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Conceptual Developments in the Economics of Transportation: An Interpretive Survey

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I. *Introduction and Historical Overview*

THE PROMINENCE of transportation economics within the discipline has had an uneven history. At the turn of the twentieth century, transportation economics featured some of the most important normative analyses that were being undertaken: e.g., John Maurice Clark (1923) and Frank Taussig (1913) were trying to develop procedures for allocating costs among particular users of transportation facilities; Francis Edgeworth (1925) and William Ripley (1912) were attempting to determine optimal rates for railroads; Arthur C. Pigou (1912) and Frank Knight (1924) were developing optimal pricing and investment rules for roads. Unfortunately the field's prominence was not sustained past the 1920s as economists began to pay greater attention to the mathematical foundations of general economic theory and macroeconomic issues. In the next few decades, relatively little attention was paid to transportation problems. Since the 1950s a slow but steady revival of interest in the field has taken place, leading to a current intensity not witnessed for more than fifty years.

Early research in transportation economics laid the foundations for a field that was ultimately concerned with addressing normative economic issues such as optimal freight and passenger fares, and the social desirability of regulating the carriers' operations. This concern with normative issues has been maintained throughout the development of the field. However, within the last few decades there have been advances in the conceptual formulation of various problems as well as the application of more sophisticated analytical tools, whose methodology led to greater precision in understanding positive issues, such as determinants of demand and the costs of providing various transportation services. They have also produced stronger analytical foundations for normative analyses of issues such as optimal pricing and investment levels for transportation infrastructure and the desirability of regulating the transportation industries. In addition, contemporary analytical tools and conceptual approaches can be, and often have been, used by economists in other fields.

Our objective in this paper is to survey the literature in transportation economics,[1] exploring two basic themes: first, the conceptual developments in the analysis of supply and demand, which recognize noteworthy aggregation biases in the empirical work on aggregate data and indicate that a correct analysis of the issues should take place at a highly disaggregated level; second, the use of these conceptual developments to evaluate efficiency aspects of transportation pricing, investment, and the impact of government regulation on resource allocation and distribution in the transportation sector. It is important to acknowledge that our survey is based on research throughout the world but our institutional perspective and, to some extent, the topics that are covered is based largely on the U.S. experience.

Historically, transportation has attracted the attention of students in a number of disciplines including engineering, economics, and management science (Edward Morlok 1978, published an overview of transportation engineering and D. Daryl Wyckoff (1974, 1976) wrote an overview of transportation management). In its inception, the primary analytical focus in each discipline was the railroads and, to some extent, pricing of and investment in the transportation infrastructure. As pointed out by Alfred Chandler (1977), the railroads were among the first modern corporations; as such, they presented a variety of challenging problems: their impact on economic growth and development, as well as the private management and public regulation of their operations. Consequently, a substantial literature appeared on a variety of economic aspects of railroad transportation, especially rates and costs (J. M. Clark 1910, and D. Philip Locklin 1933 survey this literature; Sylvester Damus 1981 also discusses it), and the basic principles of railroad operations and their effect on the economy (Stuart Daggett 1920, 1922; Dionysius Lardner 1850, Locklin 1928, Arthur Wellington 1887). Perhaps the literature's most important feature is that many issues that were raised are still of concern today: e.g., the efficiency aspects of rail rates and the cost-minimizing level of traffic density on a railroad network.

Another topic that received attention was the pricing of transportation infrastructure, particularly congested and uncongested roads (Jules Dupuit 1849, Charles Ellet, Jr. 1840, Knight 1924, and Pigou 1912). Again, the basic issues in this literature—optimal first-best and second-best pricing of public transportation facilities—continue to receive attention today.

One significant aspect of early transportation literature is that a number of important economic concepts were developed in the context of analyzing transportation problems before they were developed and incorporated into the mainstream economics literature: for example, Ramsey pricing (Dupuit 1844) and economies of scope or joint production (Wellington 1887). In addition, some of the earliest analyses of important empirical questions, such as whether a particular industry exhibits economies of scale, can be found in that same literature (M. O. Lorenz 1916). Indeed, a primary explanation for the long tradition of empirical work in transportation economics is the extensive data collection efforts that have accompanied government regulation.

[1] George Stigler (1981) comments on Paul Joskow and Roger Noll's 1981 survey on regulation, asserting that the proper time to survey a body of literature is after the subject is developed. Admittedly, while it is not clear when that is achieved, I argue that a considerable degree of stability has been reached in the ways of looking at transportation problems and the sorts of questions that are important to ask. To be sure, there is not complete agreement on many answers. However, a strong consensus about the "correct" answers might indicate that the field is stagnant.

Unfortunately, significant contributions to the early literature were unmatched, for the most part, in the next few decades, following the 1920s. Given the general movement of the profession, away from empirical and institutional issues towards theory and methodology, transportation was used primarily in economic studies to illustrate a particular point (Harold Hotelling 1938) or to motivate an analytical technique (Tjalling Koopmans 1951). To be sure, there were some important analytical contributions during this period (e.g., Martin Beckmann, Charles McGuire and C. B. Winsten 1956). However, unlike much of the early work, these were not deeply rooted in a realistic institutional framework, nor were they able to shed much light on important transportation policy.

A major revival of the field occurred with the publication of the classic book by John Meyer, Merton Peck, John Stenason, and Charles Zwick (hereafter, MPSZ) *Economics of Competition in the Transportation Industries* (1959). This was a systematic and comprehensive analysis of transportation resource allocation problems, using contemporary state-of-the-art statistical techniques for the empirical work which, in many ways, has come to represent the birth of modern transportation economics.[2]

In their study, MPSZ examined the characteristics of various passenger and freight transportation modes. They argued that a number of services (e.g., intercity railroad passenger service) and certain policies with regard to them were contributing to a considerable misallocation of resources in the United States economy. For instance, it was claimed that there would be a substantial increase in the amount of rail's freight traffic and an improvement in resource allocation if railroad rates were reduced from regulated levels to reflect the cost of providing service.

Since 1959 the field has grown at a steady rate. A number of MPSZ's conclusions, which were based on costs and technology in the 1950s, have been re-examined as the economic environment changed. Moreover, current research has placed considerable emphasis on methodological issues as well as procedures for applying and improving analytical tools. This aspect of the literature will receive particular attention here.

In the next section we identify the most important features of transportation. This discussion will serve to motivate the evolution of conceptual approaches toward certain aspects of transportation as well as to distinguish transportation economics, to a notable extent, from other fields of economic inquiry. Sections 3 and 4 examine positive economic developments in the analysis of transportation supply and demand. These have primarily drawn upon advances in the theory of cost and production, and in the theory of consumer demand. We then turn our attention (Section 5) to the normative issues of pricing and investment; in Section 6 we examine the research concerned with the impact of regulation on the behavior of transportation firms and on the performance of transportation industries. The analysis of these issues has drawn upon recent developments in public finance and industrial organization as well as on conceptual advances analyzing transportation supply and demand. The Conclusion is a discussion of future directions of research.[3]

[2] Other transportation economists had analyzed several issues addressed by Meyer et al. but no single work matched the analytical scope and depth of their book.

[3] This paper will not be concerned with urban transportation planning and policy (for thorough treatments of this topic see Lyle C. Fitch and Associates 1964, Wilfred Owen 1956, 1976). In addition, we shall not discuss the relation between land use and transportation because this topic has been thoroughly surveyed (Mahlon Straszheim 1972, José A. Gomez-Ibañez 1975, 1978, and Meyer and Gomez-

II. *Salient Features of Transportation*

Almost everyone acknowledges that transportation is a vital service because it is a factor in nearly all other economic activities. Clearly, a most important aspect of its input is the pervasive presence of government. Not only was the railroad industry one of the first in the United States to be brought under government regulation, but it and other transportation industries have been among the most extensively regulated. Specifically, price, entry, exit and operating rules for most transportation modes have been subject to some form of governmental control. Its justification and impact have been the subject of much research. In addition, because government provided a great part of the infrastructure, there has been considerable interest in determining how this infrastructure should be priced and what guidelines should be followed in making future investments.

Because most issues in transportation economics ultimately have some "real-world" policy implications, it has been especially important for economists to incorporate into their models the central institutional features of transportation in order to draw out fully the policy implications. These features include the spatial nature of the transportation product, the importance of service quality, and problems related to peaking demand. As will appear below, each feature has had significant implications for the conceptual development of the major areas of transportation economics.

The spatial nature of transportation has significantly influenced analyses of transportation supply. To begin with, one confronts the need to define the output of a transportation firm or agency. Generally, the appropriate definition, which incorporates the spatial nature of transportation, is the movement of a commodity or passenger from a specific origin to a specific destination over a particular time period; in other words, a commodity or passenger trip. Given this definition, it should be clear that the activity of a transportation firm consists of providing many different commodity and/or passenger trips over its network. The analysis of cost and production in transportation, therefore, has gradually come to grips with the spatial aspect of the transportation product by recognizing that the foundations of the subject lie in the theory of the multiproduct firm as opposed to the traditional theory of the single-output producer.[4]

In contrast to many other economic services, individuals' valuations of service quality as a percentage of their wage rate have been found to be very high (for empirical evidence, see Table 4). The potentially overriding importance of service quality to the user of transportation has had a significant influence on the development of demand analysis. The various components of service quality—travel time, comfort, reliability, etc.—are recognized as important attributes of a transportation mode. The users' valuation of these attributes will depend on the characteristics of their utility function, itself dependent on their tastes and the activity to be performed at the destination. These features have led investigators to recognize that all individual users actually face a choice among various bundles of attributes when they consider which mode

Ibañez 1981). Perhaps contrary to popular beliefs, these surveys conclude that transportation policy is unlikely to be a major force in molding large-scale changes in metropolitan land use, and that it is particularly unlikely to shape the relative growth rates of central cities or suburbs in the United States.

[4] Specifically, it has been recognized that a trip from Boston to New York is not the same output as a trip from New York to Baltimore. Moreover, although temporal aspects of the transportation product might be accommodated by the multiproduct theory, empirical problems arise because every trip must be considered as a distinct output. Emphasis, therefore, has been concentrated on characterizing the spatial aspect of the transportation product.

will maximize their utility.[5] In recent work, this perspective has been fruitfully employed in qualitative choice models of transportation demand behavior.

Demand patterns in transportation are similar to those in some other service industries in that they are characterized by large seasonal and diurnal fluctuations. Furthermore, passenger and freight transportation activity in particular periods, specifically during the morning and evening rush-hours and before major holidays, constitutes a much greater utilization of transportation capacity than activity in off-peak periods. In response, the level of capacity in a transportation system is generally one that can accommodate peak demand. This leads to two important considerations when analyzing pricing and investment. First, optimal (marginal cost) pricing and investment rules in transportation generally have been characterized by an attempt to account for the congestion externality associated with peaking demand in the process of determining the best short-run and long-run utilization of a particular facility. Second, because the technology that underlies the investment in transportation infrastructure, which is designed to accommodate peak demand, is often characterized by large scale economies, marginal cost pricing can lead to deficits that must be covered by a subsidy if transportation service is to be financially viable. Because large subsidies may not always be available, there has been considerable interest in deriving second-best prices that ensure financial viability. Second-best price and investment guidelines are also of interest because of regulatory constraints and taxes, which distort the relative prices of various transportation modes. Bearing the central institutional features of transportation in mind, we turn our attention in the remainder of the survey to the major positive and normative issues that have been addressed by transportation economists.

[5] This perspective is actually based on Kelvin Lancaster's (1966) work on demand theory.

III. *Transportation Supply*

Research on transportation supply has been primarily concerned with estimating firms' cost functions. This research has been motivated by both academic questions and policy questions. From an academic perspective, there has been considerable interest in determining whether scale economies exist in various transportation industries. If so, this is sometimes offered as a justification for regulating the industries. In addition, there has been interest in estimating cost functions for the purpose of comparing the costs of particular modes. Comparative cost analyses are potentially useful in assessing whether freight and passenger transportation services are being provided at least cost to society and in identifying the traffic levels at which a particular mode may have a cost advantage over other modes. Finally, estimated cost functions have been used to shed light on productivity growth in the transportation industries. Productivity growth estimates are helpful in evaluating the past and future economic performance of a particular transportation industry.

With respect to policy questions, transportation cost functions provide guidance to regulatory boards which need cost benchmarks to help set rates for services and to managers for purposes of budget preparation and control (Meyer and Gerald Kraft 1961).

The earliest analyses of transportation costs, specifically concerned with railroads (Wellington 1887, Ripley 1912) concluded that more than one-half of operating expenses were independent of the volume of traffic. As pointed out by Ernest Williams (1943), this generalization was later challenged by Lorenz (1916), J. M. Clark

(1923), Kent Healy (1940) and others who contend that, over a considerable range of traffic densities, it is possible to adjust operations to the needs of traffic in ways that make costs highly responsive to changes in output. The crude method by which this result was obtained—basically plotting railroad costs against an aggregate measure of railroad output (ton-miles)—was replaced by the widespread introduction of statistical cost analysis in the 1940s. (Meyer 1958, discusses statistical cost analysis in transportation, and Jack Johnston 1960, discusses this general methodology.) Continuing improvements in computational capabilities have facilitated advances in applying this methodology by permitting more detailed and theoretically sound specifications of costs. In addition, as pointed out by Alan Walters' (1963) survey of costs and production, the preponderance of available data in transportation has also facilitated the application of statistical methods, particularly in analyzing rail transportation. Since Walters' survey, there has been much statistical cost analysis of all modes of transportation.[6]

In this section we examine the conceptual development of the analysis of transportation cost functions, moving from the simple single-output approach to multiproduct approaches that are sensitive to the specification of the underlying technology. In addition, we report some specific results for illustrative purposes. Those readers interested in detailed discussions of modal-specific findings with regard to a particular cost issue are referred to the papers cited in footnote six.

A useful starting point for analyzing the specification of transportation costs is to consider the simple cost model used by Harris (1977) to estimate the costs of rail freight transportation. In order to understand fully the improvements that have been made in the model, it will be helpful to discuss it in some detail.[7] The specific total cost (TC) equation is given by:

$$TC = \beta_0 + \beta_1(\text{ton-miles}) + \beta_2(\text{tons}) + \beta_3(\text{route miles}) + \epsilon,$$

[6] For specific estimates of costs and scale economies—for railroads: Lawrence Klein (1947), George Borts (1952, 1954, 1960), Johnston (1956), Kent Healy (1961), Joseph DeSalvo (1969), Theodore Keeler (1971b, 1974), Zvi Griliches (1972), Georg Hasenkamp (1976), Robert Harris (1977), Donald Harmatuck (1979), Richard Spady (1979), Randall S. Brown, Douglas Caves and Laurits Christensen (1979), Ann Friedlaender and Spady (1981), Caves, Christensen, and Joseph Swanson (1981a, 1981b), Sergio Jara-Diaz and Winston (1981), Ronald Braeutigam, Andrew Daughety and Mark Turnquist (1982). For motor carriers: Roger Koenker (1977), Spady and Friedlaender (1978), Harmatuck (1981), Friedlaender and Spady (1981), Judy Wang and Friedlaender (1981). For urban bus and rapid rail: N. Lee and J. Steedman (1970), Herbert Mohring (1972), Gary Nelson (1972), Randall Pozdena and Leonard Merewitz (1978), Philip Viton (1980, 1981a). For inland waterways: Leland Case and Lester Lave (1970), Daniel Boger (1979). For ocean transportation: Jan Jansson and Dan Shneerson (1978), Esra Bennathan and Walters (1979). For airlines: Paul Cherrington (1958), Richard Caves (1962), George Eads, Marc Nerlove and William Raduchel (1969), Keeler (1972), George Douglas and James Miller (1974), Lawrence White (1979), Caves, Christensen, and Michael Tretheway (1980a, 1983).

For studies that use cost estimates for comparative cost analysis of competing modes—for freight modes: Meyer, Peck, Stenason, and Zwick (1959), Friedlaender and Spady (1981). For urban passenger modes: Meyer, John Kain, and Martin Wohl (1965), J. H. Boyd, N. J. Asher, and E. J. Wetzler (1973), Keeler, Kenneth Small, and Associates (1975). For intercity passenger modes: Meyer, Peck, Stenason and Zwick (1959), Keeler (1971a).

[7] For simplicity, we shall be concerned only with the fundamental concepts involved in a basic transportation cost specification. To be sure, depending on the transportation mode, there are a number of important technological considerations that should be included in the cost specification and corresponding discussion. For example, in rail freight it is important to draw a distinction between the costs of carrying bulk and high-value commodities, and to control for the effect on costs of the number of carloads originating on the rail line and at intermediate points. In addition, it is important to describe and to justify the various components that comprise the cost variable. Although these points are omitted from the discussion provided above, readers should understand that important technological considerations pertaining to the cost specification for a given mode should not be overlooked.

where ϵ is an error term that accounts for measurement error and omitted influences (e.g., factor prices) on costs. Ton-miles represents the aggregated output of a freight transportation firm (passenger-miles is the aggregated output for a passenger transportation firm) and forms the basis of estimates of economies of firm size. The variable "tons" represents an additional output measure. Its inclusion in the specification enables one to avoid the restriction, which is associated with simply using ton-miles to capture output, that the cost of moving one ton ten miles is equivalent to the cost of moving ten tons one mile. In addition, the parameter for tons can be interpreted as capturing the effect of the inverse of average length of haul (equal to tons ÷ ton-miles) on average costs. This interpretation is useful because one is often interested in identifying economies that can be attributed to making longer freight or passenger movements. Finally, route-miles, the actual number of miles of distinct routing that a firm can and must serve by law (regulation), is used as a measure of the firm's capacity.[8] Its inclusion in a cost specification is justified because it captures fixed maintenance and transportation expenses. Route-miles can be interpreted as an exogenous technological characteristic of the firm's environment because it is determined (historically) through the regulatory process.[9] This variable is important because it enables one to measure economies related to a firm's route system (network), whether the firm be a railroad, airline or transit company. These economies are referred to as economies of density because they capture the savings that result from moving larger amounts of traffic over a fixed route system (network).

[8] Note: this legal requirement stems from the common carrier obligation that accompanies operation in a regulated environment.

[9] Daniel McFadden (1978a) justifies the inclusion of exogenous technological variables in a cost specification.

Recent literature has attempted to improve upon this basic cost specification in a number of ways. First, it has been pointed out (Spady and Friedlaender 1976) that the specification of output should be adjusted to capture attributes that pertain to the quality of output, the omission of factor prices represents a potentially serious specification error, and the specification of technology that corresponds to the linear cost function is too restrictive.[10] The second set of issues, to be discussed in detail below, relates to the aggregation problems in measuring output.

The hedonic transportation cost function pioneered by Spady and Friedlaender (1978) attempted to address the first set of issues. A hedonic cost function differs primarily from a traditional cost function in that it attempts to control for the effect of the quality of output (not merely the physical quantity of output) on total costs. This cost function can be specified in the generic form for a given transportation firm as $C = C(\phi(y,q), w;t)$, where ϕ represents hedonic output that is composed of the firm's physical output y (measured in ton- or passenger-miles) and attributes that characterize the quality of the output q, such as (in principle) the firm's service time; w is a vector of factor prices facing the firm, and t refers to a vector of given technological conditions such as a firm's route miles. The functional specification of the cost function has been based upon advances made in flexible functional forms that can be used for econometric estimation, particularly the translog approximation[11] (Melvyn Fuss, Daniel Mc-

[10] In a more general setting, the restrictions on technology imposed by particular cost functions were identified and analyzed by Nerlove (1963), Walters (1963), and McFadden (1978a).

[11] To be sure, the translog approximation runs into difficulty for zero values of output. In this case, a transformation using the Box-Cox metric (Caves, Christensen and Tretheway 1980b) can be used to apply this functional form.

Fadden and Yair Mundlak 1978, survey these functional forms), and has thus imposed fewer a priori restrictions on the underlying structure of technology.[12]

Most recent studies in transportation cost analysis have focused on the production activities of individual transportation firms and developed cost models that reflect the insights that were gained from a detailed analysis of firm behavior. First, Braeutigam, Daughety, and Turnquist (1982, also DeSalvo 1969) characterized the engineering process by which a transportation firm produces its output and used this characterization to develop a cost specification. Second, Jara-Diaz and Winston (1981) attempted to incorporate the true output of a freight transportation firm—an origin-destination specific commodity trip[13]—into a cost specification, thus focusing on the multiproduct aspect of a transportation firm's production activity.[14]

By recognizing that the production process of a transportation firm is appropriately modeled in a multiproduct framework, one is able to draw upon the well-developed theory of the multiproduct firm (Elizabeth Bailey and Friedlaender 1982, surveyed this theory) to investigate questions about the existence and source of natural monopoly, multiproduct scale economies, and economies of scope in transportation firms' operations. Multiproduct scale economies indicate the behavior of costs as the production levels of a given bundle of outputs change proportionately. These scale economies are composed of economies of scope and product specific economies. Economies of scope indicate whether the total cost of producing a bundle of outputs jointly is less than the cost of producing each output separately, while product-specific economies indicate how costs change as the level of one output changes, the output of all other products remaining unchanged. These issues were investigated for a very special case, namely the production activity of Class III railroad firms, by Jara-Diaz and Winston (1981).[15] Specifically, a transportation cost function that treated the tons shipped over specific origin-destination pairs as distinct outputs was estimated. Two important empirical results of this case study are likely to generalize to more complex transportation networks. The first demonstrates that the estimates of scale economies obtained from the multiproduct approach (where outputs are not aggregated over origin-destination pairs) can be significantly different from those obtained from the aggregate single-output approach.[16] The second demonstrates that

[12] Strictly speaking, the hedonic specification given above imposes a separability restriction that output and output quality characteristics are separable from factor prices and technological characteristics. This restriction may not be warranted in practice (Caves, Christensen and Swanson 1981b); hence, a generalization of the hedonic specification that does not impose this separability restriction has been used (Friedlaender and Spady 1981).

[13] In the case of a passenger transportation firm, the appropriate output is an origin-destination specific passenger trip.

[14] Attempts to incorporate multiproducts can be found in some aggregate cost studies (for example: Klein 1947, Keeler 1974, Hasenkamp 1976, Friedlaender and Spady 1981, Caves, Christensen and Swanson 1981b) where (freight) ton-miles and passenger-miles have been used as distinct outputs of the transportation firm. This type of output disaggregation should be understood as product disaggregation (i.e., passenger-miles are distinguished from ton-miles) as opposed to spatial disaggregation (i.e., output between different origin-destination pairs is distinguished). Finally, note that the effect of multiple products on costs can be partially captured in a hedonic specification that employs product disaggregation. For example, this can be done in trucking (Spady and Friedlaender 1978) by including a variable that specifies the percentage of a trucking firm's output that consists of less-than-truckload (LTL) shipments.

[15] As far as I am aware, this is the only totally disaggregate analysis (in a spatial sense) of transportation costs. Note also that Class III railroads are quite specialized; their classification is based, as of 1978, on operating revenues of no more than ten million dollars over a three-year average.

[16] The comparison of the estimates of scale economies was effected by first fitting a time-series cost function C_t, of the form $C_t = f(x_{tj}, \alpha_j) + \epsilon_t$ where

the source of a transportation firm's multiproduct scale economies can be identified in terms of that firm's product specific economies and its economies of scope.

The general reason for the existence of a bias in the single product aggregate approach is that it requires the components of an output vector (traffic over a firm's routes) to vary proportionally in order to estimate the degree of scale economies correctly (Griliches 1972, John Panzar and Robert Willig 1977). Because it is unlikely that traffic will vary proportionally over all or most routes, the aggregate single product approach will undoubtedly yield an incorrect estimate of the degree of scale economies. Unfortunately, the qualitative impact of this imprecision is not clear.

Another advantage of the disaggregated or multiproduct approach in transportation making it especially attractive for policy analysis is that it enables one to identify sources of particular economies and to admit proper tests for natural monopoly (William Baumol 1977). On the other hand, because the totally disaggregate multiproduct approach treats the traffic flow between each origin-designation pair as a distinct output, this approach can only be carried out completely for firms with very small transportation networks (i.e., firms that serve a small number of origin-destination pairs) in order to have a reasonable number of degrees of freedom. This suggests that *some degree* of spatial aggregation is necessary if this approach is to be applied to the larger (and more typical) transportation firms. Studies of the motor carrier industry by Harmatuck (1981) and Wang and Friedlaender (1981) that aggregate outputs by shipment size and length of haul indicate that such aggregation can be sensibly carried out while retaining the advantages of the multiproduct approach. It will be worth developing in future work a variety of procedures which, in combination with institutional knowledge of the industry under study, can be used successfully for aggregation.[17] This will enable the multiproduct approach to be used to its fullest capabilities in new analyses and in studies that attempt to check the accuracy of conclusions reached in previous aggregate work. In all fairness to simple aggregate cost models, it should be kept in mind, however, that they can often be more practical than sophisticated cost models when one needs a crude but reasonably reliable estimate of costs for a particular type of movement (Meyer 1958, Friedlaender and Spady 1980a, discuss practical and methodological considerations in transportation cost analysis).

Illustrative results and applications of the various cost models, in the context of some major cost issues, are useful. To begin, cost models have been used as a basis for estimating and comparing the costs of competing modes of transportation. In Table 1 we report results from the most recent comparative cost studies for each major form of transportation. As explicitly indicated in the table, some of the estimates refer to full costs (i.e., they include the traveler's time costs as reflected by his value of time). The estimates indicate

$f(\cdot)$ was a quadratic function, x_{tj} denotes the tons shipped over a specific origin-destination pair j, α_j is a parameter vector, and the presence of factor prices has been suppressed for the purposes of this discussion. An aggregate measure of output, ton miles, was then defined as $X_t = \sum_j x_{tj}\ \theta_j$ where θ_j is the distance between each origin-destination pair. Using this aggregate measure of output, a cost function of the form $C_t = f(X_t, A) + \epsilon_t$ was estimated where $f(\cdot)$ was again a quadratic function and A is the corresponding parameter vector. It was found that the estimates of scale economies produced by the disaggregate and aggregate cost models were significantly different from one another.

[17] An interesting research topic would be the development of tests that can be used to determine whether too much aggregation of output has taken place. Presumably, one would want to employ the maximum feasible amount of aggregation if only for cost purposes. For an initial analysis of this problem, see Wang and Friedlaender (1981).

TABLE 1
COMPARATIVE TRANSPORTATION COST ESTIMATES

A. Urban Passenger[a]

		Passengers/hour		
		1,000	10,000	30,000
Cost per passenger trip (1972 Dollars)	Auto	$ 4.15	$4.15	$4.15
	Rail BART	$26.85	$5.63	$3.73
	Bus	$ 4.46	$2.89	$2.50

B. Surface Freight[b]

		Manufactured Commodities		Bulk Commodities	
		Official Region	Southwest Region	Official Region	Southwest Region
Marginal Cost (1972 ¢/ton-mile)	Rail	4.892	2.925	1.931	.981
	Motor Carrier	4.922	4.602	4.169	3.972

C. Intercity Passenger[c]

		Boston-New York	Chicago-Los Angeles
City Pair Costs (1968 Dollars)	Rail	$6.90–$9.50	$44.00–$110.00
	Bus	$ 8.40	$ 54.60
	Auto	$13.60	$132.00
	Plane	$15.00	$ 60.30

[a] Keeler, Small and Associates (1975, p. 124). Estimates are full costs (including value of time) for six mile line-haul work trip, assuming 12% discount rate, $3.00/hr value of time, and optimizing service quality.
[b] Friedlaender and Spady (1981, pp. 85, 89). Estimates are marginal costs for each commodity-shipping region pair evaluated at actual 1972 output levels of motor carriers of specialized commodities and Class I railroads. Costs for Official Region comprise New England, the Mid-Atlantic States, and the East-Central States.
[c] Keeler (1971, p. 246). Rail, bus, and plane costs are based on cost per passenger mile, auto costs are based on cost per vehicle mile. Rail costs vary due to different assumptions regarding seating plans.

that bus transportation is generally the most efficient form of urban passenger transportation as it dominates rail for all passenger densities and auto for all but low passenger densities.[18] The findings clearly indicate that fixed-rail systems, such as BART, only seem to be justified on a full-cost basis for very high passenger densities.

[18] Keeler, Small and Associates (1975) differ from Meyer, Kain and Wohl (1965) and Boyd, Asher and Wetzler (1973) in that they consider all major urban passenger modes and includes the full costs of urban travel. Nonetheless, the main result regarding the relative efficiency of bus is shared by all of the studies.

In the case of surface freight transportation, we find that rail's marginal costs are lower than motor carrier's marginal costs for the major commodity groups and shipping regions. However, it is important to note that in the case of manufactured commodities, rail's cost advantage is fairly small. Thus, when one accounts for the value of motor carrier's faster service time it is clear that rail is at a competitive disadvantage (from a full-cost basis) for these types of commodities.

Finally, we report comparative cost estimates for short-distance and long-distance intercity passenger trips. As can be seen, the cost of the surface modes is lower than the cost of air for short-distance trips, while the opposite result appears to be the case for long-distance trips, especially when one considers full costs (i.e., accounts for the value of air's faster travel time). In addition, the results indicate that rail and bus are at a competitive disadvantage for long-distance trips (from a full-cost basis) with respect to air, and auto when the travel party consists of more than a few people.

As indicated previously, one of the most important applications of transportation cost models has been concerned with estimating the degree of scale economies in a transportation industry. In Table 2 we provide estimates of cost elasticities for rail, motor carrier, and air transportation based on a variety of studies. It is interesting to observe, in the case of rail transportation, that all of the studies find the existence of some scale economies, regardless of functional or output specification.[19] The implications of this finding with regard to regulatory activity in the industry will be discussed later. In contrast, different functional specifications and output specifications in motor carrier cost models have led to different conclusions regarding the existence of scale economies. Interestingly, the most recent studies that have drawn upon the major conceptual advances discussed previously find constant returns to scale in the industry and, as such, suggest that the "scale economies" justification for regulation is inapplicable to this industry. Essentially, the more sophisticated models utilized in these studies reveal that while various economies can be achieved in particular motor carrier operations, the contributions of product-specific economies and economies of joint production (scope) in motor carrier operations lead to overall constant returns. Finally, cost studies, concerned with the existence of scale economies in the airline industry, basically find that the industry is characterized by constant returns to scale, regardless of functional form. This provides a basis for optimism that the deregulated airline industry will remain competitive. In future cost analyses of the industry, it would be useful to investigate the robustness of the scale economies' estimates with respect to multiproduct cost specifications that capture the spatial dimension of airlines' output.

Thus far we have been concerned with applications that have attempted to contribute to our knowledge of the technological characteristics of a transportation industry—in particular the degree of scale economies—and the comparative cost of various modes. Recent applications of cost models have also focused on dynamic questions such as the extent of productivity growth (or decline) in a number of transportation industries (Meyer and Alexander Morton 1975; Meyer and Gomez Ibañez 1980; Caves, Christensen and Swanson 1980, 1981a, 1981b; Caves, Christensen and Tretheway 1981; Friedlaender and Wang 1983).

Essentially, the procedure that is followed in econometric productivity studies is to incorporate a time variable into the specification of the transportation cost function. It should be noted that most econometric productivity studies of the

[19] Keeler (1983) claims that these economies are attributable to the presence of economies of density in the industry that accrue from improvements in line-haul operations (e.g., running longer and more frequent trains), and capital and maintenance expenses. As noted by John Meyer in private correspondence, there is some evidence that economies of density may be a function of historical accident or inheritance. For example, some railroads in other parts of the world (e.g., Canada) seem able to handle relatively low traffic densities without incurring sharply higher unit costs. An explanation for this is that these railroads were engineered in the first place to be efficient at relatively low density levels. This suggests that the discovery of at least some of the economies of density in the U.S. railroad industry could be explained by U.S. systems being originally engineered with more optimistic or ambitious traffic expectations in mind.

TABLE 2

ELASTICITIES OF TRANSPORTATION COSTS WITH RESPECT TO OUTPUT

Study	Functional Form	Output Specification	Cost Elasticity
A. Rail[a]			
Keeler (1974)	Nonlinear	Multiple products[b] (spatial aggregation)	.57
Harris (1977)	Linear	Single product (spatial aggregation)	.64
Friedlaender and Spady (1981)	Translog hedonic	Multiple products[b] (spatial aggregation)	.895
Caves, Christensen, and Swanson (1981b)	Translog	Multiple products[b] (spatial aggregation)	.605–.716
Jara-Diaz and Winston (1981)	Quadratic	Multiple products (spatial disaggregation)	.352–.787
B. Motor Carrier			Cost Elasticity at Sample Means
Koenker (1977)	Log-linear	Single product	>1
Spady and Friedlaender (1978)	Translog hedonic	Single product	>1
Spady and Friedlaender (1978)	Translog nonhedonic	Single product	<1
Harmatuck (1981)	Translog	Multiple products[c] (spatial aggregation)	$=1$
Wang and Friedlaender (1981)	Translog	Multiple products (partial spatial disaggregation)[d]	$=1$
C. Air			
Eads, Nerlove, Raduchel (1969)[e]	Nonlinear	Single product	≥ 1
Keeler (1972)	Linear	Single product	$=1$
Douglas and Miller .(1974)	Semi-log-linear	Single product	$=1$
Caves, Christensen and Tretheway (1983)	Translog	Single product	$=1$

[a] Keeler (1983) discusses in detail the construction of cost elasticity estimates and the range of output densities and the time frame (short run vs. long run) for which they apply.
[b] In these studies passenger-miles and ton-miles were treated as separate outputs (product disaggregation).
[c] In this study less-than-truckload (LTL) output and truckload (TL) output were distinguished (product disaggregation).
[d] The term partial-spatial disaggregation is used in this study because outputs were disaggregated by various lengths of haul as opposed to specific origin-destination pairs.
[e] Note: this study was concerned with "local service airlines" that are considerably smaller in every dimension (revenue, average length of haul, number of aircraft, etc.) than the "trunk" airlines studied by the other authors.

transportation industries have been concerned with estimating cost changes over time as opposed to output or revenue changes. This is largely because most transportation industries have been characterized by price regulation and service obligations; as a result, productivity measures that focus solely on output or revenue changes may yield potentially misleading results. The equation that can be obtained by totally differentiating an estimated transportation cost-function with respect to time can be used to simulate productivity changes: that is, in the rate of growth in total cost within a firm or industry over time. These can be allocated among other changes: output, factor prices, and a residual productivity effect.

Productivity growth calculations are potentially useful. Those based on well-specified cost functions can provide considerable insight into the sources of recent failures or successes experienced by a firm or industry. For example, studies that have found low-productivity growth (i.e., less than 2 percent a year during 1951–1974) in the railroad industry (Caves, Christensen and Swanson 1980, 1981a, 1981b; Meyer and Morton 1975) have identified, at a general level, one primary source of recent financial problems in the industry.[20] On the other hand, econometric studies have not identified precisely the specific aspects of, and reasons underlying, particular railroad operations that have contributed to low-productivity growth. In general, future work on productivity in the transportation industries will be improved if attempts are made to pinpoint the major sources of and reasons for productivity performance[21] as well as the robustness of the productivity growth estimates with respect to varying assumptions regarding the functional form of the cost function.

IV. *The Demand for Transportation*

The research on the demand for passenger and freight transportation has been motivated by an interest in estimating key parameters of the users of various transportation modes (e.g., their elasticities with respect to modal attributes such as price or service time) and their value of travel time. These parameters have been used to understand the nature of intermodal competition in freight and passenger transportation, and used as key inputs to policy issues in pricing, investment and regulation. In addition, models of transportation demand have been used to forecast the demand for a new mode.

The analysis of transportation demand has evolved from nonstructural aggregate engineering models that were developed to analyze traffic flows and routing (Thomas Domencich and McFadden, 1975, survey and critique these models) to structural disaggregate qualitative choice models (Takeshi Amemiya, 1981, wrote a general survey of qualitative choice models). It is important to note, however, that both aggregate and disaggregate models should ultimately be derivable from individual behavior: at issue, primarily, in the aggregate/disaggregate dichotomy, is the nature of the data that was employed.

The initial models that were used to estimate transportation demand were known as aggregate modal split models

[20] Additional results from productivity studies in transportation are discussed in Section 6.

[21] In this respect, it is useful to point out two transportation case studies that have identified the reasons underlying particular aspects of productivity performance in transportation industries. First, Aaron Gellman (1968) showed that high transcontinental fares resulting from CAB (Civil Aeronautics Board) regulations led to the introduction of economically inefficient aircraft (namely, the turboprop DC7), thus hurting productivity performance in the airline industry. Second, Edwin Mansfield (1965) identified the important technological improvements that increased productivity in the rail industry following World War II, in particular the replacement of steam locomotives by diesel locomotives.

(Eugene Perle 1964; J. McLynn and R. Watkins 1967; Richard Quandt and Baumol 1966; Kenneth Boyer 1977, and Richard Levin 1978). Aggregate modal split models attempt to determine the number of trips or amount of tonnage that is allocated between a given set of modes over a cross-section of city pairs, or mileage blocks, on the basis of relative travel times and costs among modes and, in some cases, on the basis of certain characteristics of the passengers or commodities that are transported. While possessing a simple structure, these models were severely criticized as having little behavioral grounding and as using highly restrictive linear functional forms (Tae Oum 1979a).

In response to the shortcomings of the nonbehavioral modal split models, aggregate behavioral models of transportation demand have been developed. The passenger demand models (Oum and David Gillen 1979) assume that travelers maximize their utility, while the freight demand models (Friedlaender and Spady 1980b, Oum 1979b) assume that firms attempt to minimize cost in their use of transportation.[22] Empirically, these models overcome restrictions associated with the modal split models by utilizing flexible functional forms. It should be stressed that the basic unit of observation of these models is still an aggregate share of a particular transportation mode at the regional or national level. Potential drawbacks of this aggregation level will be discussed shortly.

The next phase in the evolution of transportation-demand analysis, behavioral disaggregate demand-analysis is, on the one hand, consistent with the progression of conceptual development in transportation costs in that it takes a more disaggregate approach to the activity, but its developments have paralleled, rather than evolved from, recent improvements in aggregate transportation demand-models.

A number of theoretical and empirical advantages of disaggregate over aggregate demand-analysis are responsible for the recent popularity of the former in the transportation field. First, models that derive from the disaggregate approach are grounded in a theory of individual behavior, which is generally consistent with the basic unit of empirical observation. Note, this consistency is generally lacking in aggregate demand-models. Second, the disaggregate approach is conducive to a much richer empirical specification, which captures important characteristics of the decisionmaker, than is an aggregate approach. Finally, one is able to get a better understanding of the degree of intermodal competition because a disaggregate model is estimated using the actual attributes of the modes for a given movement and the characteristics of the individual or commodity that require transportation. For example, in the case of freight transportation one uses the actual shipment size and service characteristics for a given movement to judge whether it is sensible to characterize particular modes as competitors for the shipments under study. In aggregate studies, this consideration is obscured as movements are aggregated into shares at the regional or national level; in the process of aggregation a significant amount of information regarding the "competitive interface" is lost.[23] Consequently, as we shall see, estimates of important effects, such as market elasticities, are generally more accurate in a disaggregate modeling context.

[22] A concise derivation of a representative version of the passenger demand model is contained in Hal Varian 1978, p. 133. The freight demand models are derived by specifying a neoclassical cost-function for a given firm and deriving the demand for freight transportation, which is treated as an input into the production process, by Shephard's lemma: Winston 1983.

[23] The notion of a competitive interface among modes simply refers to those dimensions along which competition among modes could take place (e.g., in freight transportation: shipment size, and length of haul).

Notwithstanding the conceptual strengths of disaggregate demand models, it is important to recognize that there are a number of practical limitations to this type of analysis. First, there are considerable data requirements that must be met in order to estimate a disaggregate transportation demand model. Not only does one have to obtain a sample of individuals' mode-choices, but one must also collect data on the characteristics of all modes (chosen and unchosen) that are included in each decisionmaker's choice-set. In addition, even with the advances in computer software that have been made in recent years (Amemiya 1981, and Carlos Daganzo 1979 describe widely-available computer programs that can be used to estimate disaggregate demand-models) disaggregate demand models can be difficult to estimate, particularly when there are a large number of alternative choices under consideration and/or the specification of demand is complex. Finally, models estimated from aggregate data can be more practical than models estimated from disaggregate data in the context of large-scale analyses of transportation flows (Alex Anas 1981). That is, in practice, most disaggregate transportation demand studies have been limited to a fairly narrow sample population (e.g., commuters in the San Francisco Bay Area; shippers of manufactured commodities).

Early work in disaggregate transportation demand modeling can be found in Thomas Lisco (1967), D. Quarmby (1967), Domencich, Kraft and J. Valette (1968), Charles Lave (1969, 1970), Quandt (1970), Robert McGillivray (1970), Moshe Ben-Akiva (1973), and others. Although behavioral disaggregate models of transportation demand have been in use since Stanley Warner's study (1962), the major developments in economic and statistical ideas that form the basis for recent work are in two papers by McFadden (1973, 1974) and a monograph by Domencich and McFadden (1975). In this research, the individual decisionmaker is modeled as making the discrete choice of one of J particular modes (auto, bus, air, etc. for passengers; truck, rail or barge, etc. for shippers). The chosen mode is assumed to maximize the decisionmaker's utility. The basic model that captures this behavior is a random utility model, which is specified for a given individual as

$$U_i = V(\beta; X_i,S) + \epsilon(X_i,S) \quad i = 1, \ldots, J,$$

where U_i denotes the utility corresponding to the i-th transportation mode; it is divided into an observed component (termed the "mean" or representative utility), which is a known vector function, V, of the attributes of the mode, X_i, the socioeconomic characteristics of the decisionmaker, S, and an unknown parameter vector, β, and an unobserved component, ϵ, which contains the unobserved tastes of the decisionmaker and other unobserved influences. The individual will select mode i if $U_i > U_j$ for all $i \neq j$. Since the utilities are random across individuals this event is a probability P_i, namely

$$P_i = Prob[U_i > U_j \text{ for all } i \neq j].$$

To obtain a specific functional form for the mode-choice probabilities, one makes an assumption regarding the distribution of the ϵs. If it is assumed, for instance, that the errors are distributed according to the extreme value distribution, then one obtains the following expression for the mode choice probabilities:

$$P_i = e^{V(\beta;\ X_i,S)} / \sum_{j=1}^{J} e^{V(\beta;\ X_j,S)};$$

this is known as the multinomial logit model (MNL). If one assumes that the errors are normally distributed, then one obtains a multinomial probit model.[24]

[24] Unfortunately, probit models do not have closed form expressions for the choice probabilities and thus can be more difficult to estimate than logit models. On the other hand, they allow for considerable flexi-

The multinomial logit model has received widespread use in disaggregate transportation demand-analysis. An extensive exploration of various specifications of urban passenger mode-choice, using this model, has been done by Kenneth Train (1976) and McFadden, Antii Talvitie and Associates (1977). In addition, there have been several applications of this model in the context of household automobile type-choice (Lave, ed. 1980; Fred Mannering and Winston 1982). In the area of intercity freight transportation demand, a different discrete choice-model, the multinomial probit model, has been used by Winston (1981a) to estimate the choice of alternative freight transportation modes. Finally, Alan Grayson (1982) and Steven Morrison and Winston (forthcoming) have used multinomial logit models to estimate the demand for intercity passenger transportation. Estimates of some key parameters based on disaggregate and aggregate demand-studies are presented below.

Although passenger and freight disaggregate demand-analyses have shared a common methodology, it is worth pointing out the major differences between the analyses. First, identification of the actual decisionmaker is more difficult in freight than in passenger-demand. That is, in passenger demand studies the decisionmaker is easy to identify—generally the head of household and/or principal driver (traveler)—while in freight transportation, although the decision is embedded in the larger production, distribution, and location problems faced by a firm, it could be made, ultimately, by a shipping or receiving manager; or could reflect, quite simply, the solution to a firm's overall profit-maximization problem. Clearly, different freight demand models can result depending on how one characterizes the decisionmaking process (Winston 1983). An additional difference between passenger and freight demand models concerns their ultimate use. As will be discussed in more detail, passenger demand models have been particularly useful in addressing issues, such as alternative pricing schemes for urban highways, which require estimates of travelers' value of time, while freight demand models have been especially helpful in addressing questions regarding the desirability of rate regulation in the freight transportation industry. To be sure, as we will see, there are some similarities in the questions that these models are used to address.

Recently, the basic mode-choice framework has been extended to accommodate analysis of joint choices. These involve a discrete choice (e.g., mode) and an additional discrete (e.g., destination) or continuous (e.g., vehicle utilization or quantity shipped) choice (Steven Lerman 1976, Richard Westin and Gillen 1978, Train 1980, James Berkovic and John Rust 1981, McFadden and Winston 1981, Yu-sheng Chiang, Paul Roberts, and Ben-Akiva 1981, Mannering and Winston 1982, Morrison and Winston, forthcoming; also, Kain 1964 has published an aggregate joint-choice study). Joint-choice models are important because they characterize transportation choice in the context of other activities that either affect or are affected by the transportation decision. For example, in intercity passenger vacation travel it is important to understand how the mode-choice decision relates to the choice of destination. As such, joint-choice models are more realistic than conventional single-choice models, from a theoretical point of view, because important endoge-

bility in specifying the error structure. This feature enables them to overcome a restriction in the MNL model where errors of each alternative must be uncorrelated. (For further discussion of this problem and proposed test procedures: Jerry Hausman and McFadden 1980, and Hausman and David Wise 1978; for a complete discussion of probit models: Daganzo 1979).

nous choices are jointly analyzed instead of being treated as exogenous. In addition, this improvement in realism can lead to changes in estimation results.[25]

Essentially, the structure of a joint-choice model can be represented as follows. Let U denote the following indirect utility function[26]

$$U = V(\beta; i, Y - r_i, S, P_x, Z_i, \epsilon_i, \eta) \qquad i = 1, 2, \ldots J,$$

where

β: unknown parameter vector
i: the discrete choice of an alternative i
r_i: price of alternative i
Y: income of decisionmaker
S: additional socioeconomic characteristics
P_x: price of a continuous choice x
Z_i: attributes of alternative i and other influences
ϵ_i: unobserved attributes of alternative i
η: unobserved characteristics of the decisionmaker.

The continuous choice, x, conditional on the discrete choice, i, can then be derived by Roy's Identity, namely:

$$x = -\frac{\partial V/\partial P_x}{\partial V/\partial Y}$$

while the discrete choice probabilities are given by

$$P_i = Prob\,\{(\epsilon_1, \ldots \epsilon_J, \eta) \mid V(i, Y - r_i, S, P_x, Z_i, \epsilon_i, \eta) > V(j, Y - r_j, S, P_x, Z_j, \epsilon_j, \eta) \text{ for all } i \neq j\}.$$[27]

In practice, a number of alternative formulations have been used to model joint choices in transportation. These include formulating a choice set that combines a discrete choice with a particular interval of a continuous choice (e.g., a choice could consist of shipping by rail with a shipment size between forty-thousand and fifty-thousand pounds: Chiang, Roberts and Ben-Akiva 1981), and analyzing the choices sequentially (Train 1980).[28] In future work it will be worthwhile to apply joint-choice models to a variety of problems in transportation demand including firm location and freight mode choice, and business or pleasure trip departure time and urban passenger mode choice.

Illustrative applications and results: The primary output of any estimated choice model consists of estimates of the coefficients, β, of a particular utility function. These coefficients can be used to calculate estimates of price and service time elasticities of demand and decisionmakers' value

[25] As an illustrative case, consider the estimation of a mode-choice price elasticity from an intercity freight mode-choice model that treats shipment size as endogenous (i.e., a joint-choice model of mode and shipment size) versus a mode-choice model that treats shipment size as exogenous. In general, it can be argued that the price elasticity obtained from the joint-choice model will be larger than the one obtained from the mode-choice model. That is, in a joint-choice model the effect of, say, an increase in the price of rail will have a negative impact on an endogenous shipment size (all else being constant) because the shipper would be induced to decrease shipment size in anticipation of being more likely to use the alternative (and relatively less expensive) mode (e.g., truck). Further, because shipment size is included in the mode choice specification, this decrease in shipment size will reduce the probability of using rail because smaller shipment sizes lead to the use of truck. This effect on mode choice will combine with the direct effect on mode choice caused by the change in relative prices in the mode choice equation, to lead to a larger mode-choice price elasticity than in the case where shipment size is treated as exogenous (i.e., not influenced by the change in the relative prices of the modes).

[26] The following formulation is particularly relevant for passenger transportation. The McFadden and Winston (1981) formulation is more appropriate for freight transportation.

[27] Specification of functional forms for the continuous and discrete choices and estimation procedures can be found in Jeffrey Dubin and McFadden (1981); also, McFadden and Winston (1981).

[28] For example, the sequential procedure consists of first estimating mode choice for work trips conditional on the other choice (e.g., automobile) then estimating the auto-choice model, using the predicted utilities obtained from the mode-choice model as an explanatory variable. If one assumes that the errors for each model are distributed according to the generalized extreme value distribution (GEV), one obtains a nested logit model (McFadden 1978b).

TABLE 3

TRANSPORTATION PRICE AND SERVICE TIME ELASTICITIES

A. Freight[a]

Study	Model	Rail Price Elasticity	Rail Transit Time Elasticity	Truck Price Elasticity	Truck Transit Time Elasticity
Levin (1978)	Aggregate modal split model	− .25 to −.35	− .3 to −.7	− .25 to −.35	− .3 to −.7
Friedlaender and Spady (1981)	Aggregate behavioral model derived from translog cost function	−1.16 (petroleum products)	—	−1.81 (mineral products)	—
		− .37 (mineral products)	—	− .58 (petroleum products)	—
Winston (1981a)	Disaggregate mode choice model	−2.68 (transport equipment)	−2.33 (fresh produce)	−2.97 (leather, rubber, plastic products)	− .69 (fresh produce)
		− .08 (lumber)	− .07 (paper products)	− .04 (machinery)	− .15 (paper products)

B. Urban Passenger[b]

	Auto	Bus	Rail BART
Cost elasticity	− .47	− .58	− .86
On-vehicle time elasticity	− .22	− .60	− .60

C. Intercity Passenger[c]

	Auto	Bus	Rail	Air
Cost elasticity	− .45	− .69	−1.20	− .38
Travel time elasticity	− .39	−2.11	−1.58	− .43

[a] These estimates represent the largest and smallest elasticities reported in each study. Levin (1978) reports average elasticities.
[b] McFadden (1974), multinomial logit mode choice model for work trips in the San Francisco Bay Area.
[c] Morrison and Winston (forthcoming), multinomial logit mode choice model for vacation trips in the U.S.

of travel time.[29] In Table 3 we present some illustrative elasticity estimates for the major forms of transportation.[30] As can be seen, elasticity estimates in freight transportation vary widely, according to commodity group. As such, it is difficult to make any generalizations regarding the magnitude of freight transportation elasticities. It is interesting to note that service-time elasticities can often be as large as price elasticities, particularly in the case of perishable commodities, and that the use of disaggregate models provides potentially more accurate estimates of elasticities.[31] That is, elasticity estimates from a disaggregate model indicate a greater degree of intermodal competition (through changes in price or service-time) for certain commodities than elasticity estimates from aggregate models.

The cost and on-vehicle time elasticity estimates for major urban transportation modes are generally of similar magnitude, indicating particularly, that reductions in on-vehicle time can be as effective as fare reductions in increasing public transit ridership levels. However, the small magnitude of these elasticities suggests that public policies, such as an increase in automobile tolls and initiatives by transit agencies (e.g., reducing on-vehicle time) are not likely to cause relatively large changes in urban travelers' work trip mode choices. In addition, given that the public transit cost elasticities are generally inelastic (i.e., less than 1.0) fare increases can lead to revenue increases.

In contrast to elasticity estimates for urban passenger transportation, service-time elasticity estimates for intercity bus and rail transportation tend to be larger than the price elasticity estimates. Further, their large magnitude (i.e., greater than 1.50) indicates that reductions in service time could be significantly effective in increasing rail and bus-market share. Generally, the cost and service-time elasticities for air and auto are inelastic. This is not too surprising in view of the fact that these modes already possess a relatively large share of the United States' intercity travel market.

The parameter estimates of mode-choice models can also be used to calculate estimates of how decisionmakers value travel time. The value of travel time rep-

[29] Unfortunately, standard errors were not calculated for the value-of-time or elasticity estimates reported here. However, these measures are based on parameter estimates that were estimated with a reasonable amount of statistical precision. Further, given the benefit of a considerable amount of work in the area, it is fair to say that the elasticity and value of time estimates that pertain to urban passenger transportation demand are fairly robust with respect to alternative specifications and data sets. On the other hand, it is probably the case that more studies are needed in the areas of intercity freight and passenger demand before we can have complete confidence in the elasticity and value-of-time estimates that have been obtained thus far.

[30] In general, the *total* elasticity of demand for a mode in a market, with respect to a modal attribute (e.g., price) consists of three components: The first and usually the largest consists of modal divergence—the amount of patronage a mode will gain or lose from other modes operating in the same market in response to a change in its price in that market; second, destination divergence—the amount of patronage a mode will attract to a given *market* from other markets in response to a change in its price in that market. The final component consists of "trip generation," i.e., the additional quantity of trips by people who were already taking trips in the market and the quantity of trips by people who were not taking any trips that a mode will attract to a given market in response to a change in its price in that market. In essence, the last two components contribute to increasing (or decreasing) the amount of patronage in a given transportation market, while the first component contributes to allocating the patronage among modes.

It should be noted that the elasticities reported in Table 3 that are obtained from disaggregate demand and aggregate modal split models are properly referred to as mode diversion elasticities in that they treat market size as fixed. For further discussion see Morrison and Winston (forthcoming).

[31] In addition to possible specification inadequacies, the basic source of imprecise market elasticity estimates, from an aggregate transportation demand-model, is due to its use of average values for particular variables as opposed to actual values facing each decisionmaker.

resents the marginal rate of substitution of money for travel time, i.e., the amount of money decisionmakers are willing to sacrifice for a reduction in the amount of time that they or the commodity they ship spends in travel.[32] As pointed out by C. J. Oort (1969, and Gary Becker 1965), this value depends on the utility or disutility that a decisionmaker attaches to time spent in a particular mode and to the opportunity cost of travel. Hence, a high value placed on travel time could indicate that decisionmakers attach a significant amount of disutility to time spent in a given mode and/or that they attach a high opportunity cost to travel time, given their activity at the destination.

In Table 4 we present some illustrative value of travel-time estimates for the major forms of transportation.[33] As can be seen, there is a wide disparity among estimates in the case of freight transportation. That is, for perishable commodities (e.g., fresh produce) the value of travel time leads to a notably high, implicit, discount rate while this is not the case for low-value manufactured products. (See explanation at the bottom of Table 4.) The finding of a relatively high value of rail and truck travel time for perishable commodities most likely reflects the disutility (i.e., possibility of spoilage or damage) that is associated with the time that a perishable commodity spends on a surface-freight mode.

Estimates of the value of time in urban transportation also exhibit some disparity. The finding that the value of transit on-vehicle time is lower than the value of auto on-vehicle time most likely reflects the relative benefits of traveling by transit (i.e., being able to read, not having to fight automobile commuter congestion, etc.)[34] while the high value of transfer wait-time reflects the disutility of having to interrupt a journey by transit and spend time waiting in a station for a connection. Finally, the high value of walk-access-time most likely reflects the disutility involved in time spent walking to a bus stop or rail station before one gains access to either of these modes.

The value of travel time estimates for intercity passenger transportation indicate that the value of time associated with travel on surface modes is not particularly high. This suggests that these travelers do not perceive that time spent on these modes is particularly onerous nor do they attach a high opportunity cost to their travel time in terms of the time foregone from activities at their destinations. On the other hand, the estimates indicate that the value of time associated with air travel is rather high. This is most likely a result of the perceived opportunity cost of air travelers' time, as indicated by their use of a mode that places a premium on speed.

In addition to providing insights about users, value of travel-time estimates have been used as important inputs into cost-benefit issues in passenger and freight

[32] Operationally, the value of travel time is calculated from a disaggregate demand-model based on utility maximization as the ratio of the estimated coefficient for travel time (which is in units of utility per unit of time) to the estimated coefficient for travel cost (which is in units of utility per dollar). The resulting estimate is thus in the appropriate units of dollars per unit of time. This procedure was used to obtain the value of time estimates reported in Table. 4.

[33] Small (1978) and Nils Bruzelius (1979) discuss the value of travel time in the context of disaggregate demand-analysis. Critiques of value of travel-time estimates can be found in Ian Heggie, ed. (1976) and David Hensher (1976, 1978). Additional value-of-time estimates in different contexts can be found in a number of studies: Leon Moses and Harold Williamson (1963), Lisco (1967), Luke Chan (1975), Train (1976), Small (1982, 1983) for estimates in an urban mode-choice context, and Reuben Gronau (1970) and Arthur DeVany (1974) for estimates in an intercity passenger-demand context, based on aggregate demand models.

[34] Note: this estimate pertains to on-vehicle time. That is, it does not capture other components of the total trip-time such as wait-time, transfer wait-time and so on, which are often regarded as more onerous than on-vehicle time.

TABLE 4

VALUE OF TRANSPORTATION TIME ESTIMATES*

A. Freight[a]				
	Rail		Truck	
Value of travel time as a percentage of shipment value	21% (perishable agriculture) 6% (primary and fabricated metals)		18% (perishable agriculture) 8% (primary and fabricated metals)	
B. Urban Passenger[b]				
	Auto On-Vehicle Time	Transit On-Vehicle Time	Walk Access Time	Transfer-Wait Time
Value of time as a percentage of wage rate	178%	74%	338%	165%
C. Intercity Passenger[c]				
	Auto	Bus**	Rail**	Air
Value of travel time as a percentage of wage rate	6%	79%–87%	54–79%	149%

[a] Winston (1979).
[b] McFadden, Talvitie and Associates (1977). Estimates for work trips.
[c] Morrison and Winston (forthcoming). Estimates for vacation trips.
* It is common practice in passenger transportation studies to express value of time estimates as a percentage of the wage rate to facilitate various comparisons that can be made. While there is no common practice for reporting value of travel-time estimates in freight transportation, one can interpret the value of travel time as a percentage of the shipment value as an implicit discount rate inclusive of storage costs (Winston 1979).
** In the case of bus the lower value applies to low-income travelers and the higher value applies to high-income travelers. In the case of rail the lower value applies to high-income travelers and the higher value applies to low-income travelers.

transportation, such as evaluating alternative pricing schemes in urban highways (Small 1983), identifying the optimal scheduling of work-trips (Small 1982), determining whether to build a transit line (Christopher Foster and Michael Beesley 1963, Glenn Westley 1978), assessing the desirability of railroad mergers (Harris and Winston 1983) and airline mergers (Dennis Carlton, William Landes, and Richard Posner 1980). These estimates are most important from a policy perspective because "value of time savings" typically account for a large fraction of the claimed benefits in transportation improvements.[35]

Finally, the parameter estimates obtained from disaggregate choice models can also be used to forecast the demand for a new mode of transportation (McFadden, Talvitie and Associates 1977, Lawrence B. Wilson 1977, and Winston

[35] Other useful inputs to cost-benefit questions in transportation are estimates of travelers compensating or equivalent variations with respect to changes in the price or service quality of a particular mode. Small and Harvey Rosen (1981) have developed procedures to obtain estimates of these measures from estimated disaggregate demand models.

1981c). In these studies, disaggregate demand models were used to forecast the demand for fixed urban rail transit (BART), air freight transportation, and ocean container service on the west coast of the U.S., respectively. Forecasts of the potential demand for new transportation modes can often be of interest from a marketing perspective. For example, it is likely that forecasts of the demand for intermodal (rail-truck) freight transportation will be of particular interest to freight carriers in the recently deregulated freight transportation environment.

V. *Pricing and Investment*

The importance of transportation in the functioning of the public and private sector has generated considerable interest in the development of appropriate pricing and investment rules. Initial efforts consisted of deriving "first-best" rules which parallel those that have been developed in other areas of public economics (Anthony Atkinson and Joseph Stiglitz 1980). Recent work has recognized that the necessary conditions for first-best rules to be useful in transportation (e.g., the absence of substantial scale economies and of government-induced price distortions in competing modes) may not be satisfied. Thus, second-best rules have been developed. It is significant that empirical calculations of first-best and second-best prices and investment levels have drawn upon contributions made in the estimation of cost- and demand-functions. Indeed, one major development has been the emergence of specific estimates of optimal prices for transportation services.

The development of first-best pricing *and* investment rules in transportation has mainly focused on urban transportation; in particular, on the problem of deriving optimal tolls and investment guidelines in the presence of congestion on urban roads. The approach that is taken in this literature can be traced to the early work of Ellet (1840), Dupuit (1849), Pigou (1912) and Knight (1924). It parallels the theoretical development of peak-load pricing in public utilities (Marcel Boiteux 1949, Jacques Drèze 1964). The basic analytical framework was pioneered by Pigou (1912) and modeled formally in a short-run framework by Walters (1961). Mohring and Mitchell Harwitz (1962) recast the analysis into a long-run framework and established the relationship between optimal tolls and optimal long-run utilization of the road network. This analysis was generalized by Robert Strotz (1964) to handle a variety of assumptions regarding the characteristics of the road network.[36]

The pricing and investment problem can be formulated in terms of maximizing net social benefits, *NB*, for trips over a road. It can be specified for multiple periods as

$$\max_{Q_t, w} NB = \sum_{t=1}^{T} \left[\int_0^{Q_t} P_t(Z)dZ - Q_t AC_t(Q_t, w) \right] - \rho(w),$$

where $P_t(Z)$ represents the inverse demand curve in period t, Z a variable of integration, AC_t is the average cost function in period t and includes all the expenses of user and publicly supplied inputs (including the users' value of travel time), Q_t the flow of trips in period t, w the width of the road, and ρ the investment cost over the T periods. The optimal pricing and investment rules obtained from the first order conditions are given by

$$P_t = AC_t + Q_t \frac{\partial AC_t}{\partial Q_t} \quad t = 1, \ldots, T$$

[36] Additional refinements and extensions have been made by M. Bruce Johnson (1964), Mohring (1965, 1970), William Vickery (1969), and Donald Dewees (1979).

and

$$\rho'(w) = -\sum_{t=1}^{T} Q_t \frac{\partial AC_t}{\partial w};$$

that is, the price of a trip should be equated with its short-run marginal cost,[37] and the marginal cost of an additional unit of investment in the facility (e.g., urban roads) should be equated with the marginal value of the benefits to the users of the facility (e.g., reduced user costs from time savings) attributable to the investment. As shown by Mohring and Harwitz (1962), if there are constant returns to scale in road construction, the road will be exactly self-financing (i.e., toll revenues will cover costs) with optimal pricing and investment. If there are decreasing returns to scale it will earn a surplus, while if there are increasing returns to scale it will operate at a deficit.

Using this basic framework, Keeler and Small (1977) drew upon cost estimates from a highway cost function and value of travel-time estimates from a disaggregate demand model and found that the user tolls and vehicle speeds for urban expressways in the San Francisco Bay Area were significantly below optimal first-best levels during most time periods except slack periods. More specifically they found that optimal peak tolls (using a six percent interest rate) range from about three cents per vehicle-mile in the least-populated areas, to about 15 cents per vehicle-mile in Oakland and San Francisco. This contrasts with actual user charges (i.e., gasoline taxes) of slightly more than one cent per vehicle-mile. From a policy perspective it can be argued, in some cases, that an increase in tolls to optimal first-best levels would actually lower full-trip costs by reducing congestion significantly and consequently the time-related costs of urban travel. The basic first-best pricing and investment framework was also used by Morrison (1983) to estimate optimal tolls (landing fees) and investment levels at congested airports. In general, he found that current fees are too low in peak periods and too high in off-peak hours, indicating that some airports are overused during peak periods.[38]

Second-best considerations can be motivated in transportation for two basic reasons.[39] First, one can point to public policies that lead to pricing distortions in a particular mode such as auto, where prices are widely believed to be held below marginal costs during peak periods (e.g., Keeler and Small 1977). These distortions could also occur because of government policies such as input taxes, investment and operating subsidies, etc. Second, the presence of scale economies might prevent marginal cost (first-best) pricing from covering costs, especially in the absence of a subsidy. The next body of literature to be discussed has offered some possible solutions to these problems.

The general implication of public policies that prevent the price of a particular mode of transportation from equaling its marginal cost is that the optimal price for a competing (or complementary) mode of transportation will not be at its short-run marginal cost.[40] Assuming constant mar-

[37] The optimal congestion toll that must be set to ensure this equality is given by $Q_t \cdot \partial AC_t / \partial Q_t$.

[38] Additional empirical applications concerned with first-best pricing and investment in transportation can be found in Vickery (1963), Friedlaender (1965), Walters (1968, 1978), Rolla Park (1971), Marvin Kraus, Mohring and T. Pinfold (1976), Viton (1977, 1981b), and Bennathan and Walters (1979). Overviews of the problem are found in R. J. Smeed (1968), Meyer and Straszheim (1971); discussions of the distributional issues involved are in Foster (1975) and Small (1983).

[39] Meyer and Straszheim (1971) discuss the possible inappropriateness of second-best rules in actual transportation applications.

[40] H. Levy-Lambert (1968), M. Marchand (1968), Roger Sherman (1971), and James V. Henderson (1977) discuss this result in the context of transportation, and Boiteux (1951), Alan Manne (1952), and R. Rees (1968) provide more general discussions. A parallel development of the analysis of the second-

ginal utility of income, it can be shown (Ralph Turvey 1971) that the (second-best) price of the i-th mode, given price distortions in the other modes, is

$$P_i = MC_i - \sum_{i \neq j}^{J} \frac{\partial Q_j}{\partial P_i} \frac{\partial P_i}{\partial Q_i} (P_j - MC_j).$$

That is, the i-th mode's price should deviate from its marginal cost in accordance with the price-marginal cost distortions in competing (or complementary) modes weighted by the magnitude of cross-price effects and the slope of its inverse demand curve.

Although it is clear in many issues concerned with determining optimal transportation prices that second-best pricing rules are appropriate, thus far few researchers have carried out an empirical analysis that uses this approach (exceptions: Henderson 1977, Stephen Glaister and David Lewis 1978). Clearly, carrying out such empirical analyses, as well as investigating their implications for the accuracy of results, from first-best partial equilibrium pricing rules is an important area for future research.

In addition to their implications for pricing rules, public policies that lead to price distortions may also have implications for investment rules. That is, the first-best investment rule equates marginal benefits with marginal investment costs. However, as shown in Mohring (1970), William Wheaton (1978), Friedlaender (1981), Friedlaender and Subodh Mathur (1982), this rule will not be generally optimal in the presence of distortions caused by regulation of output or fuel taxes. For instance, in the presence of fuel taxes, the optimal second-best investment rules require larger increases in investment which, in effect, operate like a subsidy, relative to first-best levels. Unfortunately, the complexity of the problem prevents one from deriving simple formulae that characterize optimal second-best rules to be followed. On the other hand, there is some empirical evidence, in the case of the surface freight transportation industry (Friedlaender 1981, Friedlaender and Mathur 1982), that suggests the welfare cost may be fairly small if first-best investment rules are followed when second-best investment rules are appropriate. Clearly, more evidence is needed to determine whether the welfare implications of this issue justify greater attention to the problem.

The second issue that has motivated the development of second-best rules concerns the existence of significant scale economies that prevent marginal cost pricing from covering costs. As pointed out by Baumol and David Bradford (1970) in their survey, the short-run static solution to this problem is satisfied by the Ramsey pricing conditions:[41] assuming cross-elasticities of demand are zero, the percentage deviation of prices from marginal costs should be inversely proportional to the own-price elasticity of demand, and the financial constraint is indeed met by the resulting prices.

The development of "Ramsey-type" pricing rules has had a long tradition in transportation (Arthur T. Hadley 1886, E. Porter Alexander 1887, C. Colson 1910). Recently a number of empirical applications using Ramsey rules and elasticity estimates obtained from transportation demand models have been carried out. Train (1977), drawing on Boiteux's (1956) solution to the problem, estimated optimal second-best prices for rapid-rail and bus given their respective financial constraints. He found for a plausible set of

best occurred in international trade (James Meade 1955), and in the general theoretical extension of that analysis (Richard Lipsey and Lancaster 1956).

[41] Dupuit's work (1844) is generally regarded as the first treatment of the problem. An elegant general analysis, which takes a somewhat different perspective than Frank Ramsey's (1927), is in Boiteux (1956).

assumptions that, under second-best pricing, bus prices would rise relative to rapid-rail prices and that bus service would subsidize to a significant degree the operation of rail service. Levin (1981a, 1981b) and Winston (1981b), drawing on a theoretical extension of the Ramsey Rule provided by Braeutigam (1979), estimated Ramsey prices for rail in the context of intermodal (truck-rail) competition. They found that under Ramsey pricing rail prices for low-value (bulk) commodities would rise significantly relative to the rail prices for high-valued manufactured commodities.[42]

While representing an efficient pricing solution for transportation firms and agencies that face significant financial constraints, it should be kept in mind that Ramsey pricing is plagued by equity problems. They result from setting higher mark-ups over marginal costs for agents with relatively inelastic demands. In addition, there are dynamic problems associated with Ramsey pricing. For example, it has been argued in the context of rail freight transportation that Ramsey-type pricing[43] in the 1940s and 1950s and its associated markups, created incentives for shippers to change their underlying demand elasticities (e.g., through plant relocation) in ways that almost guaranteed Ramsey pricing would be undermined.[44]

Future research in the area of transportation pricing and investment should pay more attention to the actual process of implementing particular rules. Clearly, a given rule may indeed represent a potential Pareto improvement over an existing rule. However, given political and informational realities, for a rule to be implemented it may have to be demonstrated that the rule can represent an actual Pareto improvement, especially in a world of changing technology. Interestingly, in the early 1960s some attention was paid to this issue (Vickery 1963, Johnson 1964). However, recent theoretical and empirical contributions to pricing and investment in transportation have not, for the most part been complemented by the development of processes of implementation and of redistribution that are necessary for a rule to effectuate an actual Pareto improvement (an exception is Small 1983). To be sure, the development of such processes is an extremely challenging task. Nonetheless, this work should be carried out if economists are to have significant input into this area of transportation policy.[45]

VI. *Regulation*

As pointed out in Section 2, one of the most significant features of transportation is that a considerable amount of the intercity freight or passenger service that has been provided has been subject to rate, entry and exit regulation. Early writings in this area essentially described the specific regulations and their history (Stuart Daggett 1920, 1922; Locklin 1928, I. L. Sharfman 1931, James C. Nelson 1936, and more recently Gabriel Kolko 1965, George Hilton 1969, 1972), while the bulk of recent literature on regulation, directed mainly toward the surface freight and air transportation industries, has

[42] An integration of Ramsey pricing with the second-best pricing rule (Turvey pricing) discussed on page 73 has been carried out by Winston (1982). That is, prices have been derived to cover a financial constraint taking into account price-marginal cost divergences elsewhere. This leads to optimal departures from nonmarginal cost pricing.

[43] More specifically, rail engaged in value-of-service pricing, which set rates according to commodity value. This pricing procedure is analogous to Ramsey pricing in that it is likely that shippers of high-value commodities (who face higher rates) would have lower elasticities of demand because transportation expenses accounted for a lower percentage of the final commodity cost.

[44] William Tye and Herman Leonard (forthcoming) and William Brock and W. David Dechert (1982) criticize static Ramsey pricing.

[45] For examples of the possible roles that transportation economists can have in actually influencing pricing policies see Drèze (1964, p. 35).

drawn upon some conceptual advances in cost and demand analysis discussed previously and tried to quantify the welfare effects of various regulations and to assess the likely impact and desirability of deregulation. Indeed, as pointed out by Stigler (1981), one of the most fundamental changes within the last few decades, in the study of regulation, is that there have been several attempts to estimate empirically the effects of a public policy. Within the context of economic regulation, the studies on transportation regulations by Meyer, Peck, Stenason and Zwick (1959) and by Caves (1962) are regarded generally as classics. In addition to this research, recent work has analyzed the behavior of transportation firms under regulation with particular attention focused on various economic objectives that these firms may have in a regulated environment.

A. *Behavior of Regulated Transportation Firms*

Until recently, most transportation firms in the U.S. have been subject to some form of price, entry, exit, and (in principle) rate-of-return regulation. Various researchers have attempted to understand the behavior of regulated transportation firms using a variety of assumptions regarding these firms' objectives.

For instance, under the assumption that excess profits were competed to zero by noncollusive service quality competition, Douglas and Miller (1974) investigated the effects of the Civil Aeronautics Board's (CAB) price regulation on the amount of capacity that is offered in the airline industry.[46] Through the use of comparative statics analysis, they derived the relationship in a stylized market between the industry fare level, as set by the CAB, and the amount of capacity to be provided. The authors then provided some empirical evidence suggesting (subject to the zero profit constraint) that the regulated fare came close to maximizing the amount of capacity provided. As we shall discuss in Section 6.3, the implications of this finding are particularly significant with regard to evaluating the welfare effects of CAB regulation.

In a somewhat different vein, Russell Cherry (1978) and Marilyn Flowers (1972) have drawn upon the seminal work of Harvey Averch and Leland Johnson (1962) in industrial organization and analyzed the efficiency implications of regulatory constraints on earnings in the motor carrier and public transit industries, respectively. In contrast to a number of studies of this problem in other industries (Joskow and Noll 1981), these analyses found the presence of a regulatory constraint on earnings has led firms in each industry to provide its service in a manner that fails significantly to minimize costs. In particular, it appears that the labor force employed by these industries has not been efficiently utilized.

Finally, there has been some recent work, particularly applied to the transit industry (Flowers 1972, Nelson 1972, C. A. Nash 1978, Glaister and J. J. Collings 1978, Dieter Bös 1978), that has analyzed firm behavior under a variety of managerial maximization objectives, including: profit, welfare, ridership, and passenger-miles. Collectively, these studies have identified the tradeoffs that managers must make in terms of efficiency and distributional consequences, in attempting to achieve a particular goal for their company in a regulated environment.

Given the current movement toward significant deregulation of the transportation industries, it will be necessary for future researchers to analyze the behavior of transportation firms in a more competitive environment: namely, one which is characterized by decentralized price de-

[46] In a related study, White (1972) analyzed the effect of price regulation on product quality using the airline industry as an example.

termination and minimal legal barriers to entry and to exit. This impending change in the competitive environment indicates that a number of important issues concerned with pricing, service levels provided, markets served, as well as mergers and acquisitions will have to be addressed if we are to understand the reasons behind particular firm behavior and the performance of transportation industries in the coming years.

B. *The Impact of Regulation on Surface Freight Transportation*

Analysis of the welfare effects of regulation in the surface freight transportation industry brings us back to some issues that were raised in the early literature. Essentially, the three primary effects of regulation on allocative efficiency can be characterized as: first, the static deadweight loss from rate regulation, caused by setting rates in excess of long-run marginal cost; second, the dynamic welfare loss from excess capacity, attributed to exit regulation that has precluded abandonment of service; and, third, the adverse effect of regulation on technical change and productivity. The first and third effect have been important in the rail and motor carrier industry, while the second has been of primary importance in the rail industry.

Although concerns about welfare effects of rate regulation in the rail industry can be traced to the work of J. M. Clark (1910), Locklin (1925), Hotelling (1938), Healy (1957), Meyer, Peck et al. (1959), among others, the initial attempt to estimate empirically the deadweight loss from rail rate regulation was carried out by Roy Harbeson (1969). He used the comparative cost methodology which consisted of calculating the difference between truck and rail marginal cost (adjusting rail's marginal cost to account for its inferior service quality) and multiplying this difference by the amount of traffic that should be reallocated to rail (on the basis of lower freight costs). He concluded that the welfare loss was quite large (roughly two billion dollars a year in 1963 dollars). Similar conclusions in terms of the magnitude of resource misallocation from rail rate regulation were reached by Thomas Moore (1975). Boyer (1977) and Levin (1978) obtained estimates based on the use of aggregate freight demand modal split models and standard consumers' surplus measures that suggested the welfare loss was virtually negligible (i.e., roughly one-hundred million dollars) when the relative levels of service quality provided by rail and motor carrier were included. Most recently, Winston (1981b) took into account the fact that rate regulation has occurred in both the rail and motor carrier industries. An estimate of the freight system welfare loss, which lay between Harbeson's estimates and those of Boyer and Levin, was obtained with the use of a disaggregate freight demand model. Interestingly, Boyer's and Levin's estimates have turned out to be based on flawed calculations which, when corrected, yielded results that were fairly consistent with Winston's (Levin 1981a).

In summary, there now appears to be considerable agreement that rate regulation has not imposed as large a social cost as Harbeson initially claimed. On the other hand, there is also agreement that the cost has not been trivial (i.e., on the order of one-billion dollars a year, in 1977 dollars). Unfortunately, it is not clear that deregulation will eliminate this welfare loss because of the possibility that railroads will exercise market power in order to achieve financial viability (Levin 1981b). In other words, a regulation requiring rates to be set at marginal cost might be needed to eliminate the welfare loss.

The question regarding the existence of scale economies and the presence of excess capacity due to regulatory restrictions on abandonment of service has been analyzed primarily in the rail industry. Studies that have been based on estimated railroad cost functions indicate that the welfare loss from excess capacity in the rail industry is nearly 2.5 billion dollars annually (Friedlaender 1969, 1971; Friedlaender and Spady 1981; Harris 1977; Keeler 1974, 1976; also, Michael Conant 1964).[47] This view is also supported by studies that pinpoint the industry's low traffic density as an important source of its current financial plight (Harris and Keeler 1981; Levin 1981c). Thus, there appears to be a consensus: welfare losses from regulatory restrictions that have prevented the abandonment of low density lines are not only greater than those from rate regulation but, on an absolute level, are quite substantial.[48] Under deregulation, it is widely believed that a significant amount of the excess capacity that has plagued the industry for many years would be reduced.[49]

Finally, some research concludes that regulation has had an adverse impact on technical change and productivity in the surface freight transportation industry: Paul MacAvoy and James Sloss (1967) argue that rate regulation retarded the introduction of trainload service for coal. In addition, Aaron Gellman (1971) contends that railroad regulation stifled innovative aspects of piggyback operations, delayed the introduction of aluminum hopper cars and that backhaul restrictions in trucking have discouraged the industry from developing innovative, adaptable equipment to carry liquid or dry freight.

More recently, there have been some studies based on transportation cost functions that have provided an overview of the impact of regulation on productivity growth. In the case of railroads, Caves, Christensen, and Swanson (1981a) compared the productivity of U.S. railroads in the regulated environment with the productivity of Canadian railroads in a less regulated environment. Based on comparisons between typical and specific U.S. and Canadian railroads during the period in which the only major change in the U.S. and Canadian environments was the divergence in regulatory policies, they find that if U.S. railroads' productivity growth had been at the same rate as the productivity growth of the Canadian railroads', U.S. railroad costs would be several billion dollars less each year. In the case of regulated motor carriers of general commodities, Friedlaender and Wang (1983) find very modest productivity growth. However, they point out that regulation's contribution to this performance is not clear. Taken collectively, this body of research suggests that the most important welfare concern regarding regulation's effect on surface freight transportation may have been its inhibition of technical change and productivity growth. As such, it should be expected that the greatest benefits from deregulation are likely to be seen in these areas.[50]

Given the passage of the 1980 Rail Staggers Act and the 1980 Motor Carrier Act,

[47] This view is shared even though there are potential differences among studies regarding the role of track. As pointed out by Spady (1979), the amount of track a firm has is largely a reflection of its common carrier obligations, although it certainly embodies some of the firm's capital stock. A policy recommending that rail firms be allowed to abandon track does not necessarily imply, however, that the firms are overcapitalized. Rather it implies they have excessive common carrier obligations.

[48] It should be pointed out that the rail industry has also suffered from excess capacity in terminals and yards, and excessive work rules and labor costs (Harris and Keeler 1981).

[49] This is not to say that improvements in yard and terminal operations, labor costs, and work rules will necessarily occur.

[50] Another issue that relates to the dynamic cost of regulation is its effect on management incentives, the ability to recruit individuals with various management skills, etc. While this issue is difficult to analyze quantitatively, nonetheless it is believed that regulation has had an adverse effect on management quality in the regulated freight transportation industry.

future research must take a forward look toward competition in a deregulated surface freight transportation industry. In particular, how can the transition to deregulation be managed effectively? What will the new competitive environment (rates, service, labor practices, antitrust enforcement, etc.) be like? Questions about the future of the rail and motor carrier industry, such as the contestability of markets and overall market structure, the desirability and likelihood of continued merger activity, the long-run financial viability of the railroad industry, the distributional consequences of deregulation, and the likelihood of intermodal operations and ownership will have to be studied thoroughly.

C. *The Impact of Regulation on Air Transportation*

Turning to passenger transportation, the most prominent form of regulation that has been studied has been intercity air transportation.[51] Specifically, as in the surface freight transportation industries, rates, entry and exit have been regulated. What is different about the airline industry, however, is that while entry into city pair markets was limited, flight frequency was explicitly not regulated. As such, airlines engaged in intensive service competition through service frequency (scheduling) and through in-flight amenities. For the airline traveler, there are a number of potentially important issues related to the frequency of service. Douglas and Miller (1974) include the ability to get a flight at a desired departure time (the difference between the desired departure time and the closest scheduled departure time is called "frequency delay") or to minimize delay when getting a different flight, if the best-scheduled flight is unavailable due to capacity constraints (this delay is called "stochastic delay").

The importance of service quality and the presence of industry regulation have led to a body of research that attempted to incorporate service quality considerations in an evaluation of the impact of regulation on fares and service. This issue has been analyzed in two ways. First, theoretical models of optimal fares and service (capacity) under different market structures and degrees of regulation have been developed (DeVany 1975b, Douglas and Miller 1974, Eads 1975, Gary Dorman 1983, Richard Schmalensee 1977, Panzar 1979).[52] The predictions of these models have been used to compare equilibrium levels of fares and service in the regulated environment vis-à-vis those in a deregulated environment. Second, empirical analyses of the welfare effects of fare and entry regulation have been carried out (Richard Caves 1962, William Jordan 1970, Eads 1972, Keeler 1972, 1978; Douglas and Miller 1974, John Trapani and Vincent Olsen 1982). In particular, airline cost-functions have been used to obtain estimates of the markup of regulated fares over long-run marginal cost, thus providing a basis for assessing the potential impact of entry on unregulated fares. The welfare loss from these higher fares was then compared with benefits that travelers have received from the concomitant increase in service quality, more specifically increased flight frequency, that was provided in the regulated U.S. environment. Generally, each of these

[51] To be sure, other passenger modes, such as bus and rail, have been regulated. Some discussion of these modes is in Keeler (1971a) and John Wells et al., ed. (1972).

[52] The theoretical issue addressed here, namely characterizing market equilibrium with explicit consideration of service characteristics, is potentially of general interest because it may be important in many other economic situations. Additional analyses of this issue, in a transportation context, are in Douglas (1972), DeVany (1975a) and John Schroeter (1983) for taxi markets, and DeVany and Thomas Saving (1977) for trucking markets.

strands of research has concluded that airline regulation not only has led to higher fares than would be expected in a deregulated environment, but also has led to a suboptimal combination of fares and service quality, which has eroded the excess-profits that the airlines were expected to earn in the regulated environment.[53] Thus, a strong consensus has emerged from this literature that has supported deregulation of the industry.[54]

Recent work has attempted to evaluate industry performance during its transition to a deregulated environment. To begin, Bailey and Panzar (1981) present evidence that suggests most airline markets are likely to be contestable (i.e., performance should approach the competitive norm). Meyer and Clinton Oster (1981) in their analysis of the industry's early experience with deregulation, conclude that, although there have been costs associated with this policy, it still appears that the deregulation of the industry will have a beneficial effect in the long run. Recent work by David Graham, Daniel Kaplan, David Sibley (1983) concludes that the airline industry has operated more efficiently under deregulation, but casts doubt on the claim that airline markets are contestable. Finally, Caves, Christensen, and Tretheway (1982) have compared productivity growth performance in the airline industry, in the deregulated era, with airline productivity performance in the regulated period. They conclude that it is appropriate to attribute several billion dollars of cost savings to relaxed regulation. It will be the task of future research to evaluate these findings carefully as well as to monitor various effects: efficiency and distributional (Olsen and Trapani 1981) of air deregulation.

VII. *Summary and Additional Research Directions*

This survey has attempted to spotlight the modern microeconomic approach toward analyzing transportation activity. Emphasis has been on conceptual developments in supply and demand, and on the use of these contributions in the context of analyzing pricing and investment as well as regulatory issues.

In retrospect, it should be clear that these conceptual developments have led to improvements in our understanding of many issues that are important in transportation economics. To be sure, it is debatable whether these developments and particular studies that have made use of them have led or will lead to profound changes in actual policy.[55] Nonetheless, conceptual developments in the past few decades have marked considerable progress in the field. They have forged a solid analytical base from which we can carefully analyze important positive and normative transportation economics problems.

In years to come, it will be important to use this base to explore the broader implications of transportation activity on local, regional, or national economies. Specifically, analyses concerned with the impact of investments in transportation infrastructure on an economy, and the effect of transportation system performance on macroeconomic stability, aggregate production, and aggregate consumption will be necessary in the future. While it may be argued that it is appropriate to combat macroeconomic problems with macroeconomic remedies (i.e., fiscal and mone-

[53] These excess-profits were actually encouraged, given the high rate-of-return that corresponded to the CAB's regulated fare levels (Keeler 1978).

[54] To be sure, the call by economists for deregulation of the airline industry can be traced to earlier sources than the studies cited above: for example, Lucile Keyes (1951), Michael Levine (1965).

[55] In this respect, it will be worthwhile to identify academic economists' contribution to the current ICC debate about appropriate pricing policies toward rail-captive shippers.

tary policies) one major lesson that has emerged from the literature on transportation economics is that aggregate analyses, and policies based on them, may be inappropriate. Thus, we may find that microbased policies—at least toward transportation—may be effective macroremedies.

To be sure, there has been considerable research on the relation among transportation systems and the health of urban economies (Meyer and Gomez-Ibañez 1981). In addition, other pieces have appeared in the literature that attempt to consider the importance of transportation for the health of a particular economy (Lardner 1850, Friedlaender 1968, George Wilson 1969, David Kresge and Roberts 1971; also, Albert Fishlow 1965, Robert Fogel 1964). The time has now come, however, for a more concerted effort. Given the benefit of a solid microeconomic base for understanding the behavior of individual agents, exploring the broader economic implications of transportation should be fruitful.

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