Analytical studies in transport economics

Edited by

Andrew F. Daughety

The University of Iowa

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Cambridge
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Published by the Press Syndicate of the University of Cambridge
The Pitt Building, Trumpington Street, Cambridge CB2 1RP
32 East 57th Street, New York, NY 10022, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

First published 1985

Printed in the United States of America

Library of Congress Cataloging in Publication Data

Main entry under title:

Analytical studies in transport economics.

Includes index.

1. Transportation – Addresses, essays, lectures.
I. Daughety, Andrew F.
HE152.6.A53 1985 380.5'9 85-2615
ISBN 0 521 26810 9

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Preface

This book is a collection of new research papers concerned with the application of modern economic theory and analytical techniques to current issues in transportation economics, especially for many of the systems that are undergoing, or have recently undergone, regulatory change. Two themes unite the chapters of this volume. First, characterization: How should we think about the agents and interactions we see? How should we model carrier technology, shipper demand, network structure, and market equilibrium? Second, policy formation and evaluation: How can we use analytical techniques to examine policies of the past, present, and future? How do we examine the effects of regulation on industry productivity or structure, or the effects of regulatory change on industry competitiveness? All the chapters of this book involve (to varying degrees) these two themes of characterization and policy formation and evaluation.

It is especially easy to thank the appropriate people for their help with this book; the reader need only look at the table of contents to see most of the names that deserve mention. Ronald Braeutigam, Douglas Caves, Ann Friedlaender, Theodore Keeler, Forrest Nelson, Richard Spady, Michael Tretheway, and Clifford Winston all did extra duty by helping in the refereeing/reviewing process for one or more of the chapters. I also especially wish to thank Ann Friedlaender for her early support and ready commitment on this project and Donald McCloskey for his helpful advice at the formative stages of its development. Nejat Anbarci provided very able assistance by almost single-handedly performing the onerous task of constructing the index. Colin Day, Margaret Willard, and Cynthia Benn of Cambridge University Press successfully conspired to make the process of developing and producing this book pleasant. The National Science Foundation provided support under the Regulation and Policy Analysis Program, grant SES-8218684.

Contents

Introduction

CHAPTER 1

Analytical transport economics – structure and overview

ANDREW F. DAUGHETY

> The nature of the subject has made it essential to the convenient and concise demonstration of the principles which are the objects of the research, to admit the introduction of mathematical formula throughout the investigation.
>
> Charles Ellet, Jr., *An Essay on the Laws of Trade* (1839)

Since Charles Ellet's insightful analysis of optimal tariffs for a waterway in a competitive environment, a rich and extensive literature has developed involving the application of microeconomic theory and analysis to issues and policies in the economics of transportation, via the use of mathematical and statistical techniques. This book contributes to this literature in three ways. First, all of the chapters are concerned with the analysis of current issues: questions of industry productivity, of economies of density and scale, of pricing and competition, of the structure of technology, and of the prediction of equilibrium. Second, each of these essays endeavors to extend and apply microeconomic theory to its particular issue. This often involves an extension of modeling and statistical techniques in the process. Furthermore, in pursuing this second aspect the authors of the essays have been able to present their research design and methodology in more detail than is usually possible in a journal article. Thus a third contribution is to lower the costs of entry for nonspecialists into this field.

The purpose of this chapter is to help place the volume in context.[1] A mathematical structure within which to cast the chapters in the current book and those in the recent literature will be provided. A model of a carrier, incorporating aspects of its network, will be developed, followed by a related

Support by National Science Foundation grant SES-8218684 is gratefully acknowledged. This chapter has benefited from comments by Clifford Winston.

[1] Standard sources for institutional aspects of the transportation industries are Locklin (1972) and Pegrum (1968). For an early comprehensive analysis of regulatory issues in transportation, see Friedlaender (1969). Winston (1984) discusses some of the issues covered here in a less formal manner.

model for a shipper.[2] This will allow comparison and integration of the five chapters of the second part of this book, which are concerned with technology and demand. The last three chapters in the volume consider problems of forecasting equilibria, formulating optimal price regulation, and analyzing evolving market structure under deregulation. These analyses implicitly or explicitly draw on variations of the carrier and shipper models.

The essays in this volume examine a broad range of issues in technology, demand, equilibrium, pricing, and market structure. Each is self-contained, but a number of linkages exist between the chapters.

1. Agents

1.1. Technology: the carriers

Producers of transport service are called ''carriers.'' Carriers redistribute (spatially and temporally) physical quantities of goods. A carrier moves goods from one location to another, and such moves take time. The markets that a carrier serves consist of pairs of geographically separated points. For example, a railroad might provide service from New York (NY) to Chicago and then provide service from Chicago to Los Angeles (LA), and then turn around and make the Los Angeles to Chicago run, followed by return to New York. Thus, the railroad serves six markets: NY–Chicago, Chicago–LA, LA–Chicago, Chicago–NY, NY–LA via Chicago, and LA–NY via Chicago. We can imagine this as a simple three-node network as illustrated in Figure 1.1.

The arcs between the nodes (the solid lines) help to designate the markets. For convenience, let i and j be two nodes in a firm's network. If i and j are directly linked (and the link allows travel from i to j) then we can denote an ''arc'' as (i,j). A ''path'' between two nodes i and j is a sequence of arcs and nodes that are traversed in order to proceed from i to j, and is specified by a tuple that lists, in order, the nodes encountered on the path, starting at i and ending at j. Thus, for example, arcs are ''one-step'' paths.

As in the case of the railroad mentioned previously, the markets for a carrier are the paths of its network. This can be seen by examining Figure 1.1 again. If the firm could add the direct service from Los Angeles to New York (the dashed line) a new market would be added; this is a new path in the

[2] In the next subsection two agents are considered: carriers and shippers. There is, of course, a third agent, namely, the state. Positive models of this agent pursuing objective functions other than social welfare maximization have been developed; see Stigler (1971) and Peltzman (1976). However, since the only chapter in this book explicitly examining problems of regulators (Braeutigam, Chapter 8), is normative and involves a social-welfare-maximizing regulator, the following exposition will be limited to this situation.

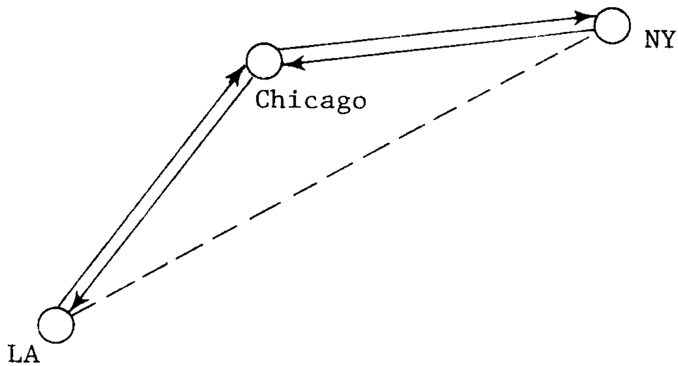

Figure 1.1. A simple network.

network, which is likely to entail different costs for the carrier from the LA–Chicago–NY path and may possibly serve different customers than the old path from LA to NY, since it is likely to incur shorter transit times than the old path.

To formalize this, let M be the set of origin–destination (OD) nodes served by a carrier (for convenience, there are m such nodes). Thus, OD pairs are drawn from $M \times M$. Further, let M' be the set of nodes that *augment* M by being locations of pure transshipment (for example, consolidation and break-bulk facilities for less-than-truckload (LTL) motor carriers).[3] Thus, the set of nodes for the firm's network is $M \cup M'$. Finally, let A be the set of arcs linking elements of $M \cup M'$. For a railroad this is line haul track; for a regulated motor carrier this is its operating rights and route authority; for a water carrier it is the river system.

In the terminology of graph theory (see Harary, 1969) the nodes and arcs describe a graph (or network) $\mathbf{G} = (M \cup M', A)$. Note that $\mathbf{G}$ represents a spatial arrangement of nodes and their interconnections, and not the actual facilities, markets, plants, roads, track, and so on. These items are part of capital inputs (to the degree that the firm must provide them).

Let $\mathcal{P}$ be the set of all paths from elements of $M \cup M'$ to $M \cup M'$. As an example, consider Figure 1.2, which shows a path p from node i_0 to node i_5 in a network. The dark lines represent the path (note that it is not the only way to get from i_0 to i_5), and the dashed lines represent the rest of the network. We can subdivide the set $\mathcal{P}$ into two parts, market paths and nonmarket paths. If i_0 (the path origin) and i_5 (the path destination) each belong to M, we will say

[3] For a railroad, M' contains the end points of stretches of a competitor's network over which the firm under study has trackage rights.

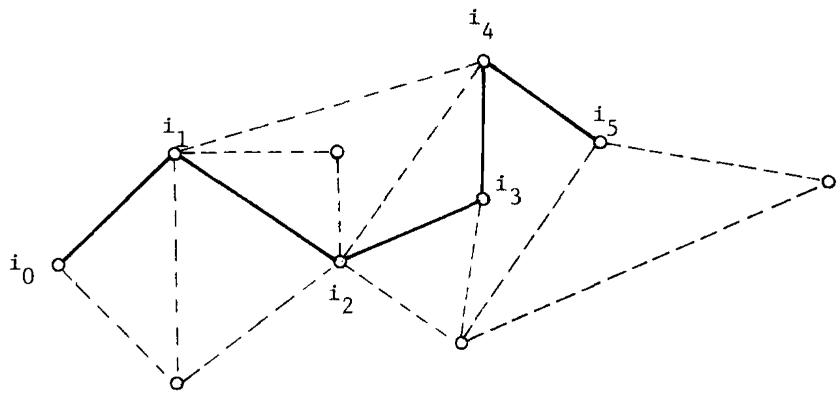

Figure 1.2. The path $(i_0, i_1, i_2, i_3, i_4, i_5)$.

that p is a "market" path; the set of such paths is denoted $\mathcal{P}^M$. All other paths will be denoted $\mathcal{P}^{\bar{M}}$, the nonmarket paths.

The set $\mathcal{P}^M$ is the set of "products" (outputs) of the carrier. Changes in this set of paths (additions, deletions) represent changes in the firm's mix of product lines. Changes in $\mathcal{P}^{\bar{M}}$ are taken to reflect purely operational effects. Thus, if a facility location is added to M' and paths change in $\mathcal{P}^{\bar{M}}$ but not in $\mathcal{P}^M$, then that change in facility location has had no effect on the firm's product mix (it may, however, affect the cost of providing service – that is, of producing the products). Elements of $\mathcal{P}^{\bar{M}}$ involve paths from M to M', from M' to M and from M' to M'. Note that concatenations of some of these paths yield paths in $\mathcal{P}^M$. Finally note that the foregoing setup is not as restrictive as might first appear. The definitions of M and M' depend upon the firm (or the analyst) and thus can be as coarse or as fine as necessary.

Associated with a path $p \in \mathcal{P}$ is a vector of quantities of goods moved and a vector of service characteristics provided. Let z_{pk} be the quantity of commodity k shipped on path p, and let $\mathbf{z} \in R^{PK}$ be the vector of such flows, where P is the number of paths and K the number of commodities. Activity on a path is also characterized by various service characteristics. Examples of service characteristics are speed; schedule reliability (some notion of variability of departure or arrival times); physical reliability (record of loss and damage, for example); availability or frequency of service and accessibility (by means of a rail spur to a plant, for instance). Let $\mathbf{s}_{pk}$ be the vector of service characteristics associated with the movement of commodity k on path p; thus $\mathbf{s}_{pk} \in R^S$, where S is the number of service characteristics. The vector $\mathbf{s} \in R^{SPK}$ provides levels of service characteristics on all paths for all commodities.

To summarize, the output of the firm is its market paths $\mathcal{P}^M$ and associated characteristics $(\mathbf{z}, \mathbf{s})^M$, where the superscript M denotes the portion of the vector $(\mathbf{z}, \mathbf{s})$ associated with the market paths. The nonmarket paths $\mathcal{P}^{\bar{M}}$ and associated characteristics $(\mathbf{z}, \mathbf{s})^{\bar{M}}$ should be thought of as intermediate products of the firm, that is, activity necessary in the production of final product.

Now let $\mathbf{x} \in R^n$ ($\mathbf{x} \geq 0$) be a vector of inputs (capital, labor, fuel, and so forth) and let $\mathbf{q} \in R^n$ ($\mathbf{q} > 0$) be the prices at which the firm can purchase $\mathbf{x}$. Finally, let T represent technology, which is an implicit transformation function relating the graph $\mathbf{G}$ and output characteristics $\mathbf{z}$ and $\mathbf{s}$ to input factor levels $\mathbf{x}$, given that $\mathbf{G}$ is specified as previously:

$$T(\cdot, \cdot, \cdot|\mathbf{G}): \quad R^{PK} \times R^{SPK} \times R^n \rightarrow R.$$

Feasible production of $(\mathbf{z}, \mathbf{s})$ occurs if there is a vector $\mathbf{x}$ such that $T(\mathbf{z},\mathbf{s},\mathbf{x}|\mathbf{G}) \leq 0$. Thus, the technology that takes inputs $\mathbf{x}$ and transforms them to path characteristics $(\mathbf{z}, \mathbf{s})$ is dependent on the graph $\mathbf{G}$; changes in $\mathbf{G}$ are thought of as shifts over a family of T functions (see McFadden, 1978 for the role of shift parameters in technology characterizations).

Dual to this technology is the firm's cost function (see McFadden, 1978 or Shephard, 1970), which is defined to be a function of $(\mathbf{z}, \mathbf{s})^M$, the input prices $\mathbf{q}$, and the graph $\mathbf{G}$.

$$C((\mathbf{z}, \mathbf{s})^M, \mathbf{q}|\mathbf{G}) = \min\{\mathbf{q}'\mathbf{x}|\ T(\mathbf{z}, \mathbf{s}, \mathbf{x}|\mathbf{G}) \leq 0\}.$$

Note that (besides $\mathbf{q}$ and $\mathbf{G}$) only output characteristics on market paths are held fixed; output characteristics on $\mathcal{P}^{\bar{M}}$ are varied optimally by the firm to achieve minimum cost.

The dimension of $(\mathbf{z}, \mathbf{s})^M$ is at least $K(1 + S)(m^2 - m)$, where m is the number of nodes in M. This is because there are K commodities, S service characteristics [and thus $K(1 + S)$ elements per path in $\mathcal{P}^M$] and at least $m^2 - m$ paths in $\mathcal{P}^M$ (assuming nodes do not ship to themselves). Even for small values of K, S, and m this dimension is large. Because of this problem, analyses have often proceeded by introducing some sort of aggregate-flow variable, the typical one being ton-miles. Let $d(p)$ be the length of path p and let $z_p = \sum_k z_{pk}$. If z_{pk} are measured in tons and path length in miles, then the standard ton-mile aggregate, y, is simply

$$y = \sum_{p \in \mathcal{P}^M} z_p \cdot d(p),$$

thereby yielding the aggregate-flow cost model $C(y, (\mathbf{s})^M, \mathbf{q}|\mathbf{G})$. Further simplification has often been achieved by ignoring service characteristics and suppressing $\mathbf{G}$, yielding the model $C(y,\mathbf{q})$. Finally, as will be seen subsequently, some railroad studies have allowed for aggregate freight and passenger variables, y_F and y_P. If "commodity" K is passengers, then this approach may be viewed as the aggregation

$$y_F = \sum_{p \in \mathcal{P}^M} \sum_{k=1}^{K-1} z_{pk} d(p),$$

$$y_p = \sum_{p \in \mathcal{P}^M} z_{pK} d(p),$$

and the corresponding cost model is $C(y_F, y_P, \mathbf{q})$.

Notions of scale and scope economies (see Baumol, Panzar, and Willig, 1982) can be precisely applied by controlling elements of **z, s,** and **G.** Following Keeler (1974) and Harris (1977), economies (diseconomies) of density occur if, holding the size of a transport system fixed, increases in throughput are associated with decreases (increases) in average costs, while economies (diseconomies) of size occur if increases in throughput are associated with decreases (increases) in average costs (allowing the size of the firm to vary). A number of considerations are implicit in the foregoing definitions. First, service characteristics on $\mathcal{P}^M$, denoted $(\mathbf{s})^M$, are held constant. Second, density economies involve holding **G** constant, whereas size economies involve varying **G** in some way such as varying M as by mergers or route expansions (note that end-to-end mergers involve changes in $\mathcal{P}^M$, whereas purely parallel mergers might affect $\mathcal{P}^{\overline{M}}$ only). Third, reference to "average costs" reflects the use of an aggregate measure of throughput, such as ton-miles (y). When cast in the more current terminology, density economies are measured as ray (or product-specific) scale economies for fixed **G,** whereas "size" economies actually depend on product-specific economies, scope economies, and cost subadditivity (since changes in the product set $\mathcal{P}^M$ are involved). The issue of "declining" cost in terms of size economies is more properly posed, then, as the question of whether (varying **G**) the technology generates a subadditive cost structure. Of course, if the cost model in question uses an aggregate measure of throughput such as ton-miles, the ability to examine scope economies is lost, although size economies are measured allowing **G** to vary. Aspects of this issue are discussed in three chapters of this book: Friedlaender and Bruce (Chapter 2), Daughety, Nelson, and Vigdor (Chapter 3), and, especially, Caves, Christensen, Tretheway, and Windle (Chapter 4).

Table 1.1 uses the foregoing model specification to classify a section of carrier cost models for railroads (RR) and motor carriers (MC). It is important to note that this table is not meant to be comprehensive. Rather, the purpose is to list studies that reflect significant differences and important commonalities in cost function models and approaches. Note also that studies involving production-function approaches have been left out because the table concen-