis of the model share consequences of the spatial alignment of supply and demand centers. Demand for transportation is assumed to be derived from the demand for commodities over space. Division of traffic between transport modes is assumed to be a function of the rate and service characteristic of competing modes. Empirical estimates are made of the demand for barge transportation of coal to three functional economic areas of the Ohio River Region--Pittsburgh, Cincinnati and Evansville. Demand functions for coal in each area were projected, supply functions for coal production areas competing for these markets were projected, and an equilibrium allocation of trade flows estimated by linear programming and utilizing minimum average transport cost from each originating region to each destination region. Choice of transport mode was estimated by utilizing discriminant functions based on current (1970) rate and service characteristics for competing modes.

Certain simplifying assumptions were made possible by the choice of date of projections (1980). Coal using technology in steel and electrical production sectors is well defined and known because of the long lead time required for introducing technological change in these industries. Longer-run projections would require a much more detailed set of analysis of technological trends which influence substitutability of alternative fuels. Similar stronger assumptions were made on technological relationships and pricing policies between transport modes, although the modal split model permits some exploration of the consequences of altering existing relationships. This issue will be discussed more fully in a forthcoming publication by IWR dealing with the division of traffic between transport modes in the Ohio River area.

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# INTRODUCTION

The Federal Government invests enormous sums of money to finance the construction and the maintenance of a network of various types of transportation lines between spatially separated economic trading centers.[1] One criterion employed by the government to determine whether to initiate or maintain a transportation project is the demand for such facilities. This use of this particular criterion requires understanding of the economic forces which determine the demand for such transportation modes that utilize the constructed transportation facilities. Currently, the interrelationship between economic factors and the substitutability of alternative modes of transportation as well as observed mode selection behavior is only partially understood. Current procedures are inadequate for projecting firms' future demand for transportation. This is due to the inability to project and interrelate future transportation services demanded and the future transport demanders' choice of mode. This research is undertaken to establish a procedure to project future demand for transportation adequately and to give the government a procedure for justifying various investment endeavors.

## Objectives and Findings

The objective of this dissertation is to project the future demand for barges to transport bituminous coal to selected economic centers.

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[1] In 1972 the U. S. government allocated 11.2 billion dollars for commerce and transportation. This is taken from U. S. President, The Economic Report of the President, Transmitted to the Congress, 1973, U. S. Government Printing Office, Washington, D. C., 1973.

This research is undertaken because current forecasting methods are unable to adequately predict a changing system. Current forecasting methods rely upon any one of a number of interrelationships that influence transportation demand. In addition, the demand for coal to be transported is most often exogenously determined, while the supply of coal is regarded as infinite. Moreover, existing forecasting models only describe a portion of the transportation market, and they do not consider the effects of parametric shift over time.

To remove some of the inadequacies of current forecasting models, the dissertation combines several techniques into one comprehensive model. This comprehensive model, in turn, consists of three interrelated economic models. Using these models eliminates the need for assumptions that have reduced the utility of previous models. The comprehensive model permits a better total economic understanding of the transportation market and enables the model to function in a changing environment.

Model I is used to estimate the quantity of coal demanded by firms and the quantity of coal furnished by suppliers within a geographical region. Demand for coal is derived from projected output of firms which utilize coal as a factor of production in manufacturing their output. Demand derivation also includes consideration of the future state of technology for those industries. Supply of coal is calculated from a set of production variables subject to coal reserves. Model I, thus, eliminates the necessity of accepting an exogenously given quantity of coal to be transported and removes the assumption of an infinite supply of coal available to consumers.

Using information from Model I enables Model II to link the coal market to the transportation sector. Model II is used to determine the least cost transportation mode to allocate the projected supply to the various demanders. Consequently, Model II removes the assumption of predetermined interregional trade patterns and a fixed quantity of coal moving along these water transportation routes.

Finally, Model III utilizes a statistical technique, discriminant analysis, to determine the mode of transportation each firm will select for transporting its coal. This procedure basically follows the method developed by Leon Moses.[1] In addition, Model III simulates the demand for barge transportation in a similar manner but uses a different mathematical procedure. In any case, discriminant analysis permits the mode selection decision process to consider monetary as well as non-monetary criteria.

With these three models, an empirical analysis was undertaken to estimate the future coal movements by water carriers to selected regions in the Ohio River Basin. Data for the models include responses from direct surveys and information from historical public documents. Three conclusions can be drawn from the analysis performed.

One: Determining the demand for coal to be transported by various modes is more adequate and sensitive a predictor of demand for coal than an assumption that specifies a given quantity for various modes. Two:

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[1] Leon Moses, et al, Cost-Benefit Analysis for Inland Navigation Improvements, U. S. Army Corps of Engineers, Institute for Water Resources, Report 70-4, Vol. 3, Washington, D. C., 1971.

It is hypothesized that a regional approach to determine users' economic transportation mode selection process presents a more accurate description of that process than the aggregate or national approach. Three: The demand curve for barge transportation is truncated in shape.

Order of Presentation

Of the seven separate chapters, the first chapter presents historical background of the difficulties in projecting the demand for transportation and mode selection. In Chapter II micro-economic theory is utilized to indicate why in the future firms will demand barge carriers to transport their coal. In Chapter III the theoretical model in Chapter II is converted into an actual empirical model and the restrictions involved in such an alteration are presented. The fourth chapter exhibits the empirical results of Model I, while in Chapter V the interregional trade results are shown, and in Chapter VI the empirical findings for Model III are presented. Finally, in Chapter VII a brief conclusion to the work is stated.

# REVIEW OF TRANSPORTATION LITERATURE

## CHAPTER I

Over the years researchers and academicians have been struggling for a method to accurately estimate the future demand for various modes of transportation.[1] In Chapter One a review of selected articles is presented describing various methods to estimate the demand for transportation and covering most of the important contributions. This review reports the most often occurring methods used to describe economic behavior of the transportation sector. It also sets forth both the objective and the method of analysis as well as the results in each article discussed. Chapter One has two basic parts: one, the review of literature on the demand for transportation, and two, a brief examination of attempts to measure the supply of transportation and future supply of coal.

### PART ONE - DEMAND FOR TRANSPORTATION

#### Interregional Trade Patterns

In this part three articles are reviewed in which research is reported that aids in determining the economic reasons for trade to occur among, and the optimal distribution of goods for, spatially separated trading centers.

While the early literature contains numerous work on determining the quantity of goods that flow between certain economic centers there exists very little research which describes flows with more than two

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[1]See bibliography - particularly items numbered 8, 24, 32, 36, and 37.

markets. One of the initial researchers is T. Koopmans.[1] He developed a linear programming model to determine the least cost manner to distribute a given amount of goods amongst a given set of markets with the demand for and the supply of goods constant. Koopmans established a method to predict the trade pattern among and the quantity of goods that flow between a set of markets based on economic criteria.

The development of linear programming resulted in a whole series of economic transportation models.[2] One of the more important contributors to the linear programming concept is Paul Samuelson.[3] He created a model in which each geographical area's "net social pay-off" was maximized. Optimization resulted in total trade equilibrium. To determine the demand for and the supply of goods for each area, Samuelson incorporated a linear production and consumption function, which improved previous work by eliminating the condition and assumption of a fixed demand and supply. Moreover, his work indicated that Koopmans' view of the problem was only partial.

Currently, Hickman, Klein and Rhomberg utilize a linear program model based on coefficients from their econometric model to solve various transportation problems.[4] Their model incorporates reasons for a flow

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[1] T. Koopmans, Activity of Production and Allocation, Cowles Commission Monograph, No. 13, New York, John Wiley, 1951.

[2] Some of the linear program models and problems can be found in the bibliography items numbered 22 and 35.

[3] Paul Samuelson, "Spatial Price Equilibrium and Linear Programming," American Economic Review, Vol XLII, No. 2, May 1962, pp. 283-303.

[4] Bert Hickman, Lawrence R. Klein, Rudolf R. Rhomberg, "A General Linear Model of World Trade," in R. J. Ball ed., International Linkage of National Models, North-Holland Publishing Company, Amsterdam (1972), forthcoming.

of commodities between different countries (markets) and can be used to determine the quantity of goods that flow between these countries. This model operates in total equilibrium as all other linear models do. To insure this, individual countries may be either an exporting or importing country, but their trading activities offset each other in order to establish a total system equilibrium. Moreover, they assume that the deficit balance of payment country does not take any action to adjust its balance of payment problems.

$$X_{ijk} = B_{ijk}\sigma_{jk} \; X_{jk} \, (P_{ijk}/P_{jk})^{\sigma}$$

$X_{ijk}$ = the demand for commodity k by region j from region i

$X_{jk}$ = the demand for commodity k by region j

$P_{ijk}$ = the price of commodity k that is sold by region i to region j

$P_{jk}$ = weighted average price of commodity k in region j

$\sigma_{jk}$ = elasticity of substitution of k produced in i for k produced in j

$B_{ijk}$ = is a constant amount of commodity k that region j demands from region i

$$X_{ik} = cP_{ik}^{\varepsilon_{i1}} \; P_{ik}^{\varepsilon_{i2}} \ldots P_{ik}^{\varepsilon_{ik}} \; S_{ik,1}^{\varepsilon_{i,m+1}} \ldots S_{ik,s}^{\varepsilon_{i,m+s}}$$

$X_{ik}$ = the supply function for commodity k by region i

c = constant

$S_{ik,s}$ = any other supply influence operating in region i with respect to to commodity k

$\varepsilon_{ij}$ = the j region demand elasticity for commodity k from region i

The goods are homogeneous with a price differential existing in different markets. Consequently, region j trades with region i for good k only if the price for good k is equal or lower in region i to that in all other regions. If, in region j, price exceeds the price in any other area

consumers will not purchase commodity k from j but from another region which offers k at a lower price. The model provides an algorithm procedure to delineate the optimal trade pattern through several iterations given price differentials in markets for k. With this model, projections of world trade might be made for any time horizon.

Research to determine the optimal allocation of goods among geographical areas progressed as theoreticians incorporated additional economic theories and subtracted a priori assumptions from their models. However, there are two major criticisms of this type of analysis. The models assume the transportation prices are independent of shipment volume and distance, and the models do not offer a method for determining or choosing the mode of transportation.

Transport Cost

William Long's, Edgar Hoover's, and John Meyer's articles below were selected to show the effects on transportation demand when transportation cost becomes a function of volume and other economic variables.[1,2,3] The first describes how transportation cost affects the allocation of goods amongst modes, while the latter two describe a means to determine the transportation cost.

The first article does not include the work of early developers of the gravity model but presents a current use of this technique indicating

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[1] William Long, "The Economics of Air Travel, Gravity Models," Journal of Regional Science, Vol 10, Dec 1970, pp. 353-365.
[2] Edgar Hoover, The Location of Economic Activity, McGraw-Hill Book Co., New York, NY., 1960.
[3] John R. Meyer, The Economics of Competition in Transportation Industries, Harvard University Press, Cambridge, 1960.

that the gravity model is still a vital economic tool for describing observed economic behavior.[1] William Long uses the gravity model technique to forecast the future demand for air transportation. Gravity models utilize the measures of two variables: quantity and distance. Long measures the response of traffic volume to a given cost function that is related to distance. This analysis produced results that indicate there is a downward sloping demand curve for air transportation. This indicates that the closer the distance (lower cost) the larger the volume of traffic, and the further the distance (higher cost) the smaller the volume. Long's gravity model aided in estimating the amount of mass that can be transported a given distance. A weakness in the transportation gravity model is that it does not show the economic characteristics of each mode of transportation. Therefore, the model can not be used to determine which transportation mode a firm will select to transport its goods.

Numerous books are available to describe the economic characteristics of different transportation modes. Two of the more important works are by Edgar Hoover and John Meyer. Edgar Hoover explains that transportation price is related to a series of variables. Moreover, John Meyer's classic work shows that different modes possess different values for similar variables, which results in different transportation prices. Consequently, once modes can be distinguished by price, firms have a modal choice.

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[1] A more detailed description of gravity model technique can be found in Walter Isard's Methods of Regional Science, Massachusetts Institute of Technology, Cambridge, 1960.

Unfortunately, neither Long nor Hoover describe a procedure for predicting which mode of transportation a firm will select.

Mode Selection

Development of procedures to determine the mode selection process by firms requires incorporation of additional economic notions. In their transportation model, W. Baumol and H. Vinod use the profit motive, which is a fundamental economic concept.[1] With this concept, the model can be used to determine how a firm selects a transportation mode. Transportation mode selection is based on a single criterion - the price the transporter charges the firm. Obviously, the firm selects the least cost mode of transportation, reducing one of the firm's costs to minimal levels and thus helping the firms to reap the most profit.

Since the single price criterion did not accurately describe firm's observed mode selection behavior, models using additional criteria were developed. Discriminant analysis appears to be a more promising technique to handle this multi-criteria function. Two of the early researchers to utilize discriminant analysis to determine the modal split are J. A. Joseph and A. Mongini.[2,3] A modal split occurs when in the course of a good traveling to a market more than one transportation mode can be used. The model is used to describe the limit to one mode's use. The Joseph and Mongini

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[1] W. Baumol and H. D. Vinod, "Studies on the Demand for Freight Transportation," Mathematica, Vol. 1, Princeton, 1967.

[2] J. A. Joseph, "A Discriminant Analysis Approach to Modal Split," Northeast Corridor Transportation Project, Tech. Paper No. 7, U. S. Dept. of Transportation, Feb 1967, pp. A1-A7.

[3] A. Mongini, "Some Aspects of Discriminant and Other Inter-Urban Modal Split Models," Northeast Corridor Transportation Project, Tech. Paper No. 7, U. S. Dept. of Transportation, Feb 1967, pp. B1-B18.

models incorporate monetary as well as non-monetary criteria in the mode selection process. This allows the choice of mode to be based on a combination of variables for each mode. Therefore, this work provides a means to predict future modal selection without having to rely strictly on transportation prices.

The above research utilizes various economic notions and statistical models to predict the firm's modal choice. However, all the models assume a given and fixed quantity of goods to be transported. The allocation of goods is also predetermined.

DEMAND ANALYSIS

With methods to determine the firm's choice of mode and the use of computers, the development of a model to simulate the demand for a particular mode with the existence of an alternative mode became possible. Using a discriminant analysis program, Bruce Allen developed an economic model to estimate the demand for air freight transportation.[1] In the model it is assumed that the firm's marginal revenue for selling a product is constant, and only the air transport cost fluctuates. Higher transportation cost pushes the product cost curves upward, reducing the demand and consequently the output of the product and the demand for air transportation.

In applying empirical data to the model, Allen used a discriminant analysis. This multivariate analysis is used to determine mode selection and, with slight alteration of the model, can be used to simulate the demand for air transportation. Unfortunately, the empirical test of the

[1] Bruce Allen, "A Model of the Demand for Transportation, The Case of Air Freight," Cost-Benefit Analysis for Inland Navigation Improvements, Vol. II, U.S. Army Corps of Engineers, Institute for Water Resources, Alexandria, Va., 1970.

model did not produce convincing proof of the validity of the method used.

Further study utilizing discriminant analysis has been done by George Antle and Richard Haynes.[1] Their investigation attempted to determine the adequacy of discriminant analysis for use in predicting the modal split and simulating the demand for barge transportation. Their model used data collected from recent surveys of actual users, not second hand information.

Both of the above studies were used to produce a truncated demand curve for barge transportation. Statistical testing of variables and sample size indicated that discriminant analysis is an appropriate method to approximate a firm's mode choice process and to simulate a demand curve for a particular mode. The two research endeavors were merged to provide a method to derive a demand curve. However, both methods rely on a given quantity of goods to be transported and a predetermined trade pattern. Hence, methods to determine the demand for transportation, trade pattern and the demand for and supply of a good have developed, but there exists no integration between these various concepts to form a comprehensive model.

PART TWO - SUPPLY ANALYSIS

In this dissertation it is assumed that an adequate supply of all transportation modes is available to the firm. A brief statement about

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[1] L. G. Antle and R. W. Haynes, An Application of Discriminant Analysis to the Division of Traffic Between Modes, U. S. Army Corps of Engineers, Institute for Water Resources, Report 71-2, Alexandria, Va., 1971.

two research endeavors gives a glimpse into the difficulty of calculating the supply of transportation. After the transportation supply discussion, we will turn to a discussion of the supply of coal.

Supply of Transportation

While there is extensive literature on operating and production cost analysis for various modes of transportation, there exist very few studies which describe in detail the cost function components of various modes. Two of the most thorough analyses of rail and water mode cost functions are the studies of Joseph S. DeSalvo and Leland S. Case.[1,2] Although both develop models to describe the economic cost component of transportation, they each concentrate on a different aspect of the cost function.

DeSalvo only investigates the problems of estimating the line haul cost for railroad and barge. In the barge analysis a line haul cost function is constructed to define the direct line haul cost and to describe the economic effects of barge delay, acceleration time, and reassembling time. Unfortunately, data for railroads were unavailable which prevented formulation of a rail line haul cost function. Converting engineering data into economic data still resulted in an incomplete line haul cost function. Therefore, only a limited comparison of line haul cost between the modes is possible, due to insufficient data. A further analysis of operating

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[1] Joseph S. DeSalvo, "Linehaul Process Functions for Rail and Inland Waterway Transportation," Cost-Benefit Analysis for Inland Navigation Improvements, Vol. 2 of 3, 70-4, Institute for Water Resources, Washington, D.C., 1970.

[2] Leland Steward Case, "Estimation of Production and Cost Functions for Inland Waterway Transportation," Cost-Benefit Analysis for Inland Navigation Improvements, Vol. 2 of 3, 70-4, Institute for Water Resources, Washington, D. C., 1970.

cost of barges is undertaken by Leland S. Case. He examines the production and cost function of the barge mode. The results of the analysis depicts the cost of moving a cargo with consideration of such factors as equipment involved, tow size, waterway characteristics, back haul, and season characteristics. There does not exist a similar detail analysis for other modes. Therefore, because of the inadequacy of data for other modes, only the barge mode can be simulated to determine its reaction to various parameter alteration.

The difficulties in determining the cost functions for all modes and how these modes of transportation react to competition become quite visible, from these studies. Basically, analytic difficulties result from the lack of sufficient data with which to perform an adequate analysis of the cost functions.

SUPPLY OF COAL

Two methods are described to estimate the future supply of coal available to consumers. Supply of coal studies' conclusions vary because of the discovery of additional reserves with the use of more sophisticated equipment and techniques and the variation in the rate of extraction of coal in the coming years. To illustrate these studies, two articles are presented on the supply of coal.

To estimate the demand for coal, it becomes necessary to determine whether there is an adequate reserve of coal available. Estimating the current reserves of coal available requires the mapping and exploration of all geographical areas for coal. Paul Averitt coordinated such a study for the Bureau of Mines to determine the coal supply available in the

U. S.[1] His study states that there exists a sufficient supply of coal to meet the foreseeable future. In 1967, he estimates $6.71 \times 10^{11}$ tons of bituminous coal are still available. However, this study assumes a fixed rate of extraction and did not consider the effects of increasing cost to extract the coal.

Determining the extraction rate for coal requires analysis of reasons coal is utilized and appropriate cost of production. Resources for the Future uses this approach by integrating the demand for and supply of coal into an analysis projecting the quantity of coal to be extracted.[2] However, this analysis did not consider the effects of higher cost of obtaining coal or the effects of parametric shifts over time.

CHAPTER SUMMARY

This review of the literature provides a glimpse of some of the important models used in determining the demand for transportation. From this review it can be seen that previous models did not adequately describe a total methodology to estimate the future demand for a transport mode. Each model presented did utilize at least one component of this complex problem. However, researchers failed to integrate existing methods for determining the demand for transportation into their models, which would have improved the overall economic analysis. Therefore, this dissertation improves on current methods by combining several of these models

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[1] Paul Averitt, Coal Resources of the United States, January 1, 1967, Geological Survey Bulletin 1275, Washington, D. C., 1969, pp. 8-14.

[2] H. H. Landberg, L. L. Fischman, J. L. Fisher, Resources in America's Future, published for Resources for the Future, Johns Hopkins Press, 1963, pp. 414-416.

into a unified model of the transportation market which enables the derivation of the future demand for barges to transport coal. The supply of transportation is not discussed in this dissertation because it is assumed that there exists an adequate supply of transportation, and the concept of the supply of transportation is considered to be a complete topic in itself.

# METHODOLOGY TO PROJECT FIRMS' FUTURE DEMAND FOR TRANSPORTATION

## CHAPTER II

Projecting the firms' demand for transporting coal by various modes to selected regions requires a better understanding of how certain variables affect the demand for coal transport.[1] An economic model is built to explain the relationship between these variables and the demand for coal transport in the observed transportation market. With this general model, a method is established to determine firms' future demand for transport by various modes.

The literature historically has reported research that examined only a portion of the problem at any one time. This proposed model herein improves on the existing approaches by utilizing and combining several portions of the previous research. It combines the three major areas of research in the field of transportation: (1) What quantity of coal as factor of production will individual firms require to manufacture an output; (2) Where is the coal to be transported; and (3) What quantity of coal will each mode of transportation carry. Thus, this model forms a more comprehensive economic model of the transport market than the prior models.

To understand the unification and the interaction of the three research areas -- pulled together in this new approach -- the model is presented in

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[1] A few of the variables that affect the demand for transporting coal by various modes are: price of transportation--all modes; price of coal, technology, and annual tonnage shipped.

three parts. Also, individual parts are so arranged that the results of one part are inputs of the next part and any direct or indirect correlation between the areas of research can be identified. In Part One the methodology involved in determining the quantity of coal (as a factor of production) to be transported is described. This part is further divided into two sections for a more detailed analysis. In Section One the demand for coal (as a factor of production) is derived and in Section Two the supply of coal is derived. In Part Two the interregional trade patterns are developed as is a method to approximate the quantity of coal that flows between the various trading centers. Given the quantity of coal that flows along the known interregional trade patterns, the mode of transportation the users select to transport their cargoes is determined in Part Three, providing a method to simulate the demand for a particular mode of transportation. This approach permits an understanding of each part, how they link together to form the comprehensive model, and finally, states what the demand for coal transportation would be, given a set of initial conditions.

## PART ONE - WHAT QUANTITY OF COAL AS FACTOR OF PRODUCTION INDIVIDUAL FIRMS WILL REQUIRE IN MANUFACTURING AN OUTPUT

### Section One - Demand for a Factor (u) of Production

Section One presents a theoretical procedure to determine the future demand for coal (as a factor of production) used by firms in manufacturing an output. This requires the estimate of the future output each firm intends to produce. At the same time, this necessitates the construction of a dynamic conversion coefficient to estimate the quantity of coal (the factor of production) sufficient to manufacture one unit of the future

output. Using this information enables the derivation of the future demand for coal (as a factor of production) by a firm or total firms.

PROJECTED OUTPUT

In determining the future demand for coal, first an examination is required of firms that utilize now and could potentially utilize coal in the production of an output. This presents the reasons for use of and the relationships between the factor of production (coal) and the output. Using this approach makes the coal projection partially dependent on the firm's output and also gives the model a method to explain given changes in the demand for coal. Hence, development of an economic model to project the firm's output with the set of given conditions is undertaken.

Examining the consumption data on coal by sector shows that three sectors (electrical utility, bituminous coke plants and primary metal plants) consume the vast majority of coal.[1] Moreover, these sectors operate within an imperfect market structure.[2] Consequently, this model only provides a means to estimate the quantity of output for those firms in the selected three sectors by projecting their observed demand function.

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[1] U. S. Department of Interior, Bureau of Mines, Minerals Facts and Problems, 1970 Edition, Washington, D. C., 1971, pg. 43.

[2] This model provides a means to estimate the quantity of output an individual firm produces in an imperfect market. An imperfect market condition occurs because actions of buyers and sellers in the observed output market have a perceptible influence on prices (actions such as government controls, long-term contracts, and price leaders represent some reasons for the imperfect market). Existence of a high capital cost barrier which restricts firms from entering or leaving the market represents another reason for the imperfect market.

Numerous examples of the existence of this market condition and these production relationships exist in today's markets. For example, the electric energy industry manufactures a homogeneous output, but the price of a megawatt is set by government agency, while the steel industry (as well as electric energy industry) exhibits a high capital cost barrier restricting entrance into the market. Also, the price of steel is administratively set by each firm. To project the future output of either industry (to explain actual occurrences) requires an understanding of how these and other components interrelate and affect management production decisions. However, economic analysis of all the various imperfections of the market is beyond the scope of this research endeavor.

Hence, this investigation is undertaken to project the future output for firms from the selected industrial sectors with a given future price for their output.[1] The method of setting the given price for each output is due to some imperfection in the market whose exact mechanism is not the concern of this thesis.

With the future price level for each firm's output and the observed demand function and given the theoretical cost curves for each firm, it becomes possible to theoretically determine the output for each firm. The derivation only requires the firms to be economically rational. With these premises, the individual firm manufactures that level of output where its marginal cost intersects the given marginal revenue, since this position represents the point where the firm maximizes its profit. Therefore, this model will enable a description of the quantity of output each firm manufactures under a set of conditions.

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[1]This assumes that the basic demand structure does not bring about important relative price changes.

## TECHNOLOGICAL COEFFICIENT

The technological coefficient provides a linkage between the firm's output and the demand for coal (as a factor of production).[1] In addition, it converts the various output units into a commensurable unit. Future technological coefficients describe the expected state of technology and indicate the amount of coal necessary to manufacture a projected level of output.

Two constraints are placed on the technical coefficient. One, there exists no immediate substitute for coal in this region. Resources for the Future indicate that all existing alternatives to coal are too scarce and too expensive to replace coal in any great quantities.[2] Two, any innovation that permits the utilization of an alternative to coal, or coal as an alternative to something else, requires a period of time before industries adopt the innovation.[3] Obviously, the recognition and the engineering acceptance of the innovation does not occur instantaneously, nor does the determination of the economic justification for converting to alternative factors. For either case to occur requires the passage of time and the implementation of capital investment.

## DEMAND FOR INPUT

A method to derive the individual firm's demand for an input now becomes possible. This procedure involves the division of the ith firm's

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[1] Technological coefficient is defined as the output unit that can be produced from one unit of coal.

[2] H. H. Landsburg, L. L. Fischman, and J. L. Fisher, Resources in America's Future, published for Resources for the Future by Johns Hopkins Press, 1963, pp. 405-414

[3] Federal Power Commission, 1970 National Power Survey, Part II, Washington, D. C., pp. 11-2 - 11-126.

projected output by the ith firm's technological coefficient. The results of this determines the quantity of coal (as a factor of production) necessary to manufacture the projected output by the ith firm. Repeating the process for each firm determines the demand for factor (coal) by each individual firm. Summation of all the individual firm's demand equals the total demand for coal as a factor of production.

This is a demand function for firm's output that incorporates the assumption that supply of output will be available at appropriate prices to meet the forecast demand.[1] Interviews with industry officers indicate this assumption is realistic.

Model 1 determines the output each selected firm manufactures in t+x period (future period).

Symbolic Form of Model 1

Each $F_i$ produces only one $O_j$

i. $O_{jt} = f(Y_1 \ldots Y_n)$

ii. $O_{jt+x} = f(Y_1 \ldots Y_n)$ t+x assuming supply of jth output is adequate

$F_i$ = ith firm produces the $O_j$ output

$O_j$ = demand for the jth output

t = time period

t+x = x number of years beyond t

$Y_i$ = variables that determine the output

The set of Y's for the thermal (coal) generating electrical industry are:

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[1]Supply of output is perfectly elastic.

$Y_1$ = price of electricity per kilowatt

$Y_2$ = per capita income for geographical region

$Y_3$ = population of geographical region

Y set for the steel industry:

$Y_1$ = retail price of durable goods

$Y_2$ = price of steel per ton

Y set for the coke industry:

$Y_1$ = steel production (domestic)

$Y_2$ = price of coke per ton

The output model is used to determine the output each firm manufactures in the t+x period. The model assumes the ith firm manufactures one and only one output, the jth output. The demand for the jth output is a function of a set of $Y_i$ variables in the t period. Projecting the set of $Y_i$ variables for t+x period and given the cost and the price for jth output in t+x period reveals the jth output function for the t+x period. Having this function, the jth future output can be determined for the t+x period.

iii. $\alpha_{ut} = O_{jt}/f_{ut}$

$\alpha_{ut+x} = O_{jt+x}/f_{ut+x}$

$O_{jt+x} = a + b_1Y_1 + b_2Y_2 + \ldots + b_nY_n$

$\alpha_{ut}$ = technological coefficient for the ith firm in the t period

$f_{ut}$ = factor (u) of production the ith firm consumes in the t period

$b_j$ = the amount of change in the calculated value of $O_j$ which accompanies a change of one unit in $Y_i$ when the effects of other independent variables are also being considered.

Technological coefficient determines the quantity of j output that is produced from the consumption of one unit of coal in the t+x period. To determine this, the model requires the known jth output in previous periods to be divided by the known quantity of coal the ith firm purchased for the same periods. This assumes all coal purchased in those periods is consumed within those periods.[1] With these data, the t+x technological coefficient can be extrapolated for the ith firm. Utilizing this information, the demand for coal by each individual firm in the t+x period can be implemented. This procedure just divided the firm's projected output of commodity j in the t+x period by the technological coefficient.

SUMMARY OF SECTION ONE

Thus, Section One presents a model to project the firms' demand for coal without accepting an exogenously given quantity of output for each firm. Moreover, in this model the relationship between the firms' output and the demand for coal (as a factor of production) is shown. Changes in the demand for output or technological changes produce an immediate effect on the demand for coal. Previous methods might show similar changes in demand for coal, but would not indicate the particular sector in which this change in demand would occur or the reasons

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[1]Price is exogenously determined for coal input but an argument for its utility in examining the model is presented on II-13.

for these changes. Hence, incorporating the output and technological effects into the model assist in verifying projections and makes the model sensitive to possible changes.

Section Two - Supply of Input

Section Two presents a method to estimate the future supply of coal. Furthermore, it permits determination of whether there exists an adequate supply of coal (factor of production) to meet the future demand for coal. This model can be presented in the symbolic form:

$S_{bt} = f(Z_1 \ldots Z_c)\ t \qquad b = i \ldots\ldots m$

$S_{bt+x} = f(Z \ldots Z_c)\ t+x$

$S_{bt}$ = the amount of coal the $b^{th}$ supplier supplies in the $t^{th}$ period

$Z_i$ = set of variables determining the quantity of coal the $b^{th}$ supplier supplies

The quantity of coal the $b^{th}$ supplier furnishes in the t period is a function of set of Z variables. Projecting this function indicates the quantity of coal the $b^{th}$ supplier furnishes in the t+x period. Summing all the suppliers determines the total coal available to selected firms. Finally, comparing this result with the demand projections determines the adequacy of the future supply of coal.

Assumptions

The supply model includes two assumptions for simplification. One, assume that suppliers operate in a purely competitive market. Two, assume the existence of a finite quantity of coal, and that each individual supplier possesses some portion of this quantity

which represents a material constraint. As consumption of the irreplaceable coal approaches the finite limit, the slope of the cost curves (average and marginal) become positive, because diminishing returns set in. This means each additional coal unit requires more economic effort to extract than the previous unit. This causes the long-run average cost curve to display a positive slope, which represents a cost constraint for continuing extraction of coal by a supplier. With these two assumptions, the model is used to develop a method of determining the quantity of coal suppliers furnish to the demanders.

Economic Explanation of the Supply Model

Profit maximizers supply that quantity of coal indicated by intersection of their marginal revenue and marginal cost. The manner of attaining an equilibrium in the supply market requires analysis of the suppliers' behavior in response to alterations in their revenue functions. It should be remembered that suppliers operate with a U-shape cost function, and the price of coal is given. Thus, it is only necessary to determine the plant size to derive individual supply.[1]

To begin with, assume the market sets the price for coal at $P_1$, and suppliers initially start at plant size one. Thus, suppliers furnish the quantity of coal such that their marginal cost intersects the marginal revenue at that quantity. This results in the quantity $q_1$ being produced. On expanding to plant size two and operating at the

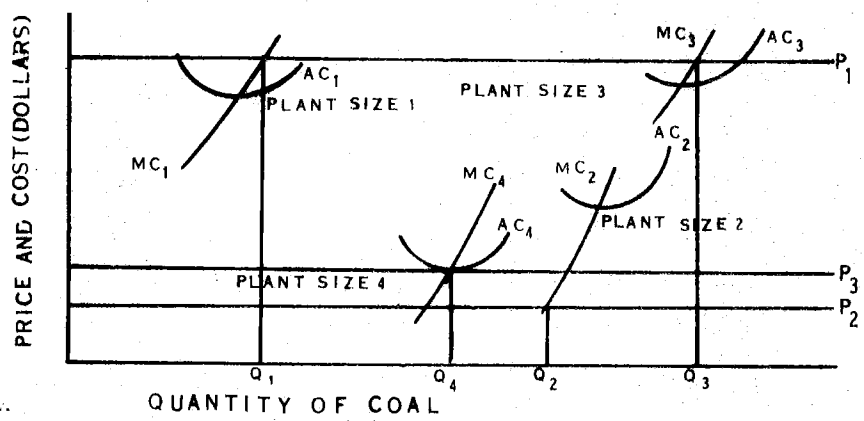
[1]Assume all suppliers have a homogeneous cost function.

point where $MR=MC_2$, suppliers discover they reap a pure economic profit at $P_1$. This expansion of plant size continues until any further plant expansion results in their cost exceeding their revenue, which is not a situation considered oriented to the firm's goals. Thus, a supplier having a similar cost function would produce the quantity $q_3$. At the same time, the pure economic profit being earned by suppliers attracts new suppliers into the market. The combination of higher output by each supplier and the addition of new suppliers shifts the market supply curve to the right. The shift in the market supply curve results in lowering the coal price to $P_2$. However, price $P_2$ affects the supplier's production decision, entrance of new plants into the industry and the plant size of operation. Since $P_2$ is less than $P_1$, it results in lowering the suppliers' marginal revenue curve. With a lower marginal revenue curve, suppliers operating at plant size three (Figure II-1) are no longer operating at the optimal economical plant size. Suppliers' cost now exceeds their revenue at any production level. To reduce this deficit, the supplier reduces his plant size but still produces that quantity of coal where his MC intersects MR. This results in the supplier furnishing a smaller quantity of coal than he previously did when the price of coal was at $P_1$ (plant size 2).

The lower marginal revenue removes the suppliers' pure economic profit. This loss results in discouraging new suppliers from entering the market and even forces some of the existing suppliers to seek better returns elsewhere.

FIGURE II-1

SUPPLIER'S PLANT SIZE




The quantity of coal each supplier produces and the choice of plant size each supplier operates at is a function of his cost curves and his given marginal revenue curve.

With less production by individual supplier and the reduction in the number of suppliers, the market supply curve shifts to the left. This establishes a new equilibrium price at $P_3$, the lowest price where AR=AC=MR=MC with the least costly plant size the suppliers can have. At this position, a supplier neither makes a pure economic profit nor losses. This position also does not encourage the entrance into or exit of suppliers from the market. The supply of coal furnished by each supplier can be determined. Summing all the individual suppliers derives the total supply of coal available for consumption.

Interfacing the projected total demand for and total supply of coal may not result in an intersection between the two projections. To establish an intersection between the demand for and supply of coal requires introduction of the price of coal, which acts as the adjustment factor because it affects both the demand for and supply of coal.

The findings of testing for demand and supply equilibrium presented only a 2% discrepancy between demand and supply for coal. If this discrepancy needed further analysis for resolution the following would have to be done. Demand for coal depends on the quantity of output firms manufacture utilizing coal as factor of production. Shifts in demand for output causes shifts in the demand for coal. A decline in the firms' output production causes the demand for coal to be lower. Obviously, a reduction in prices result in the reverse situation, assuming prices are flexible. Thus, indirectly the price of coal affects the quantity of coal demanded. At the same time, the price of coal directly affects the quantity of coal suppliers furnish, for it is the suppliers' marginal revenue which is a price determinant of the quantity of coal each supplier produces (with marginal cost). Consequently, increases in the price of coal cause the production of coal to increase, while a decrease in the price of coal results in a reduction in the quantity of coal suppliers furnish.

Further, with the price of coal having an inverse relationship with the demand for coal, and a direct effect on the supply of coal, any imbalances in the totals can be adjusted.[1] Although varying the price of coal does accomplish this feat, adjustment does not occur instantaneously. In fact, the readjustment process may produce several intermediate price levels before the equilibrium is attained. However, the price

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[1]This assumes the shape and slope of the demand curve do not become altered but only parametric shifts can occur.

oscillations that occur are dampened due to the knowledge gained from previous experiences. Therefore, we have a method to estimate future demand for coal based on economic market factors and the existence of a supply function.

## PART TWO - LOCATION OF THE COAL TO BE TRANSPORTED

### Model II - Interregional Trade Patterns

Model II presents a means to connect the factor (coal) market with the transportation market. Model I was used to determine the quantity of coal demanded and supplied within a geographical area. The quantity of coal to be transported from the different suppliers to the various consumers is unknown. Model II is a model to resolve this problem. The model construction will reveal the interregional trade patterns between the producers and consumers of coal. To accomplish this, it is necessary to introduce the transportation cost and markets into the analysis. The relationship between the cost and distance is positive. The further the distance, the higher the cost, and the shorter the distance, the lower the cost. Obviously, firms desire to purchase their coal as nearby as possible to minimize their cost. Model II describes a method to minimize transport cost. Model II is used to determine the least cost manner to allocate the supply to the demander. The following symbolic form shows this basic concept.[1]

---

[1] Mathematical notions from Robert W. Llewellyn, Linear Programming, Holt, Rinehart and Winston, New York, 1964, pp. 97-100. This dissertation used the non-negative constraint linear program developed by University of Wisconsin Computer Center, SIMPDX/SIMPLX Linear Programming Subroutine Reference Manual, MACC, Madison, 1970.

$a_{11}x_1 + a_{12}x_2 \cdots\cdots\cdots\cdots a_{1n}x_n = b_1$

$a_{21}x_1 + a_{22}x_2 \cdots\cdots\cdots\cdots a_{2n}x_n = b_2$

$a_{m1}x_1 = a_{m2}x_2 \cdots\cdots\cdots\cdots a_{mn}x_n = b_n$

and which minimizes

$Z = c_1x_1 + c_2x_2 \cdots\cdots\cdots c_nx_n$

$a_{ij}$ = the amount of coal the ith firm wants from the $x_j$ source

$x_j$ = the amount of coal the jth supply has available

$b_i$ = the total amount of coal the ith firm requires

$c_k$ = the cost of transporting the coal from a $x_k$ supply source to the ith firm

$Z$ = the lowest total cost for all firms to satisfy the $b_1$ condition

For simplicity the model uses a direct cost function to determine the cost of transporting coal from all supply sources to all consumption sites. This function determines the transport price by relating a cost for moving coal a predescribed distance. For this analysis, the transportation prices are fixed, however, this condition will be relaxed in determining the demand for transportation. Since the various firms and suppliers are known, determination of distances between all points becomes possible. Moreover, the demand for and the supply of coal for each individual consumer and supplier is also known. The cost of transporting the coal to each firm from each supply source is calculated. This produces a set of all possible transportation prices for the firm in attaining its supply of coal.

Since the supply of coal is finite for each supplier, it is improbable that each firm can obtain its total supply of coal from the nearest supply source. This results in firms searching for alternative supply sources to obtain its total supply of coal. To determine the firm's alternative supply sources, an algorithm procedure is initiated. This is used to derive the lowest total transportation cost for all coal movements. The future trade patterns with the lowest total cost represent the theoretical optimum allocation of coal. Therefore, this procedure develops a theoretical means of determining the future interregional trade patterns and the quantity that flows between the suppliers and demanders.

PART THREE - WHAT QUANTITY OF COAL DOES EACH MODE TRANSPORT

Model III - Mode Selection

Part III presents Model III to estimate the demand for transportation. This model is used to determine the modal split and to derive a theoretical demand curve for transportation. Part III is divided into two separate sections; in Section One only one mode of transportation is available to firms for transporting coal. The removal of alternative means of transportation shows the firm's basic procedure in determining the quantity of coal to be transported. In Section Two the model is expanded by including an alternative mode of transportation. Inclusion of a second mode shows the mechanism used in determining the quantity each mode transports under various conditions.

A symbolic form of Model III economic model is described to give a better understanding of how a firm selects a mode.

Single Mode Available to the Firm

i. $\pi = TR_1 - TC_1$

$TR_1 = (P-t)\ Q$

$TC_1 = g(Q)$

$\pi$ = Firm's profit

Determining the maximum $\pi$ possible for the firm is:

ii. $\frac{\partial \pi}{\partial Q} = (P-t) = g'$, where $o < t < P$ and $q = \frac{Q}{\alpha}$

TR = total revenue

TC = total cost

P = price of the jth output the firm receives in the market - market price is fixed

t = transportation rate for transporting the coal to the ith firm

Q = quantity of output

g(Q) = cost to manufacture Q output

q = coal to be utilized by ith firm

The model uses the profit function to determine the quantity of coal the kth mode transports. It accomplishes this by determining the output the ith firm produces for various t values. Each output level requires a certain amount of coal, and therefore, the demand for transporting coal by the kth mode for the ith firm is determined.

Two Modes Available to the Firm

iii. $\pi_1 = TR_1 - TC_1$ $TR_1$ = Total revenue using Mode 1

$\pi_2 = TR_2 - TC_2$ $TR_2$ = Total revenue using Mode 2

If $t = o$ then $\pi_1 = \pi_2$

iv. If $t > o$ then $TC_1 \neq TC_2$

$\therefore \pi_1 \gtrless \pi_2$

This model uses the same procedure as the first model. However, in this case, the firm selects that mode of transportation which has the lowest total transportation cost.

Section I - Single Mode of Transportation

Section One summarizes the method developed by Leon Moses to be utilized to determine the quantity of coal a firm transports from a set of places.[1] Describing just this mechanism also allows the fundamental workings of the later procedure to be more easily recognized and analyzed.

Assumptions

There are three basic assumptions in the "Moses" method to derive the quantity of coal the firm will transport from various locations. These assumptions do not conflict with previous premises or alter previous models.

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[1]Leon Moses, op. cit.

The first assumption: a firm attempts to maximize its profit by producing that quantity of output indicated by the intersection of its marginal revenue and marginal cost. The second assumption: the firm's marginal revenue is horizontal and given. The third assumption: each firm displays U-shaped average cost curves. These average cost curves include all costs except that for transporting the factor of production. With these three assumptions, a theoretical procedure to derive the quantity of coal (factor of production) to be transported from various geographical points can be presented.

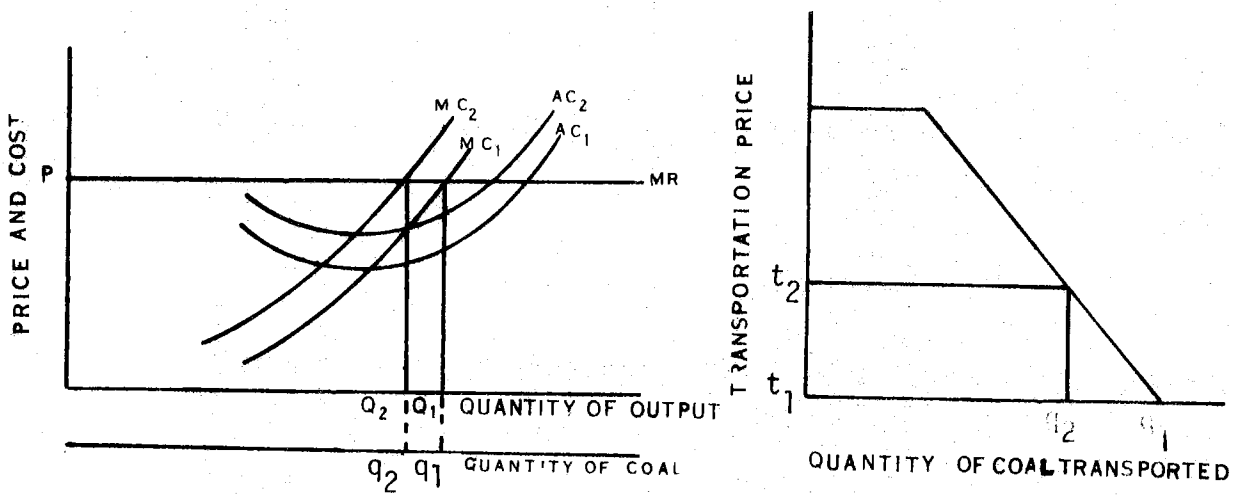
Mode Model

The analysis begins with the transportation price at zero for moving a factor of production from supply site B to consuming site A. This allows the firm's cost curves to remain unchanged. Knowing profit maximizers always produce that quantity of output indicated by the intersection of their marginal revenue and marginal cost allows the quantity of output each firm produced to be quantified.

In this case, the firm produces the quantity $Q_1$ of output. To manufacture this quantity of output requires a firm to demand and transport the quantity $q_1$ of coal (as a factor of production). Therefore, the point $(q_1, t_1)$ represents one point on the demand curve for transporting coal.

FIGURE II-2

QUANTITY OF COAL A MODE TRANSPORTS




While holding all other things constant, the constraint of zero transportation price is removed. With various positive transportation prices, the model is manipulated to determine the quantity of coal the firms will demand and transport at various transportation prices. Suppose the transportation price is now $t_2$, which is greater than zero, but less than the firm's marginal revenue curve. This positive increase in transportation price raises the firm's cost some finite amount above the original cost curves. The firm still produces the output indicated by the intersection of their MR and MC. The additional cost causes an upward shift in the marginal and average cost curves, and the firm will now discover a new optimum point which will force it to produce less output than before. Thus, the lesser output requires a lesser quantity of coal to be transported to the firm. Point $(t_2,q_2)$ represents a second point on the demand function for transport of factor (u) by a single mode of transportation.

Repeating this procedure with various transportation prices produces a series of points on the firm's demand curve for transportation mode. The positive increase in transportation price continues until the average cost becomes tangent to the marginal revenue. (MC = MR = AC). Any further increase in transportation price (beyond this point) results in the average cost exceeding the average revenue. Therefore, the analysis indicates the quantity of coal to be transported by a mode at various prices.

Section II - Modal Split

Section Two describes a model used to determine the firm's mode selection process, incorporating more than one mode of transportation. Two modes of transportation exist, both capable of transporting coal. Consideration of only two modes allows the economic explanation to be simplified and less obstructed than if there were more modes, but does not alter the technique for determining the firm's mode choice.

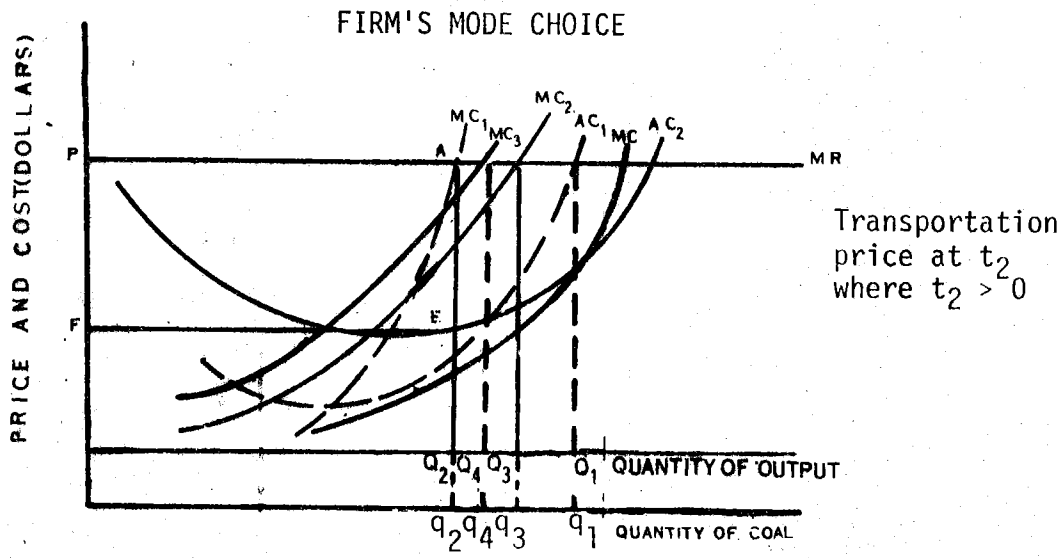
Assumptions

Two additional assumptions are added. One: the cost curves for the various modes are dissimilar. This causes the firm's U-shape curves to display different minimum points and slopes. Without this assumption, a firm would be indifferent in the selection of modes. Two: the criterion in selecting a mode is strictly economic. A firm selects the mode that minimizes the total cost for transporting a given quantity of coal. Including these assumptions, with those previously stated, enables each firm to select a particular mode of transportation based on some economic reason.

To begin with, suppose the transportation price is zero. In this case, the firm is indifferent to the mode of transportation. At zero cost, the firm's cost curves are unaltered by transportation price and it will produce the quantity $Q_1$ of output (MC = MR). This level of production requires the quantity ($q_1$) of coal (factor of production) to be transported to the firm. The removal of zero cost and the insertion of some positive transportation cost results in the formation of two sets of cost curves. By an earlier assumption, these cost curves are dissimilar, and thus the MC curves of transportation intersect the given marginal revenue curve at two different points.

FIGURE II-3

FIRM'S MODE CHOICE




Using mode one, the economic optimal position ($MC_1$ = MR) results in production of output level $Q_2$, while utilizing mode two results in production of output level $Q_3$ ($MC_2$ = MR). To determine the mode the firm selects, it is only necessary to compare the economic costs for each mode at a given quantity of output with MR given. Mode one enables firms to optimally produce the quantity $Q_2$ of output. However, at $Q_2$,

using mode two would allow the firm to reap a pure economic profit (area AEFP). Realizing that by increasing the output $Q_2 + 1$ the firm would receive an even larger total profit, the firm increases its output until $MC_2 = MR$. In this case, the firm selects mode two to transport the coal, for such selection results in a larger profit than mode one. Output level $Q_3$ requires the firm to transport by mode two the quantity $q_3$ of coal. This point $(q_3,t_2)$ represents one dot on the demand for transportation curve for mode two.

To place all points on the demand curve, additional transportation charges are placed on mode two, while holding all other costs constant. This action raises only mode two's cost curve. Now re-examine the firm's selection process with the new conditions. Even though mode two's cost curves shift upward, the firm still selects mode two because it still has a lower total cost than mode one. With higher cost there is a reduction in the amount of output a firm manufactures; this means mode two transports a smaller quantity of coal than before.[1] The point $(q_4,t_3)$ represents another point on the demand for transportation curve for mode two.

This increase in the transportation cost of mode two continues until the costs of both modes to the firm are equal. At this point, the firm is indifferent to the selection of mode of transportation; this being represented by the last point on the demand curve for mode two, since any further positive increments on mode two cost raises the cost curves for mode two, which results in a higher cost to the firm than would occur

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[1]Assumes firms only purchase that quantity of coal to manufacture a particular level of output. All excess supply of coal a firm purchases would be irrational.

if mode one were chosen. Hence, the firm now selects mode one, because its selection permits a larger profit than mode two.

Once the switch to another mode occurs, the remaining demand would apply to mode one. The demand curve for mode one could be determined in the same process as for mode two, but the end point for the demand for the alternative mode occurs, when $AC_1 = MC_1 = MR$. Any further augmentation in the cost would lead to zero output level because all forms of transportation result in income being less than cost. Therefore, the method for determining the modal split and quantity to be moved by each mode is accomplished.

Summary of Models

To review, the procedure incorporates three models. The first model determines the quantity of coal demanded and available. While the second links the coal market to the transportation market, and the third model determines the mode selection with the firm's transportation mode selection responsiveness to transportation price increases. The integration of these models into a comprehensive model provide analysts with a way of rapidly detecting and explaining changes in the demand for transporting coal. Therefore, it is an improvement over the existing rigid methods and independent models in projecting future coal traffic currently in use by federal agencies (and as reported in current literature - see Chapter 1).

# SCOPE OF EMPIRICAL MODEL

## CHAPTER III

Herein empirical data are applied to the theoretical models described in Chapter II to observe their predicting power, and to test and determine the feasibility and the practicability of this approach. To test the practicability, feasibility, and to attain the necessary data for the model, it is advisable for the model to be limited in scope. Examining the model without any constraint makes the analysis a complex and massive problem. In fact, the economic working of the model may become hidden within this complexity. In addition, attaining the necessary data for the analysis would be a difficult task in itself. A brief examination of the constraints on the theoretical models, to be able to use collected data, is contained in this chapter.

### DESCRIPTION OF PARAMETERS

#### Modes

This study only examines barges on the Ohio River waterway and rail carriers in the Ohio River Valley as forms of transportation. Table III-1 shows that barge and rail mode transport over seventy percent of the coal moved within the U. S. Moreover, these movements are only all rail or all water and do not include any joint movements. Since these two modes transport the vast majority of coal in the U. S., they shall represent the only modes available to firms in the analysis.

TABLE III-1

PERCENTAGE OF COAL MINED IN THE U. S. MOVED

BY BARGE AND RAIL MODE IN 1970[1,2]

| Tons Moved | Percent Each Mode Transport |
|---|---|
| All Rail - | 53% |
| All Barge - | 20% |
| | 73% |

The rail movements are further divided into two distinct types, regular trains and unit trains. Describing the rail mode in more detail should clarify their differences. The regular train is a set of cars which in themselves do not make up a complete train, and the remaining cars of the train do not necessarily contain coal. Since the selected cars represent only a single component of the complete train, the probability of reaching their destination directly (in one train) is not very high. Usually a train makes several stops which might require that these cars become part of another train. Therefore, this form of rail movement usually has several delays before reaching its destination. A second type of rail movement is the unit train, which forms a complete train to a single destination. This differs from the regular train in that the unit train always carries one good. Moreover, the unit train never has to be disassembled and reassembled, and as a result, reduces the transport time. However, the flexibility of the movement becomes restricted because of the point to point transport instead of network travel.

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[1] U. S. Dept. of Commerce, Interstate Commerce Commission, Bureau of Economics, State to State Distribution , Statement SS-1 and SS-2, Washington, D. C., 1968.

[2] U. S. Dept. of Interior, Bureau of the Mines, Bituminous Coal and Lignite Distribution, Washington, D. C., 1971.

## Area

The geographical region for this analysis is the Ohio River Valley. The selection of this area is based on two reasons. One, the area possesses one natural water transportation route, the Ohio River, and the area also has a complete network of rail lines criss-crossing the area, connecting major cities. The area offers the individual firm both types of modes by which to transport their coal. Furthermore, the United States Department of Commerce, Office of Business Economics, has divided the Ohio River Valley into several statistical economic regions.[1] Three of these regions are located with access to water and rail facilities, and represent the consuming sites ($L_i$) in the analysis. The three areas are: OBE 66 (Pittsburgh), OBE 62 (Cincinnati), and OBE 55 (Evansville). Map III-1 indicates the geographical locations of these areas.

TABLE III-2

RELATIVE IMPORTANCE OF COAL TO THE TOTAL TRAFFIC FOR EACH MODE OF TRANSPORTATION WITHIN THE SELECTED REGION FOR 1970[2,3,4]

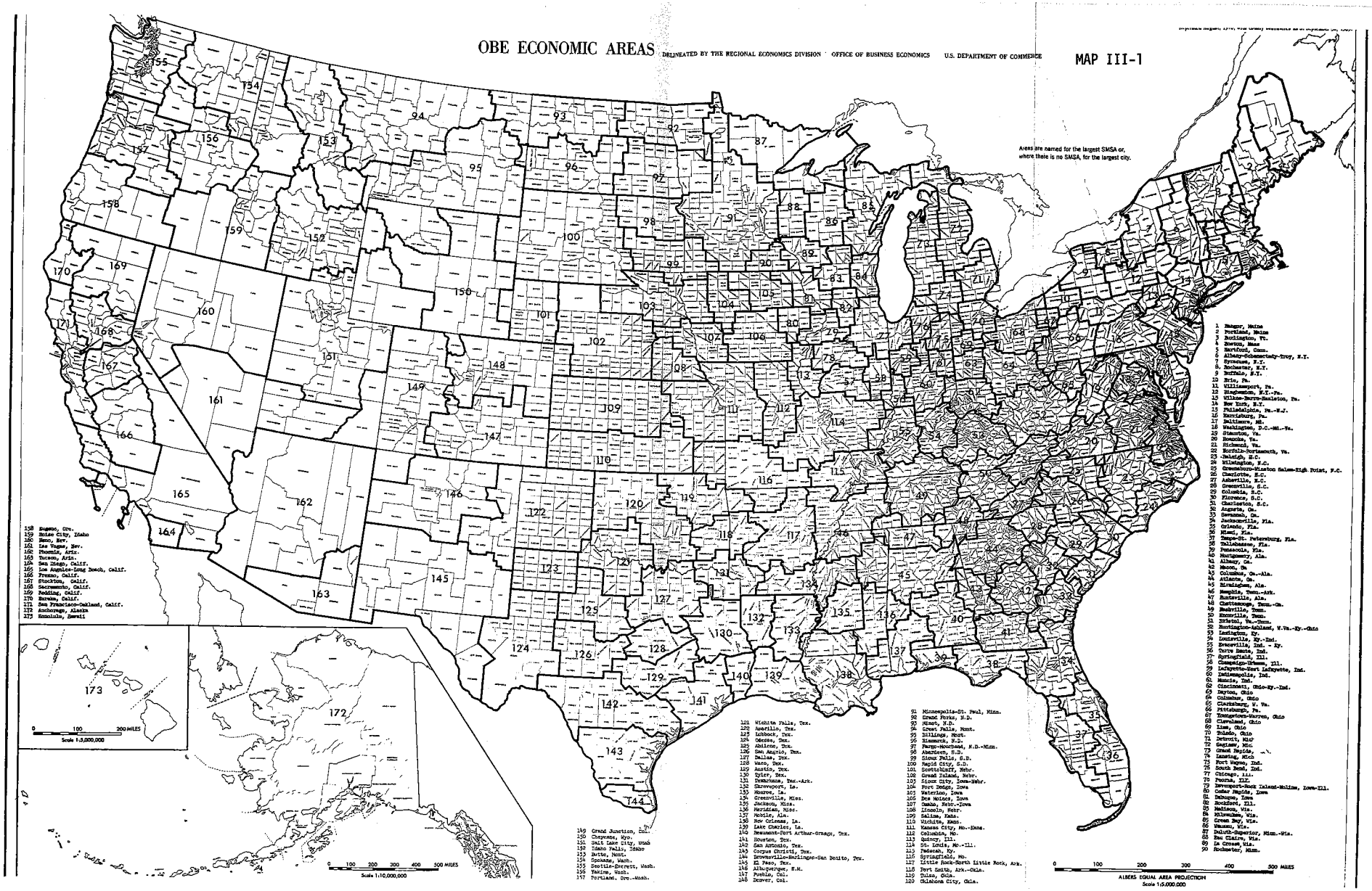
| Mode | $\frac{\text{Tonnage of Coal a Mode Transports}}{\text{Total Tonnage a Mode Transports}} \times 100$ |
|---|---|
| Rail | 42% |
| Barge | 45% |

[1] U. S. Dept. of Commerce, Office of Business Economics, OBE Economic Areas, Washington, D. C., 1969.
[2] U. S. Dept. of Interior, Bureau of the Mines, Mineral Facts and Problems, 1970, Washington, D. C., 1971.
[3] American Waterway Operation, Inland Waterborne Commerce Statistics, 1970, Washington, D. C., 1971.
[4] U. S. Dept. of the Army, Corps of Engineers, Waterborne Commerce of the United States, Calendar Year 1970, Washington, D. C., 1971.

# OBE ECONOMIC AREAS

DELINEATED BY THE REGIONAL ECONOMICS DIVISION · OFFICE OF BUSINESS ECONOMICS · U.S. DEPARTMENT OF COMMERCE

MAP III-1



Two, Table III-2 shows that over 40% of the tonnage moved by either mode within this area is coal. This represents the single most important good for transporters, since numerous steel, coke and utility companies are located within these geographical boundaries and these firms purchase a significant quantity (65.0 million tons) of coal to manufacture their output. Moreover, two major coal fields are located in the river valley, furnishing all the necessary coal for the consumers. For these two reasons, the Ohio River Valley is selected as the region for the analysis.

Factor (u) of Production (Coal)

The examination of all factors of production for all industries is not undertaken, due to the infeasibility and the difficulty of collecting sufficient and accurate data. Instead, a detailed analysis is done on one factor. The analysis is limited to the production and consumption of bituminous coal for three basic reasons. One, coal is one of the major commodities transported by various modes of transportation in the Ohio River Valley. Table III-2 shows that coal movements represent approximately forty percent of the total tonnage barges or rails transport.

Two, coal is an essential factor of production for several types of industries. The analysis is limited to examine only the major users, instead of all firms that utilize coal as a factor of production. Table III-3 exhibits the various users of coal. This analysis examines only the electrical power, primary metals and coke consumers of coal, because these three industries consume approximately eighty percent of the total coal consumed in the U. S.

TABLE III-3

PERCENTAGE OF INDUSTRIES DEMAND FOR COAL IN THE U. S.[1,2]

| | |
|---|---|
| Commercial | 3% |
| Electrical | 59% |
| Food and Kindred | 1% |
| Paper | 3% |
| Primary Metal (incl coke) | 20% |
| Stone and Clay | 3% |
| Transportation | 0.1% |
| Chemical | 4% |
| All other | 6% |
| | 99.1% |

Three, data for analysis are available, historically compiled by the Bureau of Mines annually. In addition, these data include historical information on several other variables needed for the analysis.

Coal is the good examined in this analysis, since it represents a vital factor of production, limits the number of users to be examined, represents an important commodity to transporters, and historical information on consumption and production is readily available.

Time Period t+x

There exist several reasons for limiting the time period (x) to such a short horizon. One, it limits the possibility of alternative factors of production (natural gas or petroleum) being a substitute for coal in manufacturing the selected outputs. This (substitution) appears unlikely because of the current shortage of the alternative factors.[3] Already the natural gas companies

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[1] U. S. Dept. of Interior, Bureau of Mines, Facts and Problems Yearbook 1970, Washington, D. C., 1971.
[2] Net exports excluded from this figure.
[3] Landsburg, Fischman, Fisher, op. cit., pp. 405-414.

cannot meet the growing demand, much less furnish a sufficient supply of natural gas to power electrical generators year around, while the petroleum companies are predicting a shortage of petroleum for the next decade.[1,2] Dr. Earl Cook predicts the exhaustion of these two factors will occur before society consumes all the coal.[3] This corresponds with United States Department of Interior, National Petroleum Council report that the gas price will increase 20% faster than coal for an equivalent amount of energy by 1985.[4] Moreover, the current high interest rate represents another economic constraint against switching factors of production.[5] Therefore, research into methods to utilize alternative energy sources is hindered and encourages firms to continue using coal.

Second, the interregional trade remains somewhat constant, for several firms form contracts and agreements with mine operators who furnish a sufficient supply of coal to the firms for a predetermined number of years. A majority of these agreements are valid through 1980. This provides a means to determine future trade patterns to 1980 for those firms which continue to use coal. Therefore, limiting the time horizons helps to provide a means for an adequate description of the future firms' demand for coal and the future trade patterns for several movements.

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[1] Earl Cook, "The Role of Energy in Our Society," American Association for the Advancement of Science, 139th Meeting, Washington, D. C., Dec. 29, 1972.

[2] "Business and Media," Newsweek, July 2, 1973, pg. 59-60.

[3] Earl Cook, "Energy for Millenium," Technology Review, Vol. 15, Number 2, Dec. 1972, Cambridge, Mass., 1972.

[4] United States, Department of Interior, National Petroleum Council, U. S. Energy Outlook, Washington, D. C., 1972.

[5] Federal Reserve Board of Boston, New England Economic Indicators, March 1973, Boston, Mass., 1973.

## Alteration of Models

### Supply Model

The supply model contains two assumptions in the empirical model to determine the future supply of coal suppliers will make available to consumers.

One, even though there exist several grades of coal, the study assumes that coal is homogeneous. This implies that firms may utilize whatever grade of bituminous coal available to manufacture a particular output without any technological deficiency or quantitative effects. The assumptions permit a larger sample to be taken to meet certain statistical standards. Second, the supply of coal is limited and irreplaceable for each mine. This indicates that suppliers can not extract more coal than their existing reserves. Also, the model prohibits the importation of coal to supplement the existing supply, because coal reserves are more than adequate to meet the three OBE regions' demands. In 1967, the Bureau of Mines survey indicated that over 600,000 million tons remain in the Ohio River Valley.[1]

## Mode Selection Model

The mode selection model contains four assumptions that constrain the theoretical model, so that empirical data can be applied. These assumptions are placed on the model due to the lack of adequate data.

One, in the empirical model it is assumed that firms select that mode which represents the most economical and profitable means of

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[1] Paul Averitt, Coal Reserves of the United States, Jan. 1, 1967, Geological Survey Bulletin 1275, U. S. Government Printing Office, Washington, D. C., 1970.

transportation to the firm. This eliminated the need to calculate the cost curves for each mode, for the firm attempts to receive the largest profit possible, and therefore, selects the mode which represents the least total cost.[1]

Two, the model is used to estimate the future mode selection based on the following set of criteria.

a. If the supply source is located where no water mode has access, then the mode of transportation for those firms is rail. Since this study does not include joint movements, it is impossible for barges to move the cargo. Therefore, the rail mode must transport the coal to the production site. This involves approximately 26% of the sample size.

b. If a firm purchases coal from a supply source located with access to a water mode and previously transported coal by barge, and the projected demand for coal increases over the 1970 base, the model will prescribe that those firms move coal by barge. The reason for this limit is that the cost of readjusting the plant intake, unloading facilities, and capital investment would make it uneconomical to switch modes without some immediate benefits.[2] This involves approximately 18% of the sample.

c. All other selections are based on the 1970 regional discriminant function.[3] This function includes only those variables already

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[1] L. Moses, loc. cit.
[2] Berry, Cannelli, Sasaki, IWR-ORD Summer Survey, 1970.
[3] To derive this function, the observed 1970 data was applied to a discriminant analysis program. A further explanation of the discriminant analysis program is contained in Chapter VI. With this function, the 1980 data was inserted to classify the firms' mode selection.

projected (annual tonnage, average size shipment, and distance to supply source). Using these coefficients, the 1980 data is inserted into the 1970 function to classify an unknown user's demand for a particular mode. The classification of a shipment by the function presents the mode a firm will select in 1980. The results show only two misclassifications of mode selection occur. These were due to the fact that the tonnage increased tremendously and the average size shipments were so large. Therefore, these movements were considered to switch modes in 1980.

The third constraint assumes the future transportation prices users pay to transporters is only the additional cost each mode is projected to incur. These additional costs are only the difference between the projected future total cost minus the existing total cost as discussed in the United States Interstate Commerce Commission's and the U. S. Army Corps of Engineers' reports.[1,2] The future costs are determined by extrapolating previous cost along a linear function to 1980 while the current total cost for each mode can be found in the I. C. C. and U. S. Army Corps of Engineers' reports. These additional costs for each mode are then added to the 1970 observed transportation price to represent a proxy for the future transportation price.

These alterations and assumptions allow the empirical test of the model. Installing such restrictions is mainly due to the lack of obtaining adequate data and not to the inability of the model. These assumptions

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[1] U. S. Army Corps of Engineers, Estimated Costs of Operating Towboat, 1962-1970, (unpublished report), Washington, D. C.

[2] U. S. Dept. of Commerce, Interstate Commerce Commission, Bureau of Accounts, Rail Carload Cost Scales by Territories for the Years 1970-1969-1968-1967-1966, Washington, D. C., 1973.

and restrictions should be questioned and instigate a further investigation into these areas so that techniques are developed to eliminate these constraints. This would give the model a more realistic method of describing the transportation market. Although several assumptions are incorporated into the theoretical model, the altered model still represents a more inclusive procedure in estimating an endogenous demand for transporting an input by the barge mode. The model is ready to now insert empirical evidence to examine the results and determine the feasibility and practicality of such a procedure.

# EMPIRICAL RESULTS OF MODEL I

# CHAPTER IV

Chapter IV contains the empirical test of Model I: a method to project firms' future demand for coal. To estimate these quantities, Model I requires the establishment of an equilibrium between the demand for and the supply of coal. Model I not only can be used to project the future demand for coal, but can also be used to estimate the quantity of coal suppliers will furnish to demanders. Therefore, Model I improves the existing methods to determine the quantity of coal various firms demand by relating the future coal market forecast to existing demand and supply influences instead of accepting an exogenously given demand for coal. To better understand the interrelationship of variables and to show the mechanisms used in deriving these estimates, the analysis is presented in three parts.

Part I presents the empirical calculation of the future demand for coal by determining the quantity of coal various firms require (as a factor of production) in manufacturing their future output. In Part II the empirical derivation of the supply of coal on the basis of reserve capacity and anticipated revenue from future sales is presented. Part III presents an interface of the projected supply and demand for coal to determine the realism of the projected demand.

## Future Demand for Coal

### Part I - Overview

In Part I the future demand for coal by a firm is calculated. To empirically derive this quantity requires the development of an economic

model consisting of three phases. In phase one a demand function is constructed which estimates the future output an individual firm will manufacture. In phase two a future technological conversion coefficient is estimated which establishes a linkage between the firms' output levels and the coal consumption. Finally, in phase three the projected results from phase one for each firm are divided by its future technological coefficient to derive the quantity of coal an individual firm will demand annually. The sum of these individual demands equals the total future demand for coal for a region.

Procedure to Calculate Future Coal Demand From the Output Level

Since the three sectors (electric, coke and primary metals) consume 90% of the coal transported within the selected region, the analysis concentrates on and constructs output functions for only those sectors.[1] Each function includes those variables that are thought to be the most significant in projecting that sector's future output. Thereby it enables each sector's demand function to be applied to any firm in that sector to determine its future production. For convenience, the functions are presented as linear.

Comprehending the mechanism of the functions requires an understanding of the economic relationship of the variables in the demand functions.

Demand Functions for the Specific Outputs

This study uses the following demand functions to determine the future quantity of output:

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[1]Berry, Cannelli, Dworkin, Elliott, Kuhn, Sasaki, op. cit. In the survey firms in the Ohio River Valley were interviewed to determine the reasons for selecting a particular mode of transportation and to provide the basis for conclusions about the competitiveness of the transport sector.

Equation One

$D_e = F\ (P_e, C, H)$

$D_e = a + b_1\ P_e + b_2\ C + b_3\ H$

Where

$D_e$ = Demand for electricity from the ith firm

$P_e$ = Price of electricity per kilowatt

C = Per capita income for geographical region

H = Population of geographical region

a = The constant in the equation in which $D_e$ is being estimated by use of $P_e$, C, and H

$b_1$ = The amount of change in the calculated value of $D_e$ which accompanies a change of one unit of $P_e$ when the effects of C and H are also being considered

$b_2$ = The amount of change in the calculated value of $D_e$ which accompanies a change of one unit of C when the effects of H and $P_e$ are also being considered

$b_3$ = the amount of change in the calculated value of $D_e$ which accompanies a change of one unit of H when the effects of $P_e$ and C are also being considered

Equation one provides a means to determine the number of kilowatts each steam generating station will need to provide in 1980. This equation states that the demand for electricity is positively related to the per capita income and the population of an OBE

region.[1,2] This indicates that as the value of the two variables increase in magnitude, the demand for electricity also increases. As the population increases, the number of people capable of purchasing electricity also increases.[3] Moreover, as the per capita income increases consumers are able to spend more income on goods that directly or indirectly utilize electricity.[4] This results in a rightward parametric shift of the demand curve as income and population change positively.

However, the price of electricity (price of a kilowatt) is thought to be inversely related to the demand for electricity.[5] This means consumers view electricity as a normal good and react to price changes accordingly.

<u>Equation Two</u>

$$D_s = F\ (R,\ P_s)$$

$$D_s = c + u_1\ R + u_2\ P_s$$

Where $D_s$ = Demand for steel

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[1] If electricity is a normal good the coefficient for $P_e$ is expected to be negative, since the Law of Demand states that price of a normal good is inversely related to the quantity of the good demanded.

[2] Changes in the per capita income changes consumers budget constraint. This change directly affects the quantity of electricity a consumer can purchase if electricity is considered a normal good. Hence, the expected coefficient for C is some positive value.

[3] Assumes consumers have a homogeneous utility function.

[4] Direct goods that use electricity: air conditioners, electric ranges, and other electricial appliances. Indirect goods that use electricity: movie theaters, amusement parks and industrial demand to produce household appliances.

[5] Assume each consumer uses a certain quantity of electricity. Given this condition, changes in the population of consumers would have a direct effect on quantity of electricity demanded.

$R$ = Retail sales of durable goods for U. S. (dollars)

$P_s$ = Price of steel per ton

$c$ = The constant in the equation in which the $D_s$ is being estimated by use of $R$ and $P_s$

$u_1$ = The amount of change in the calculated value of $D_s$ which accompanies a change of one unit in $R$ when the effects of $P_s$ are also being considered.

$u_2$ = The amount of change in the calculated value of $D_s$ which accompanies a change of one unit in $P_s$ when the effects of $R$ are also being considered.

Equation two provides a means to determine the quantity of steel each steel plant within the study area will need to produce in 1980. This equation states the demand for the steel is positively related to retail sales of durable goods in the United States.[1] As retail sales of durable goods increase, the amount of steel to produce these goods also increases. The American Iron and Steel Institute statistics indicate the average amount of steel each durable good contains.[2] Therefore, an increase in sales of durable goods, assuming the quantity of

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[1]Assume each durable good contains a certain quantity of steel. Any changes in number of durable goods sold would directly affect the amount of steel necessary to manufacture those goods. Hence, the coefficient for R is expected to be positive.

[2]This assumes consumers of steel view the steel as a normal good, American Iron and Steel Institute, Iron and Steel Statistics, 1963-1970, Washington, D. C., 1971. In addition, we assume no major substitution of plastics or other materials for steel. For the short run time limit envisioned herein, there is in fact only limited substitution. Since, in more time, substitution is bound to occur, this analysis has to be updated periodically.

steel needed remains the same for each product, results in a larger demand for steel. However, the price of a ton of steel is inversely related to the demand for steel. (This assumes steel is a normal good.)[1] Thus, a higher price on steel raises the price of the output which results in a lesser demand for the output and thereby lessens the demand for steel. Moreover, higher prices on steel result in the importation of foreign steel into the market and use of substitute metals in the production of outputs which reduce the demand for domestic steel and coal.

Equation Three

$D_c = F(S, P_c)$

$D_c = k + v_1 S + v_2 P_c$

Where

$S$ = Steel production (domestic)

$P_c$ = Price of coke per ton

$k$ = The constant in the equation in which $D_c$ is being estimated by use of $S$ and $P_c$.

$v_1$ = The amount of change in the calculated value of $D_c$ which accompanies a change of one unit in $S$ when the effect of $P_c$ is also being considered.

$v_2$ = The amount of change in the calculated value of $D_c$ which accompanies a change of one unit in $P_c$ when the effects of $S$ are also being considered.

---

[1] If steel is considered a normal good, the coefficient for $P_s$ is expected to be negative, since the Law of Demand states that the quantity of a good demanded is inversely related to the price of that good.

Equation three provides a means to determine the amount of bituminous coke each coke plant will need to produce in 1980. The hypothetical equation states that the demand for coke is inversely related to the price of coke while it is directly related to the quantity of steel produced in the geographical area.[1] The inverse relationship between the price of coke and the amount of coke produced assumes that higher coke prices force the final goods' price up which results in a decrease in demand for the final good and decreases the demand for coke. Moreover, the higher coke price that forces the final goods' prices upwards may make it economically feasible for the importation of similar final good or steel into the market which also results in a lower demand for coke. The equation states the amount of coke produced is positively related to the amount of steel made in the United States.[2] As domestic steel production increases, the quantity of coke necessary to heat and melt the ores must also increase.

Data

Data for the linear output model were collected from two major sources. First, in a direct survey 42 firms that were interviewed utilize coal as a factor of production in three consuming regions in

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[1] If coke is a normal good, the coefficient for $P_c$ is expected to be negative, since the Law of Demand states that the price of coke is inversely related to the quantity of coke demanded.

[2] Assume each ton of steel requires a certain quantity of coke to melt the ores. Any changes in the quantity of steel produced directly affects the quantity of coke necessary to manufacture the steel. Hence, the coefficient for S is expected to be positive.

the Ohio River Valley. From these interviews, a sample of 92 separate coal movements was generated.[1,2] These interviews identified firms to be used in the analysis and a certain portion of the data from these interviews is used in the linear models to determine the future output by each firm. Second, historical data representing action by these firms were taken from private and public documents.[3,4,5] From these publications, data were put together for other firms in a similar manner as those interviewed in the IWR transportation data program. Hence, each of the 42 interviewed firms had its actions established for the previous nine years. This results in the establishment of 828 coal movements that can be stratified by date to use in projecting the amount of coal each of the interviewed firms require in 1980.

Accepting information from historical sources for various variables makes it unnecessary to determine the majority of values. One of the main sources for secondary historical information was the Federal Power Commission which furnished data on all the steam generating stations in the study area so that none of those data inputs had to be constructed by proxy. Unfortunately, a complete historical picture of the steel and coke industries was unattainable. Information concerning these industries

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[1] C. Berry, J. Cannelli, and B. Sasaki, op. cit.
[2] C. Berry, J. Cannelli, J. Dworkin, L. Elliot, L. Kuhn, and B. Sasaki, op. cit.
[3] U. S. Dept. of the Interior, Bureau of Mines, Mineral Yearbook, Domestic Section, Washington, D. C., 1963-1970.
[4] U. S. Dept. of the Interior, Bureau of Mines, Mineral Industry Surveys, Washington, D. C., 1963-1970.
[5] Federal Power Commission, Steam-Electric Plant Construction Cost and Annual Production Expenses, Washington, D. C., 1963-1970.

was partially constructed from various public and private documents. The usual procedure for such construction was to pro-rate the available aggregate data over the number of firms, guided by some known performances. Moreover, simple averages were used to determine the price of firms' outputs when similar outputs were sold in the same geographical area. Only 66 out of 828 movements had to have some portion of data derived to form a complete observation.

TABLE IV-1

BREAKDOWN ON CONSTRUCTED DATA

| Variables | Number of Data That Had To Be Constructed |
|---|---|
| Price of Electricity | 0 |
| Per Capita Income of Population | 0 |
| Quantity of Electricity Produced | 0 |
| Price of Steel | 11 |
| Retail Sales of Durable Goods | 0 |
| Number of U. S. Automobiles Produced | 0 |
| Quantity of Steel | 15 |
| Price of Coke | 12 |
| Amount of Steel Produced | 12 |
| Quantity of Coke | 16 |
| TOTAL | 66 |

## Results

Testing to determine the acceptability of a linear demand function with existing and constructed data was performed. Table IV-2 shows the

results of a least square analysis on the aggregate data for each sector.

TABLE IV-2

LEAST SQUARE ANALYSIS OF AGGREGATE SECTORS

| Sectors | | |
|---|---|---|
| Electrical | $r^2 = 0.92$ | $D_e = 36921.8 + \underset{(18.8)}{31.5(H)} - \underset{(1.2)}{3.7(P_e)} + \underset{(5.3)}{16.3(C)}$ |
| Coke | $r^2 = 0.88$ | $D_c = 22376.4 + \underset{(32.1)}{67.4(S)} - \underset{(8.7)}{12.8(P_c)}$ |
| Primary Metal | $r^2 = 0.85$ | $D_s = 14335.3 - \underset{(14.3)}{32.4(P_s)} + \underset{(52.1)}{126.8(R)}$ |

The $r^2$ (coefficient of determination) indicates there exists a relationship between the dependent and independent variables. In addition, the signs on the coefficient agree with those in the hypothesized linear model. However, to justify these relationships requires the testing of the Null Hypothesis for each $r^2$.[1] Results of this test show each equation value exceeds the value for the significance level of 10%.[2] Thus, the Null Hypothesis can be rejected for this level of significance, indicating there exists a linear association between the dependent and independent variables in describing the output for each sector. Since the linear correlation is significant, the estimating coefficients and the constants are used to project the future output for each firm in the analysis.

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[1]Null Hypothesis assumes there is zero correlation between the dependent and independent variables.

[2]Assumes all other factors of production are given and supplied in an adequate amount.

## Technological Coefficient

To link the output a firm manufactures to the firm's demand for coal necessitates the derivation of a mechanism that converts the output amount into factor of production amount. The technological coefficient provides this mechanism, for it indicates the amount of output a firm can manufacture from the consumption of one unit of coal. Using the technological coefficient enables the firm's output to be converted into a quantifiable demand for coal. Moreover, the technical coefficient converts various outputs (kilowatts, and tons of coke and steel) into a commensurable unit, tons of coal.

Determining the magnitude of the technical coefficient requires the utilization of the firm's previously complied output data, and the quantity of coal the firm purchased for the same year. The quantity of coal the firm purchases yearly is obtainable from public and private documents, and from the survey. The survey provides the 1970 data base, while secondary sources furnish the historical data on coal consumption. Only 171 out of 828 total observations had to have constructed data for coal purchases for various years, because the desired data were unattainable.[1] Having this information enables the technological coefficient for each firm to be derived. This is accomplished by dividing the firm's output data by its coal purchases.

With the yearly technological coefficients a time series analysis is performed to calculate the technological coefficient and to provide

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[1] 143 pieces of information were concerned with the development of the amount of coal each firm purchases for various years in producing their output. The remaining data were taken from previous analysis.

a means by which changes in the technological coefficient for each firm to 1980 can be observed.

Results

A time series analysis was run on each sector and the future technological coefficient was derived. The equation to determine the technological coefficient is presented on IV-13. Table IV-3 displays the results of the sector approach for 1980.

TABLE IV-3

TECHNOLOGICAL COEFFICIENT FOR ALL AREAS - 1980[1]

| | | |
|---|---|---|
| Electrical | = | 2.28 |
| Coke | = | 0.70 |
| Primary Metal | = | 1.38 |

The results indicated that on the average every ton of coal furnishes enough energy to produce either 2.28 megawatt-hours of electricity, 0.70 tons of coke, or 1.38 tons of steel. Presenting an accurate projection of the demand for coal requires that each individual firm's coefficient ($\alpha$) also be calculated. Thus, a similar approach was undertaken to derive the future technological coefficient for each firm.

Quantity of Coal Demanded

Method and Data

Utilizing the two previous pieces of information, a method to calculate the future demand for coal was developed. The method only requires an algebraic manipulation of the definition of the technological coefficient. This process can be seen in the following equation:

---

[1]The $r^2$ for each sector exceeded a value of .90 and each equation was significant at the 10% level.

$$\alpha_{it} = O_{it}/f_{it}$$

$$f_{t+x} = O_{it+x}/\alpha_{it+x}$$

$\alpha_{it+x}$ = the ith firm technological coefficient for the t period

$O_{it}$ = the ith firm's output for the t period

$f_{it}$ = the amount of factor of production the ith firm purchases in t period

$t+x$ = x number of years beyond t period

Thus, future demand for coal becomes equal to the firm's future output divided by its future technological coefficient.

Table IV-4 shows the summation of the individual demands for coal for each OBE area, and by sector; and the total demand for bituminous coal. The table also includes the actual 1970 demand for coal, so a comparison can be made.

TABLE IV-4

DEMAND FOR COAL BY AREA AND SECTOR

FOR 1970 AND 1980 IN TONS ($10^3$)

| | | 1970 | 1980 |
|---|---|---|---|
| OBE 55 | | | |
| | Steel | 1,872 | 2,622 |
| | Electrical | 10,171 | 15,995 |
| OBE 62 | | | |
| | Steel | 2,732 | 3,863 |
| | Electrical | 12,836 | 17,233 |
| OBE 66 | | | |
| | Steel | 3,467 | 3,762 |
| | Coke | 11,632 | 12,324 |
| | Electrical | 19,432 | 21,749 |
| TOTAL | | 63,142 | 77,547 |

The survey indicated several small firms are leaving the market.[1,2] Even though there is a reduction in the number of firms (-9) demanding coal projected for 1980, the total demand for coal increases by 26%. This occurs because a few new firms (+4) will be entering the market which should consume several times the exiting firms' total demand for coal, in order to manufacture larger quantities of output. Considering these two effects, the total demand for coal will increase over the next ten years in this geographical area and in these sectors.

A major portion of the future consumption of coal is by the electric companies and systems (SIC 49). Even though nuclear power plants in the future will be furnishing greater proportions of electricity to the public, the total electricity generated from these nuclear plants is anticipated to still be inadequate to furnish all the necessary energy to satisfy the projected 1980 demand.[3] Moreover, the number of nuclear plants to be operating by 1980 may be below the estimated figure.[4] Therefore, the steam electric plants are maintained in the system to supplement the nuclear plants in furnishing an adequate supply of energy to the market. Also, the steel and coke projections seem adequate with the

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[1]Berry, Cannelli, Rothenbush, Sasaki, op. cit.
[2]Berry, Cannelli, Dworkin, Elliott, Kuhn, Sasaki, op. cit.
[3]Berry, Cannelli, Sasaki, op. cit.
[4]For example, Cincinnati Gas Electric was anticipating completion of the Zimmer nuclear power plant by 1975, but due to delays it will be end of 1977 for the completion of the reactor only. This date will be further extended due to the numerous legal conflicts in order to attain the necessary approval for operation. Obviously, these delays mean steam plants must furnish enough energy to offset the absence of this plant.

anticipated state of technology. These findings results in empirically projecting 77.5 million tons of coal to be consumed by three sectors located in the selected OBE regions.

This procedure removes the necessity of accepting an exogenously predetermined demand for coal. Moreover, projecting the future demand for coal in this manner improves the current forecasting methods in which demand is arbitrarily fixed. The more complete method is useful to explain why given changes in demand for coal occur.

Part II

Supply of Coal

The model is now used to calculate the quantity of coal that suppliers will make available to consumers. All the suppliers in the analysis are located in the Ohio River Valley. Within its geographical boundaries are two of the major coal fields in the United States. These fields are the Appalachian Regional coal field located in the Eastern Provinces of the United States and the Eastern Regional coal field located in the Interior Province of the United States.[1] Also, the coal reserves from these fields are presently more than sufficient to furnish an adequate supply of coal to demanders for a considerable period of time.[2] Since the suppliers in these regions are capable of furnishing all the necessary coal, it becomes unnecessary to import coal from other regions to supplement the existing supply.[3]

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[1]U. S. Dept. of the Interior, U. S. Geological Survey, Coal Fields of the U. S., Washington, D. C., 1960.

[2]This based on the present rate of consumption given the existing reserves.

[3]Aventi, op. cit.

Supply Model

To quantify the amount of coal suppliers will make available, a model based on economic criteria is developed. This model is used to project the tonnage of coal extracted within each county (to be purchased by one of the three selected industries in the three OBE regions). For convenience, the supply function is assumed to be linear. The following linear equation represents the hypothesized supply function for determining the quantity of coal suppliers will make available to the selected consumers.

$$S_c = f\ (P,M,T)$$

$$S_c = g + w_1P + w_2M + w_3T$$

Where P = Price of coal

M = Number of mines

T = Productivity of worker

$S_c$ = Supply of coal

g = The constant in the equation in which $S_c$ is being estimated by use of P, M and T.

$w_1$ = The amount of change in the calculated value of $S_c$ which accompanies a change of one unit in P when the effects of M and T are also being considered.

$w_2$ = The amount of change in the calculated value of $S_c$ which accompanies a change of one unit in M when the effects of T and P are also being considered.

$w_3$ = The amount of change in the calculated value of $S_c$ which accompanies a change of one unit in T when the effects of P and M are also being considered.

Assuming the supply function to be linear permits the function to be written in the above form. This indicates that the independent and dependent variables are all positively related. A brief explanation of this relationship is presented below.

Price of coal is defined as that revenue a supplier receives from selling one unit of coal. In this case, price of coal is positively related to the extraction of coal.[1] This hypothetical relationship can be explained by micro-economic theory. First, an increase in the price of coal raises the suppliers' marginal revenue curve. This gives suppliers an economic incentive to extract a larger quantity of coal. Second, a lowering of the price of coal causes the opposite effect, and results in suppliers furnishing a lesser quantity of coal.[2] Thus, the extraction of coal is directly related to the price of coal.

Productivity of a worker is thought to be positively related to the quantity of coal.[3] This relationship states that as the productivity of the worker increases so does the quantity of coal the suppliers make available. If the number of workers increases or remains constant, an increase in productivity by a worker results in a direct increase in

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[1]Changes in the price of coal changes the coal suppliers' marginal revenue curve. This change directly affects the quantity of coal a profit maximizing supplier furnishes. Hence, the coefficient for P is expected to be positive.

[2]Unless the supplier has a high fixed cost in which case a decrease in the coal price would raise supplier willingness to supply a larger quantity.

[3]Productivity of a worker is the ratio of output to man-hours worked. Thus, a change in productivity has a direct effect on output and the coefficient is expected to be positive.

the amount of coal extracted. Therefore, the productivity of workers is positively related to the coal production.

Finally, it is hypothesized that the number of mines is directly related to the output.[1] Assume that all mines produce an equal quantity of coal, and there exists w number of mines in operation. Summing the mines' production yields y amount of coal that suppliers furnish. Obviously, all mines do not supply an equal amount of coal, but the addition of a new mine (or more productive mines) to existing number of mines increases the total supply of coal available. The reduction in the number of mines in general should have the reverse effect. Therefore, the number of mines is, in a general sense, related to the output.

Data

Projecting the future coal production by each county simplifies the data collection process. Consequently, the combination of two sources provided the majority of necessary county data for the analysis. One, utilizing a survey, reveals the location of suppliers in 1970.[2,3]

Unfortunately, the supply location for demanders for previous years is unknown. This model assumes the 1970 relationships holds for past years. Moreover, the 1970 supply counties represent the

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[1] Any change in the number of mines should directly affect the amount of coal suppliers furnish. Hence the coefficient for M is expected to be positive.

[2] Berry, Cannelli, Rothenbush and Sasaki, op. cit.

[3] Berry, Cannelli, Dworkin, Elliott, Kuhn, and Sasaki, op. cit.

only possible counties firms can obtain their future supply of coal from. This reduces the number of counties from 158 to 19 from which data must be collected and projected. Second, from private and public documents data for the supply function for these selected counties for the past eight years can be established.[1,2] The information from the secondary sources for each county included: the total quantity of coal extracted, the number of mines, the average productivity of a miner, and total value of coal for each year.

Some of the data had to be adjusted to describe the supply function each year. The total number of mines is pro-rated to counties from the state total based on the survey data to indicate the number of mines within a county supplying coal to the consuming firm each year. The average tonnage of coal a supplier mines each year is multiplied by the pro-rated number of mines for that county to derive the total tonnage of coal available for the selected firms for that year.

Finally, the price of coal that a supplier receives from selling one unit of coal can be derived and established from these secondary sources. To estimate these prices it is only necessary to divide the total value of coal sold by a county, by the number of tons that county sold. The

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[1] U. S. Department of the Interior, Bureau of Mines, Minerals Yearbook, 1970, Washington, D. C., 1963-1971.

[2] Keystone Coal Buyer's Manual, McGraw Hill Book Co., New York, N. Y., 1963-1970.

two secondary sources, therefore, provide all the necessary historical data, identified by the survey, for those counties.

Results

Inserting the data into a least square regression model indicates the association in an aggregate linear model. The model used is referred to on page IV-16.

$$S_c = 5667.63 + \underset{(5.37)}{7.36P} + \underset{(15.14)}{32.83M} + \underset{(15.99)}{74.38T}$$

$$r^2 = .58$$

The $r^2$ was only 0.58, however, all the signs on the coefficients were correct. The confidence level of the linear correlation between the independent and dependent variables is significant at 15% level of significance.[1] The limited correlation is due to the large variance in the price variable. A closer examination of the coal prices shows that there exists a large county coal price difference. Table IV-5 shows the average price of coal for several counties in 1970.

TABLE IV-5

VARIATION IN COUNTY COAL PRICES

| County | Price of Coal by County/Per Ton |
|---|---|
| Brooke, W. Va. | 3.78 |
| Lewis, W. Va. | 3.96 |
| Monongahela, W. Va. | 4.73 |
| Kanawha, W. Va. | 4.85 |
| Marion, W. Va. | 5.17 |
| Allegheny, Pa. | 5.84 |
| Washington, Pa. | 6.57 |

[1]This procedure used the Null Hypothesis approach with Null Hypothesis being the zero correlation between dependent and independent variables. Table used in determining critical value is Chi Square Distribution Table, taken from G. W. Snedecor and W. G. Cochran, Statistical Methods, 6th Ed., Iowa State University Press, Ames, Iowa, 1968.

This variable is a major factor in the $r^2$ results. To see whether the low $r^2$ value was the result of the intra-county difference in coal prices, a least square regression analysis was run for each county. The results of these runs indicate that intra-county differences in coal prices caused the low $r^2$ value, because the $r^2$ for each county exceeded the aggregate value of .58, with a range $r^2$ value being .78-.89 for the county data. Moreover, the signs in all cases were correct and the level of confidence for variable correlation was at 10% level of significance for all counties except three. These three counties remained at the 15% level of significance because of the poor correlation in the employment size to supply of coal for the past eight years. The employment in the mid 1960's for these three counties was directly correlated to the supply but in the late 60's employment appeared to be inversely related due to the sudden extensive use of capital.

These results indicate there exists a linear relationship between the independent and dependent variables in describing the quantity coal suppliers furnish to selected consumers. Extrapolating the linear function for each county determines the amount of coal that each county will furnish in 1980 to selected firms. Table IV-6 shows the projected supply for each county and the total supply available for consumers in 1980.

TABLE IV-6

SUPPLY OF COAL COUNTIES FURNISH
TO SELECTED CONSUMERS IN 1980

| | |
|---|---|
| Gallatin, Illinois | 1,700,000 tons |
| Saline, Illinois | 5,300,000 |
| Pike, Indiana | 625,000 |
| Warwick, Indiana | 50,391 |
| Hopkins, Kentucky | 7,600,000 |

TABLE IV-6 (continued)

| | |
|---|---|
| Muhlenberg, Kentucky | 9,900,000 |
| Ohio, Kentucky | 2,230,000 |
| Pike, Kentucky | 2,370,000 |
| Webster, Kentucky | 400,000 |
| Belmont, Ohio | 2,560,000 |
| Washington, Ohio | 6,400 |
| Allegheny, Pennsylvania | 10,901,945 |
| Greene, Pennsylvania | 3,710,000 |
| Washington, Pennsylvania | 4,270,000 |
| Brooke, West Virginia | 1,140,000 |
| Kanawha, West Virginia | 4,330,000 |
| Lewis, West Virginia | 5,247,000 |
| Marion, West Virginia | 12,900,000 |
| Monongahela, West Virginia | 5,850,000 |
| TOTAL | 76,090,736 tons |

This model provides a means to make supply projection with more validity and flexibility than older techniques that accepted exogenously predetermined quantities to be supplied (assuming, for example, that adequate supplies were available to meet demand).

Part III

EQUIVALENCY OF DEMAND AND SUPPLY

In order for the two projections to be acceptable, the supply and demand must be reasonably equal. The two projections are examined here to determine if the imbalance between demand and supply falls within an acceptable statistical limit. A comparison of Table IV-4 (p. IV-13) and Table IV-6 (p. IV-21) indicates the difference in the demand for and supply of coal is a little over 2% in favor of the demand. Since there is no information regarding coal substitutes for goods using coal in their manufacture, and there are no readily apparent good reasons for not accepting this difference (that the difference is too large, for instance) the

difference is regarded as insignificant. This aspect must be analyzed further to find the limits of significance of differences between supply and demand. Historical data analysis would provide the beginning of such analysis. Because this study is focusing on transport, the difference problem is left at this point.

# EMPIRICAL RESULTS OF MODEL II

## CHAPTER V

In Chapter V a procedure is implemented to derive the location and tonnage of coal that flows from various suppliers to satisfy the projected demand. The analysis is designed to determine where transporters have to transport a particular quantity of coal. The procedure does not indicate the particular mode of transportation, but only shows the necessity of transportation. This allocation process forms a linkage between the coal market and the transportation market. The empirical analysis is broken into two parts. In part one the number of firms that will maintain current trade patterns into the future is determined, while in part two the remaining firms are examined to determine the future interregional trade pattern for those firms.

### Predetermined Trade Patterns

Numerous firms' transportation patterns will not be altered over time. These fixed trade patterns are the result of firms making long term agreements with suppliers. The agreements are in the form of a contract or a captive mine.[1] A contract binds the firm to purchase a certain quantity of coal yearly from the contractor, for a stipulated period of time, while a captive mine is a mine which furnishes all its

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[1]A captive mine refers to a situation where a firm purchases all the coal extracted from that mine. This usually results in either the firm establishing a contract for the life of the mine (until the supply of coal is exhausted) or else the firm purchases and operates the mine to supply the firm with coal; as defined by G. R. Dreese and H. L. Bryant, Cost and Effects of a Water Quality Program for a Small Strip Mining Company, U. S. Army, Corps of Engineers, Institute for Water Resources, Alexandria, Virginia, 1971.

coal to one firm. In either case, the firms continue to purchase coal from their present location for a period of time. It is unnecessary to develop a procedure to determine the future trade patterns for certain firms with the above supply situation.

Table V-1 tabulates the number of firms and the type of agreements they have with mine operators.

TABLE V-1

TYPE OF AGREEMENTS DEMANDERS HAVE WITH SUPPLIERS

| Area | Number of Firms With | | | |
|---|---|---|---|---|
| | Captive Mine | Contract | | No Contract |
| | | Agreement Less Than 10 Years | Agreement More Than 10 Years | |
| OBE 55 | 3 | 1 | 9 | 4 |
| OBE 62 | 2 | 10 | 14 | 10 |
| OBE 66 | 6 | 8 | 16 | 8 |

Approximately 76% of the firms in the survey have some type of agreement with mine operators. Only 54% of firms in the survey have fixed transportation patterns, at least to 1980. Of this total, 12% are captive mines and 42% are contracts of 10 year periods or longer. The transportation pattern for 50 of the 92 possible movements are known and do not need to be derived for 1980.

Undetermined Trade Patterns

Obviously, there are no assurances that the remaining 42 independent movements will maintain their current trading patterns to 1980. Economic

and statistical techniques are utilized to determine the future distribution of coal from suppliers to these consuming firms.[1] The linear program represents a method to determine the allocation procedure, for by using it, it is possible to derive the most economical method for the remaining firms to get their supply of coal.[2] This procedure only requires economic information to be inserted in the model.

The necessary information is the remaining data concerning the individual firm's demand for coal, the supply of coal, and the price of transportation. These data (demand and supply) have been derived through the use of Model I. Transportation prices are derived and do not represent any one particular mode. Rather, they represent a general transportation charge. Therefore, this process only determines the future transportation location patterns and not the mode selection process.

Even though numerous methods exist to construct transportation prices, all these models are complicated and require a considerable amount of unattainable data. However, all transport price models include a distance variable in their context. This procedure relates distance to some fixed cost, and the data are attainable.

This procedure uses the estimated cost figures developed by the Interstate Commerce Commission for Motor Common Carriers to determine the cost of transporting the coal from a supplier to the firms.[3,4] These

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[1]To insure that the model did not degenerate, a dummy value was entered so that the demand and supply were equal.

[2]This program uses the simple algorithm procedure to find the solution.

[3]U. S. Dept. of Commerce, Interstate Commerce Commission, Bureau of Accounts, Cost of Transporting Freight by Class I and Class II Motor Common Carriers of General Commodities, Midwest Region - 1967, Washington, D. C., 1971.

[4]Since the mode of transportation does not enter into the analysis and straight line mileage is used, motor carriers' cost represents an adequate indicator of transportation cost.

cost figures are determined for smaller mileage intervals than the other modes and hence, offer a better procedure to estimate cost for transporting a good various distances.[1]

The cost figures used in this analysis are based on the number of miles a common motor carrier transports a given quantity of good. A straight line from each known supplier to a firm determines the number of miles the coal must be transported.

Using this procedure, all the possible transportation costs for a firm in attaining its supply of coal are computed. By repeating this process for all firms, all the empirical cost figures for the analysis can be derived.

Having all the data enables the program to statistically allocate the coal supply. Moreover, the linear program minimizes the total transport cost. Therefore, it establishes a method to economically determine the future transportation patterns for firms which do not have a predetermined trade pattern for 1980. The model links the coal market to the transportation market.

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[1]Motor carriers' costs are indicated at every 10-20 mile interval for the first 800 miles while the other modes use 20-50 mile intervals for the first 800.

# CHAPTER VI

## Empirical Results of Model III

In Chapter VI the empirical results of Model III are presented with two distinct outputs. First, Model III is used to empirically determine the mode of transportation a firm selects in transporting a given quantity of coal from a known supplier to a known production site. Second, manipulating Model III permits a demand curve for a particular mode of transportation to be derived. With these outputs an analysis and application to actual situations can be accomplished to determine the adequacy and feasibility of such an approach.

Chapter VI is broken into three parts. In Part one the empirical results of the mode selection model are described. This part contains two analyses. One is based on data for the total demand for transportation, while the other uses regional data to derive the transportation mode selected by each OBE area demander. Part two repeats an examination of the three OBE areas, but with investigation of the firms' responsiveness to a change in barge transportation price. Finally, Part III presents a short conclusion from and evaluation of Model III.

### PART I - MODE SELECTION

#### Overview

In Part one a method to predict various firms' mode choice to transport coal to their production site is described. To accomplish this task, the statistical technique of discriminant analysis is used to model the different firms mode selection process. Discriminant analysis is a multivariate statistical technique used to estimate the extent to

which distinct groups overlap or diverge from one another.[1] In this model, the technique allocates a given demand for coal transportation among the various modes of transportation through linear functions to describe the characteristics of each mode of transportation. These functions serve as an index for discriminating between the modes of transportation and enable each firm to be assigned to a particular mode.[2]

Discriminant Function

Discriminant analysis is used to construct linear functions describing the characteristics of each mode of transportation.[3] Each linear function contains six separate variables. The numerical differences between similar variables for different modes of transportation enable distinct linear functions to be derived. These distinguishing differences permit the calculation of an index to separate the firms among the various modes of transportation.

The six variables are:[4]

$X_{1j}$ = The annual tonnage of coal a firm purchases in one calendar year using mode j.

$X_{2j}$ = The number of miles a mode of transportation actually travels to transport the coal using mode j.

$X_{3j}$ = The number of hours it takes a mode of transportation to transport the coal using mode j.

$X_{4j}$ = The average shipment size of coal a firm receives per year using mode j (tons)

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[1] M. G. Kendall and A. Stuart, The Advanced Theory of Statistics, Vol. 3, 2nd Ed., Hafner, New York, 1968.
[2] G. S. Snedecor and W. G. Cochran, Statistical Methods, 6th Ed., Iowa State University Press, Ames, Iowa, 1968.
[3] See appendix for further explanation.
[4] Berry, Cannelli, Dworkin, Elliot, Kuhn, Sasaki, IWR-ORD Summer Survey, 1971.

$X_{5j}$ = The transportation rate the firm pays to the transporter for moving the coal using mode j (dollars per ton)

$X_{6j}$ = The handling cost that the firms incur for storage, unloading and delivering the coal to the plant using mode j (per ton)

Data

The data for the analysis were obtained directly or indirectly from the two previous models. These and the minor alteration of the existing data, already explained in Chapter III, account for all the necessary data. However, a brief statement defining the data sources for each variable is presented in review.

Variable one, future annual tonnage of coal a firm purchases, was attained from the output of Model I. Variable two, number of miles, is computed from the origin-destination matrix (output of Model II). Number of hours equals 1970 transit time revealed in the surveys for firms with fixed contracts. The unfixed contract movements' transit time are calculated in the following manner. Time of transit for these movements is derived by an averaging method. This method takes the average of three similar modes of transportation moving coal to similar distances to represent the time of transit. Variable four, average size of shipments, uses the same number of shipments in 1970 but divides that number of shipments into 1980 annual tonnage to derive the average tonnage. Variable five, transportation price, is adjusted upwards based on the 1970 survey data. Finally, handling cost figures are based on adjusted 1970 data.

The hypothesis is that the regional approach herein is a more adequate predictor of transportation users' mode selection process than the more traditional aggregate approach. To test the hypothesis, the

data are inserted into the discriminant analysis program in two forms and then the results are compared. Two inserts are made. In one, all the anticipated movements are inserted at once. This represents the aggregate approach. In two, only data for a single OBE is inserted at one time. This represents the regional approach. The analysis begins by comparing the aggregate and then the regional data trials.

Aggregate Approach

The aggregate data are further divided into data trials. The first trial examines the data for two modes, while the second trial uses three modes. The two mode case examines the mode choice of firms with only barge and rail transportation facilities available. The three mode case adds unit trains as possible means for transporting coal to the firm. The two data trials or sets are run to discover whether there exists any differences in allocation pattern detectable by using the two forms of aggregate data.

Two Mode

The first analysis deals with the aggregate data with only two modes available. All the discriminant analysis runs are done on a Univac 1108 Executive Computer with a 07M Biomedical Computer Program (BMD) performing the calculations.[1]

One of the main features of this program is that it enters the variables in sequential manner, depending on their significance.[2,3]

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[1] W. J. Dixon, ed., Biomedical Computer Programs, Berkeley: University of California Press, 1968, pp. 214a-214e.
[2] Ibid., pp. 214i-214j.
[3] This significance is based on the f value of the variable.

In this run the actual transportation price proved to be the most important determinant in separating the transportation populations. The pattern of entrance of the remaining variables is:

TABLE VI-1

ENTRANCE OF VARIABLES FOR AGGREGATE MODEL WITH TWO MODES AVAILABLE[1]

| Entrance Order of Variable | Mean Value | |
|---|---|---|
| | Rail | Barge |
| $X_5$ | $3.26 per ton | $0.72 per ton |
| $X_3$ | 92.08 hrs | 62.2 hrs |
| $X_2$ | 145.7 miles | 159.5 miles |
| $X_4$ | 1551 tons | 9017 tons |
| $X_6$ | $0.36 per ton | $0.29 per ton |
| $X_1$ | 53638 tons | 144583 tons |

Table VI-1 also includes the mean values of each variable for the two modes. The dissimilarity of the variables' mean values gives some indication as to their use in classification of firms by mode. Discriminant analysis bases the separation of modes of transportation on the dissimilarity of common variables' mean values and the order of importance. Thus, the larger differences between earlier entering variables assist in classifying the mode correctly. In this case, the cost of transporting coal enters the analysis first, and displays a wide variation between the two modes. Railroads' prices are on the average more than four and one-half times more than the barge lines prices for transporting the coal. Also, rails' average time of transit were longer than

[1]For an example of the procedure used to calculate the discriminant analysis displayed in Table VI-2, see pages A1-A7 in the appendix.

barges' time by approximately 50%.[1] These two dissimilarities and remaining ones indicate that modes can be fairly well separated.

The second major output of the BMD program is the mode classification printout.[2] This output tabulates the results of the analysis. Along the diagonal of the matrix are the modes of transportation correctly classified, and all modes off the diagonal are misclassified. Table VI-2 shows the results of aggregate analysis, the barge movements are perfectly classified, but the rail movements are not. Five actual rail movements are statistically categorized as barge movements. These errors occur because those observations exhibit characteristics more common to barge than rail. Examining the data more closely reveals that all the misclassified movements are actually unit train movements. These movements exhibit values for critical variables (annual size shipment, average size shipment and time of transit) exceeding one deviation from the rail average for those variables. In fact, the numerical values of these variables approach the barge mean values. Hence, the combination of these factors places these rail movements into the barge group.

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[1]This finding (rails' transit time is longer than barge) does not indicate a general pattern but only for this particular sample.
[2]Dixon, op. cit., pg. 214r.

TABLE VI-2

RESULTS OF DISCRIMINANT ANALYSIS
FOR AGGREGATE ANALYSIS USING TWO MODES

Number of Firms' Coal Movements Classified Into Mode

| Mode | Rail | Barge |
|---|---|---|
| Rail | 34 | 5 |
| Barge | 0 | 53 |

Unit Train

In an attempt to remove these misclassifications, and to improve the analysis a second run was performed including unit train as a separate mode. Even with the new mode of transportation, transportation price remains the most important variable, and the annual tonnage shipped remains the least important. The order of entrance of the other variables did not correspond to the aggregate two mode case. Table VI-3 shows these changes as well as the mean value of the three mode case.

TABLE VI-3

ENTRANCE OF VARIABLES FOR AGGREGATE MODEL WITH THREE MODES AVAILABLE

| Entrance Order of Variables | Mean Values Rail | Barge | Unit Trains |
|---|---|---|---|
| 5 | $3.612 | $0.72 | $0.88 |
| 4 | 1367 tons | 9017 tons | 2800 tons |
| 3 | 102.6 hrs | 62.2 hrs | 24.2 hrs |
| 6 | $0.34 | $0.29 | $0.48 |
| 2 | 159.5 mi. | 159.5 mi. | 51.7 mi. |
| 1 | 47556 tons | 144583 tons | 94996 tons |

The removal of five rail movements affects all the rails' mean values. The new rails' transportation rate increases by a positive 12%, transportation time increases 11%, number of miles increases 6%, average size shipment decreases by 12%, and annual size shipment of coal decreases by 11% when compared to the previous run. These alterations would indicate that including unit trains as a separate mode improved the mechanism to separate barge and rail. However, several unit trains mean values approach the barge mean values. Unit trains exceed the barges' transportation cost by only 16 cents per ton. In addition, the discrepancy between barge and unit train mean transit time is a negative 40 hours while the discrepancy between barge and rail transit time is a positive 40 hours. Consequently, these differences in the rails' mean values and the unit trains should cause several misclassifications to occur. Table VI-4 shows a four-fold increase in the number of errors.

TABLE VI-4

RESULTS OF DISCRIMINANT ANALYSIS
OF AGGREGATE ANALYSIS WITH THREE MODES

| | Number of Firms' Coal Movements Classified Into Mode | | |
|---|---|---|---|
| Mode | Rail | Barge | Unit |
| Rail | 27 | 0 | 7 |
| Barge | 0 | 38 | 15 |
| Unit | 0 | 0 | 5 |

A closer examination of the pivotal variable (transportation price) may further explain the reason for the number of misclassifications. The

removal of several rail observations changes the rails' mean values. In doing so, rail values which differ greatly from the previous general mean value (transportation rate, annual tonnage, and transit time - refer to Table VI-1) of the second run now correspond to unit train rather than rail. These movements generally represent those firms which transport large quantities of coal a short distance, at low transport cost. These movements resemble unit trains, rather than ordinary rail transport. Therefore, these rail observations are misclassified as unit trains.

At the same time, the allocation of movements to barges proves to be imperfect, too. These allocations are due to three characteristics of unit trains. One, unit trains have the capability of transporting a sizeable quantity of coal at a single time, which make unit trains similar to barges. Two, unit trains require fewer hours to transport their cargoes, because of the avoidance of delays at various terminals. This increases the average speed of delivery, thus shifting the unit train transport time towards that of barge. Finally, the transportation rate differential is only $0.16 over the barge cost. Unit trains' price (variable 5), being close to barge price, represents the most significant variable. The combination of these three factors produces an overlap of the barge and unit trains population. Therefore, fifteen of 53 barge observations are misclassified.

Regional Approach

The aggregate analysis produces several errors or misallocation. These misallocations occur in part, because of the differences in utilization characteristics in each OBE area. Consequently, the aggregate

analysis with two modes or three modes does not present an accurate description of the mode selection process. Attempting to improve the analysis, separate runs were made for each OBE area. This is the regional approach. The following section presents the empirical results and explanation of the discriminant analysis runs for each OBE region.

OBE 55

Only the firms that demand coal from OBE region 55 are used in this analysis. This results in the development of a regional discriminant function to allocate the firms to various modes. Unit trains and rail movements are put into one population due to the inadequate sampling of unit trains in the area.

With this data arrangement, the BMD program for OBE 55 enters variable five as the most significant factor. This agrees with the order of two previous runs, but the remaining order of variables does not correspond to either aggregate run. Table VI-5 shows the stepwise pattern of entering the variables, and the mean values for each variable.

TABLE VI-5

ENTRANCE OF VARIABLES - OBE 55

| Entrance Order of Variables | Mean Value | |
|---|---|---|
| | Barge | Rail |
| 5 | $0.475 | $1.46 |
| 6 | $0.175 | $0.406 |
| 1 | 114873 tons | 106587 tons |
| 4 | 4633.3 tons | 2570.5 tons |
| 2 | 37.8 miles | 67.5 miles |
| 3 | 7.33 hrs | 23.64 hrs |

Comparison of the Regional Mean Values to the Aggregate Data

The regional mean values for each variable varies from the mean value of the aggregate data. This indicates that regional determinants differ from the aggregate. These different determinant magnitudes determine the new discriminant function, which allocates the firms to various modes of transportation. A brief description of some of the different characteristics is presented.

First, the distance coal must be transported is reduced considerably. Rails now transport only 42% of the distance they did before (all cases compared to the aggregate approach with three modes). Barges only transport 23% of the distance they previously did. This means that the source of supply for OBE 55 is closer to the consumer than the aggregate approach would indicate. The shorter distance to transport the coal enables a transporting mode to reduce its transport time. Also, both modes increase their speed by more than 70% over the aggregate approach. This is due to the fewer terminal delays the modes encounter in transporting the coal. Hence, rails transport the coal 78.9 hours faster in the regional approach than with the rails' aggregate approach, while the water carriers reduce their time by 69.9 hours.

Next, regional annual tonnage moved by each mode in OBE 55 differs from the aggregate approach. The rail lines in OBE 55 transport twice the cargo the aggregate average train carries. In addition, the regional annual tonnage the barges transport is approximately 35% less than in the aggregate case. Increased rail tonnage per firm, and the decrease in barge tonnage per firm, results in narrowing the differences between the

two modes. Thus, in OBE 55 the two modes transport an almost equivalent quantity of coal. This differs considerably from the aggregate approach, which indicates barges transporting on the average twice as much coal per firm as rail.

Finally, the transportation price for the two modes exhibit a large reduction. Regional railroad transportation price decreases more than $2.00 over the aggregate approach, while the barge declines by $0.27. This reduces the difference in prices from a five fold difference to a three fold difference. Consequently, the regional transportation price does not resemble the aggregate price. However, variable five still represents the most significant factor in separating the modes of transportation.

Thus, regional data have different values for the mode characteristics for the different modes of transportation. Using the regional characteristics, the BMD program statistically allocates each firm to a mode of transportation. Even with the inclusion of unit trains and the reduction in the numerical differences between the modes, Table VI-6 shows all the anticipated movements correctly classified.

TABLE VI-6

RESULTS OF DISCRIMINANT ANALYSIS OF OBE 55

Number of Firms' Coal Movements Classified Into Mode

| | Barge | Rail |
|---|---|---|
| Barge | 6 | 0 |
| Rail | 0 | 11 |

Mean Differences Between the Groups

A brief analysis is presented to explain why the regional discriminant analysis function correctly allocates all movements, while the aggregate is unable to. For example, firms using unit trains which were misclassified in the aggregate approach are now correctly allocated. This occurs because of the general similarity between the unit and regular trains in OBE 55. Table VI-7 shows that regional rails resemble the aggregate unit trains mode characteristics. Consequently, the unit trains are not misclassified as barge movements, indicating that regional data describe the mode characteristics more adequately than the aggregate data.

TABLE VI-7

COMPARISON OF REGIONAL AND AGGREGATE DATA

| | | Aggregate | | Regional | | Aggregate |
|---|---|---|---|---|---|---|
| Variable | Values | Unit | Rail | Rail | Barge | Barge |
| 1 | tons | 94996 | 47556 | 106587 | 114873 | 144583 |
| 2 | miles | 51.7 | 159.5 | 67.5 | 37.8 | 159.2 |
| 3 | hours | 24.2 | 102.6 | 23.64 | 7.33 | 162.2 |
| 4 | tons | 2800 | 1367 | 2570 | 4633.3 | 9017 |
| 5 | $ | .88 | 3.612 | 0.475 | 1.46 | 0.72 |
| 6 | $ | .29 | .34 | .406 | .175 | .48 |

At the same time, all firms using barge modes are correctly allocated, for the barge mode still maintains a sizeable differentiation among the variables. Table VI-7 shows a comparison of these values. It should be noted that the transportation price differential is a five fold increase

over the second run. These differences between rail and barge averages permit firms using barges to be correctly allocated.

A third output of the program shows the graphical separation of the two modes. The axes are the first two canonical variables.[1] From the graph, it can be seen that there exists a definite separation in the modes. In fact, the lines show that each distribution does not overlap with others. This indicates there exists no misclassification. The letter R signifies the rail mode, while B represents the barge mode.

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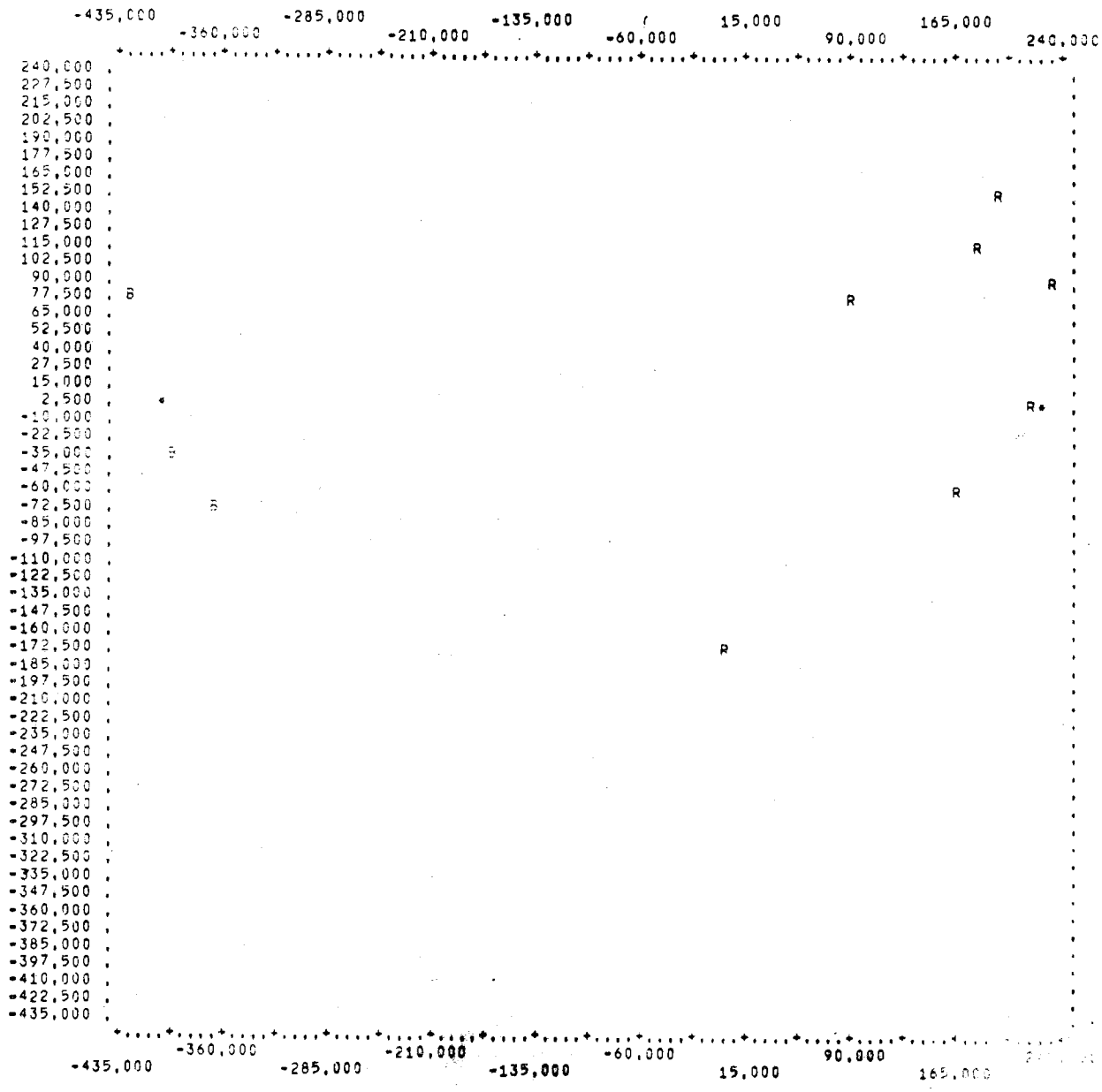
[1] J. Dixon, op. cit., pg. 214j.

FIGURE VI-1

Canonical Separation for OBE 55




X Axis = Annual Tonnage

Y Axis = Distance

The values printed on each axis are generated in the computer plot. The numbers should be read for magnitude differences, not absolute value.

OBE 62

OBE 62 is located between the two major coal fields (see Map III-1). This provides the firms the opportunity to purchase coal from one or both the major coal fields.[1] Data for firms located in OBE 62 demanding bituminous coal are used to derive a discriminant function for this region. Table VI-8 shows the pattern of entering variables in forming the function, and the mean values for each variable. As in the previous runs, the transportation price is the most significant variable to the firms. However, the entrance order of the remaining variables does not correspond to the other runs. This signifies that the mode characteristics of OBE 62 differ in value from the aggregate and OBE 55. Thus, each region so far produces unique mode demand characteristics, which assist in distinguishing mode characteristics and regions.

TABLE VI-8

ENTRANCE OF VARIABLES OF OBE 62

| Entrance Order of Variables | Mean Value Barge | Mean Value Rail |
|---|---|---|
| 5 | $0.938 | $4.115 |
| 3 | 88.45 hrs | 133.5 hrs |
| 2 | 280.9 mi. | 209.5 mi. |
| 1 | 118,145 tons | 49168 tons |
| 6 | $0.358 | $0.346 |
| 4 | 9825 tons | 1131 tons |

[1]Eastern or Interior Province coal fields.

Comparison of the Regional Mean Values to the Aggregate Data

Mean values determine the linear functions which describe the mode characteristics. Table VI-8 shows that the regional mean values differ from the aggregate average. A brief description of the major dissimilarities between the regional and aggregate data follows.

Transportation price for both modes is above the aggregate value. Regional barge price exceeds the aggregate barge price by 29%, while the regional rail price is 14% above the aggregate rail value. Additionally, the average regional transportation prices are the highest among the three OBE regions. These higher transportation prices are a result of the increased distance the cargoes must be transported. Barges transport coal 121.4 miles further than their aggregate average, while rails transport coal an additional 50 miles beyond their aggregate average.

Annual tonnage of coal transported to OBE 62 shows barges transport a significantly larger quantity than rails per firm, even though rails transport a larger quantity of coal than their aggregate rail mean value, while barges transport a smaller quantity of coal per firm annually than their aggregate average value. This large difference occurs because the tonnage OBE 62 rails move is only one-half the tonnage per firm that OBE 55 rails handle. This decrease in tonnage occurs because unit trains are not operating in the OBE 62. Moreover, the tonnage barges transport on the average exceeds OBE 55 average tonnage moved by barge. Thus, in OBE 62 the decrease in tonnage moved by rail and the increase in tonnage moved by barge creates a larger difference between the two modes than in OBE 55.

TABLE VI-9

RESULTS OF DISCRIMINANT ANALYSIS OF OBE 62

Number of Firms' Coal Movements Classified Into Mode

| Mode | Barge | Rail |
|---|---|---|
| Barge | 20 | 0 |
| Rail | 0 | 16 |

Using these firms' transportation data, OBE 62 discriminant function is formed. Table VI-9 shows the summary of the discriminant function classification routine, using the regional data. OBE 62's discriminant function produce a perfect allocation of firms using the modes of transportation. This implies that a sufficient dissimilarity exists between the two modes of transportation to distinguish among them. A brief examination of differences amongst values for input variables is presented below.

Mean Differences Between the Groups

The rail transportation price is four times greater than the barge average rate. The transportation price is most significant in separating the modes. In fact, by using just transportation price the discriminant analysis procedure permits allocation of all the firms using barges correctly but not rails. This is due to the wide separation of the mean values and their small variance.

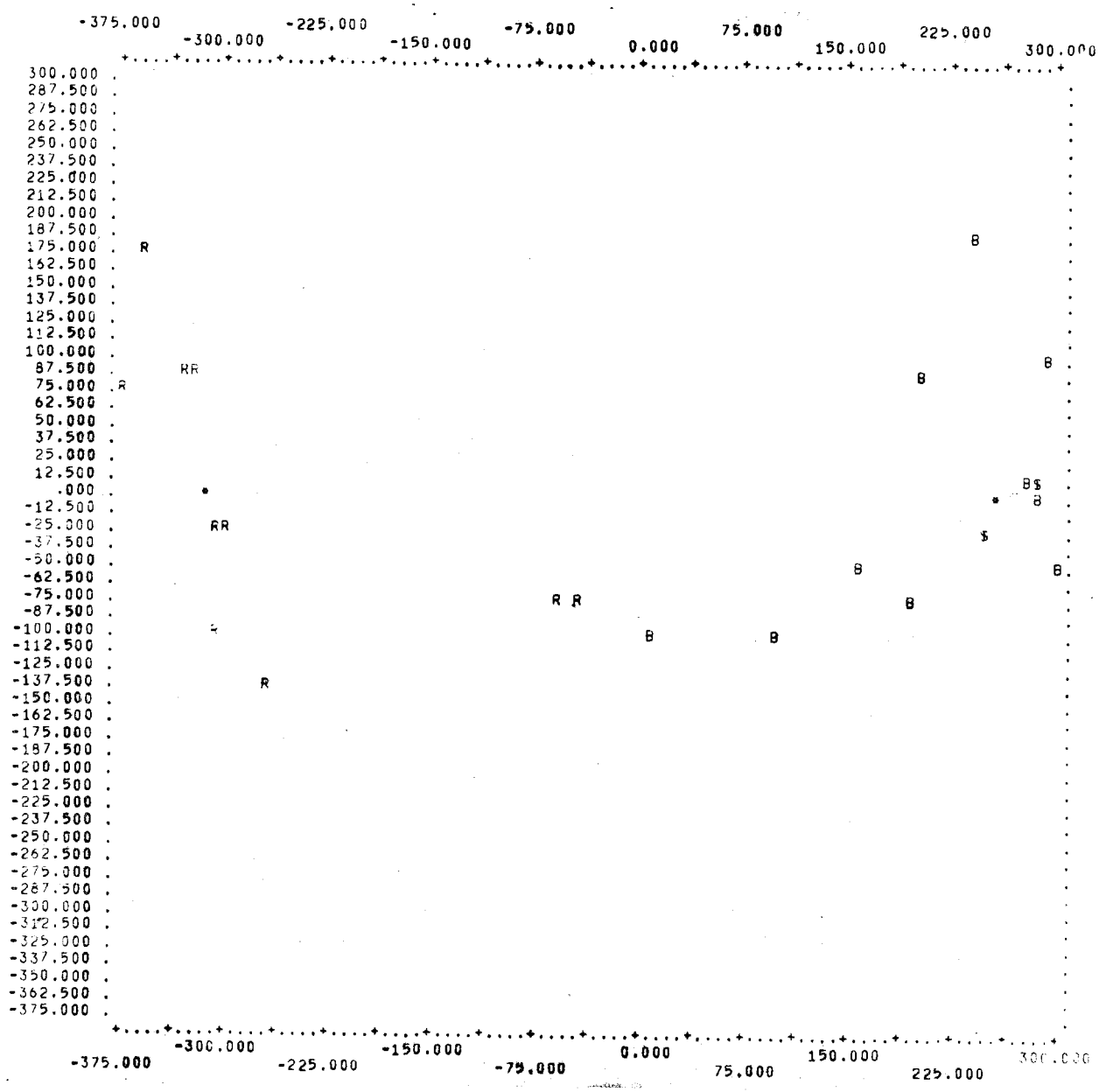
The use of the remaining data variables in the discriminant analysis limits the misallocation of firms. Rails require, on the average, 45 more hours to transport their cargoes than barges, even though the barges transport the coal approximately 71 miles further on the average than rail. In

addition, barges on the average transport 2.4 times the quantity of coal annually to a firm than do rails. Combining these dissimilarities between barge and rail permits the formation of unique characteristics for each mode. Consequently, all modes are identified and firms using them are correctly classified.

Graph VI-2 shows the separation of the modes based on only transportation price and transit time. The power of the function is seen by wide division of the modes, for none of barges (B) approach rails (R) grouping. Consequently, all firms using modes are correctly allocated.

FIGURE VI-2

Canonical Separation for OBE 62




X Axis = Annual Tonnage

Y Axis = Distance

The values printed on each axis are generated in the computer plot. The numbers should be read for magnitude differences, not absolute value.

OBE 66

Within the boundaries of OBE 66 is located a heavy concentration of industrial coal users. In fact, OBE 66 has the largest coal demand of the three regions. Data representing OBE 66 is inserted into the Biomedical Program to determine various firms' mode choice in transporting coal to OBE 66.

The analysis enters variable five (transportation price) into the program as the most significant variable. In all the computer runs, the transport price firms pay to transporters proves to be the most decisive factor. Moreover, the order of entrance of the remaining variables did not correspond to any other run. This implies that each region's transportation characteristics are unique and differ from the aggregate characteristics. Table VI-10 shows the order in which the remaining variables enter the program and the computed mean values for each variable.

TABLE VI-10

ENTRANCE OF VARIABLES OF OBE 66

| Entrance Order of Variables | Mean | |
|---|---|---|
| | Rail | Barge |
| 5 | $3.77 | $0.62 |
| 2 | 132 mi. | 96 mi. |
| 4 | 936 tons | 9392 tons |
| 1 | 64394 tons | 185,583 tons |
| 3 | 99.5 hrs | 54.8 hrs |
| 6 | $0.34 | $0.27 |

Comparison of the Regional Mean Value to the Aggregate Mean Value Data

Annual tonnage of coal shipped into OBE 66 by either mode exceeds aggregate average tonnage value. Barge industry transports 28% more coal than their aggregate average tonnage value, while the railroad carries 35% more coal to OBE 66 than their aggregate average tonnage value. This larger tonnage of coal shipped into OBE 66 is due to the larger number of consumers in the region.

OBE 66 is located in the Appalachian coal fields of the Eastern Provinces in the United States. Consumers of coal take this as an opportunity and purchase coal from nearby suppliers. This is reflected in the below average distance the modes transport coal. Barges on the average transport the coal 66 fewer miles than the aggregate average barge movement, while rails in OBE 66 transport coal on the average 27 fewer miles than the aggregate average rail movement.

The shorter transport distance also assists in reducing the transportation time. Table VI-10 shows that regional barge and rail transport times are below their aggregate time. Regional barges travel approximately 31% slower than their aggregate average speed, while regional rails travel 15% slower than their aggregate average speed.

Transportation price did not change in the same direction and magnitude as in the two previous OBE regions. Regional rail average transport price exceeds their aggregate average price by 4%, while regional barges were 14% below their aggregate value.

TABLE VI-11

RESULTS OF DISCRIMINANT ANALYSIS OF OBE 66

Number of Firms' Coal Movements Classified Into Mode

| Mode | Rail | Barge |
|---|---|---|
| Rail | 12 | 0 |
| Barge | 0 | 27 |

Mean Differences Between the Groups

Combination of these variables produces a regional discriminant function. Table VI-11 shows the summary of the classification routine. Since all firms lie along the diagonal, the function produces a perfect allocation of firms using these modes. This indicates the mean values for each mode are quite distinctive.

Only two major dissimilarities between the modes of transportation are important to notice. One, the rail transportation price is six fold greater than the barge transport price. Rail average transportation price is so large that none of the individual barges transportation price exceed it. In fact, using just transportation price yields a perfect allocation of firms amongst all modes except one. The exception was a rail movement, which was classified as a barge. This firm's transport price approaches the barge transportation price. Therefore, the movement is classified into the barge mode which exhibits a similar characteristic.

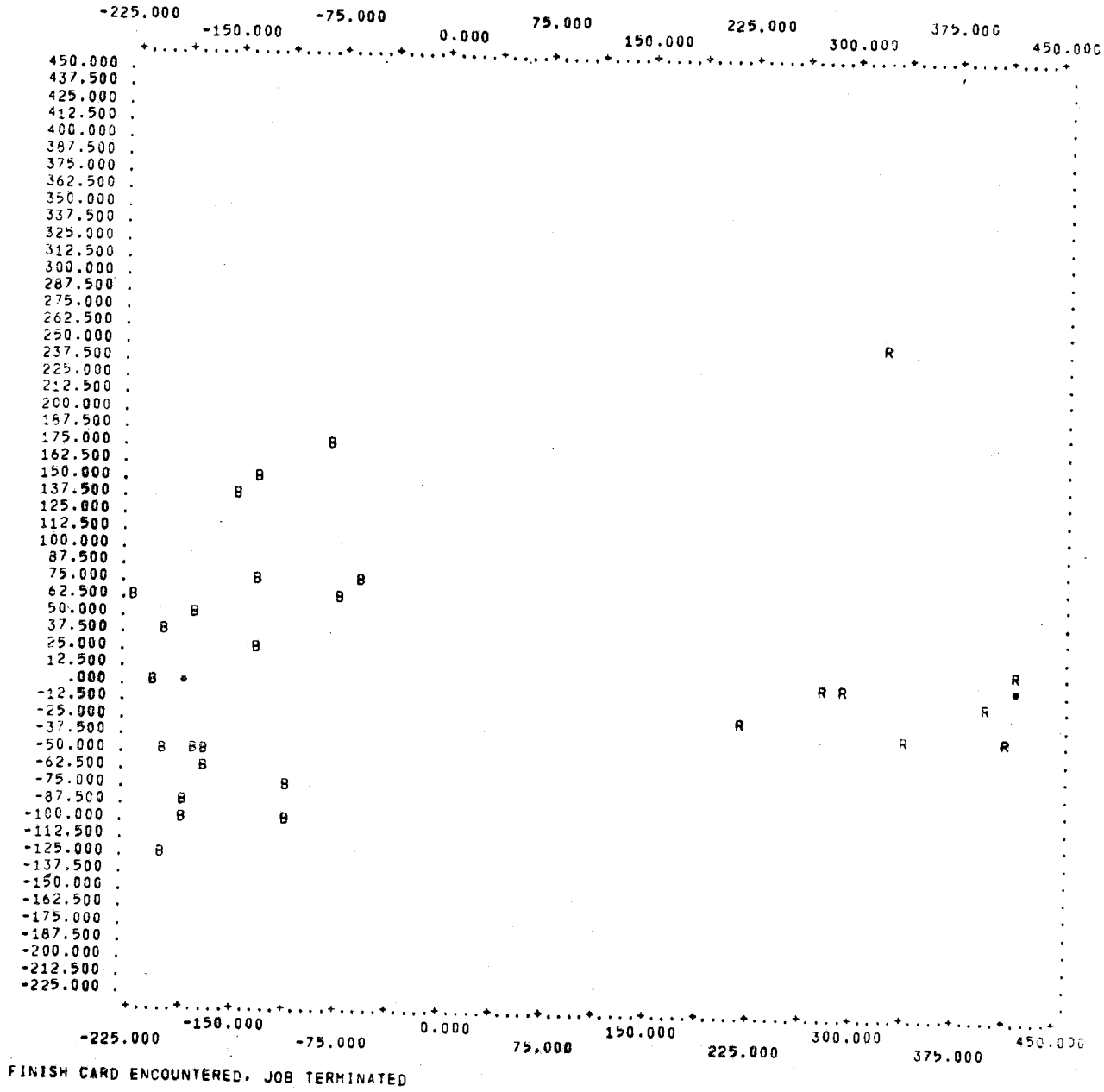
Second, the tonnage moved by barge annually and the per average size shipments are several times larger than rail. In fact, none of the rail movements in OBE 66 exceeded the average barge tonnage, and using just annual tonnage results in a perfect allocation amongst all modes except

that one barge movement was misclassified. Thus, the tonnage variable assisted the use of the discriminant function to separate the rail from the barge population.

These two factors and the differences in the remaining variables separated the two modes. Figure VI-3 verifies that the two modes do not overlap or approach each other. Consequently, the discriminant function allocates all firms using the modes perfectly.

FIGURE VI-3

Canonical Separation for OBE 66




X Axis = Annual Tonnage

Y Axis = Distance

The values printed on each axis are generated in the computer plot. The numbers should be read for magnitude differences, not absolute value.

## SUMMARY OF THE THREE AREAS

Each OBE region displays unique mode characteristic values. In addition, each mode of transportation operating in each area has unique mode characteristic patterns. To show this, each regional mode characteristic is computed and compared. If a particular mode of transportation average regional data for a variable exceeds the corresponding average aggregate data, the regional data for that variable is signified by a plus sign. However, if the regional data is less than the aggregate data, the variable is symbolized by a negative sign.

With this information, an area code is developed for each OBE region. This code enables a further distinction between areas. The ± or ∓ symbolism refers to the rail barge combination, with the top sign being the rail and the bottom sign the barge regional signs for that variable. The single sign area code occurs when both modes in the area signs for that variable are identical.

TABLE VI-12

DIFFERENCES BETWEEN AGGREGATE AND REGIONAL

| Variables | OBE 55 | | | OBE 62 | | | OBE 66 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rail | Area[1] Code | Barge | Rail | Area[1] Code | Barge | Rail | Area[1] Code | Barge |
| $X_1$ | + | ± | - | + | ± | - | + | + | + |
| $X_2$ | - | - | - | + | + | + | - | - | - |
| $X_3$ | - | - | - | + | + | + | - | - | - |
| $X_4$ | + | ± | - | - | ∓ | + | - | ∓ | + |
| $X_5$ | - | - | - | + | + | + | + | ± | - |
| $X_6$ | + | ± | - | 0 | 0 ∓ | + | 0 | 0 ∓ | - |

Table VI-12 shows the average characteristics (plus, minus or zero) for each area and mode of transportation within each OBE.

Using the regional data provides more adequate data to use in determining firms' mode selection, since with a regional approach all movements are allocated correctly, while using aggregate data in the discriminant analysis creates several errors. This occurs because each OBE has unique mode characteristic values that differ from the aggregate characteristic value. Therefore, the aggregate discriminant function does not present an accurate picture of each individual area demand function for each mode. To model the mode selection process involving several different economic areas, a regional approach should be undertaken.

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[1]Area code represents the combination of mode characteristic of that region. As can be seen, even these area codes to not exactly resemble each other or the aggregate function.

## PART II - DEMAND ANALYSIS

### Firms' Reaction to an Increase in Transportation Price

A method to derive an empirical demand curve for barge transportation was undertaken. This method is based on a basic economic technique, mainly, the alteration of only barge price, while holding everything else constant. This method is used to show the responsiveness of barge demanders to the alterations in price. Plotting the demand for barge transportation at the different prices produces a demand curve for barge transportation.

Of the six variables that could be used in modeling the barge demand function, only transportation price is altered. For all previous computer runs, transportation price proved the most significant to demand determination. In fact, the transportation price could be used by itself to actually separate the barge mode from rail. Thus, the demand derivation and analysis focused on the alteration of this variable.

Shifting the barge transportation price toward rail average transportation price reduced the difference between the two transportation rates, and each set of mode characteristics began to resemble each other.[1] Consequently, the overlap of mode characteristics results in barge users being classified as rail demanders. These misclassifications are economically interpreted as a decrease in demand for barge transportation because of the increase in transportation price. Continuing to raise

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[1]George Antle and Richard Haynes, An Application of Discriminant Analysis To The Division Of Traffic Between Transport Modes, U. S. Army Corps of Engineers, Institute for Water Resources, Alexandria, Va., IWR Report 71-2, 1971.

the barge transportation price will eventually result in all the anticipated barge users being allocated as rail demanders. Therefore, it is important to present a method to derive an empirical demand curve for barge transportation using other than just price data.

A demand function for barge transportation was derived for each OBE region. The approach using aggregate data was not undertaken, because it proved inadequate to describe the mode characteristics. The regional data were used to describe the mode characteristics to facilitate allocating firms to all modes correctly. Therefore, to derive a function presenting an accurate response to an increase in transportation price only the regional data were used. The following analysis describes the results from a simulated analysis for each OBE region and explains the reasons for the shape of the demand curve.[1]

Demand Analysis for OBE 55

Holding regional data variables constant and changing only barge transportation price permits a simulated demand analysis for barge transportation to be derived. Data for only OBE inland waterway carriers' prices are positively incremented. The new data are inserted into OBE 55 regional discriminant function. This yields a mode classification of the barge users with a certain positive increment on barge transportation price. Repeating this procedure for different price increments produces a simulated demand schedule for barge transportation. Table VI-13 displays the results of the analysis. Plotting these points on Figure VI-4 on page VI-33 reveals the shape of the demand curve.

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[1]The analysis is performed by an altered 07M BMD program.

TABLE VI-13

DEMAND SCHEDULE FOR OBE 55

| Price Increase Above The Average Transport Price | Classification of Barge Using Firms | Quantity - Tons |
|---|---|---|
| $0.47 | 6-0 | 6,892,403 |
| 0.72 | 6-0 | 6,892,403 |
| 0.97 | 6-0 | 6,892,403 |
| 1.07 | 6-0 | 6,892,403 |
| 1.12 | 5-1 | 6,338,588 |
| 1.17 | 2-4 | 6,007,208 |
| 1.27 | 1-5 | 498,435 |
| 1.32 | 0-6 | 0 |

The truncated curve consists of two sections. One is the inelastic and the other, the elastic section. The point that connects the two sections is the kink point. A brief description of each section is presented below.

The inelastic section of the demand curve has a coefficient of elasticity for the demand for barge transportation of less than unity. The inelastic section stretches from the initial transportation price of $0.47 to a total price of $1.17.[1] At a price of $0.97 the demand function is perfectly inelastic. However, continuing to increase the price beyond $0.97 brings the elasticity towards unity. The last calculated point on the inelastic section of the demand function is $1.17, with the elasticity coefficient for barge demand still less than one.

[1]Initial price of barge transportation refers to the average barge transportation price for a particular OBE.

The kink is the position where the inelastic section of the demand curve intercepts the elastic section of the demand curve. For OBE 55, the point occurs between a $1.17 and $1.22. At $1.22, the elasticity coefficient is greater than one. Consequently, the unitary point falls between the two values. A graphic interpretation indicates the point is at $1.18. Thus, at this price, the elasticity coefficient is unitary.

The elastic section of the barge demand curve is that section of the curve where the elasticity coefficient is greater than one. This section for OBE 55 stretches from the kink point to an augmentation of $0.85 over the average barge transport price since at $1.32 none of the few remaining firms demand barge transportation. Thus, the elastic section and the total demand curve have been derived.

Price Level at Kink Point

The changeover in the demand elasticity coefficient occurs while the simulated barge companies average transport rate is still beneath the rails' average rate (Table VI-14). This indicates that the remaining variables contribute to shifting transport users to an alternative mode. This results from the similarity amongst modes within the OBE, effectively making price similar at some point. In Table VI-5 (page VI-10) observe the similarities in the mean values for each variable.

The combination of these variables allows the rail and barge populations to overlap initially, and increases in the barge price (most significant variable, Table VI-5) result in the occurrence of a number of misallocations, because several of the barge movements now correspond to rails' mode characteristics rather than the barge mode characteristics.

The barge price attains approximately 75% of the rail price before reaching the kink point. This represents the closest the barge price can come to the rail for all three OBE regions before the elasticity becomes greater than one. However, the initial average barge transport charge for barge is the lowest of the modes. Consequently, the absolute monetary increase to attain the kink point is also the smallest of the three areas.

FIGURE VI-4

EFFECT OF TRANSPORTATION PRICE INCREASE ON ELASTICITY COEFFICIENT OF DEMAND

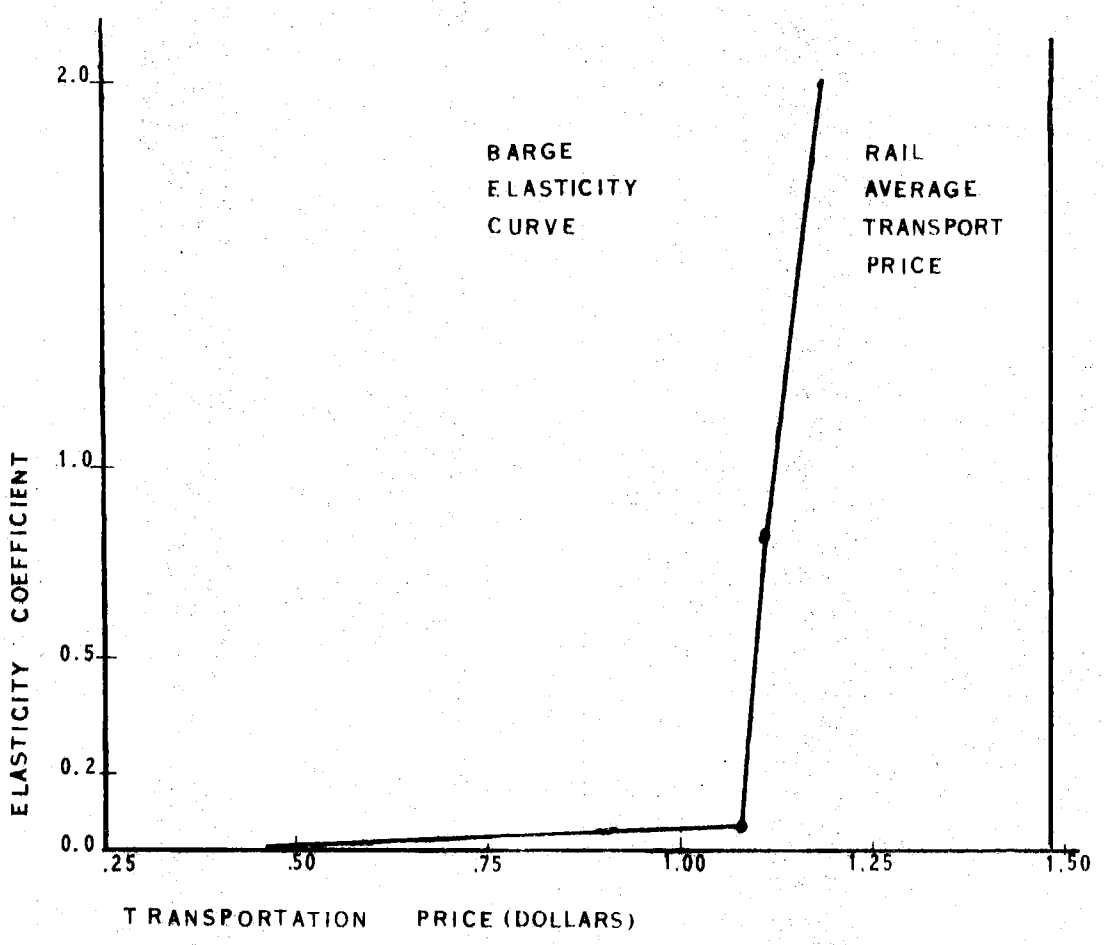


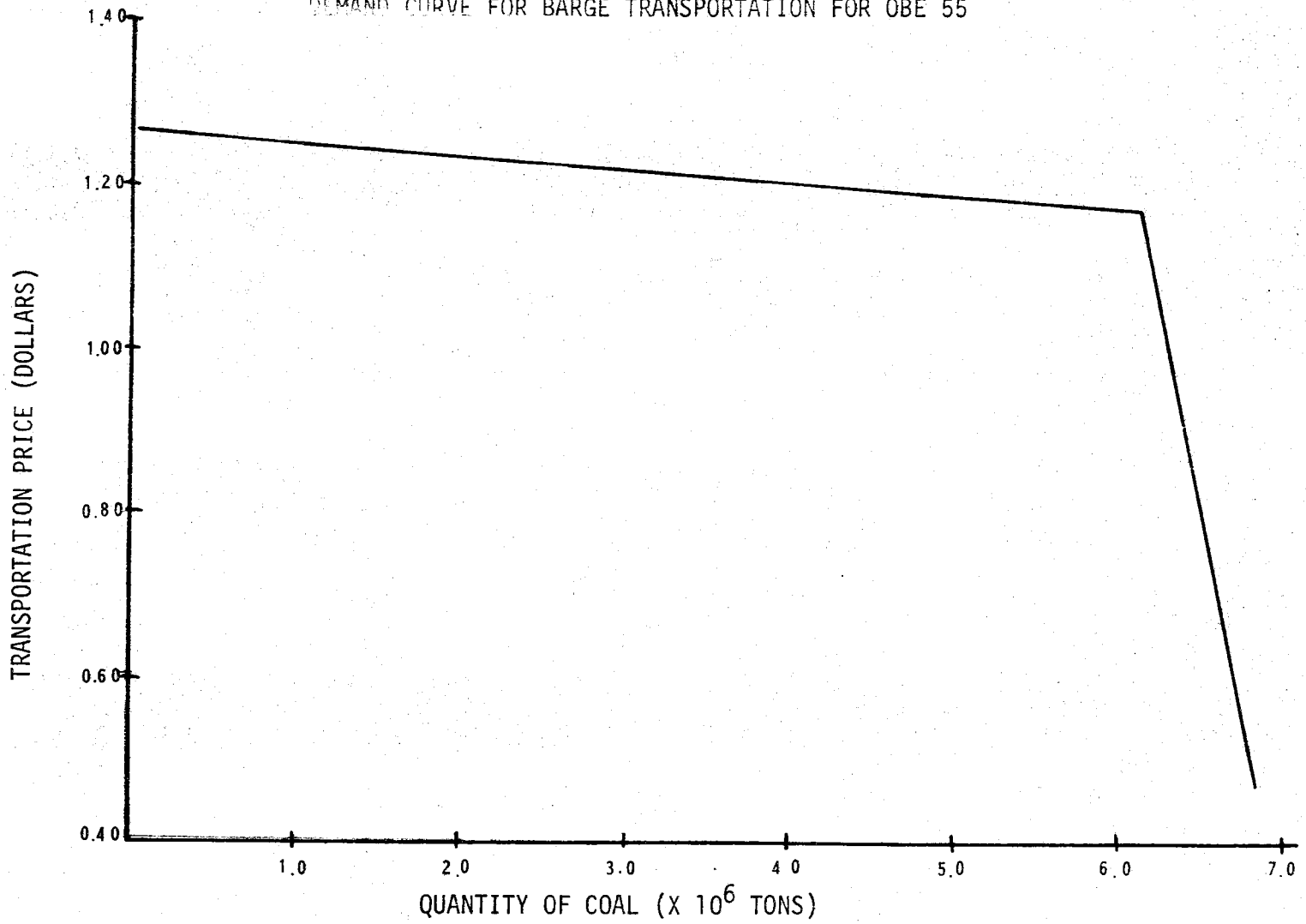
TABLE VI-14

ELASTICITY TABLE FOR OBE 55

| Change in Barge Transportation Price (Dollars) | Change in Quantity (Tons) | Elasticity Coefficients |
|---|---|---|
| 0.50 | 553,815 | 0.042 |
| 0.15 | 5,564,153 | 5.61 |
| 0.15 | 138,000 | 0.90 |
| 0.05 | 138,000 | 3.53 |
| 0.25 | 498,435 | 7.0 |

FIGURE VI-5

DEMAND CURVE FOR BARGE TRANSPORTATION FOR OBE 55



OBE 62

Simulating the barge transportation price in OBE 62 results in a truncated demand curve. This curve consists of an inelastic and elastic section. The kink point connects the two linear sections, which forms the empirical demand curve for barge transportation. The inelastic section stretches from the initial price of $0.935 to a total price of $2.59. The next point on the demand curve is the unitary elasticity point. Points above the $2.60 level have an elasticity coefficient greater than one. From Table VI-15, these points can be identified and are plotted on Figure VI-6.

TABLE VI-15

DEMAND SCHEDULE FOR OBE 62

| Price Increase Above The Average Price | Classification of Barge Firms | Quantity - Tons |
|---|---|---|
| $0.93 | 20-0 | 19,629,049 |
| 1.93 | 18-2 | 17,859,377 |
| 2.18 | 17-3 | 17,789,377 |
| 2.43 | 15-5 | 15,012,129 |
| 2.68 | 12-8 | 11,951,305 |
| 2.73 | 12-8 | 11,951,305 |
| 2.83 | 7-13 | 10,641,241 |
| 2.93 | 3-17 | 7,011,241 |
| 3.93 | 0 | 0 |

Within the inelastic section a total of 4.6 million tons of coal, which represents 23% of that potentially moved by barge, is simulated to be transported by rail. However, the majority of users remain with the barge mode. This occurs because the firm absorbs the additional cost without having to switch modes. However, as the incremental price approaches the kink point, the elasticity of demand also approaches unity. Economically, this means that the two modes' price is approaching equivalency.

Continuing to increase the barges' price results in eventually attaining the unitary elasticity point. This position is the point where the average total prices for both modes of transportation are equal and firms are indifferent to choice of mode. In OBE 62, the kink point lies somewhere between a $1.50 augmentation of the average barge rate and $1.75 augmentation. Estimating with graphic techniques yields a value of $2.59 for the kink point.

At all positive values, increases above the kink point for barge price are considered part of the elastic portion of the demand curve, for the demand for barge transportation in this section has an elasticity coefficient greater than one. Increasing barges' transport price continues until the demand for barge mode is zero. Thus, the elastic section of the demand curve is derived. Extrapolating the elastic section of the demand curves estimates the last point on the demand curve to occur at $3.25.

As before, barge transportation price did not become equivalent to the rails' average transport price before the elasticity coefficient became larger than one. In fact, barges' simulated transport price

only attained 64% of the rails' average transport cost before the kink point occurred. However, at OBE 62 kink point the highest absolute monetary levels of all the regions price is attained before the elasticity coefficient became greater than one.

Table VI-16 shows the initial average transportation price for three OBE regions. OBE 62 displays the largest difference between the two modes. In addition, OBE 62 has the highest initial average barge transportation price. The combination of these two factors permits the monetary value of OBE 62 kink point to exceed that of the other region.

TABLE VI-16

AVERAGE TRANSPORTATION PRICE AND DIFFERENCES BETWEEN MODES FOR EACH REGION

| | OBE 55 | OBE 66 | OBE 62 |
|---|---|---|---|
| BARGE | 0.475 | 0.620 | 0.938 |
| RAIL | 1.460 | 3.776 | 4.1150 |
| DIFFERENCE IN RATE | -0.985 | -3.156 | -3.177 |

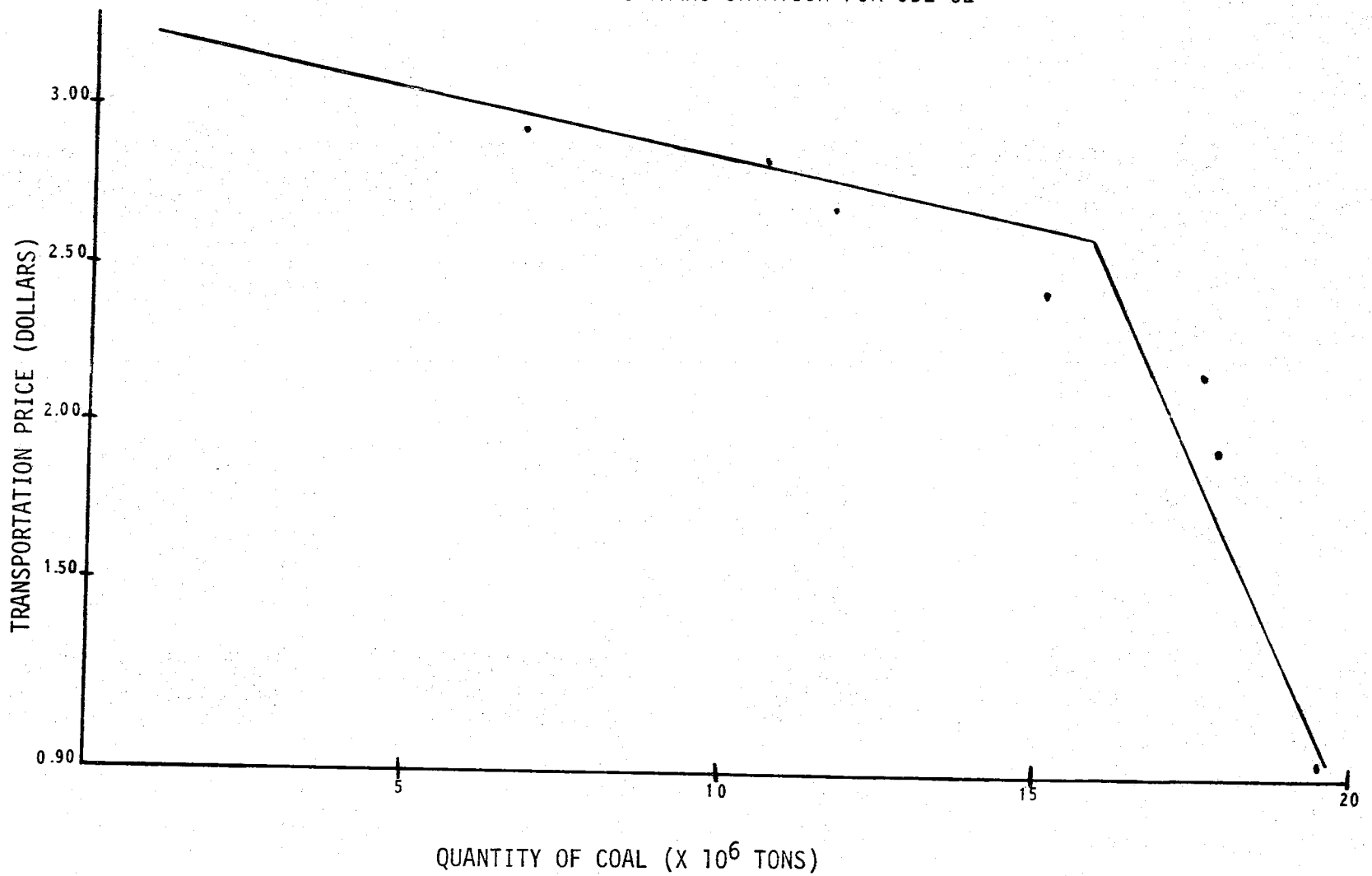
TABLE VI-17

ELASTICITY TABLE FOR OBE 62

| Change in Barge Transportation Price (Dollars) | Change in Quantity (Tons) | Elasticity Coefficients |
|---|---|---|
| 1.00 | 1,769,672 | 0.05 |
| .25 | 70,000 | 0.02 |
| .25 | 2,777,248 | 0.90 |
| .25 | 3,060,824 | 1.48 |
| .15 | 1,310,064 | 2.15 |
| .10 | 3,630,000 | 8.02 |
| 1.000 | 7,011,241 | 5.0 |

Figure VI-6

DEMAND CURVE FOR BARGE TRANSPORTATION FOR OBE 62



OBE 66

Finally, a simulated demand analysis of the barge movements for OBE 66 is undertaken. Manipulating the barge transportation price in the same manner as before results in a simulated demand curve. Table VI-18 shows the demand schedule from this manipulation. Plotting the quantity moved by barge for various transportation prices reveals a truncated demand curve.

TABLE VI-18

DEMAND SCHEDULE FOR OBE 66

| Transportation Price | Classification of Barge Using Firms | Quantity - Tons |
|---|---|---|
| 62 | 27-0 | 29,107,400 |
| 1.62 | 26-1 | 28,107,400 |
| 1.87 | 24-3 | 24,629,900 |
| 2.12 | 18-9 | 18,773,600 |
| 2.22 | 16-11 | 16,335,100 |
| 2.32 | 11-16 | 10,034,400 |
| 2.47 | 8-19 | 6,572,200 |
| 2.52 | 5-22 | 8,308,800 |
| 3.72 | 0-27 | 0 |

The demand curve is divided into two distinct sections; an inelastic section and elastic section. The inelastic section is that part of the demand curve with an elasticity coefficient of less than one, while the elastic portion has an elasticity coefficient greater than one. The kink point is the point that connects the two sections of the demand curve and has an elasticity coefficient of exactly 1.00.

Within the inelastic section, as the transportation price increases the quantity moved by barges decreases at a decreasing rate, for barge mode characteristics only begin to resemble the rails' characteristics. The monetary range for the inelastic section is from the initial average barge rate to an additional $1.50 increase. The initial transportation price for barge is $0.62.

Since the transportation price is the most significant variable, the increase in transport price eventually overwhelms the values of the remaining variables. This results in barge characteristics now resembling the rails' mode characteristics. Thus, a small increase in transportation price causes a decrease of coal moving by barge at an increasing rate. The elastic range stretches from $2.14 to an extrapolated $2.62 which just exhausts the demand for barge transportation.

The kink point that connects the two curves displays an elasticity coefficient of approximately one. Using graphic techniques, the kink point is derived. On this graph, the monetary value of this kink point is $2.13. In OBE 66 the kink point occurs before the modes' transportation prices became equivalent. This value represents only 54% of the rails' average transportation price. This would indicate either that the transportation price is an overpowering variable, which causes barge mode characteristics to change rapidly, or there exists a significant overlap of mode characteristics between the modes of transportation initially. After examining the mode characteristics and the discriminant function, it is apparent that the former reason applies, because the

coefficient of the fifth variable is approximately twenty times larger than the next two significant variables. Therefore, increases in barges' transport price result in large shifts in the mode characteristics and represent an overpowering variable.

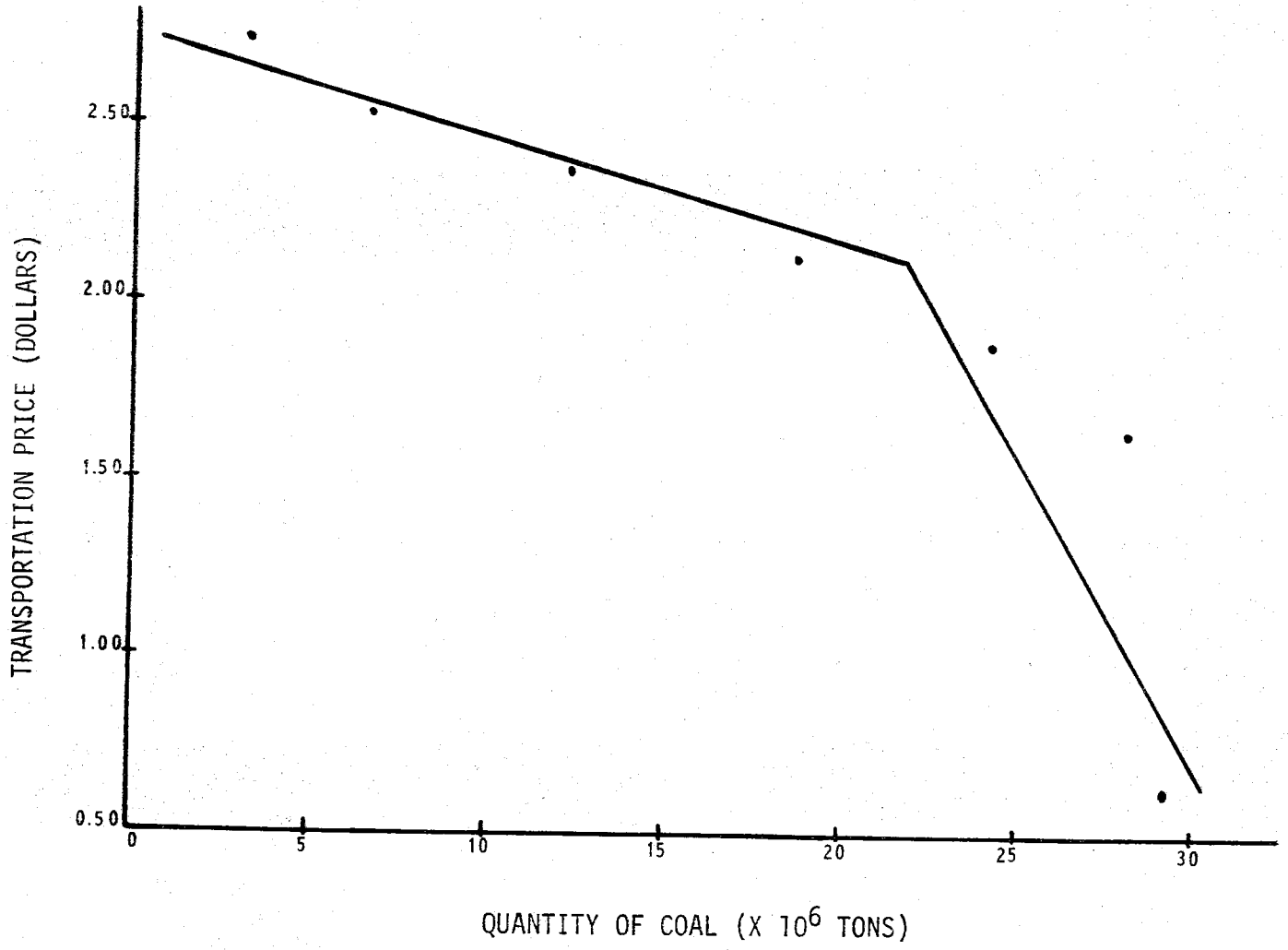
TABLE VI-19

ELASTICITY TABLE FOR OBE 66

| Change in Barge Transportation Price (Dollars) | Change in Quantity (Tons) | Elasticity Coefficients |
|---|---|---|
| 1.00 | 1,000,000 | 0.09 |
| .25 | 3,477,500 | 0.34 |
| .25 | 3,856,300 | 0.75 |
| .10 | 2,438,500 | 6.03 |
| .10 | 6,301,000 | 15.52 |
| .05 | 3,462,200 | 8.16 |
| .25 | 3,263,400 | 5.00 |

FIGURE VI-7

DEMAND CURVE FOR BARGE TRANSPORTATION FOR OBE 66



PART III

Summary of Chapter

Chapter VI contains the empirical results of Model III, testing the utilization of discriminant analysis as a method for predicting firms' mode choice for transporting coal. Also, the model simulates barge users' responsiveness to increases in barge transportation price. From analysis, the regional data proves to be a more adequate data form for determining the firms' mode selection process, for use of aggregate data permits the misclassification of several firms as barge users. This occurs because the aggregate data did not accurately describe the mode characteristics for each mode of transportation. On the other hand, the regional approach allocates all the coal movements correctly. This indicates that the regional approach sufficiently describes the mode characteristics, and improves on the aggregate approach. Thus, the regional data are more useful in determining the mode of transportation a firm selects in transporting its coal than are aggregate data.

Since the aggregate approach did not adequately describe the mode characteristics correctly, a simulation model to determine the demand for barge transportation was made of each OBE region. The regional analysis shows that all three regions display a downward sloping demand curve for barge transportation. This implies that the demand for barge is a normal good as previously assumed.

# SUMMARY AND CONCLUSIONS

## CHAPTER VII

Over the years, several economic models to estimate future demand for transportation have been presented. Unfortunately, each model only partially explained why the demand for transportation occurs. This implies that each model acts independently of any other model, and it requires each model to utilize various weak assumptions or given conditions. Consequently, traditional approaches have been unable to show how numerous economic variables affect the demand for transportation.

This dissertation attempts to correct some of these problems by developing a more complete economic model of transportation demand. Accomplishing this task requires that a single model incorporate several economic hypotheses and theories about the demand for transportation. Including these concepts removes the dependency on several exogenous conditions (assumptions) of previous models. This development, a dependent model, is capable of explaining how alteration in the value of various economic variables affects the demand for transportation. Therefore, it represents an improvement over traditional models used for projecting transportation demand.

Using this model, empirical data were applied to project the future demand for barge transportation to transport coal to selected destinations on the Ohio River. Using the model we project 56,628,904 tons out of 77,500,000 tons of coal used in the Ohio River Valley will be transported by barge in 1980. In addition to this projection, three major conclusions result from the analysis reported in this dissertation.

One, deriving the quantity of coal to be transported should improve the analysis rather than accepting an exogenously given quantity of coal to be transported. The derivation procedure includes a mechanism that could be used for detecting sudden changes in the demand for coal.[1] This improves the traditional procedure, because in previous independent models the demand for coal cannot be immediately altered to detect future transportation demand changes and/or determine the reasons for these changes in the demand for coal. Also, the transportation mode selection procedure is not fixed nor does it rely on just monetary criteria. From the analysis, the transportation price can be used to allocate all the anticipated barge movements correctly amongst modes, except for the rail mode. To remove misclassifications of movements requires the incorporation of non-monetary variables into the mode allocation model. Consequently, in these models several traditionally exogenously given conditions are removed facilitating more complete understanding of the transportation market. This approach improves traditional techniques for projecting future demand for transportation.

The economic transportation model, to be an adjustable and a sensitive model, incorporates four separate forecasting models. Moreover, there must exist understandable economic linkages between the models, variables, and the results. With these interrelationships, a comprehensive model can be used to derive the quantity of coal each mode of

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[1]This mechanism permits the model to be sensitive to alteration in the total demand for coal for economic reasons.

transportation transports. The model is capable of being used to adjust these quantities with changes in the economic environment. A brief summary of the four forecasting models, and results from these models follows:

a. The first forecasting model estimates the future demand for coal by firms utilizing coal as a factor of production. This indicates why firms demand coal, and is used as a general indicator to determine the quantity of coal that must be supplied to a region. The analysis reported herein only concentrates on the major consumers of coal. In this case, three industrial sectors purchase over 90% of the total coal consumed in the three selected Office of Business Economic Regions in the Ohio River Valley. Steam-electrical generating sector consumes over 71% of the coal, and the remaining percentage is divided among the coke and primary metal industries (coke, 17%, primary metal, 12%).[1] The model can incorporate future changes in the demand for coal in two ways. One, if a firm intends to go out of business or switch to an alternative factor of production, the model would indicate a decline in the demand for coal. Two, if additional industries that consume coal enter the market or existing firms increase their output, the model indicates an increase in the demand for coal. Therefore, this economic model gives a planner a method to use in anticipating any alterations in the future demand for coal with less delay and a basis for these changes - a way to go to look for changes that may appear.

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[1]Percentage is based on sample survey projections.

b. Incorporating future technological changes enables the second model to be used to determine the effects of future technology alteration on the demand for coal. In this study, the total demand for coal in 1980 in the three OBE regions is predicted to be approximately 77,500,000 tons of coal.

c. The third forecasting model is the model used to estimate the supply of coal to be furnished in 1980. This model does not require accepting the notion of an infinite quantity of coal available. The supply model projects, for 1980, 76,000,000 tons of coal to be extracted from the Ohio River Valley to satisfy the selected firms' future demand for coal. In addition, the model aids in establishing an equilibrium between the supply and demand for coal. The analysis shows there exists a 2% discrepancy, in this author's opinion, an insignificant discrepancy.

d. Using statistical techniques (Model IV, the discriminant analysis) with previous information improves the transportation mode selection analysis. This model incorporates monetary as well as non-monetary variables to produce a perfect allocation of coal movements among modes. It enables planners to predict firms' future mode selections by only observing mode characteristics and a firm's demand. A simulation of barges' transport prices indicates users' responsiveness to changes in price.

From the study, it can be concluded that this approach is a better method in explaining future demand for transportation than the traditional approach.

The second major conclusion is that the utilization of regional information proves superior to using national or aggregate data to

determine the transportation mode characteristics, since using aggregate data causes several coal movements to be misclassified. This indicates the aggregate approach is inaccurate in describing mode characteristics. On the other hand, the regional discriminant function allocates all the anticipated movements correctly, thus implying the regional approach describes the mode characteristics more adequately than the aggregate approach.

TABLE VII-1

DIFFERENCES BETWEEN AGGREGATE AND REGIONAL

| Variables | OBE 55 | | | OBE 62 | | | OBE 66 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rail | Area Code[1] | Barge | Rail | Area Code[1] | Barge | Rail | Area Code[1] | Barge |
| $X_1$ | + | ± | - | + | ± | - | + | + | + |
| $X_2$ | - | - | - | + | + | + | - | - | - |
| $X_3$ | - | - | - | + | + | + | - | - | - |
| $X_4$ | + | ± | - | - | ∓ | + | - | ∓ | + |
| $X_5$ | - | - | - | + | + | + | + | ± | - |
| $X_6$ | + | ± | - | 0 | 0 | + | 0 | 0 | - |

Table VII-1 shows the similarities and dissimilarities of regional data compared to the aggregate data. From the table, only two regional variables correspond in value to the aggregated variable. Moreover, each region displays unique transport characteristics, making

[1]Area code represents the combination of mode characteristic of that region. As can be seen, even these area codes do not exactly resemble each other or the aggregate function. See page VI-27 for full description of table notation.

it improbable for a single aggregate function to adequately describe the firms' mode demand characteristics. Regional data proves superior to the aggregate data to describe firms' mode demand characteristics. See pages VI-26 and VI-27 for a complete explanation of symbols.

Third, the analysis was used to discover a common shaped demand curve for all three regions. It is tentatively concluded that the demand curve for barge transportation is kinked. However, each OBE region's kinked demand curve for barge transportation did not display similar lengths, magnitudes or kink points. The reasons for the similar type demand curve occurring for each OBE region and the difference between the kinked demand curves is briefly explained.

All three OBE regions display a kinked demand curve for barge transportation. This curve is composed of two separate demand curves (elastic and inelastic) that intersect each other.

A reason for this particular shape is the inability of alternative modes of transportation to compete in price or time of transport with the barge mode. However, the availability of substitutes enables users to switch modes in attaining the most economical method of transportation. Obviously, the presence of substitutes makes the slope of the demand curve for barge transportation more elastic.

The absence of competition is a result of several factors that form an economic barrier that alternative modes of transportation cannot climb. Several major reasons explain the existence of the non-competitive range or inelastic portion of the demand curve. Examining the price for each mode of transportation reveals a large price difference between the modes of transportation. Rail average price is

approximately 4.6 times larger than the barge price. This makes rail carriers on the average unable to compete in price against barges. It should also be recalled that transport price represents the most significant variable for the firms in selecting a transportation service. In addition, rails on the average transport coal only 13.82 miles further than barges, but require an additional 29.91 hours to transport coal. Finally, barges transport on the average, per firm, several times the quantity the rails do. The combination of these three factors hinder the railroads in economically competing for coal hauls. This results in the inelastic section of the demand curve for barge transport.

Simulating an increase in barge transport price reduces the differences between the two modes' (rail and barges) transport price. This price increase also causes the characteristics of each mode of transportation to begin to resemble each other. Continuing to increase the barge price eventually results in the alternative mode of transportation price becoming equal to barges. At this point, substitute forms of transportation become economically capable of competing against the barge mode for coal hauls. Consequently, with such competition firms have the opportunity to select from among modes of transportation for the one which maximizes their profit. The availability of substitutes raises the demand elasticity coefficient for barges and alters the shape of the demand curve from an inelastic slope to an elastic slope. Even though slopes of the curves differ, all three OBE regions display the same effect noted above.

The differences between the kinked demand curves (shape, slope and kink point) for each region is due to the degree of competition among modes within each region. A brief description of how these competitive conditions affect the kink point price follows.

In OBE 66 surveys indicate that the vast majority of firms believe that competition does not exist between the two modes of transportation (rail and barge). This explains the large differences in transport prices between the two modes of transportation. The separation is also assisted to some degree by the existence of a high degree of intra-mode competition, for intra-barge competition forces the transport price to remain low, because each barge company is competing to maintain its present traffic and attract new traffic. Thus, an increase in transport price by an individual barge company results in loss of traffic and revenue. Barge companies, to maintain their share of coal haul, are forced to keep the transport price at competitive market value, which may differ from their individual profit maximization point.

However, in OBE 55, there exists a high degree of competition between the modes of transportation. This causes the area to exhibit the lowest average transportation rate for each mode, and in OBE 55, the least price increments were needed to eliminate the price differences amongst modes. Two factors facilitate this higher degree of competition.

One, in OBE 55, the firms demanded the smallest total quantity of coal of all three areas. This quantity of coal to be moved by barge is insufficient to support a large number of companies. In

addition, rail companies in OBE 55 utilize unit trains to offset the barge advantage on the haul size. This also indicates that there exists less opportunity for intramode competition to occur.

Two, both modes of transportation on the average move the coal the fewest number of miles per shipment in OBE 55. The relatively short haul distances reduce the transporters' expenses. This shows up as a reduction in transportation price. Rail transportation price is approximately $2.00 less than in the other regions. Moreover, unit trains are offering a transportation price well below the average rate. For barges to remain competitive, they are forced to reduce their transportation price as well. Table VI-16 shows OBE 55 has the lowest transportation prices. Consequently, the smallest percentage difference between the transportation prices of the two modes is in OBE 55. This indicates the high degree of intermode competition does not permit a large difference between the modes' transportation prices.

In summary, the existence of intra or intermode competition greatly affects the position of the kink point in the demand curves. This analysis shows that intermode competition results in lower than average transportation price for both modes. Competition results in the smallest absolute difference between the modes' transport price. Thus, intermode competition inhibits the monetary range of the inelastic section of the barge demand curve. However, a region that exhibits no intermode competition but only intra-mode competition displays a large difference between the modes' transport price. This happens because transportation price is low because several barge companies are competing for the same

traffic. This prohibits individual barge companies from raising their prices. By increasing the price of all barge companies equally results in a larger monetary increase than with intermode competition to reach the kink position. This implies that the lack of competition between the modes allows the initial rates of different modes to have a wide divergence and permits an increase in the barge transportation price several times that where no intra-mode exists to bring all mode prices to the same level.

The type of competition does affect the shape and slope of the demand curve and, again, the regional data proves a more adequate means for describing these conditions than the aggregate data approach.

Figures VI-5, VI-6 and VI-7 show these kinked demand curves. As can be seen, each curve varies in slope and magnitude. This results from the unique mode characteristics in each region. Even though the regional characteristics are unique, they still produce a similar kinked demand curve. It is tentatively concluded that the demand curve for transporting coal by barge is truncated in shape.

The study offers the government an expanded procedure to estimate the future demand for use of a mode, with and without the existence of an alternative mode, and to derive a demand curve which incorporates several economic variables. The government would have a decision tool to determine whether a public works project should receive necessary funds to initiate or maintain a facility devoted to particular transportation modes. The implementation of such a model would be useful

to the industries in minimizing their transportation costs and to the government in maximizing investment opportunities. The presently used analytical system accepts an exogenously derived demand for coal and assumes an elasticity coefficient for barges on the basis of inadequate data and techniques.

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## APPENDIX

## A BRIEF DESCRIPTION OF DISCRIMINANT ANALYSIS

Economics has increasingly made use of mathematical modeling made possible by the use of modern high speed computers. More and more academicians and practitioners alike have progressed from the intuitive to mathematical orientation and frequently they have employed sophisticated techniques in economic research. One such technique is presented here to explain its usefulness as well as its limitations as a tool for economic research.

In discriminant analysis attempts are made to establish a linear function to separate a universe into different populations or groups. This classifies or describes a set of observations into a population which possesses the most similar a-priori characteristics with minimum misclassification. To understand the method of analysis, a brief summary of the mathematical concept involved is presented below.

### Two Population Cases

This case is confined to the allocation of a random sample (of attributes of a universe) into one of two populations having known probabilities.[1] Assume a single variate case $X_1$ having two normally distributed populations with known means $U_1$, $U_2$ and a similar standard deviation for both populations, where $U_1$ represents the mean value of variable $X_1$ for population one and $U_2$ the mean value of variable $X_1$ of population two. Allocating the attributes from the random sample to

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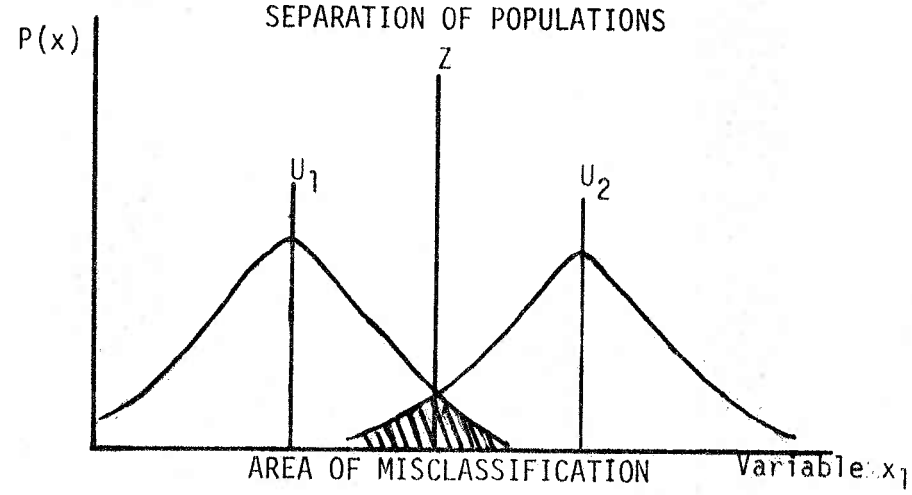
[1] G. W. Snedecor and W. G. Cochran, Statistical Methods, 6th Edn., Iowa State University Press, Ames, Iowa, 1968, pp. 416-418.

the proper population requires that the means are not equal. The boundary line between the populations becomes the arithmetic mean of the total sample.

In the usual case where $U_1$ is less than $U_2$, the natural method of separating permits the placing of an observation into population 2 if the value of X is greater than $1/2(U_1 + U_2)$ and into population 1 if X is less than $1/2(U_1 + U_2)$. In other words, if a random observation has an $X_1$ value less than Z, it will be placed in population 1; if the random observation $X_1$ is greater than Z, it will be placed in population 2.

FIGURE A-1

SEPARATION OF POPULATIONS




In Figure 1, the two populations are obviously separated. However, there exist two types of possible misclassifications as indicated by the area of overlap. In this area some population 1 observations are included in population 2 and vice versa. The misclassification occurs because the tails of each distribution overlap with some of the population lying on the other side of the boundary line.

$$\frac{x - u_1}{\sigma} > \frac{\frac{u_1+u_2}{2} - u_1}{\sigma} = \frac{u_2 - u_1}{2\sigma} = \frac{\gamma}{2\sigma}$$

when $\gamma = (U_1 - U_2)$ equals the distance between the means.

Increasing the distance between the two means separates the populations further apart and reduces the overlap area. This divergence minimizes the number of misclassifications. To accomplish the widening of the split requires more than one variable. Let's examine a multivariate case. Assume there exists a number of variables normally distributed, denoted by $x_{iw}(i=1,2,\ldots.P;w=1,2\ldots n)$, which classify the universe into two populations by separating the means of the two populations designated by $\delta_i = \bar{x}_i^1 - \bar{x}_i^2 (i=1,2\ldots P)$. To discriminate between the means a linear function is developed which separates the two sets of variables.[1]

$$Z = a_1 d_1 + a_2 d_2 \ldots . a_p d_p$$

This function Z, should be maximum relative to its variance and the variance must be proportional to

$$B = \sum_{i=1}^{P} \sum_{i=1}^{P} k_i k_m \sum_{w=1}^{M} x_{iw} x_{mw}$$

By keeping the variance constant and forming a Lagrange multiplier, a maximum is obtained:

$$F = Z^2 - \lambda Q = \sum_{i=1}^{P} \sum_{i=1}^{P} k_i d_i d_m - \lambda k_i k_m \sum_{w=1}^{N} x_{iw} x_{mw}$$

This function can then differentiate partially with respect $k_m (m=1,2\ldots P)$. It can be simplified to obtain

$$d_m \sum_{i=1}^{P} k_i d_i = \lambda \sum_{i=1}^{P} k_i \Sigma x$$

---

[1] G. Tinter, Econometrics, Wiley & Sons, New York, 1952.

This equation can then be set up to form a set of simultaneous equations. In this case two linear equations are generated with a certain $R^2$ value which determines into which population an observation should be placed. If an observation has an $R^2 < Z$ the sample is placed in population one and $R^2 > Z$ the sample if placed in population two.

The multivariate case involves the separation of universe into several mutually exclusive populations. The types of misclassification now become more complex and may overlap into more than one population. As a result, we will attempt to minimize the number of misclassifications that might occur.

Using T. R. Anderson's method[1] a discriminant function which minimizes the number of misclassifications can be derived, with an a priori probability of selecting an observation from $\pi_i$, that displays $\pi_i = N(\mu^1 \Sigma)$ $(i = 1,\ldots m)$.

Where

$\mu^i$ = the mean of each variable and no two means for the same variable are identical.

$\Sigma$ = covariances which are similar.

The discriminant functions permit the separation of the universe into several different populations. This case assumes that the costs of misclassification (C, j/i) are equal. These functions may be represented by

$$u_{jk}(x) = \log \frac{P_j(x)}{P_k(x)} = \left[x - \frac{1}{2}\left(\mu^{(j)} + \mu^{(x)}\right)\right]' \Sigma (\mu^j - \mu^k)$$

---

[1] T.R. Anderson, Introduction to Multivariate Statistical Analysis, Wiley & Sons, New York, 1958, pp. 133-143.

The population of classification $R_1, \ldots R_m$, can be determined in the following manner so as to minimize the error.[1] The conditional probability of an observation coming from $\pi_i$ is

$$\frac{q_i P_i(x)}{\sum_{k=1}^{M} q_k P_k(x)}$$

If this observation is classified as from population $\pi_j$, the expected loss becomes:

$$\sum_{\substack{i=1 \\ i \neq j}}^{M} \frac{q_i P_i(x)}{\sum_{k=1}^{M} q_k P_k(x)} C(j/i)$$

By selecting j so as to minimize the expected loss we derive

$$\sum_{\substack{i=1 \\ i \neq j}}^{M} q_i P_i(x) C(j/i)$$

Assuming the <u>a priori</u> probabilities are known, the population $R_j$ may be defined by those x's that satisfy

$$R_i: u_{jk}(x) > \log \frac{q_k}{q_j}, \quad k=1,2\ldots m; k \neq j$$

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[1] For a further explanation see bibliography - particularly items numbered 6, 16, 25, and 31.

As an example of the discriminant analysis used in this dissertation, the 07M BMD computer program, the following is presented:

1. Using data to calculate the values in Table VI-1, manipulations are performed to:

   a. Calculate the standard deviation

   b. Within group covariance matrix

   c. Within group correlation matrix

The calculation results in the following displays:

```
BMD07M - STEPWISE DISCRIMINANT ANALYSIS - REVISED JULY 24, 1969
HEALTH SCIENCES COMPUTING FACILITY, UCLA

PROBLEM CODE          R/B

NUMBER OF VARIABLES      6

NUMBER OF GROUPS         2

NUMBER OF CASES IN EACH GROUP     39     53

VARIABLE FORMAT           (4X,F7.6,4X,F4.3,5X,F4.3,4X,F5.4,4X,F5.4,5X,F4.3)

DATA INPUT FROM CARDS

MEANS  (THE LAST COLUMN CONTAINS THE GRAND MEANS OVER THE GROUPS USED IN THE ANALYSIS)

              GROUP
               RAIL          BARGE
VARIABLE
   1         .53638        1.44583        1.06030
   2         .14569         .15951         .15365
   3         .09208         .06217         .07485
   4         .15512         .90170         .58522
   5        3.26179         .72381        1.79969
   6         .36179         .29321         .32228

STANDARD DEVIATIONS

              GROUP
               RAIL          BARGE
VARIABLE
   1        1.18017        1.66397
   2         .10115         .13488
   3         .07845         .05720
   4         .15561         .59353
   5        1.62437         .43837
   6         .28324         .26996

WITHIN GROUPS COVARIANCE MATRIX

              VARIABLES
                 1             2             3             4             5             6
VARIABLE
   1         .00022
   2        -.00001         .00000
   3        -.00000         .00000         .00000
   4         .00004         .00000         .00000         .00002
   5        -.00005         .00001         .00001        -.00001         .00012
   6        -.00001         .00000         .00000        -.00000         .00000         .00001

WITHIN GROUPS CORRELATION MATRIX

              VARIABLES
                 1             2             3             4             5             6

VARIABLE
   1        1.00000
   2        -.30924        1.00000
   3        -.33690         .06980        1.00000
   4         .54641         .15503         .03232        1.00000
   5        -.30801         .60190         .75700        -.10646        1.00000
   6        -.21411         .12330         .20713        -.32806         .06289        1.00000
```

d. Calculate the most significant variable based on F- test

The following displays indicate order and the nature of the separation between modes:

```
*****************************************************************************************
STEP NUMBER          0
VARIABLE ENTERED

VARIABLES NOT INCLUDED AND F TO ENTER - DEGREES OF FREEDOM    1   90

  1   64938          2   .2892          3   44768          4   585757          5 1161306          6   13911
*****************************************************************************************
STEP NUMBER          1
VARIABLE ENTERED     5

VARIABLES INCLUDED AND F TO REMOVE - DEGREES OF FREEDOM    1   90

  5 1161306.

VARIABLES NOT INCLUDED AND F TO ENTER - DEGREES OF FREEDOM    1   89

  1       0.          2      59          3      66          4      32          6       0.

U-STATISTIC                0.      DEGREES OF FREEDOM    1    1   90
APPROXIMATE F        1161306       DEGREES OF FREEDOM    1     90.

F MATRIX - DEGREES OF FREEDOM    1   90

              GROUP
             RAIL
GROUP
 BARGE     1161306
```

e. With all variables a discriminant function is calculated

| VARIABLE | FUNCTION RAIL | BARGE |
|---|---|---|
| 1 | 4047 | 2540 |
| 2 | -57012 | 50590 |
| 3 | -412215. | -82061 |
| 4 | 33440 | 51780 |
| 5 | 51164 | 8582. |
| 6 | 81607 | 69211. |
| CONSTANT | -78753 | -39917 |

f. Allocates each observation to a particular mode based on discriminant function resulting in the display in Table VI-2

## 2. Data

```
@DATA,IL  BS.
DATA PROCESSOR LEVEL    4
000001      PROBLM R/B   6 20101     YESYESYESYESYES
000002      COVAR 0.00010.0001
000003      SAMSIZ    39    53
000004      GPLABL RAIL  BARGE
000005      (4X,F7.6,4X,F4.3,5X,F4.3,4X,F5.4,4X,F5.4,5X,F4.3)
000006          11919      91     288     800     4.00     0.45
000007          20553     315     288    1000     6.50     0.90
000008          25419     245     144     240     5.34     0.20
000009          33125     280     144     300     5.34     0.20
000010          62995     200     120     350     5.34     0.20
000011           2735      45      35     200     2.44     0.30
000012            821      90      60     120     3.00     0.80
000013        4760000      45       6    2000     2.00     0.20
000014         599566      60      20     700     3.10     0.25
000015         888430      80      32     800     3.30     0.25
000016        1199072      60      28    4000     2.25     0.30
000017         122633      75      30     733     2.70     0.28
000018          30000     240     168     600     4.86     0.30          52-62
000019          20000     220     168     600     4.86     0.30          52-62
000020          30000     220     168     600     4.77     0.30          53-62
000021          20000     245     168     600     4.49     0.30          52-62
000022           5000     240     168     600     4.49     0.30          51 62
000023          25000     280      96     600     4.49     0.30          53-62
000024          40000     210     168    1800     4.77     0.42          52-62
000025         100000     115     168    1800     4.77     0.42          52-62
000026         118000     320     120    1500     4.15     0.12          51-62
000027         291000     370     120    1500     4.15     0.12          51-62
000028         120000     240      96    1700     4.29     0.12          52-62
000029         180000      33      24    4000     1.02     0.12          52-62
000030         410925      30      24    4000     1.02     0.12          52-62
000031          38000     210     192     380     4.81     0.30          52-62
000032          16500     190     144     350     4.41     1.00          53-62
000033          16500     190     144     350     4.49     1.00          53-62
000034          35000      75      48    2000     1.00     1.00
000035          35000      90      24    2000     0.50     1.00
000036          65153      35       6    2700     1.65     0.35
000037          35950      70      24    2500     1.85     0.45
000038        4088890      30       1    2000     0.87     0.16
000039         256000      85      48    1500     1.87     0.15
000040         281000      93      48    1500     1.87     0.15
000041        4200000     195      48    8000     1.95     0.16
000042        1763348      15       2    2000     1.15     0.15
000043         963636      25       3    4000     1.85     0.15
000044            590      30       8      75     1.50     0.75
000045         413557     300      70    8000     1.34     0.50
000046        5883942      60      15   15000     0 46     0.50
000047        3737500      40      12   12000     0 36     0.50
000048        6417500      15       3   18000     0 36     0.50
000049         290627      90      24    5000     0.36     0.45
000050         342601     300     240    5000     1.24     0.45
000051        2747248      29       5    4000     0.20     0.25
000052        1432327      50       8    3000     0.15     0.25
000053        1132108      56       8    3000     0.15     0.25
000054        1883103      83     168   18000     0.60     0.30
000055        1541713     244     168   12000     1.80     0.30

000056          77033      45     168    6000     0.60     0.30
000057         599556     340     168    8000     1.60     0.30
000058        1837988      95      72   12000     0.85     0.25
000059         466539     120      95    9000     1.42     0.34
000060        4420721       6       1   15000     0.12     0.08
000061        6629872      19       2   22000     0.24     0.08
000062        1260436      70      24    7000     0.41     0.08
000063         427956       2       2    3600     0.10     0.08
000064         641998     260      72   10800     1.60     0.08
000065        1069983     117      50   15000     0.80     0.08
000066         707672      25       4    9000     0.30     0.30
000067         120789      35       7    4000     0.34     0.30
000068         904000      48      24    3600     0.69     0.30
000069        2276517      38      24   11000     0.70     0.30
000070        2017823      60      24   11000     0.52     0.30
000071         826347      42      24    3600     0.60     0.30
000072        3000000     275      72   10000     1.00     0.15          52-62
000073          30000     210      96    1600     0.80     0.35          52-62
000074         210000     350      96    3200     1.10     1.00          52-62
000075         210000     360      96    3200     1.10     1.00          52-62
000076         210000     355      96    3200     1.10     1.00          52-62
000077        2197034     309     120   13500     0.88     0.10          55-62
000078         893856     212     120   13500     0.88     0.10          55-62
000079        1699474     292     120   13500     0.88     0.10          55-62
000080         360000      17       5    4500     0.50     0.15          55-62
000081         328688     375      96   15000     0.76     0.13          52-62
000082         328688     370      96   15000     0.76     0.13          52-62
000083         328688     370      96   15000     0.76     0.13          52-62
000084         249000     370      96   15000     0.76     0.13          65-62
000085        1083484     375      96   20000     1.22     0.13          55-62
000086        1083484     375      96   20000     1.22     0.13          55-62
000087        2747248     163      48   10000     1.00     0.15          52-62
000088        3114733     308      96   12000     1.00     0.15          55-62
000089        1409672     150      36    5000     1.00     0.15          55-62
000090          75000     190     120    1500     1.00     1.24          55-62
000091          70000     192      72    1800     1.05     0.75          52-62
000092         553815      50       8    1200     0.40     0.25
000093         553815      95      24    1200     0.60     0.25
000094        5010338      15       3   18000     0.20     0.10
000095         498435      15       3    5000     0.55     0.15
000096         138000      26       3    1200     0.55     0.15
000097         138000      26       3    1200     0.55     0.15
000098      SUBPRO                     YESYES
000099      CONDEL11111111111
000100      FINISH
```