RECENT DEVELOPMENTS IN THE ANALYSIS OF TRANSPORTATION COSTS AND PRODUCTIVITY

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Abstract

This paper reviews work on transportation costs and productivity published since 2000. With the survey of Winston (1985) as a benchmark, it addresses three questions. First, have there been significant changes in methodology since 2000 which have enabled economists to better incorporate real-world features into their cost models? Second, what are the new or revised empirical findings about the nature of transportation costs and productivity? Third, what are the implications of these findings for transportation policy?

I. Introduction

There are three logical points of reference for a survey of recent contributions to the analysis of transportation costs and productivity. The first is the comprehensive overview of the transportation economics literature by Winston (1985). The second and third are reviews of the transportation cost literature by Oum and Waters (1997) and Braeutigam (1999).

In his interpretive survey of "Conceptual Developments in the Economics of Transportation" Winston identifies two important periods in the history of transportation economics. The first occurred at the beginning of the 20th Century when well-known economists like Ripley (1912), Pigou (1912), Taussig (1913), Clark (1923), Knight (1924) ,and Edgeworth (1925) provided normative analyses of transportation pricing and investment questions. The second began with the 1959 publication of Meyer, Peck, Stenason and Zwick's *Economics of Competition in the Transportation Industries*. This study and many papers that followed provided stronger analytical foundations for the analysis of transportation markets. The methodological challenge in all areas of transportation economics, Winston stressed, was to incorporate real-world features into the formal models since most analyses have policy implications.

After 25 years of additional research in transportation economics, the innovative methods of using flexible functional forms to model costs and discrete choice specifications for demand have become commonplace, but economists continue to do work that provides a strong analytical basis for understanding transportation markets and assessing transportation policies. The methodological challenge of incorporating real-world features into these analytical models remains. There is no reason, therefore, to revise Winston's account of the history of transportation economics or of the methodological challenges that practitioners face. Nor does it make sense to review work that was well-covered by Winston, Oum and Waters and Braeutigam. The focus of this paper is on studies of transportation costs and/or productivity published since

2000.[1] With Winston's survey as a benchmark, it addresses three questions. First, have there been significant changes in methodology since 2000 which have enabled economists to better incorporate real-world features into their cost models? Second, what are the new or revised empirical findings about the nature of transportation costs and productivity? Third, what are the implications of these findings for transportation policy?

II. Methodological Developments

Much of the modern work that economists have done on transportation costs and productivity had its origins in the Rail Form A (RFA) regulatory accounting system that the Interstate Commerce Commission (ICC) had used since the 1930s. Rail Form A was an activity-based costing system in which various rail expenditure accounts (track maintenance, crew expenses, etc.) were regressed on a capacity measures (typically track-miles) and an output measure (train miles or ton-miles) to differentiate the fixed and variable components of rail cost. The output-related parameters were then used to project movement-specific variable costs.

In 1976 Congress ordered the ICC to develop a new costing system to estimate average variable costs more precisely than Rail Form A. The idea was not to expand the agency's authority but to limit the scope of ICC rate review by defining a more precise revenue-to-cost ratio below which rates were presumed to be reasonable. The ICC and its successor agency, the Surface Transportation Board (STB), have labored for many years to develop and defend this Uniform Rail Costing System (URCS). One positive consequence of the development work was a series of academic papers that combined available ICC rail data with the new flexible functional cost and production functions generally associated with McFadden (1978). The translog (TL) functional form was applied to railroads by Caves, Christensen, and Tretheway

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[1] Like Winston, Oum and Waters and Braeutigam, we do not consider the extensive operations research literature devoted to optimizing performance and/or prices on transportation networks or the extensive economic literature on trade and transportation which is *sui generis*. Nor do we consider recent work on the estimation of shipper costs which are of central importance in understanding freight markets but which are properly seen as elements of transportation demand.

(1980), Spady and Friedlaender (1976), and Caves, Christensen, and Swanson (1981). It also was used extensively to analyze the airline and trucking industries in regulatory transition.

Oum and Waters attribute the TL's popularity to ease of estimation and interpretation but they also point to shortcomings. One is the well-known problem of imposing curvature conditions on the TL without losing flexibility. Another is the problem of analyzing scope economies with a functional form that does not allow for a direct treatment of zero output levels. Finally, and more generally, there is the problem of how to treat quasi-fixed capital stocks.[2] Some but not all of these problems are addressed in recent literature but the TL remains a staple of transportation cost and productivity studies.

One methodological development closely related to the TL is the use of the Generalized McFadden (GM) flexible functional form first proposed by Diewert and Wales (1987). The main advantage of this form is that neoclassical curvature conditions can be imposed globally without sacrificing flexibility. Let *w* be an *n*-dimensional vector of input prices, *t* a *q*-dimensional vector of technological factors, and *y* an *r*-dimensional vector of outputs. The GM function can be written:

$$(1) \quad C = C(w, y, t, u, \epsilon) = a'w + 0.5\frac{w'\Delta w}{\theta' w}(b'y)^2 + w'\Lambda z + 0.5(\theta' w)z'Tz + w'u + y'\epsilon$$

here *z* is a *K*-dimensional vector (*K* = *G'* + *J*) that includes the output vector *y* and a vector of technological factors *t*, *a* is an unconstrained *I*-dimensional parameter vector, Δ is an *I* by *I* symmetric parameter matrix, Λ is an *I* by *K* parameter matrix of nonnegative elements, Γ is a *K* by *K* symmetric parameter matrix, and *b* and *θ* are column vectors of fixed parameters of dimension *G'* and *I*. The GM is concave in w if the estimated matrix Δ is negative semidefinite. If not, concavity can be imposed by setting Δ = −BDB′ where B is a lower triangular matrix with the sum of its diagonal elements equal to 1 and D is a nonnegative diagonal.

[2] Oum and Zhang (1997) observe that in the transportation literature it is often the case that estimatesd variable cost functions have wrong positive signs for capital. They argue that these functions are mis-specified because they do not model a kink in the relationship between the annualized cost of capital and the quasi-fixed stock of capital

Economists have also used stochastic frontier analysis (SFA) to analyze the cost structure and technological performance of transportation firms. These techniques address the problematic assumption in traditional econometric studies that all firms are operating on the efficient frontier. Aigner, Lovell and Schmidt (1977) showed how to use SFA to estimate production and cost functions where the efficiency assumption was not required. This was done by specifying the error term of the function as $\epsilon = u + v$ where u was a non-negative technical inefficiency component and v was a two-sided noise component. Aigner, Lovell and Schmidt recommended a joint density function for ε where u was assumed to be half-normal or exponential distribution. The SFA was widely applied in the electric utilities and telecommunications areas in the 1990s but Oum and Waters noted that few applications had been made to transportation. That has changed and there has been a fairly steady stream of papers applying SFA methods to airlines, railways and transit.

Distance functions have also been used in recent years to specify the structure of transportation technology and costs where there are multiple outputs, multiple inputs, and different levels of efficiency across firms. The input distance function $D_I(y,x)$ is defined as

(2) $$D_I(y, x) = \max\, [\lambda : \tfrac{x}{\lambda} \in L(y)]$$

where x is an input vector, y an output vector, and $L(y)$ the feasible input sets for y. The parameter λ measures the maximum amount by which a producer's input vector can be radially contracted and still remain feasible for the output vector it produces.[3] The output distance function is defined symmetrically. The distance function is a technological specification but cost-relevant results are based on the duality between input distance function and the cost function. The stochastic distance function can be written

(3) $$D_O(y_i, x_i; \beta) = \exp\,\{v_i - u_i\}$$

where u and v are error terms as described above.

[3] See Kumbhakar and Lovell (2000) pp. 28-32 for details.

A fourth methodological innovation in the transportation economics literature has been the incorporation of demand side information and strategic considerations into the analysis of costs and productivity. Economists have recognized for some time that it is unrealistic to assume that the output levels of firms operating in deregulated markets without common carrier obligations are exogenous. The standard approach has been to use instrumental variables to control for the endogeneity of outputs. Recent analyses extend this approach by employing techniques that Bresnahan (1989) developed in the New Empirical Industrial Organization (NEIO).

The point of departure for NEIO is the first order condition for profit maximization for the individual firm in a market where $Q = \sum Q_i$. This can be written

(4) $$P_i = MC_i - \frac{\partial P}{\partial Q} Q_i \theta$$

where P_i is the price of a good or service, MC_i is the marginal cost, Q_i the output of firm i and θ is a conduct parameter. If prices and quantities are observed, market conditions and marginal costs can be recovered. Examples of papers using the NEIO approach are Fischer and Kamerschen (2003) for airlines and Wilson and Bitzan (2003) for freight railroads.

A more recent approach to costs and technology in the context of market structure is based on the work of Berry (1994) and others who developed the econometric analysis of differentiated product markets into an important tool for merger assessment using a discrete choice demand framework. Under the usual logit distributional assumptions, for example, the probability s_{gh} that freight shippers in a particular market g (e.g. bulk) choose choose a particular railroad h is

(5) $$\ln s_{gh} - \ln s_{g0} = X_{gh}\beta_g - \alpha_g p_{gh} + \sigma_g \ln s_{gh|H} + \xi_{gh}$$

where

s_{g0} is the probability that shippers chooses an alternative transport mode,

X_{gh} is a matrix of demand-related variables in market g,

β_g is a vector of parameters,

α_g is the marginal disutility of a price increase in g,

p_{gh} is the price offered by firm h,

ξ_{gh} represents the characteristics of railroad h not observed by researchers.

The share expression $s_{gh|H}$ is the conditional probability that shippers chooses firm h given they have selected the rail mode. The parameter σ is a nested logit parameter that captures the degree to which shippers' preferences are correlated across firms. At the aggregate level, the choice probability coincides with the market share of firm h.

A full structural model in this context is a system of equations that express a) prevailing demand conditions, b) strategic hypotheses regarding pricing, and c) cost structures of firms participating in the market. Strategic assumption are incorporated into the model by adding a set of equilibrium conditions in which each transportation firm maximizes its profit with respect to prices (or quantities) conditional on the prices (or quantities) set by differentiated competitors. This allows the researchers to differentiate, for example, between Bertrand and Cournot market behaviors. Given the specification of the demand function described above, for example, under a multiproduct Bertrand-Nash equilibrium, the first order condition for profit maximization yields the expression of price – cost margins as

$$(6) \qquad p_{gh} - c_{gh} = \frac{1-\sigma_g}{\alpha_g(1-\sigma_g s_{gh|H}-(1-\sigma_g)s_{gh}}$$

where c_{gh} stands for the marginal cost effect of a change in output level for y_{gh}.

A significant limitation of many papers in this tradition is the assumption that the merging firms exhibit constant marginal costs. This makes it impossible to directly estimate merger efficiency gains—gains which applicants claim are the basis for mergers. In Peters (2006), for example, putative (and constant) marginal costs (c_{gh}) are recovered from a Bertrand pricing equation similar to (6) using price data and the parameters from an estimated demand system. Recent structural papers in transportation include cost parameters in the models to account for efficiency effects. Ivaldi and McCullough (2005, 2010) include a fully flexible, multi-product GM cost function in a structural model of U.S. rail markets.

III. Empirical Results

A. Railroads and Transit

Formal economic analysis of transportation has early origins in the study of railroad markets. In fact, Dionysius Lardner's *Railway Economy: A Treatise on the New Art of Transport* (1850) is the earliest work cited in Winston's survey. Economists also exerted a direct influence on the shape of rail policy during the 20th century revival of transportation economics. In the 1970s, for example, work by Meyer, Peck, Stenason and Zwick (1959), Spady and Friedlaender (1976) and others informed Congress's decision to deregulate U.S. rail markets. In the 1980s expert testimony by economists William J. Baumol and Robert D. Willig convinced the ICC to adopt Ramsey Pricing as a regulatory ideal for U.S. rail freight markets.[4]

The combination of these two policy changes—one legislative and the other administrative—helped to facilitate a complete economic restructuring of the industry and a financial revival. The number of Class I railroads has fallen from 41 in 1978 to seven today, and the ratio of revenue to total cost has increased significantly.[5] This in turn has raised two sets of closely-related issues that economists have addressed with cost models in the first decade of the 21st century. First, what has been the overall effect of U.S. rail mergers on industry performance and/or economic welfare? Second, does it make sense to limit the market power of merged rail firms by mandating open access to the rail network?

Bitzan and Wilson (2007) use a translog cost function to evaluate the efficiency effect of U.S. rail mergers using panel data on Class I rail firms for the period 1983-2003. (See Table 1).

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[4] See testimony submitted on May 11, 1981, April 13, 1982, July 28,1983, and October 4, 1984 in *Ex Parte No. 347 (Sub-No. 1) Coal Rate Guidelines – National*, and *Ex Parte No. 347 (Sub-No. 2) Rate Guidelines – Non-Coal*

[5] Ivaldi and McCullough (2007) estimate that the ratio grew from 0.8 in 1981 to almost 1.2 in 1993.

They project 1993 industry costs at a level of $33.6 billion (1992$) without mergers versus $29.8 billion with mergers—a 11.4 percent cost reduction.

Winston, Dennis and Maheshri (2008) and Winston, Maheshri and Dennis (2009) present structural models of market power effects in specific rail markets. The 2008 paper uses observations from 48 electric utility plants that operated between 1984 and 1998 to analyze the effect of duopoly competition between Union Pacific and Burlington Northern railroad for coal movements from the Powder River Basin of Wyoming and Montana. It concludes that the two railroads moved over time toward a competitive Bertrand price equilibrium (with prices approaching marginal costs).

The 2009 paper analyzes the effect of mergers between Union Pacific and Southern Pacific and between Burlington Northern and Santa Fe on overseas grain shippers. It is based on observations from the STB Waybill Sample of grain movements from 11 states to seven destination ports in the period 1989 to 2006. The authors find that efficiency-related effects of the two mergers are significant—especially given the presence of truck-barge competition in the grain markets. Estimated welfare effects on grain shippers were negative and significant immediately following the mergers (which were accompanied by service breakdowns), but surplus effects have been neutral in recent years.

Ivaldi and McCullough (2005, 2010) reach a similar conclusion about the overall welfare effects of U.S. rail mergers.[6] Their results are based on a structural analysis of mergers and consolidations involving 24 major railroads in the U.S. between 1978 and 2006. The results show that aggregate shipper surplus declined between 1978 and 1985 but recovered starting in 1986. Total shipper surplus in rail freight grew to $103.7 billion (1982$) in 2006—an increase of 38 percent from its low point in 1985—but below the 1979 level of $108.5 billion (1982$). The analysis identifies three types of operating outputs—bulk car-miles, intermodal car-miles and general freight car-miles—and an additional output measure (ties laid annually in replacement)

[6] An early version of the Ivaldi and McCullough paper based on 1986-2001 data was published in 2005 by the Center for Economic Policy Research (CEPR-DP5000). This summary is based on a significantly revised and updated version based on 1978-2006 data and published by in 2010 by Institut d'Economie Industrielle (IDEI) as *Working Paper No. 344*.

for infrastructure-related activity. The major welfare effect that Ivaldi and McCullough observe is a shift in the composition of surplus away from general freight shippers and in the direction of bulk and intermodal shippers.

A second issue engaging rail economists in the U.S. has been legislative attempts to mandate open access regimes on the rail network. Bitzan (2003) analyzes a database of Class I railroads for the period 1983 – 1997 using unit train-miles, through train-miles, and way train-miles as operating types. He finds that there are cost complementarities between infrastructure and operations and also between operational types. Ivaldi and McCullough (2008) use a GM cost function to test for subadditivities between above-rail and below-rail activities and also across operating activities and find similar results.

The European Union (EU) has also undertaken railway reform—partly in an effort to increase freight flows on networks that are still dominated by passenger traffic. Friebel, Ivaldi and Vibes (2010) identify three types of reform: a) unbundling infrastructure and operations, b) creation of independent rail regulatory authorities, and c) open access to national rail markets. These authors employ a stochastic frontier cost model to quantify the effects of reform on 11 EU national railways in the period 1980-2003. They find that reforms have increased productivity growth most effectively when they are implemented sequentially and not as a single package.

Among the other papers finding increased productivity gains on EU railways (Table 2) are Loizides and Tsionas (2004) using a translog cost function, Lan and Lin (2006) using a stochastic frontier cost function, and Khumbhakar et al. (2007) using a distance function. Growitsch and Wetzel (2009) use a distance function to analyze economies of scope on the EU rail system in the period 2000-2004. They find significant economies of scope in the performance of 54 railway companies in 27 European countries using a database that includes integrated rail firms, infrastructure managers, passenger operators and freight operators.

Farsi, Fetz and Fillipini (2007) find economies of scope in transit operations using a quadratic cost function and a database of 16 Swiss transit operators for the years 1985-1987. Mizutani (2004) uses a translog cost function to study the optimal scale of urban passenger rail operations in Japan. He analyzes a data set of 56 privately owned railway companies operating in Japan between 1970 and 2000. He concludes that the optimal density for a Japanese passenger railway is 231 million vehicle-km per year and a network of 63.8 km.

B. Trucking

Trucking is by far the dominant form of freight transportation worldwide, but the data is much more difficult to obtain than rail data. It is therefore not surprising that there are far fewer economic studies of trucking technology. Nevertheless economists have recognized the critical importance of trucking and have focused especially on the relationship between information technology and trucking productivity (Table 2).

Hubbard (2003) estimates the impact of electronic vehicle management systems (EVMS) on capacity utilization in the U.S. trucking industry defined as loaded miles per period in use. He uses data from the U.S. Census Bureau's Truck Inventory and Use Survey (TIUS) from 1992 and 1997. Hubbard argues that since the truck to driver ratio in the industry did not change appreciably between 1992 and 1997 capacity utilization can be considered a measure of labor productivity. Hubbard finds that EVMS increases capacity utilization by 13% for trucks that adopted the technology in 1997. He finds virtually no impact in the 1992 data, which leads him to conclude that the benefits of this technology accrue with a lag.

Barla, Bolduc, Boucher, and Watters (2008) estimate the impact of EVMS on the Canadian trucking industry using data from a subsample of the 1999 National Roadside Survey, which consists of trucks that have travelled in Quebec. Capacity utilization here is the load factor reported by survey respondents in percentage increments (0, 25, 50, 75, 100) for each trip. The authors estimate the impact of EVMS adoption using a multinomial probit model and find increased in capacity utilization of 6.5% for trucks that adopted EVMS. In a simulation based on their probit estimates they find that EVMS is associated with an increased capacity utilization on the return trip of 16%, but a decrease of 7.6% on outbound trips. This suggests a "rebound effect" attributed to the fact that the technology improves the probability of finding a return trip thus allowing fixed costs to be spread over a larger total haul.

Boyer and Burks (2009) use information on the physical characteristics of the U.S. trucking fleet from TIUS for 1977-1997 to estimate productivity gains taking into account the change in truck traffic composition over time. They argue that previous studies have inflated measured productivity because they do not account for the fact that the share of commodities that are easy to transport has increased along with the share of long-distance hauls. To capture the effects of these compositional changes Boyer and Burks categorize trucks by range (e.g., long-haul, short-haul, etc.), sector and commodity transported. They find that trucking productivity increased overall, but lagged compared to the rest of the US economy. They find an overall average annual increase of 1.85% in ton-miles per truck between 1982 and 1997, but when composition is held constant, average annual ton-miles per truck increase by only 1.31%. Moreover, if the size of the trucks is restricted to the average size in 1982, average annual ton-mile gains are only 0.84%.

C. Airlines and Airports

Berry and Jia (2010) begin their analysis of the performance of U.S. airlines by stressing the amount of turmoil in the last decade. Four of the six legacy carriers—US Airways, United, Delta and Northwest—declared bankruptcy. Only American Airlines and Continental escaped. The financial problems occurred despite the fact that by 2006 airline revenue passenger miles had returned to pre-2001 levels and load factors increased from 71.2 percent in 1999 to a record 80.5 percent in 2007. Berry and Jia estimate a structural model of airline markets to identify the causes of airline financial distress. Their analysis is based on 214,809 trips in 1999 and 226,532 trips in 2007 using the U.S. Department of Transportation (DOT) Origin and Destination (O&D) Survey. The loss of margin is attributed to increased price sensitivity and a stronger preference for non-stop flights on the demand side, and increases in the marginal costs of operating connecting flights on the supply side.

An earlier paper by Peters (2006) uses a discrete choice structural model of Bertrand competition in the airline industry to simulate prices of five carriers formed by mergers in the early 1980s.[7] His analysis is based on 122,871 observations from the O&D Survey on trips involving 32 carriers from 1985:1 to 1985:4. His predicted prices are significantly different from realized prices. He attributes the differences to possible unobserved cost changes not captured by his model or to pre-merger collusion between airlines.

Estimates of U.S. airline costs and productivity are provided by Chua, Kew and Yong (2005), Duke and Torres (2005), and Fare, Grosskopf and Sickles (2007). Chua, Kew and Yong estimate a translog cost function using observations on 10 U.S. airlines for the period 1994:1 to 2001:1. Returns to output, measured on the basis of revenue passenger miles, are estimated to be roughly constant at 0.9968. Duke and Torres evaluate TFP growth on U.S. airlines for the long period 1972-2001. They find an average 2.0 percent rate of TFP growth. Fare, Grosskopf and Sickles estimate distance functions with a database of 10 U.S. airlines for the period 1987:1 to 1994:4 and construct a Malmquist Index for each year. The index for 1994 is 1.0003, indicating a slight degree of TFP growth. When the index is adjusted for flight circuitry it drops below 1. When it is adjusted for on-time performance it rises above 1.

European airlines also undertook significant reforms in the final decades of the 20th century. Prior to 1980 air traffic to and from European countries was controlled by bilateral agreements that permitted collusive behavior among carriers which were frequently state-subsidized. As Gagnepain and Marin (2006) point out, the liberalization process involved a series of directives from the EU which gave carriers pricing flexibility, freedom to adjust capacity, and the ability to enter and exit markets. These commercial freedoms were accompanied by privatization. Gagnepain and Marin evaluate the performance of deregulated European airlines with a structural model that includes a stochastic frontier cost specification. Their analysis of 10 major EU carriers over the period 1985-1999 finds a 23.4 percent marginal cost reduction attributable to reform and a decrease in the Lerner index from 0.645 pre-1992 to 0.376 post-1992.

[7] The five mergers are Northwest-Republic, TWA-Ozark, Continental-People Express, Delta-Western, and US Air-Piedont.

Economic analysis of air transportation efficiency has not been limited to airlines. Oum, Yan and Yu (2008) employ a stochastic frontier analysis (translog cost function) to study the effect of ownership structures on airport efficiency. The authors point to a world-wide trend toward airport privatization with the U.S. and Canada as exceptions. They analyze a panel of observations on 109 airports for the years 2001-2004 and find that airports where the majority ownership involves private shareholders, public corporations or airport authorities are more efficient than government-owned and managed airports. The least efficient airports are owned and managed by port authorities.

D. Social Costs / Environmental Effects

The focus of transportation policy in the 19th and 20th Centuries was on transportation investments aimed at extending the benefits of access and mobility to more locales and to more citizens. The focus of policy in the 21st Century has also been on reducing the harmful external costs of transportation. Economists continue to work on estimating the external transportation costs associated with safety, congestion, sprawl, and pollution. These estimates are used to identify the full marginal costs—direct costs and external costs—of transportation activities and also to identify the benefits of transportation investments which reduce external costs. (Table 3).

Ozbay, Bartin and Berechman (2001) estimate the full marginal costs—inclusive of congestion, air pollution, noise and accident costs—of highway transportation in northern New Jersey. The authors compare an estimated average full marginal cost of $1.252 for a 10-15 mile trip on the network to the average amount charged by the government of New Jersey for such a trip: $0.428. They calculate that the state of New Jersey would need to charge a fuel tax of $1.247 per gallon to internalize the estimated full marginal cost. This is far in excess of the current tax of $0.1038 per gallon.

Studies estimating external costs in the airline industry focus primarily on noise and emissions costs. Lu and Morrell (2006) estimate the external costs of air travel for communities surrounding airports. They use data on three UK and two Dutch airports and the surrounding residences to estimate the average external cost per landing and the annual external cost. Their hedonic pricing model projects annual noise costs ranging from €1.3 million at Stansted to €179.5 million at Heathrow. Emissions costs are calculated using the standard approach: enumerating the pollutants involved in airport operations then evaluating their monetary impact. The authors estimate annual emissions costs ranging from €7.5 million at Maastricht to €456.6 million at Heathrow. Total external costs (noise plus emissions) range from €10.8 million at Maastricht to €645.1 million at Heathrow.

Dekkers and van der Straaten (2009) also use a hedonic pricing model to calculate the social cost of transport-related noise inclusive of road, rail and airport noise. They estimate the marginal cost of transport-related noise increases using data from the neighborhoods surrounding Schiphol Airport in Amsterdam. They estimate a total cost of a 1 dB noise increase of €48.8 million per year. Day, Bateman and Lake (2007) use a two-stage estimation process to estimate the value of peace and quiet, (i.e. of avoiding noise associated with air, train and road transportation) using data from the city of Birmingham, UK. They first estimate a hedonic pricing function to calculate implicit prices. Next they estimate demand functions for peace and quiet associated with road and rail noise. Since demand functions identify household preferences, they are able to calculate welfare values that can be applied beyond the Birmingham market. The mean estimated values for lack of transportation noise range from £31.49 per annum for a 1dB noise reduction from a 56dB baseline to £91.15 per annum for the same change from an 81 dB baseline.

A desire to reduce the external costs of transportation is often used to justify transportation investments. Careful analyses of these claims are contained in three papers published by Winston and others in the *Journal of Urban Economics*:

- Winston and Maheshri (2006) assess the contribution that urban rail passenger operations have made to social welfare in the cities they serve. The authors finds that with the exception of Bay Area Rapid Transit (BART) these systems reduce welfare. Their analysis is based on panel data of 25 urban rail systems operating in the United States between 1993 and 2000. They estimate cost and demand functions that include network characteristics and then compare the difference between users' consumer surplus and agency deficits. Their overall finding takes into account the estimated effect of rail systems on highway congestion.

- Winston and Langer (2006) evaluate the effect that government highway spending has on road users' congestion costs. The model is

$$(7) \qquad Costs = \exp\,(\sum\sum\sum\beta_{ijk}PerCapSpending_{ijk} + \beta_1 Geography + \beta_2 Weather$$
$$+\beta_3 Transit + \beta_4 Trucks + \beta_5 Employment + \beta_6 Offpeak + \mu$$

where costs are motorists' delay costs, the spending subscripts indicate highway types, and the non-spending regressors are additional factors that should increase (e.g. trucks) or decrease (e.g. transit) congestion. The data is a panel of highway expenditures for the 74 largest U.S. cities in the period 1982-1996. The authors find that some types of highway expenditures reduce congestion but that on average $1 of spending reduces congestion costs by 11 cents. Optimally targeted spending (with respect to congestion) would only bring the benefit to 40 cents for every dollar spent.

- Morrison and Winston (2007) assesses the effect that expenditures by the Federal Aviation Administration (FAA) had on air traffic delays at 78 U.S. airports from October, 1999 through September, 2000. The model is similar in structure to the highway spending model above. The left hand side variable is the average air carrier delay experienced by passengers on commercial and commuter planes. Regressors include weather, airline operational characteristics and FAA expenditures. Hausman test results fail to reject the authors' hypothesis that FAA expenditures can be treated as exogenous in a model of airport delays. Regression results show that a $1 expenditure reduces the cost of delay to airport users by $2.13. Optimal expenditures would reduce the cost of delay by $4.67.

E. Macroeconomic Effects

One of the two final conclusions that Winston reaches in his 1985 survey of the transportation literature is: "it will be important to use the new base of conceptual developments to explore the broader effect of transportation activity on local, regional, or national economies (p.86)". Much work remains, but several recent studies have attempted to demonstrate that traditional cost-benefit analysis of investments in transportation ignore their broader economic effects. Improved transportation effectively increases the extent of the market, facilitating increased competition and specialization. It lowers commercial transactions costs, especially in international trade, and it facilitates the dissemination of knowledge and technology spillovers.

There is theoretical support for positive external effects from transportation investments, but it comes with important caveats. Investment in transportation, especially in infrastructure, is often undertaken by the public sector. Endogenous growth theorists have shown that public investment can increase steady-state growth rates via an increase in the marginal product of capital (Crafts 2009). However, to the extent that public investment is misallocated or funded by distortive taxation its benefits are significantly diminished. The new economic geography literature suggests that transport infrastructure facilitates increased agglomeration thereby indirectly raising TFP. But to the extent these investments increase congestion, the agglomeration effects could diminish.

The studies in Table 4 represent four different approaches to evaluating external gains from transportation investment. All four focus on road infrastructure, but could more or less be extended to evaluate other types of investment in transport technology and infrastructure. Researchers have access to a wealth of microeconomic evidence of the positive correlation between transport infrastructure and various economic indicators. However, estimating a causal relationship is challenging because it is difficult to rule out the notion that this correlation reflects increased economic activity spurring investment rather than the converse.

Canning and Bennathan (2007) estimate the rate of return to investment in paved roads using a pooled cross section of data for 41 countries at different levels of per-capita income for

1960-90. The authors postulate a common worldwide aggregate production function that depends on physical capital, human capital and infrastructure capital per capita. The common production function is estimated with a translog specification in order to capture complementarity and substitutability among the three types of capital. To address the potential for reverse causation the authors estimate the production function using co-integration methods.

The ratio of the estimated rate of return on paved roads to the rate of return on physical capital for a subset of the countries in Canning and Bennathan's sample is presented in Table 4. A value greater than one indicates that additional investment would be productive. This ratio varies widely across countries. Examining the rate of return on investment in paved roads for countries at different levels of income, a U-shape relationship appears. It is highest for a set of middle-income countries that feature low levels of infrastructure relative to physical and human capital. On the other hand, the rate of return on paved roads is very low for high income countries and very poor countries.

Kopp (2007) calculates the return on investment in roads in Western Europe using a growth accounting exercise. He defines a Solow-style growth model where gross output is a function of capital, labor and transport services. He addresses the potential for reverse causation by hypothesizing that transport intensive countries benefit relatively more from an increase in the road stock. If countries build roads as a response to increased GDP growth, one would not expect a relationship between a country's transport intensity and its economic performance when the road stock increases. Kopp does not report rates of return for each country, but indicates that they are about 5% for many countries. He argues that potential rates of return might be higher than his estimates, which might reflect misallocation at the local level.

Jacoby and Minten (2009) use the canonical agricultural household model as a framework to study the gains from investing in rural roads in a developing country. They avoid reverse causation problems by using data from a group of small villages in Madagascar that feature tremendous variation in transportation costs due to rugged terrain, but are otherwise relatively homogenous. The authors to estimate a demand curve for transportation using non-parametric econometric techniques. The area under this demand curve represents the direct benefit of making the household in the most remote location at least as well off as the household at zero distance to market. The authors estimate this at 17% of average annual income. To obtain the full benefit of the road, the authors augment the direct benefit with the value of access greater non-agricultural labor opportunities. When this is added, the benefit jumps to 52% of average annual income.

Venables (2007) explores the gains to investment in urban transport infrastructure in the context of the new economic geography literature. He models infrastructure investment as a reduction of the cost of commuting in a standard urban economics model. In Venables' model, transport improvements lower the cost of commuting. This brings additional employees into the city center, boosting the productivity of new and existing workers. A distortionary tax system provides an additional gain: New commuters choose to work in the city center based on their post-tax income, while the output increment produced by the marginal worker is defined by pre-tax income. The difference accrues to the government. Assuming that the government spends this money well, the total gain is thus further increased.

Venables performs a numerical simulation of a 20 percent reduction in commuting costs along one of four routes leading into a city center. He does not calibrate his model to any data, but uses parameters of "reasonable orders of magnitude". He argues that real income gains resulting from road investment in his model are much larger than those typically found in traditional cost-benefit analysis.

IV. Policy Implications

In their 1999 book *Secret Origins of Modern Microeconomics: Dupuit and the Engineers*, Ekelund and Hébert argue that the rigorous analytical tradition in microeconomics inquiry was initiated by members of the *Corps des Ingénieurs des Ponts et Chaussées* (roads and bridges) in France. One could argue (with some bias, admittedly) that microeconomics owes its existence to the problems presented by transportation. Economists have had only partial success in repaying the favor.

Clearly, economics has had an impact on airline markets and on railroads and surface freight. The empirical results reported above suggest that deregulation has ~~increased welfare~~ improved performance in U.S. rail freight markets [Bitzan and Wilson (2007); Winston, Dennis and Maheshri (2008); Winston, Maheshri and Dennis (2009); Ivaldi and McCullough (2005, 2010)] and European rail passenger markets as well. Airline deregulation has increased efficiency (and volatility) in U.S. passenger markets [Berry and Jia (2010)] and has had a positive effect on airline performance in Europe [Gagnepain and Marin (2006)].

Not all of the policy issues have been resolved. Rail networks pose a special challenge for competition advocates because they sometimes resist the unbundling of vertically integrated activities into a common infrastructure entity and competing operating entities. Econometric studies of rail firms in the U.S. and Europe find there are economies of scope *between* operations and infrastructure and *among* operational activities [Bitzan (2003); Ivaldi and McCullough (2008); Growitsch and Wetzel (2009)]. This suggests that firms operating on network infrastructure may still exhibit characteristics of natural monopoly.

There are also unresolved problems in the management of airports and airspace. Exogenous FAA spending on the airspace is effective but it could be much more effective [Morrison and Winston (2007)]. It is unlikely that airports in the U.S. and Canada will reach their potential while government ownership is prevalent [Oum, Yan and Yu (2008)] .

Though the details are not well understood, it is clear that transportation infrastructure has a profound impact on the macroeconomy by decreasing transportation costs [~~See~~ Krugman (2009)] and promoting agglomeration economies [Glaser and Gottlieb (2009)]. Direct spending on transportation in 2006 was $2.3 trillion or 17.5 percent of GDP, and when travelers' value of time and logistics costs are added to that the figure grows to $5 trillion [Winston (2010)].

This makes it imperative that the highway system which accounts for the bulk of passenger travel and freight movement is managed effectively and maintained judiciously. Yet serious problems remain in the highway mode where politicans, engineers, and planners have paid little attention to economics. Economic research suggests that highway impose significant social costs, especially in the form of congestion [Ozbay, Bartin and Berechman (2001)]. Winston and Langer (2006) show that the benefit cost ratio of government highway spending vis-à-vis congestion is 0.10. Economists have argued for decades that the effective approach to highway system is a pricing and investment regime based on marginal costs. The rational policy for ~~road~~ highway infrastructure is "Price and provide". The current policy is "Predict and provide."

Rail transit systems have minor impacts compared with highway systems but they do carry a significant number of passengers in some cities. Winston and Maheshri (2006) show that, with the exception of BART, the effect of government spending on urban rail transit is to reduce social welfare. Again, the economic solution which includes privatization is "Price and provide." The policy is "Pretend and provide."

What can we expect in the next decade? The flow of papers on transportation economics will continue, of course. The policy question are too interesting—and the available data sets too rich--for economists to pass up. But the second conclusion that Winston reached in 1985 is telling.

> 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* [emphasis added]. (p. 86)

The more things change, the more they remain the same.

TABLE 1

TRANSPORTATION COST ESTIMATES

A. Air Transportation

Study	Specification	Data	Estimate
Fischer & Kamerschen (2003)	NEIO Translog	10 major U.S. 1991:1-1996:4	Marginal Cost $0.05-$0.09 per ASM*
Chua, Kew & Yong (2005)	Translog	10 major U.S. 1994:1=2001:1	Returns to output (RPM)** 0.9968
Gagnepain & Marin (2006)	Structural Stochastic Frontier	10 major Europe 1985-1999	Lerner index 0.465 (pre-1992 reform) 0.376 (post-1992 reform)
Berry & Jia (2010)	Structural	Multiple U.S. 1999 and 2006 4,000 O-D pairs	Marginal costs/Lerner index $0.06 per ASM* (MC) 0.63 (1999 Lerner index) 0.60 (2006 Lerner index)

* ASM – Avalailable seat-mile

** RPM – Revenue seat-mile

B. Rail Transportation

Study	Specification	Data	Estimate
Christopoulos, Loizides & Tsionas (2001)	SFA (Translog)	10 EU RRs 1969-1992	Input Technical Efficiency 70.66 to 100.0 (Capital) 80.55 to 100.0 (Labor)
Loizides & Tsionas (2001)	Translog	10 EU RRs 1969-1994	Density Effects 0.83 to 1.03 (Return to density)
Mizutani (2004)	Translog	Pvt Japan RRs 1970-2000	Density and Scope Effects 1.638 (Returns to density) 1.102 (Return to scope)
Ivaldi and McCullough (2007)	Generalized McFadden	U.S. Class Is 1981-2004	Marginal operating cost $0.35 per car-mi (Bulk) $0.92 per car-mile (General) $380.62 per tie (Infrastructure) 1.31 (Return to density)
Bitzan & Wilson (2007)	Translog	U.S. Class Is 1983-2003	Projected Industry Costs (Yr) $33.6 billion (without mergers) $29.8 billion (with mergers)

Study	Specification	Data	Estimate
Wheat & Smith (2008)	Double-log	UK Track Cos. 2005-2006	Marginal track costs 0.0014 € per ton-km 0.421 € per train-km
Ivaldi and McCullough (2009)	Generalized McFadden	U.S. Class Is 1978-2001	Projected firm-level costs (Yr) $1.1 billion (Integrated firm) $1.4 billion (Separated firm)

C. Transit

Study	Specification	Data	Estimate
Farsi, Fetz & Fillipini (2007)	Quadratic	16 Swiss Cos. 1985-1987	Density and Scope Effects 1.19 (Return to density) 0.25 (Return to scope)

TABLE 2

TRANSPORTATION PRODUCTIVITY ESTIMATES

A. <u>Rail Transportation</u>

Study	**Specification**	**Data**	**Estimate**
Bitzan & Keeler (2003)	Translog Cost	U.S. Class Is RRs 1983-1997	<u>Annual TFP Growth</u> 3.1 percent
Loizides & Tsionas (2004)	Translog Cost	10 EU RRs 1969-1993	<u>Annual TFP Growth</u> 1.5323 percent
Duke & Torres (2005)	Tornqvist index	U.S. airlines 1972-2001	<u>Annual TFP Growth</u> 2.0 percent (1972-2001) 5.1 percent (1973-1979) 0.8 percent (197-1990) 1.9 percent (1990-2000)
Lan & Lin (2006)	Stochastic Frontier	Non-U.S. RRs 1995-2002	<u>Efficiency index (1.0)</u> 0.828 (W. Euro. RRs) 0.497 (E. Euro. RRs) 0.586 (non- Euro. RRs)

Khumbhakar *et. al*. (2007)	Distance Functions	EU RRs 1971 – 1994	Annual TFP Growth 1.5 percent
Fare, Grosskopf & Sickles (2007)	Malmquist Index*	10 U.S. airlines 1987:1-1994:4	Efficiency index (1.0) 1.0003 (1994 index) 0.9976 (1994 Circuitry) 01.0013 (1994 On-Time

*Malmquist Index – Ratio of Output Distance Functions for periods *t+1* and *t*.

B. Truck Transportation

Study	**Measure**	**Data**	**Estimate**
Boyer and Burks (2009)	Physical Productivity	U.S. trucks 1982-1997	Ton-Miles/Year** 1.85% (1997 wtd ave.) 1.31% (1982 wtd ave.) 1.33% (1997 wtd. ave., 1982 length) 0.84% (1982 wtd. ave., 1982 length)
Shaik et al (2009)	Stochastic Frontier	U.S. trucks 1994-2003	Ave. Efficiency Score 0.615, Gen. Freight LTL 0.623, Gen. Freight TL

Study	Measure	Data	Estimate
			0.715, Heavy Machinery 0.689, Petroleum 0.698, Refrigerated Solid 0.474, Dump Trucking 0.627, Ag. Commodities 0.559, Motor Vehicles 0.705, Building Materials 0.743, Other
Hubbard (2003)	Productivity Increase due to IT	U.S. trucks 1997	Loaded Miles per period 12.7% for adopters 3.3% total fleet
Barla et al (2008)	Productivity Increase due to IT	Canadian trucks 1999	Tons/Km 6.3% for adopters 0.83% total fleet

*Average annual change

TABLE 3

SOCIAL AND ENVIRONMENTAL COST ESTIMATES

Study	Specification	Data	Externality	Estimate
Winston and Maheshri (2006)	Linear Demand Function Linear Cost Function	U.S. Urban rail transit 1993-2000	Congestion	<u>Social Net Benefits</u> -$3,842 million, total U.S. $99.8 million, BART (San Francisco) -$454.3 million, NYC transit
Ozbay, Bartin and Berechman (2001)	One-Route Marginal Cost	Northern New Jersey Highways 1990s	Congestion Air pollution Noise Accidents	<u>Ave. Full Marginal Cost</u> $1.389, Operating cost $3.786, Congestion cost $1.009, Accident cost $0.062, Infrastructure cost $0.114, Air pollution cost $0.158, Noise cost Average FMC, 10-15 mi. trip $1.252

Study	Specification	Data	Externality	Estimate
Lu and Morrell (2006)	Hedonic for noise Weighted sum of emissions for air pollution	3 UK and 2 Dutch Airports	Noise Air pollution	Annual external cost €645.1 million, Heathrow €470.7 million, Schiphol €161.2 million, Gatwick €82.1 million, Stansted €10.8 million, Maastricht
Dekkers and van der Slaaten (2009)	Hedonic	Neighborhoods in the vicinity of Schiphol Airport	Rail, Road and Airport Noise	Marginal Cost/yr -€49 million, 1 dB noise increase -€57 million, 2dB -€67 million, 3dB -€77 million, 4dB -€87 million, 5dB
Day, Bateman and Lake (2007)	2-Step Hedonic	Birmingham, UK residential properties 1997	Rail, Road and Airport Noise	Ave. Consumer Surplus/Yr. £31.49, for 1dB road change £83.61, for 1dB rail change

TABLE 4

GAINS FROM INFRASTRUCTURE INVESTMENT

Study	Model	Data	Estimation Approach	Estimate
Canning and Bennathan (2007)	Common Worldwide Translog Aggregate Production Function	Length of paved roads, Various countries	Pooled OLS with short-run adjustment terms	ROR Roads/ROR Capital* 0.34 Botswana 0.45 Pakistan 13.33 Argentina 36.95 Korea, Rep. 0.26 USA 0.32 UK *Additional countries reported
Kopp (2007)	Solow Growth Model	Road Stock Western Europe	Country and Time Fixed Effects	Rate of return to roads "For many countries around 5%"

Study	Model	Data	Estimation Approach	Estimate
Venables (2007)	Standard Urban Economics Model	Urban Transit, Not calibrated to data	Numerical Methods	<u>Real Income gains</u> *(%base income)* 0.909, Linear commuting costs 0.530, Non-linear commuting costs *Elasticity of production with respect to CBD employment: 0.045*
Jacoby and Minton (2009)	Canonical Agricultural Household Model	Road Infrastructure Rural Madagascar	Non-parametric	<u>Benefit/Income Ratio</u> 0.17 Direct Benefit 0.518 Direct + Non-farm earnings

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