Estimation of Modal Demand Elasticities in Grain Transportation*

William W. Wilson

Recent legislation in the transportation industry has stimulated a move toward more flexibility in railroad pricing and has consequently provided the impetus for the analysis of transportation demand. Modal demands for grain transportation are analyzed in this paper using a derived demand approach assuming dual relationships between production and cost functions of shippers' distribution activities. Hypotheses were introduced in the empirical specification about the effects of rail car shortages and the introduction of multiple-car rail rates. The model was estimated and hypotheses tested in the case of eastbound wheat and barley shipments from North Dakota.

Regulation of railroad rates by the Interstate Commerce Commission has traditionally been an important public policy affecting the grain transportation industry. However, recent legislation has encouraged a trend toward less regulation over railroad rates. Although regulation of railroad pricing has only been partially relaxed, the thrust of both the Railroad Revitalization and Regulatory Reform Act of 1976 (4R Act) (U.S. Congress, 1976) and the Staggers Rail Act of 1980 (U.S. Congress, 1980) has encouraged more flexibility in railroad pricing.[1] In the new regulatory environment, competitive forces will play a greater role in rate determination. There are several competitive forces which affect rates in the transportation industry. Intermarket or geographic competition is the effect of spatially separated demands for commodities competing for limited supplies, and both commodity and transport prices allocate movement. Intermodal and intramodal competition are other potential forces affecting the rate level. The presumption in reducing regulation over railroad rates is that the combination of these forms of competition is sufficient to regulate modal rates. The effect of deregulation on modal pricing depends on the nature of competition in particular movements as reflected in demand elasticities. The aggregate demand for transport is traditionally assumed to be price inelastic. Modal demands, however, are less price inelastic because of the possibility of intermodal substitution (Wilson). In the case of grain, most rail movements have either immediate or potential substitutes from trucks and/or barges. One of the implications of deregulation is that the emphasis of research, both public and private, will likely

---

William W. Wilson is an Associate Professor in the Department of Agricultural Economics at North Dakota State University.

* Journal Paper No. 1335, Agricultural Experiment Station, North Dakota State University, Fargo. The author has benefited from discussion and suggestions from T. Oum and Won Koo of Queen's University and North Dakota State University, respectively, and two anonymous reviewers.

---

[1] The article by Johnson (1981) and subsequent reply (Johnson 1983) provide a review of potential impacts of deregulation on agriculture. In addition, impacts of the changing regulatory environment are discussed in a report by the USDA Office of Transportation.

Western Journal of Agricultural Economics, 9(2): 244–258

be oriented more to the analysis of demand and demand relationships.

Several methodologies have been used to analyze the demand for transportation in general and by mode. These include optimization models, models of modal choice, *ad hoc* specified and estimated demand functions, and derived demand models. Optimization models in the analysis of transport demand incorporate the interactions of commodity supply and demand conditions with transportation rates as well as constraints inherent in the system. Koo and Bredvolt (1982a) constructed a national model of grain transportation to analyze the effects of constraints, expanded output and different rate structures. Fuller and Shanmugham analyzed intramodal competition (rail/rail) in the southern plains states using an optimizing transshipment model. A more recent study by Fuller *et al.* uses similar methodology to analyze potential effects of deregulation.

The second type of transportation demand analysis is estimation of a modal choice behavioral function (McFadden). Endogenous variables in the two-mode case are binary and indicate utilization of the two modes. Exogenous variables typically include both rate and service characteristics (e.g., frequency of service and transit time). This technique has been used in studies by Levin, Miklius *et al.*, and Johnson (1976). More recently, Oum developed the theoretical assumptions underlying the use of linear logit models for transport demand studies (Spring 1979). The linear logit model imposes several rigid *a priori* restrictions on estimated parameters and a structure of technology which is irregular and inconsistent; consequently, it may not be appropriate for use in the case of transport demand studies. A third type of demand analysis is specification of behavioral equations using *ad hoc* conceptual reasoning. These are characterized by regression models of shipments as a function of exogenous variables which are introduced without rigorous specification. Examples in agriculture include the recent study by Fitzsimmons. *Ad hoc* models are typically useful for forecasting but suffer in several respects in the analysis of price responsiveness of demand. The proper set of exogenous variables, and the functional form of the model, are both somewhat arbitrary. Coefficients estimated from these models are typically sensitive to the functional form and included exogenous variables.

Estimation of derived demand models provides another methodology for analyzing modal demands for transportation. Assuming dual relationships between production and cost functions of shippers' distribution activities, and flexible forms of the cost function, modal factor shares can be derived. Parameters are estimated from either factor share equations and/or the cost function and can be used to derive elasticities of modal substitution, own- and cross-price elasticities, and ordinary (Marshallian) demand elasticities. Friedlander and Spady applied these procedures to a cross section of shipments from U.S. manufacturers. Oum applied similar procedures in Canada using cross-sectional data (Autumn, 1979) and time series data (1978).

The duality approach to analyzing intermodal competition in transportation is attractive because its functional specification is consistent with neoclassical economic relationships. Further, hypotheses about changes in behavior of demand parameters can easily be incorporated into the model and tested. The duality approach is used in this study to analyze intermodal competition in grain transportation from North Dakota. The model is expanded to analyze the effects of rail car shortages, and of multiple-car rates on the behavioral equations.

Model Specification

Theoretical Development

The parameters of the derived demand function for each mode are developed from the theory of the firm with a particular technology. The firm in this case is the country elevator which engages in the handling and distribution of grain commodities. An aggregate twice differentiable production function is assumed which relates gross output to the services of three major inputs: capital (K), labor (L), and transportation (T). Transport services are assumed separable from the other inputs in the production function. This implies that the rate of technical substitution between any pair of modes is invariant to the levels of capital and labor employed in the country elevator sector.[2]

Corresponding to the production function exists a cost function which reflects the technology. Assuming these dual relationships means that information about technology can be recovered by evaluating a cost function, which is simply a summary of all economically relevant aspects of the firm's technology. The concept of duality with respect to cost functions has been developed previously. See, for example, Shephard, Uzawa (1962 and 1964), McFadden, and Diewert. Minimization of cost subject to the production function results in a cost function relating total cost to output and prices of inputs. Due to the homothetic separability theorem (Blackorby *et al.*), a sectoral cost function for transport service can be specified as:[3]

$$C = g(Q, P_1, P_2, \ldots P_n) \qquad (1)$$

where C is the cost of distribution activities, and P_i ($i = 1, 2, \ldots n$) is the input price for mode i.

A specific functional form for g must be assumed for estimation. A highly general function form is desired which places no *a priori* restrictions on the Allen partial elasticities of substitution. The translog function was chosen to be used in this study. It is homogenous of degree one in prices which does not impose homogenous of degree one on the production function. The translog function is a continuous function of prices and can serve as a local second-order approximation to an arbitrary cost function. Variables used in estimating translog functions can be interpretated as deviations from the point of approximation, which in this case is taken to be the sample's arithmetic mean. The translog cost function has been used frequently in empirical studies because of its flexibility and other attractive properties. Development is attributed to Christensen *et al.* and it has been used in energy-related studies by Berndt and Wood, Christensen and Greene (1976, 1978) and Stevenson; in analyses of the agricultural sector by Binswager and by Lopez (see also the review by Pope); and in the analysis of transport demand by Oum (1978, Autumn 1979) and Friedlander and Spady.

The translog cost function has the following specification:

$$\begin{aligned}\ln C = {} & \ln a_O + a_Q \ln Q + a_{QQ} \tfrac{1}{2} (\ln Q)^2 \\ & + \sum_i a_i \ln P_i + \tfrac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j \\ & + \sum_i \gamma_{iQ} \ln P_i \ln Q. \qquad (2)\end{aligned}$$

The variables are as previously defined, and a_O, a_Q, a_{QQ}, a_i, γ_{ij} and γ_{iQ} are parame-

---

[2] Separability of transportation in the production function is an empirical question which cannot be tested here due to the lack of necessary time series price data on capital and labor in the country elevator sector. Oum (1978) tested the separability assumption of transportation services in Canada for aggregate shipments and concluded that it was valid.

[3] If the production function is increasing and satisfies the conditions of continuity, monotonicity and quasiconcavity, the homothetic separability theorem states that the separability of transport services from other inputs in the production function, is equivalent to the separability of the price of transport from prices of other inputs in the cost functions.

ters. Equation (2) can be reduced by imposing several theoretical conditions on the parameters. The Hicks-Samuelson symmetry condition, $\gamma_{ij} = \gamma_{ji}$, states that the elasticities of substitution between modes are symmetric. The second condition is that of linear homogeneity which implies the following restrictions on parameters:

$$\begin{aligned} &\sum a_i = 1 \\ &\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = \sum_i \sum_j \gamma_{ij} = 0 \\ &\sum_i \gamma_{iQ} = 0 \end{aligned} \tag{3}$$

These imply homogeneity of degree one in prices but do not impose homogeneity on the production function. Imposing the above conditions in the two-mode case reduces the number of parameters to be estimated to a_O, a_{QQ}, a_Q, γ_{11}, and γ_{1Q}.

Factor share equations can be derived by differentiating Equation (2) with respect to each of the input prices and applying the Hotelling-Shephard Lemma:

$$S_i = a_i + \sum_j \gamma_{ij} \ln P_j + \gamma_{iQ} \ln Q \tag{4}$$

where $S_i = Q_i P_i / C$ and is the proportion of total transportation cost spent on mode i. From the mode's perspective, S_i is its share of the total transportation revenue.

The parameters in the factor share equations are the same as those in the cost function and can be interpreted directly or used to calculate elasticities. γ_{iQ} is the nonhomothetic parameter and shows the effect of changes in Q on factor shares. If γ_{iQ} equals zero, the production structure is homothetic meaning that at constant factor prices, factor shares are not affected by the output level. The other parameters have little economic meaning by themselves. However, they can be used to derive elasticities. Uzawa has shown that the elasticities of substitution are:

$$\begin{aligned} \sigma_{ij} &= (\gamma_{ij} + S_i S_j)/S_i S_j \\ \sigma_{ii} &= [\gamma_{ii} + S_i(S_i - 1)]/S_i^2 \end{aligned} \tag{5}$$

If $\gamma_{ij} = 0$ the elasticity of substitution is equal to one. Berndt and Wood have shown that Hicksian own-price and cross-price elasticities of demand are:

$$\begin{aligned} E_{ii} &= \sigma_{ii} S_i \\ E_{ij} &= \sigma_{ij} S_j \end{aligned} \tag{6}$$

Hicksian elasticities describe price responsiveness assuming constant output (i.e., on the same isoquant). In the two factor case, $E_{11} = -E_{12}$ and $E_{22} = -E_{21}$ because the compensated modal elasticities sum to zero. The elasticity of Marshallian ordinary demand is:

$$F_{ij} = (\sigma_{ij} + \eta) S_j \tag{7}$$

Where η is the own-price elasticity of the commodity being transported (Oum, Autumn 1979). The Marshallian elasticity allows for the effect of changes in modal rates on commodity prices.

Hypothesis Formulation

In addition to the output level and modal prices, the cost function for distribution activities in the grain industry is potentially affected by the existence of rail car shortages which can be introduced as a service quality variable. Johnson (1976), as well as others, has emphasized the importance of service quality in transport demand analysis. Oum (Autumn 1979) has demonstrated the incorporation of service quality in translog functions. Given the institutional environment in which rail rates were established (at least in the time period of this study), equipment shortages did not have an effect on rail rates. However, rail car shortages potentially result in higher truck rates which are reflected in the theoretical and empirical model. In addition to the effect of rail car shortages on truck rates, other effects may occur during periods of rail car shortages. These are posed in the theoretical model in the form of hypotheses as follows:

$$\begin{aligned} \ln C = {} & \ln a_O + a_Q \ln Q \\ & + \tfrac{1}{2} a_{QQ} (\ln Q)^2 + a_r R \end{aligned}$$

$$
\begin{aligned}
&+ \sum_i a_i \ln P_i \\
&+ \tfrac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j \\
&+ \sum_i \gamma_{iQ} \ln P_i \ln Q \\
&+ \sum_i \gamma_{ir} \ln P_i R + \phi_1 \ln QR \qquad (8)
\end{aligned}
$$

$$
\begin{aligned}
S_i = a_i &+ \sum_j \gamma_{ij} \ln P_j \\
&+ \gamma_{iQ} \ln Q + \gamma_{ir} R \qquad (9)
\end{aligned}
$$

where R is a binary variable equal to one if a shortage of rail cars exists. Linear homogeneity requires that $\sum_i \gamma_{ir} = 0$ in addition to the restrictions specified in Equation (3). The effect of rail car shortages on these equations can be evaluated in terms of the first and second order partial derivatives. Of particular interest are the parameters γ_{ir} and ϕ_1. γ_{ir} indicates the extent that rail car availability affects modal revenue shares and is expected to be negative. If $\phi_1 \neq 0$, the responsiveness of total distribution costs to the output level (rail car shortages) varies with the existence of rail car shortages (output level).

A second hypothesis relates to the effects of the introduction of multiple-car rates for railroads. From an intermodal demand perspective the Staggers Rail Act had three potentially important effects.[4] First, the use of contracts between individual shippers and carriers was allowed. While contract rates have the potential to be an important factor in the future, their use at the country elevator in North Dakota has been limited, especially in the time period of this study. Second, the Staggers Rail Act allowed for and encouraged more frequent changes in rail rates in response to demand conditions. Third, the Staggers Act facilitated and encouraged introduction of multiple-car rates, even though there was no legislative mandate prior to Staggers obviating use of these rates. In fact, multiple-car rates were used extensively elsewhere in the country and in westbound shipments from North Dakota prior to Staggers. The Staggers Rail Act was an institutional change, but in practice at the country elevator level its impact was reflected in the level of rail rates—both in terms of more frequent changes and by the introduction of multiple-car rates.

Multiple-car rates affect intermodal competition because they are at a lower level than single-car rates. Hence, using the lower multiple-car rate, which went into effect in July 1981 for movements analyzed in this study, reflects a change in rail rates. This effect is included in the basic model in the rail rate variable. In addition to the "rate-effect" described above, multiple-car rates may have an impact on the cost and derived demand function in grain distribution. The second hypothesis was posed to test for non-neutral impacts of the innovation of multiple-car rates on modal demands.

A dummy variable was included in the theoretical model to account for a potential structural change after the introduction of multiple-car rates.[5] The model with the inclusion of the effects of rail car shortages and the imposition of multiple-car rates is:

---

[4] One other important effect of Staggers was elimination of railroad rate bureaus, which prohibited explicit collusive pricing between railroads. This effect was not analyzed in this study because historical pricing practices resulted in rates which were the same for all railroads in the rate bureau. Indeed, ever since elimination of the rate bureau, rate changes for one firm are matched by the others. Consequently, time series of rates for each railroad would be perfectly correlated making estimation of theoretical demand functions, one for each firm, impossible.

[5] An alternative means to formulate hypotheses of these structural changes would be to treat the rail price as including all dimensions of service. In this case the effective railprice, P_r' depends on the nominal rate level, P_r and the characteristics of rail service and institutional effects, X. The cost function would be respecified with output Y, other input prices P_0, and P_r' as explanatory variables. P_r' would also be specified to be functionally related to P_r and X, and could be estimated as a block-recursive system.

$$
\begin{aligned}
\ln C = {} & \ln a_0 + a_Q \ln Q \\
& + \tfrac{1}{2} a_{QQ} (\ln Q)^2 \\
& + a_r R + a_m M \\
& + \sum_i a_i \ln P_i \\
& + \tfrac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j \\
& + \sum_i \gamma_{iQ} \ln P_i \ln Q \\
& + \sum_i \gamma_{ir} \ln P_i R \\
& + \sum_i \gamma_{im} \ln P_i M \\
& + \phi_1 \ln QR + \phi_2 \ln QM \qquad (10)
\end{aligned}
$$

$$
\begin{aligned}
S_i = {} & a_i + \sum_j \gamma_{ij} \ln P_j \\
& + \gamma_{iQ} \ln Q \\
& + \gamma_{ir} R \\
& + \gamma_{im} M \qquad (11)
\end{aligned}
$$

where M is a binary variable equal to one for the period of time after the introduction of multiple-car rate. Linear homogeneity requires that $\Sigma \gamma_{im} = 0$ in addition to the other restrictions. The effect of multiple-car rates is included in the model in several ways. First, an important effect is reflected by the lower rail rates for multiple-car shipments which were used in the period in which they were applicable. This effectively implies a movement along the rail revenue share function. Other potential effects of multiple-car rates are implied in the theoretical functions which allow for potential structural changes and are represented in the following first order partial derivatives:

$$\frac{\partial \ln C}{\partial M} = a_m + \sum_i \gamma_{im} \ln P_i + \phi_2 \ln Q \qquad (12)$$

$$\frac{\partial S_i}{\partial M} = \gamma_{im}. \qquad (13)$$

Equation (12) represents the percentage change in cost of distribution that can be attributed to the availability of multiple-car rail rates. At the sample mean $\partial \ln C / \partial M = a_m$ which is the extent that total costs change as a result of multiple-car rates. Equation (13) shows the effect of multiple-car rates on modal revenue shares. For example, if $\gamma_{im} > 0$ the introduction of multiple-car rates would have resulted in an increase in mode i's revenue share (i.e., multiple-car rates were mode i intensive). Incorporation of structural changes or differences have been treated similarly in studies using dual derived demand functions by Oum (Autumn 1979) and Friedlander and Spady in transportation; Binswager in agriculture; and Stevenson and Christensen and Greene in power generation.

Empirical Specification and Estimation

The translog cost and factor share equations form a system of three equations with common parameters. Single equation estimation of any one of the factor share equations would neglect additional information contained in the cost equation. An alternative estimation procedure would be to estimate the cost and factor share equations jointly. The effect of this would be to add additional degrees of freedom without adding any unrestricted parameters. As a result, the parameter estimates would be more efficient than applying ordinary least squares to any one of the equations (Christensen and Greene, 1976: 662).

An empirical specification is derived by adding a vector of additive error terms to each of the theoretical equations. At each observation, summation of the factor shares equals one and summation of the error terms equals zero. Consequently, the disturbance covariance matrix of the full three-equation system is singular and nondiagonal and cannot be used for estimation. The parameter estimates can be derived, however, by dropping one of the factor share equations and applying Zellner's technique for efficient estimation. Kmenta and Gilbert have shown that iterating the Zellner estimation procedure yields maximum-likelihood results and Barten has shown that maximum-likelihood estimates are indifferent to the choice of deleted equation. The truck factor share equation, S_2, was arbitrarily dropped, and the translog cost function was jointly estimated with S_1, subject to the parameter restrictions.

Time-series data are used in this study, and consequently adjustments need to be introduced into the equation system to allow for potential dynamic behavior of the shippers and the error terms. In particular, a potential exists for lagged responses in model shares to price changes and serial correlation. The dynamic behavior of decision makers may include a partial adjustment process similar to Nerlove's adjustment model. Transformation of the translog cost and modal share equations results in two equations which are nonlinear in parameters. β_c and β_s are the partial adjustment parameters and ρ_c and ρ_s are the first order autoregressive parameters where c and s denote cost and modal share, respectively. If $\beta_c = \beta_s = 1$, then the adjustment process is instantaneous. In this case, the model reduces to an autocorrelated model with no time lag between a change in an exogenous variable and costs or factor shares. If ρ_c and $\rho_s = 0$, the model would be a partial adjustment model without a first order autoregressive scheme. The potential for dynamic lags in shippers' responses and autocorrelated error terms are hypotheses which were posed in the form of restrictions placed on each model. These were tested using the procedure discussed below and follow the nesting used by Oum (1978).

Estimation

The two empirical equations with common parameters form a system of equations, and as discussed above, iterative three-stage least squares (IT3SLS) is the appropriate estimation technique. The procedure used to estimate the parameters in these models is a combination of the Zellner technique and the Gauss-Newton method of nonlinear least squares. The estimated parameters are asymptotically efficient and equivalent to maximum likelihood estimates.

The model specified above implies that P_1 and P_2 are exogenous variables and that the regressors are uncorrelated with the disturbances. However, it is likely that in the case of grain transportation, the rate charged by exempt motor carriers, P_2, should be treated as endogenous. Truck rates are exempt and respond to railroad rates and rail car availability. To account for this simultaneity, the method of instrumental variables is used. Estimates using this method are consistent but they are not unbiased. The variables used as instruments were linear and nonlinear combinations of an index of rail car availability, grain prices, and index of truck costs and total shipments from the state. Similar procedures were used in Friedlander and Spady, and Berndt and Wood.

Hypothesis Testing

The technique developed by Gallant and Jorgensen is used for testing these hypotheses. It is the 3SLS analog of the likelihood ratio test and allows making statistical inference on the appropriateness of restrictions. The test involves estimating the model first without the restrictions and then with the restrictions, and comparisons are made across the estimates. It is necessary, however, to use the S matrix (covariance of errors across models) from the unrestricted model in estimation of the restricted model. The null hypothesis is the restriction imposed on the model versus the unrestricted model. The test statistic is:

$$T^0 = n(S_r - S_u)$$

where S is the value of the criterion function and the subscripts r and u indicate the restricted and unrestricted model, respectively. T^0 has an asymptotic chi-square distribution with the number of degrees of freedom equal to the difference between the number of parameters in the unrestricted and restricted models.

Data

The system of two equations was estimated for grain shipments from North Dakota to major terminal markets. The time period of study was from July 1973 to December 1982, and monthly observations were used. Wheat and barley were the commodities analyzed and separate equations were estimated for each. These grains are traditionally the two most important grains shipped from the state and normally comprise about 75–80 percent of the grain shipments. Data necessary for the analysis include shipment and price (or rate) data for each mode. Shipment data were those collected by the North Dakota Public Service Commission and represent grain shipments from all licensed warehouses. The destinations used in the analysis were Minneapolis and Duluth, which are the principal destinations for North Dakota wheat and barley shipments, and separate equations were estimated for each.

Rail rates were taken from the Minneapolis Grain Exchange Rate Book. A central point was chosen for each of the nine Crop Reporting Districts and monthly rates were collected for each of the grains to each of the destinations. The rate from each origin was weighted by the proportion of total movements shipped from that origin relative to the state. Rates from each origin were the same to both destinations during the sample period. However, rates for barley to Minneapolis were greater than those for wheat. Throughout the study period rail rates varied due to experimentation with seasonal rates, general rate changes (increases and decreases), and the introduction of multiple-car rates in July 1981. At that time rates were published for 26-car multiple origin, 26-car single origin, and 52-car unit trains. After discussions with trade representatives, it was decided that the 26-car single-origin rate was most appropriate and it was used throughout the remainder of the time period.

One of the main problems which impedes transportation modal demand analysis in the grain industry is the unavailability of time series data on rates for exempt motor carriers. Nine elevators scattered throughout eastern and central portions of North Dakota were identified which have maintained records on rates paid for truck transportation for the duration of the study period. Monthly rates from each shipping point to each destination were collected. An average rate was calculated across these origins and used to represent the time series of truck rates in North Dakota.[6]

Both rates were deflated by the Wholesale Price Index (WPI) with 1967 = 100. Modal prices and revenue shares averaged across marketing years are shown in Table 1. Besides the adjustments apparent in the real prices in Table 1, seasonal rates were in effect for part of the study period. The rail revenue share varied throughout and reached a low in 1978/79 in wheat shipments and in 1976/77 in the case of Duluth barley shipments. The railroads have always held a significant market share in barley shipments to Minneapolis despite their high relative rates because of traditional marketing practices for malting barley.[7]

---

[6] Correlation coefficients for truck rates across these origins ranged from .82 to .96 indicating that the temporal variability in truck rates is similar.

[7] An important factor favoring rail shipments was the high proportional rate structure for barley beyond Minneapolis. Inbound rail shipments were required to apply against the proportional outbound rail rate which was less than the flat rate. Consequently, inbound shipments by truck were financially penalized and discouraged. These provisions were recently changed.

TABLE 1. Annual Average Modal Prices and Revenue Shares for Grain Shipments from North Dakota (1967 = 100).

Marketing[a] Year	Modal Prices (¢/cwt.)					Rail Revenue Shares			
	Truck		Rail			Wheat		Barley	
			Duluth		Minneapolis[c]				
	Duluth	Minneapolis	Wheat	Barley	Barley	Duluth	Minneapolis	Duluth	Minneapolis
1973/74	27.4	26.9	20.5	28.9	27.8	.72	.66	.40	.97
1974/75	23.5	23.3	22.9	32.7	31.4	.83	.80	.81	.98
1975/76	27.0	26.9	30.8	40.4	38.8	.76	.74	.65	.97
1976/77	27.7	27.1	31.9	41.8	40.1	.75	.69	.28	.96
1977/78	29.3	28.4	32.7	34.2	35.9	.75	.70	.39	.93
1978/79	30.3	29.0	31.2	27.3	31.0	.60	.62	.58	.93
1979/80	32.9	31.8	31.4	26.8	36.6	.73	.64	.67	.96
1980/81	32.9	33.2	39.1	32.6	49.2	.78	.71	.60	.98
1981/82	30.8	30.7	30.6	26.0	50.9	.77	.67	.64	.95
1982/83[b]	31.5	32.0	30.5	26.6	43.1	.80	.68	.67	.90

[a] July to June marketing year.
[b] Includes July to December.
[c] Rail rates for wheat are the same to Minneapolis and Duluth.

Empirical Results

Separate models were estimated for wheat shipments to Duluth and Minneapolis and for barley shipments to these two destinations. The second order parameters with respect to output in the cost function were insignificant in all cases. Because this is not a parameter of importance, it was deleted from the results presented here. Empirical tests were conducted to determine the appropriateness of the alternative time series transformations. In each case the model with a first order autoregressive structure was chosen. Four models are presented in these results. Model 1 is the basic translog equation and excludes the effects of rail car shortages and multiple-car rates. Model 2 includes the effects of rail car shortages. The effects of multiple-car rates are included in Model 3, and both effects are included in Model 4. These models are distinguished empirically by constraining parameters for the excluded variables to zero. Estimated parameters for each model are shown in Tables 2 and 3 for wheat and barley shipments, respectively.

Hypotheses were posed and tested to determine the effects of rail car shortages and multiple-car rates, individually and jointly, on the structure of the cost and derived demand functions. The hypotheses were tested by constraining the value of the parameters to zero and making comparison to the unrestricted (Model 1). The test statistics are shown in Table 4 along with the appropriate χ^2 statistic. In all cases, the test statistic was less than the critical value; thus, the null hypothesis (i.e., the restriction imposed on the model) could not be rejected.

The car shortage hypothesis tested whether $a_r = \gamma_{ir} = \phi_1 = 0$. In all cases, the estimates of these parameters were small relative to their asymptotic standard error. The only exception was the case of wheat shipments to Duluth, which would indicate that rail car shortages result in a reduction in the rail revenue share. However, the joint hypothesis could not be rejected. Rail car shortages have resulted in a change in relative prices and modal shares but they have not had a significant effect on the structure of the cost and derived demand equations.

The estimated parameters associated

TABLE 2. Parameter Estimates for Cost and Derived Demand Equations for Wheat Shipments from North Dakota to Duluth and Minneapolis (Asymptotic Standard Errors in Parenthesis).

Parameter	Duluth Shipments				Minneapolis Shipments			
Model	1	2	3	4	1	2	3	4
a_0	−0.11	−0.06	2.00	−0.05	−0.02	−0.02	−0.03	−0.04
	(0.11)	(0.06)	(18.73)	(0.24)	(1.002)	(0.05)		(0.07)
a_Q	1.01	1.00	1.01	1.01	0.005	1.00	1.003	1.003
	(0.03)	(0.01)	(0.007)	(0.009)	(0.15)	(0.06)	(0.005)	(0.007)
a_1	0.19	0.16	0.28	0.23	0.11	0.15	0.17	0.17
	(0.17)	(0.17)	(0.36)	(0.20)	(−0.07)	(0.19)	(0.12)	(0.21)
γ_{11}	−0.12	−0.13	−0.08	−0.13	0.14	−0.07	−0.06	−0.05
	(0.20)	(0.17)	(0.19)	(0.18)	(0.07)	(0.16)	(0.14)	(0.16)
γ_{1Q}	0.05	0.07	0.04	0.05	0.02	0.06	0.06	0.06
	(0.02)	(0.02)	(0.02)	(0.02)	(0.94)	(0.02)	(0.19)	(0.02)
ρ_c	1.03	0.82	0.99	0.98	0.91	0.94	0.96	0.96
	(0.13)	(0.23)	(0.11)	(0.12)	(0.16)	(0.18)	(0.13)	(0.13)
ρ_s	0.97	0.89	0.97	0.94	0.91	0.91	0.90	0.91
	(0.05)	(0.09)	(0.06)	(0.08)	(0.08)	(0.09)	(0.08)	(0.08)
a_r		−0.08		−0.06		0.0009		−0.003
		(0.09)		(0.12)		(0.09)		(0.09)
γ_{1r}		−0.09*		−0.05		−0.0006		0.02
		(0.05)		(0.06)		(0.05)		(0.05)
ϕ_1		0.009		0.007		−0.0006		−0.00007
		(0.01)		(0.01)		(0.01)		(0.01)
a_m			−0.04	−0.06			0.01	0.01
			(0.29)	(0.27)			(0.09)	(0.10)
γ_{1m}			0.16	0.12			0.02	0.03
			(0.10)	(0.10)			(0.07)	(0.07)
ϕ_2			0.001	0.005			0.0002	0.0003
			(0.03)	(0.03)			(0.01)	(0.01)
System MSE	0.305		0.357	0.361	0.438	0.438	0.479	0.478

with multiple-car rates in Tables 2 and 3 are not substantially larger than their asymptotic standard error except for wheat shipments to Duluth in Model 3. In that case, the estimated parameter indicated that the innovation of multiple-car rates has been rail intensive. However, the joint hypothesis that $a_m = \gamma_{im} = \phi_2 = 0$ could not be rejected. Multiple-car rates have resulted in a change in rail rates, and consequently a change in modal shares, but these results indicate that there has not been a structural change in the cost and derived demand equations. In other words, their effect has been neutral with respect to modal revenue shares. It would not be appropriate to draw sweeping conclusions from this result primarily because an adjustment process may be necessary for a structural change to evolve. However, these results, though tentative, are interesting and demonstrate the application of duality in the analysis of structural change in the grain transportation industry.[8]

---

[8] A further test about the effects of multiple-car rates was conducted, but not reported here. The hypothesis was posed that as a result of multiple-car rates, the substitutability between modes would change.

TABLE 3. Parameter Estimates for Cost and Derived Demand Equations for Barley Shipments From North Dakota to Duluth and Minneapolis (Asymptotic Standard Errors in Parenthesis).

Parameter	Duluth Shipments				Minneapolis Shipments			
Model	1	2	3	4	1	2	3	4
a_0	0.03	0.12	0.02	0.12	0.01	−0.002	0.04	0.03
	(6.37)	(0.16)	(0.49)	(0.15)	(0.02)	(0.02)	(0.04)	(0.04)
a_Q	0.99	0.98	0.99	0.98	1.00	1.01	0.99	0.99
	(0.01)	(0.01)	(0.01)	(0.01)	(0.001)	(0.002)	(0.002)	(0.003)
a_1	0.97	0.99	0.99	0.98	0.66	0.71	0.66	0.69
	(0.04)	(0.25)	(0.05)	(4.93)	(0.25)	(0.23)	(0.26)	(0.31)
γ_{11}	−0.11	−0.08	−0.08	−0.05	0.006	−0.009	0.004	−0.02
	(0.13)	(0.39)	(0.33)	(0.14)	(0.07)	(0.08)	(0.06)	(0.07)
γ_{1Q}	−0.09	−0.08	−0.09	−0.08	0.03	0.03	0.03	0.03
	(0.02)	(0.03)	(0.02)	(0.02)	(0.01)	(0.01)	(0.006)	(0.01)
ρ_c	0.98	1.04	0.98	1.04	0.95	0.93	0.97	0.97
	(0.08)	(0.08)	(0.08)	(0.10)	(0.12)	(0.12)	(0.07)	(0.08)
ρ_s	0.96	0.99	0.95	0.98	0.97	0.97	1.00	0.99
	(0.07)	(0.07)	(0.08)	(0.07)	(0.07)	(0.07)	(0.04)	(0.04)
a_r		−0.12		−0.14		0.04		0.02
		(0.18)		(6.20)		(0.03)		(0.04)
γ_{lr}		0.13		0.14		−0.01		−0.01
		(0.10)		(0.10)		(0.02)		(0.02)
ϕ_l		0.02		0.02		−0.006		−0.003
		(0.02)		(0.03)		(0.004)		(0.005)
a_m			−0.10	−0.12			−0.03	−0.02
			(0.28)	(0.35)			(0.04)	(0.04)
γ_{lm}			0.006	0.03			−0.02	−0.02
			(0.16)	(0.17)			(0.03)	(0.03)
ρ_2			−0.001	0.01			0.005	0.004
			(0.005)	(0.04)			(0.004)	(0.005)
System MSE	1.357	0.319	0.368	0.327	0.525	0.51	0.507	0.498

Other estimated parameters of particular interest are γ_{1Q}, which can be interpreted directly, and γ_{11}. The nonhomotheticity parameter, γ_{1Q}, indicates the effect of changes in output on factor shares assuming constant modal prices. In nearly all cases, γ_{1Q} was substantially greater than the asymptotic standard error. For wheat shipments to Duluth and Minneapolis, and barley to Minneapolis, $Y_{1Q} > 0$ which means that changes in output are rail intensive. Increases and decreases in total shipments result in a greater change in the quantity shipped by rail than by truck. On the other hand, for barley shipments to Duluth, $\gamma_{1Q} < 0$ which means that changes in total shipments are truck intensive.

The estimate of γ_{11} is similar across the four models and was not substantially larger than its standard error. The hypothesis that $\gamma_{11} = 0$, which implies $\sigma_{12} = 1$, was posed and tested. The test statistics were 0.14 and 0.72 for wheat shipments and 0.85 and 1.01 for barley shipments to

---

The results indicated that there was not a significant difference in γ_{11} in the two time periods and that therefore, the elasticity of substitution has not changed.

TABLE 4. Test Statistics for the Effects of Rail Car Shortages and Multiple-Car Rates.

	Model 4 Versus			Model 3 Versus	Model 2 Versus
	Model 1	Model 2	Model 3	Model 1	Model 1
Restrictions	6	3	3	3	3
Critical χ^2 (10%)	10.64	6.25	6.25	6.25	6.25
Wheat Shipments to:					
Duluth	2.12	1.68	0.51	2.53	0.38
Minneapolis	2.34	1.08	1.18	2.03	0.11
Barley Shipments to:					
Duluth	3.38	0.88	3.37	1.26	3.17
Minneapolis	3.10	1.06	1.45	2.10	1.55

Duluth and Minneapolis, respectively. Consequently, it is not possible to reject the null hypothesis that $\gamma_{11} = 0$ and that the elasticity of substitution equals 1.

Estimates of γ_{11} are of little interest directly but can be used to calculate the elasticity of substitution and Hicksian elasticities of demand, i.e., constant output elasticities. These were calculated using the estimated parameters in Model 1 and mean levels for factor shares and are presented in Table 5. The price elasticities indicate that in all cases the railroads are operating in the inelastic portion of their demand function. The values of the elasticities vary across movements with the least being for barley shipments to Minneapolis. In the two-mode case $E_{ii} = -E_{ij}$ because the compensated elasticities of a mode sum to zero, i.e., $E_{11} + E_{12} = 0$ and $E_{21} + E_{22} = 0$. Consequently, the mode's own-price elasticity is equal and opposite from its cross-price elasticity. The own-rate elasticity for the motor carrier industry is larger than that of the railroads. The motor carrier industry is operating in the elastic portion of their demand function for wheat shipments to Duluth and barley shipments to Minneapolis.

In assessing the reasonableness of the elasticities estimated in this study, three points should be considered.[9] First, the calculated elasticities are for intermodal competition and do not indicate intramodal effects, i.e., these are regional-industry-demand elasticities rather than carrier-firm-level elasticities. As such the effects of intramodal competition, particularly between railroads (see footnote 4) are not captured. In judging the effectiveness of competitive pressures on modal rates, consideration must also be given to

---

[9] The elasticities estimated by Oum (1978), which is the only study that has used time series data and the derived demand approach to demand estimation in transportation, are generally less than those estimated here.

TABLE 5. Estimates of Modal Rate Elasticities for Grain Shipments from North Dakota.

	Wheat		Barley	
	Duluth	Minneapolis	Duluth	Minneapolis
Rail Factor Share (S_1)	.75	.69	.57	.94
Truck Factor Share (S_2)	.25	.31	.43	.06
σ_{12}	1.59	.97	1.49	2.24
E_{11} ($= -E_{12}$)	−.40	−.30	−.64	−.13
E_{22} ($= -E_{21}$)	−1.19	−.67	−.85	−2.10

competition between supply regions and intramodel competition. Second, the calculated elasticities are Hicksian, which are not comparable to elasticities from many other transport demand studies. The Marshallian effects of a change in modal rates could also be evaluated [Equation (7)], but this requires knowledge of the price elasticity of demand for the commodity. Given the Hicksian elasticities calculated in this study, the commodity price elasticity would have to be very large before a decrease in modal rates would increase total revenue. Finally, there is no reason that elasticities should be comparable across regions or commodities. Friedlander and Spady, and Michaels, Levins and Fruin, as well as Koo and Bredvolt (1982b), have all suggested that intermodal competition varies spatially and/or by commodity.

Conclusions

Recent legislation in the transportation industry has stimulated a move toward more flexibility in railroad pricing. Consequently, characteristics of transport and modal demands are becoming increasingly important in public policy analysis as well as in pricing decisions by transportation firms. The purpose of this study was to develop the derived demand approach to the analysis of transport demand by mode and to make empirical estimates in the case of grain transportation from North Dakota. Transportation was treated as a factor input to the grain distribution (i.e., country elevator) firm with a specific translog technology. Hypotheses about the effect of rail car shortages and multiple-car rates were also posed and tested. This approach has several attractive attributes relative to others in the analysis of the price responsiveness of demand. The specification is nonarbitrary in either inclusion of variables or functional form. Second, the translog model is in the general category of flexible functional forms and imposes on *a priori* restrictions on the Allen's partial elasticity of substitution or on other demand parameters.

One of the effects of both rail car shortages and multiple-car rates is a change in relative modal prices which are incorporated in the basic translog model. The model was expanded to test whether either rail car shortages or multiple-car rates has had other effects on the structure of cost and derived demand functions. In all cases, it was concluded that both of these effects have not resulted in a significant change in the structure of the cost and derived demand functions. Rail car shortages do result in changes in relative modal prices and modal shares, but they have not been truck intensive as hypothesized. Multiple-car rates were introduced in North Dakota in July 1981. While this innovation has resulted in a change in relative rates and market shares, it was not possible to conclude that a change in the structure of the derived demands has occurred. The results indicate that changes in output were rail intensive for wheat shipments to Duluth and Minneapolis and truck intensive for barley shipments to Duluth. Elasticities of substitution between rail and truck were calculated and in all cases were not significantly different from 1. Own-rate and cross-rate Hicksian elasticities were calculated from the estimated parameters. The own-rate elasticities for the railroads varied across movements but in all cases were inelastic. Own-rate elasticities for the motor carrier industry were elastic for wheat shipments to Duluth and barley shipments to Minneapolis, but were inelastic in the other two cases. These elasticities reflect the effects of inter-modal competition but do not capture the effects of competition between transport firms or supply regions.

References

Barten, A. P. "Maximum Likelihood Estimation of a Complete System of Demand Equations." *European Economic Review*, 1(1969): 7–73.

Berndt, E. R. and D. V. Wood. "Technology, Prices, and Derived Demand for Energy." *The Review of Economics and Statistics*, (August 1975):3 259–68.

Binswager, H. P. "A Cost Function Approach to the Measurement of Elasticity of Factor Demand and Elasticity of Substitution." *American Journal of Agricultural Economics*, 6(May 1974):2 377–85.

Blackorby, C. D., P. Primont, and R. R. Russel. *Duality, Separability and Functional Structures: Theory and Application*. North Holland, Amsterdam, 1977.

Christensen, L. R. and W. H. Greene. "Economies of Scale in U.S. Electric Power Generation." *Journal of Political Economy*, 84(1976):4 655–76.

Christensen, L. R. and W. H. Greene. "An Econometric Assessment of Cost Savings from Coordination in U.S. Electric Power Generation." *Land Economics*, 54(May 1978): 139–55.

Christensen, L. R., D. W. Jorgensen, and L. J. Lau. "Conjugate Duality and the Transcendental Logarithmic Production Function." *Econometrica*, (July 1971): 255–256.

Diewert, W. E. "An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function." *Journal of Political Economy*, (May–June 1971): 481–507.

Fitzsimmons, E. L. "A Statistical Sketch of the Demand for Rail Transportation of Grain and Soybeans." *Transportation Journal*, 20(Spring 1981): 3 59–65.

Friedlander, A. F. and R. H. Spady. "A Derived Demand Function for Freight Transportation." *Review of Economics and Statistics*, 62(August 1980): 3 432–41.

Fuller, S., L. Makus, and M. Taylor. "Effects of Railroad Deregulation on Export Grain Rates." *North Central Journal of Agricultral Economics*, 5(January 1983):1 51–63.

Fuller, S. and C. V. Shanmugham. "Effectiveness of Competition to Limit Rail Rate Increases Under Deregulation: The Case of Wheat Exports From the Southern Plains." *Southern Journal of Agricultural Economics*, 13(December 1981): 11–19.

Gallant, A. R. and D. W. Jorgensen. "Statistical Inference for a System of Simultaneous Nonlinear Implicit Equations in the Context of Instrumental Variable Estimation." *Journal of Econometrics*, 11(1979): 275–302.

Johnson, M. "Estimating the Difference of Service Quality on Transportation Demand." *American Journal of Agricultural Economics*, 58(1976):3 496–503.

Johnson, M. "Impacts on Agricultural Deregulating the Transportation System." *American Journal of Agricultural Economics*, 63(1981):5 913–20.

Johnson, M. "Impact on Agriculture of Deregulating the Transportation System: Reply." *American Journal of Agricultural Economics*, 65(1983):1 190–91.

Kmenta, J. and R. F. Gilbert. "Small Sample Properties of Alternative Estimators of Seemingly Unrelated Regressives." *Journal of the American Statistical Association*, 58(Dec. 1968):1180–1200.

Koo, W. W. and S. T. Bredvolt. *An Economic Analysis of U.S. Grain Marketing and Transportation System*. Agricultural Experiment Station Report No. 98. North Dakota State University, Fargo, 1982a.

Koo, W. W. and S. T. Bredvolt. *An Economic Analysis of U.S. Rail Rate Structure and Deregulation*. Ag. Econ. Research Report No. 152. North Dakota State University, Fargo, 1982b.

Levin, R. C. "Allocation of Surface Freight Transportation: Does Rate Regulation Matter?" *Bell Journal of Economics*, 9(Spring 1978):1 18–45.

Lopez, R. E. "Applications of Duality Theory to Agriculture." *Western Journal of Agricultural Economics*, 7(December 1982):2 353–66.

McFadden, D. "Conditional Logit Analysis of Qualitative Choice Behavior." In *Frontiers in Econometrics*, pp. 105–142, ed. P. Zaremba. Academic Press, New York, 1974.

Michaels, G. H., R. A. Levins, and J. E. Fruin. "Rail/Truck Competition for Grain Traffic in Minnesota: Implications for Rate-Making." *American Journal of Agricultural Economics*, 64(May 1982):2 276–77.

Miklius, W., K. Casavant, and P. Garrod. "Estimation of Demand for Transportation of Agricultural Commodities." *American Journal of Agricultural Economics*, 58(May 1976):2 217–23.

Oum, T. H. "Derived Demand for Freight Transport and Intra-Modal Competition in Canada." *Journal* *of Transport Economics and Policy,* 12(January 1978): 149–68.

Oum, T. H. "A Warning on the Use of the Linear Logit Models in Transport Mode-Choice Studies." *Bell Journal of Economics,* 10(Spring 1979):1 374–88.

Oum, T. H. "A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada." *Bell Journal of Economics,* 10(Autumn 1979):2 463–82.

Pope, R. D. "To Dual or Not to Dual." *Western Journal of Agricultural Economics,* 7(December 1982):2 337–52.

Shephard, R. W. *Theory of Cost and Production Function.* Princeton University Press, Princeton, 1970.

Stevenson, R. "X-Inefficiency and Interfirm Rivalry: Evidence from the Electric Utility Industry." *Land Economics,* 58(February 1982): 52–66.

U.S. Congress, *Railroad Revitalization and Regulatory Reform Act of 1976.* PL74-210, 94th Congress, S.2178, Washington, D.C., February 1976.

U.S. Congress. *Staggers Rail Act of 1980.* S.1946, Washington, D.C., October 1980.

U.S. Department of Agriculture, Office of Transportation, *An Assessment of Impacts on Agriculture of the Staggers Rail Act and Motor Carrier Act of 1980.* Washington, D.C., 1982.

Uzawa, H. "Production Function With Constant Elasticity of Substitution." *Review of Economic Studies,* (October 1962): 291–99.

Uzawa, H. "Duality Principles in the Theory of Cost and Production." *International Economic Review,* 5(1964): 216–19.

Wilson, G. "Notes on the Elasticity of Demand for Freight Transport." *Transportation Journal,* (Spring 1978): 5–15.

Zellner, A. "An Efficient Method of Estimating Seemingly Unrelated Regression and Tests for Aggregation Bias." *Journal of American Statistical Association,* 57(June 1962): 585–612.