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A Derived Demand Function for Freight Transportation: An Update of the 1980 Friedlaender Spady Analysis

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by

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Abstract

This analysis complements the short-run estimates of price elasticity that are routinely obtained using logit models of freight demand. It does this by updating a study that Ann F. Friedlaender and Richard H. Spady reported in the *Review of Economics and Statistics* in 1980. In the Friedlaender and Spady analysis, shipper decisions are modeled using an economic cost function whose arguments include industry-level outputs, capital and materials, labor prices, and generalized prices for truck and rail. From the cost function, they derive input demands and price elasticities for rail and truck. The updated analysis presented here combines North American Industry Classification System (NAICS) data from the 1997, 2002 and 2007 Economic Census reports with shipment data from the Commodity Flow Survey. The elasticity results based on this data are consistent with those reported by Friedlaender and Spady but larger in absolute value. The analysis identifies two effects that increased truck prices could have on rail freight markets. First, a significant, non-transitory increase in truck prices would divert shipments directly off the highway and onto the rail network. Second, an increase would give railroads an opportunity to attract additional traffic by duplicating truck service levels.

Keywords: freight systems, railroads, transportation systems, trucking

JEL codes: L92, R4

1. Introduction

This analysis complements the short-run estimates of price elasticity that are routinely obtained using logit models of freight demand. It does this by updating a study that Ann F. Friedlaender and Richard H. Spady reported in the *Review of Economics and Statistics* in 1980. In the Friedlaender and Spady analysis, shipper decisions are modeled using an economic cost function whose arguments include industry-level outputs, capital and materials, labor prices, and generalized prices for truck and rail. From the cost function, Friedlaender and Spady derive input demands and price elasticities for rail and truck.

The updated analysis presented here combines North American Industry Classification System (NAICS) data from the 1997, 2002 and 2007 Economic Census reports with shipment data from the Commodity Flow Survey. The elasticity results based on this data are consistent with those reported by Friedlaender and Spady but larger in absolute value. They are also larger in absolute value than many logit elasticities and act as an upper bound.

The updated analysis identifies two effects that increased truck prices could have on rail freight markets. First, a significant, non-transitory increase in truck prices would divert shipments directly off the highway and onto the rail network. Second, an increase would give railroads an opportunity to attract additional traffic by duplicating truck service levels. Railroad failure to attract this traffic could result in a loss of welfare.

Logit models present a relatively fixed assessment of freight demand that is shipment focused and market specific with respect to both commodities and geographic pairs. The Friedlaender Spady (hereafter FS) analysis is based on a more generalized economic framework in which shippers have the flexibility to choose a range of productive inputs that include truck and rail freight transportation along with labor, materials and capital. The FS framework thus provides a somewhat broader and longer term perspective on the potential that railroads have to attract freight. The logit estimates can be viewed as identifying the lower bounds of the cross-price elasticities between truck and rail while the FS estimates identify the upper bounds.

The basic assumption of the FS analysis is that rail and truck freight services are inputs to the production process along with capital, labor, and materials. This means that shipper decisions are modeled using an economic cost function whose arguments include industry-level aggregate outputs, quasi-fixed stocks of capital and materials, labor prices (wages), and generalized prices for truck and rail. Freight prices are generalized by including a measure of service quality along with the transport rate. From the cost function, FS derive input demand equations for rail and truck. Parameters of these equations are estimated and the estimates show how freight expenditures respond to relative changes in input prices.

Freight movement data for the FS study is a cross-section of 96 three-digit Standard Transportation Commodity Code (STCC) manufacturing industries in the 1972 Census of Transportation. Non-transportation data on the 96 industries is from the Economic Census (Annual Survey of Manufactures) for 1972. The STCC categories used by FS correspond directly Standard Industrial Classification (SIC) system categories used in the Economic Census.

FS use the parameter estimates from the input demand equations to calculate a set of industry-specific own and cross price demand elasticities for rail and truck freight services. The elasticities that FS report are summarized in Table 1.

Table 1

Friedlaender Spady (1972 census of Transportation)

Price Elasticities of Demand for Freight Service

Industry	Rail Own Price	Truck Own Price	Truck-Rail Cross Price	Rail-Truck Cross Price
Food Products	-2.583	-1.001	0.004	-0.023
Wood Products	-1.971	-1.547	-0.129	-0.050
Paper &Rubber	-1.847	-1.054	0.003	0.007
Stone, Clay & Glass	-1.681	-1.031	0.016	0.025
Iron & Steel	-2.542	-1.083	-0.013	-0.053
Fabricated Metal	-2.164	-1.364	-0.099	-0.059
Nonelectrical Machinery	-2.271	-1.085	-0.010	-0.032
Electrical Machinery	-3.547	-1.230	-0.061	-0.151

The updated FS analysis presented here also combines industry level data from the Economic Census and shipment data from the Commodity Flow Survey in a derived demand model of freight transportation. The 1972 cross sectional data that FS use is replaced by a panel of observations on industry sectors for 1997, 2002 and 2007, and the translog (TL) cost function that FS use is replaced by a

Generalized McFadden (GM) cost function. The GM has the same flexible characteristics as the TL but (as explained below) better accommodates the data available in the recent Economic Surveys. The elasticity results based on the panel data and the GM cost function are consistent with those in FS but larger in absolute value. They are also larger in absolute value than the logit elasticities.

2. Specification of the Freight Demand System

The TL cost function is a generalization of the Cobb Douglass cost function that is widely used in economics. A two-input Cobb-Douglass with constant returns to scale can be written in log form as

$$lnC(w,y) = \beta_0 + \beta_1 lnw_1 + \beta_2 lnw_2 + lny \tag{1}$$

where the *w'*s are input prices and *y* is output level. The TL is written

$$lnC(w,z) = \alpha_0 + \sum_i \alpha_i lnw_i + \sum_h \beta_h lnz_h + 0.5 \sum_i \sum_j \alpha_{ij} lnw_i lnw_j + \sum_i \sum_h \beta_{ih} lnw_i lnz_h + 0.5 \sum_h \sum_s \gamma_{hs} lnz_h lnz_s \tag{2}$$

where *w* is a set of input prices and *z* = (*y,F*) includes multiple outputs (*y*) and multiple fixed factors(*F*). The interaction of prices with prices, prices with outputs and fixed factors, outputs with outputs and fixed factors, and fixed factors with fixed factors gives the TL its "flexibility", i.e. its ability to model costs for industries whose technologies are more complex than those that can be represented by the Cobb Douglass.

Shepherd's Lemma is a formal result in microeconomic theory which holds that the derivative of the cost function with respect to an input price expresses the conditional demand for that input. In FS the demand for rail and truck freight services derived from the TL are

$$\frac{\partial lnC}{\partial lnw_i} = \frac{w_i x_i}{C} = S_i = \alpha_i + \sum_j \alpha_{ij} lnw_j + \sum_h \beta_{ih} lnz_h \tag{3}$$

where w_i represents the price of mode *i* (i.e. truck or rail) , x_i represents the quantity of mode *i*'s freight service used, and S_i is the share of overall industry expenditure on mode *i*. The left-hand-side dependent variables in the FS model are the expenditure shares for truck and rail that the 96 three-digit SIC industry sectors reported in the 1972 Economic Census. The explanatory variables are from the Economic Census and the Commodity Flow Survey.

The 1997, 2002 and 2007 Economic Census reports provide details on output levels, expenditures for labor and other intermediate inputs, and capital stocks for industries using the new North American

Industrial Classification System (NAICS). However, the public NAICS reports do not identify the expenditures which industries make on freight transportation either in the aggregate or on specific modes. This means that a TL-based model of the type used by FS cannot be implemented using recent Economic census data because the expenditure shares are not available.

An alternative to the TL is the Generalized McFadden cost function proposed by Diewert (1987). This flexible cost function can be written

$$C(w,y,F) = \sum_i \alpha_i w_i + 0.5 \sum_i \sum_j \beta_{ij} \left({}^{w_i w_j}/_{w_k} \right) + \sum_i \gamma_i w_i y + \sum_i \sum_h \delta_{ih} w_i F_h + \sum_h \pi_h F_h y \tag{4}$$

where *y* is a single output, w_k is a price that serves as numeraire, F_h is the set of fixed factors, and α, β, γ, δ, and π are parameter vectors. Use of w_k as a numeraire is a technical device which insures that the cost function is homogeneous of degree one in input prices—consistent with microeconomic theory.

Application of Shepherd's Lemma gives a vector of input demands for rail and truck freight services. Each element has the form:

$$\frac{\partial C}{\partial w_i} = x_i = \alpha_i + \sum_j \beta_{ij} \left({}^{w_j}/_{w_k} \right) + \gamma_i y + \sum_h \pi_h F_h \tag{5}$$

where w_i is the price of truck or rail service and x_i is the corresponding volume of truck or rail service demanded. The left hand side in this equation is the quantity of rail or truck freight services demanded by each three-digit NAICS industry in 1997, 2002 and 2007. These data are available in the Commodity Flow Survey.

Let the subscripts *R* represent rail, *T* truck, and *L* labor, and let *y* represent industry output, *tx* time (in years), *mx* material stock (in dollars), and *kx* capital stock (in dollars). Equations (6) through (9) comprise the full set of equations that is estimated.

$$x_R = \alpha_R + \beta_{TR} \left(\frac{w_T}{W_L} \right) + \beta_{RR} \left(\frac{w_R}{W_L} \right) + \gamma_R y + \pi_{R\tau} tx + \pi_{Rm} mx + \pi_{Rk} kx + \varepsilon_1 \tag{6}$$

$$x_T = \alpha_T + \beta_{TT} \left(\frac{w_T}{W_L} \right) + \beta_{TR} \left(\frac{w_R}{W_L} \right) + \gamma_T y + \pi_{T\tau} tx + \pi_{Tm} mx + \pi_{Tk} kx + \varepsilon_2 \tag{7}$$

$$w_R = \theta_{R0} + \theta_{R1} LOH_R + \varepsilon_3 \tag{8}$$

$$w_T = \theta_{T0} + \theta_{T1} LOH_T + \varepsilon_4 \tag{9}$$

Equations (8) and (9) are pricing equations. These follow FS in using average length of haul (LOH) for each NAICS industry and each mode to incorporate quality of service into the rate.

The own price elasticities of truck and rail and the cross price elasticities of truck for rail and rail for truck are point estimates that are calculated for each observation in the data set. Own price elasticity for truck is

$$\epsilon_{TT} = \frac{dxt}{dwt}\frac{wt}{xt} = \beta_{TT}\frac{wt}{xt} \qquad (10)$$

where w_T and x_T are the observed truck price and the observed truck ton-mileage for a particular NAICS industry in a particular year (1997, 2002 or 2007). Own price elasticity for rail is calculated in the same way.

The cross price elasticity of rail with respect to truck price is

$$\epsilon_{RT} = \frac{dxr}{dwt}\frac{wt}{xr} = \beta_{RT}\frac{wt}{xr} \qquad (11)$$

and cross price elasticity of truck with respect to rail price is

$$\epsilon_{RT} = \frac{dxt}{dwr}\frac{wr}{xt} = \beta_{RT}\frac{wr}{xt} \qquad (12)$$

Both are point estimates and both are calculated using β_{RT} along with observed levels of truck and rail prices and truck and rail output levels.

3. Data Elements

Appendix Table A1 lists the variables that are used to estimate equations (6) to (9) and identifies the sources of the data.

The basic units of observation in the study are industry sectors identified at the three digit level in NAICS. NAICS is now the standard classification system used by the U.S. government in collecting and publishing data on business activity. NAICS classifications extend to six digits but in order to relate NAICS economic data to shipment data in the Commodity Flow Survey's three-digit NAICS classifications are used. At the three-digit level NAICS describes industry *sectors* such as Agricultural Products (111), Wood Products (321), Chemicals (325), and so on. The NAICS sectors used in the current analysis are listed in Table 2.

NAICS was adopted by the federal government in 1997 to replace the Standard Industrial Classification (SIC) system that FS used. The NAICS industry data in the Economic Census are based on surveys conducted by the U.S. Bureau of the Census. The Economic Census contains detailed financial accounting data and other operating data. In the current analysis, the financial and operating data is combined with corresponding shipment data from the Commodity Flow Survey using Standard Transportation Commodity Group (SCTG) classifications. These also were adopted by the federal government in 1997 to replace the STCC codes that FS used. The key to establishing a linkage between the NAICS data and CFS is Table CF0700A15 *Shipment Characteristics by Origin Geography by NAICS by Mode: 2007*. [1] This table is shipment data by mode for each of the three-digit NAICS industry sectors.

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[1] This table and all other tables are at http://factfinder.census.gov/

Table 2

NAICS Industries included in Analysis

(With SCTG Source)

1997, 2002, 2007

NAICS Code	Industry Description	SCTG Source
111	Agricultural Products	02,03
112	Livestock	01
311	Food Manufacturing	06,07
312	Beverages and Tobacco	08,09
317	Textiles & Apparel	30
321	Wood Product Manufacturing	26
322	Paper Manufacturing	27,28
323	Printing and Related Activities	29
324	Petroleum and Coal Products	17,18,19
325	Chemical Manufacturing	20,21,22,23
326	Plastic and Rubber Products	24
327	Nonmetallic Mineral Products	31
331	Primary Metal Manufacturing	32
332	Fabricated Metal Manufacturing	33
333	Machinery Manufacturing	34
334	Computers and Electronic Products	35
335	Electrical Equipment and Appliances	38
336	Transportation Equipment	36
337	Furniture and Related Product	39
339	Miscellaneous Manufacturing	40

The final data elements in the current analysis are price series for rail, truck and labor from the Bureau of Labor Statistics Producer Price Indices and Occupational Employment Statistics. The base period for the rail and truck price series is December 1996. Following FS, sector-specific labor prices are calculated by dividing annual payroll for each sector by the reported number of employees.

The FS analysis is restricted to the manufacturing industries listed in Table 1. This list was expanded somewhat in the current analysis but a number of SCTG categories were not included—because production data on the commodities whose movements they describe could not be identified in the public NAICS data. Those categories are identified in Table 3.

Table 3

Excluded SCTG Categories

SCTG Code	Description
4	Animal Feed
5	Meat, Fish, Seafood
10-12	Stone and Sand
13	Other Minerals (Salt)
16	Crude petroleum
25	Logs
37	Railway Equipment & Aircraft

4. Estimation Methodology

The focus of the FS analysis and of the current analysis is on industry sectors where rail and trucks compete effectively for freight traffic. To limit the effect of outliers FS eliminated from their data any industry where the mode share of rail was less than five percent. The current study adopts the same protocol. The NAICS industries included in the estimation are Agriculture (111), Food and Kindred (311), Beverages and Tobacco (312), Wood Products (321), Paper (322), Petroleum and Coal Products (324), Chemicals (325), Plastics and Rubber Products (326), Nonmetallic Mineral Products (327), Primary Metal manufacturing (331), Fabricated Metal Products (332), Non-electrical Machinery (333), Transportation Equipment (336). Producers of minerals and ores are important users of rail but NAICS 212 was excluded from the analysis because estimation results showed that the nature of rail service in these markets is essentially different from service in truck competitive markets.

The system estimated in equations (6) to (9) presents several econometric issues.

The first issue is related to the structure of the data in equations (6) and (7). The first 13 observations in equation (6), for example, represent the demand for *rail* services by NAICS sectors in 1997, and the first 13 observations in equation (7) represent demand for *truck* services by the same industries in 1997. This pattern is repeated in equations (6) and (7) for 2002 and 2007. This means that the error terms in equations (6) and (7) are contemporaneously correlated and therefore heteroscedastic. The usual approach to estimating a system of this type is to use a Seemingly Unrelated Regression (SUR) estimator which is a form of generalized least squares (GLS).

The second issue derives from the fact that the price variables w_R and w_T appear as regressors in equations (6) and (7) and as dependent variables in equations (8) and (9). The pricing variables w_R and w_T are endogenous along with the rail and truck factor demands x_R and x_T and this means that the SUR estimator would be inconsistent.

To control for both heteroscedasticity and endogeneity a three stage least squares (3SLS) or a full information maximum likelihood (FIML) estimator is required. The current analysis uses the FIML estimation procedure in SAS© Version 9.3. The endogenous variables are w_R , w_T , x_R and x_T , and the exogenous variables are *wl, y, tx, mx, kx*, LOH_R and LOH_T .

The parameter results and elasticity projections based on the FIML estimation are discussed in Section 5.

5. Estimation Results

The parameter results from the FIML estimation are presented in Table 4. All of the parameters have the expected signs and the key parameters are significant.

Table 4

Nonlinear FIML Parameter Estimates

Parameter	Estimate	Standard Error	t Value
α_T	3.66E+11	4.10E+10	8.92
α_R	1.31E+11	1.95E+10	6.71
β_{TT}	-1.18E+13	4.38E+12	-2.7
β_{TR}	1.37E+13	4.39E+12	3.13
β_{RR}	-1.86E+13	4.61E+12	-4.04
γ_{TY}	0.257666	0.167	1.54
γ_{RY}	-0.03605	0.1299	-0.28
θ_{T0}	113.7303	1.7493	65.01
θ_{T1}	0.000791	0.000482	1.64
Θ_{R0}	117.084	3.1665	36.98
θ_{R1}	-0.00053	0.00039	-1.36
π_{RT}	-1.64E+10	1.04E+09	-15.77
π_{RM}	0.025472	0.1907	0.13
π_{RK}	0.393097	0.0836	4.7
π_{TT}	-5.52E+10	1.48E+09	-37.31
π_{TM}	-0.23155	0.2447	-0.95
π_{TK}	-0.06819	0.1049	-0.65

The intercept terms for rail (α_R) and truck (α_T) are positive and significant. The larger value for truck reflects the fact that the highway mode starts with larger initial shares than rail in most commodity markets.

The own price parameters for rail (β_{RR}) and truck (β_{TT}) are both negative as expected and are significant at the one percent level. The cross-price parameter between rail and truck (β_{RT}) is positive as expected and is also significant at the one percent level. This suggests that there is effective competition between truck and rail—especially when intermodal movements are taken into account.

The control variables for time, ($\pi_{R\tau}$) and ($\pi_{T\tau}$), are negative and highly significant. This means that the derived demand curves for truck and rail have shifted down over time--suggesting that the relative amount of transportation resources that manufacturers consume in production and distribution has declined over the 1997-2007 time period.

Finally, the slope parameters for rail Length of Haul (θ_{R1}) and truck Length of Haul (θ_{T1}) in equations (8) and (9) are significant but with opposite signs. The generalized price of truck is positively related to length of haul while the generalized price of rail is negatively related. This is consistent with the observation that rail service becomes more competitive as shipping distances increase.

The elasticities reported in Table 5 are point estimates for the year 2002 which is at the midpoint of the data. All of the estimated elasticities have the expected signs and all are generally consistent with the FS estimates reported in Table 1.

Two areas where the newer elasticities are significantly larger in absolute terms are the cross price elasticities between truck and rail. This suggests a higher degree of competition between the two modes than FS found using 1972 data. It can be explained in two ways.

First, the FS results are based on a *cross-section* while the current analysis is based on a *panel* of observations that spans a 10 year period. This gives shippers time to adjust their logistics systems to reflect the underlying economic characteristics of the two modes.

Second, the FS analysis of 1972 data would not reflect the dominant role of intermodal containers in enabling railroads to compete with trucks. U.S. railroads began moving a significant number of containers in the 1960s but the technology did not mature until the 1980s when double-stack movements were introduced. The current analysis treats carload and rail intermodal traffic as a single rail mode.

Table 5

NAICS	Description	Rail-Truck Cross Price	Truck Own Price	Railroad Own Price	Truck-Rail Cross Price
311	Food and Kindred Products	1.341	-0.714	-1.763	0.806
312	Beverages & Tobacco	1.587	-0.773	-2.086	0.872
321	Wood Products	3.091	-1.203	-4.062	1.357
322	Paper	0.805	-0.799	-1.058	0.902
324	Petroleum and Coal Products	0.690	-0.652	-0.907	0.736
325	Chemicals	0.388	-0.419	-0.509	0.473
326	Plastics and Rubber Products	1.541	-0.920	-2.026	1.038
327	Nonmetallic Mineral Products	1.560	-0.951	-2.050	1.073
331	Primary Metal Manufacturing	1.043	-0.822	-1.371	0.928
332	Fabricated Metal Products	1.255	-0.726	-1.650	0.819
333	Machinery, Except Electrical	1.117	-0.641	-1.468	0.723
336	Transportation Equipment	0.560	-0.407	-0.737	0.459

6. Diversion Effects

One aim of this analysis is to predict the longer-term effects that increased energy costs, highway congestion, and highway user fees would have on the demand for railroad freight service. The question is: What effect would significant increases in truck prices have on the levels of railroad freight traffic? The answer has two parts.

First, a significant increase in truck prices would have a direct effect on rail freight traffic by diverting shipments off the highway and onto the rail network. These effects are estimated in Table 6.

Second, a significant increase in truck prices would have an indirect effect on rail freight traffic by causing shippers to reduce expenditures on truck transportation and to consider alternative expenditures on labor, materials or capital. These potential shifts would give railroads an opportunity to further increase rail freight traffic by matching the service levels that trucks provide. The secondary effects are presented in Table 7.

The methods used to calculate both types of effect require some explanation.

The direct effects in Table 6 are estimated by rearranging the first two expressions in equation (11) to isolate dxr/xr, the percent change in rail ton-mileage. This gives

$$\frac{dxr}{xr} = \epsilon_{RT} \frac{dwt}{wt} \qquad (13)$$

The percent change in rail traffic is a product of the cross-price elasticity and a percent increase in truck price. The ε_{RT} values used in this calculation are the estimated NAICS-specific cross-price elasticities reported in Table 5 and the ratio *dwt/wt* is the stipulated value of a percent change in truck price For example, the 2002 rail market share for NAICS 322 (Paper) was 32.4 percent and the estimated rail-truck cross elasticity was 0.0805. A stipulated 10 percent increase in the *normalized* truck price would lead to an 8.1 percent increase in rail ton-miles. That translates into the increase of 2.9 percent in overall rail market share seen in the second column of Table 6.

There is an important clarification needed here. The diversion calculations are based on increases in truck prices. For the technical reason cited in Section 3.1 truck prices are normalized by sector specific labor prices.[2] This means that a hypothetical 10 percent increase in the normalized truck price would actually require a 10 percent incremental increase over whatever change would occur in the labor price. During the 1997 to 2007 study period labor prices increased by 30 to 40 percent across NAICS sectors, so a 10 percent increase in the normalized truck price would require a 45 – 55 percent increase in the actual truck price. [3]

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[2] Microeconomic theory requires that the cost function be homogeneous of degree one in input prices. This in turn means that the factor demand equations derived from the cost function must be homogeneous of degree zero in input prices. Normalization by w_L guarantees this.

[3] Assume that the *normalized* truck price increases by 10 percent. Let *a* index the truck price and *b* index the labor price. Letting w_T and w_L be the base truck and labor prices, we have $\frac{a*wt}{b*wl} = 1.1$, or $\frac{(a*wt)}{wl} = b*1.1$. If b=1.35 then a=1.485 since the base w_T and w_L are unchanged. This implies an increase of about 50 percent in the truck price.

Table 6

Friedlaender Spady Model

U. S. Freight Markets - NAICS Basis

Projected Rail Shares

(Truck Diversion Effects)

NAICS	Description	Base Rail Share	50% Rate Increase[1]	75% Rate Increase[2]	100% Rate Increase[3]
311	Food and Kindred Products	0.257	0.298	0.359	0.462
312	Beverages & Tobacco	0.254	0.302	0.375	0.496
321	Wood Products	0.425	0.567	0.781	1.000
322	Paper	0.324	0.353	0.396	0.469
324	Petroleum and Coal Products	0.329	0.358	0.401	0.473
325	Chemicals	0.427	0.444	0.471	0.516
326	Plastics and Rubber Products	0.305	0.357	0.434	0.564
327	Nonmetallic Mineral Products	0.196	0.230	0.281	0.366
331	Primary Metal Manufacturing	0.279	0.313	0.365	0.451
332	Fabricated Metal Products	0.133	0.154	0.185	0.236
333	Machinery, Except Electrical	0.053	0.068	0.089	0.126
336	Transportation Equipment	0.214	0.231	0.256	0.298

[1] Example: Non-transitory increase in 2007 dry van rates (300-750 mile haul) from $2 to $3 per mile.

[2] Example: Non-transitory increase in 2007 dry van rates (300-750 mile haul) from $2 to $3.66 per mile.

[3] Example: Non-transitory increase in 2007 dry van rates (300-750 mile haul) from $2 to $4 per mile.

The rail shares shown in Table 6 are projections based on *non-normalized* increases of 50, 75 and 100 percent in truck prices. They project what would happen, for example, if per-mile dry van rates for movements in the 300-750 mile range were to increase from a $2.00 level to $3.00, $3.67, or $4.00 levels, and if other prices including rail rates and labor prices were unchanged. The assumption here is that truck rates would respond in a significant and differential way to increased energy prices and/or highway congestion and/or road user fees.

The indirect effects in Table 7 are estimated by rearranging the first two expressions in equation (10) to isolate *dxt/xt*, the percent change in truck ton-mileage that would result from an increase in truck rate. The rearrangement is

$$\frac{dxt}{xt} = \epsilon_{TT}\frac{dwt}{wt} \qquad (14)$$

In words, the percent change in truck traffic is a product of the own-price elasticity of truck and a percent increase in truck price. The ε_{TT} values used in this calculation are the NAICS-specific own-price truck elasticities reported in Table 5 and the ratio *dwt/wt* is the stipulated value of the percent change in truck price. The same *caveat* regarding *normalized* versus *non-normalized* price increases applies here. A hypothetical 10 percent increase in the normalized truck price would be a 10 percent incremental increase over whatever change occurred in the labor price. Given that labor prices increased by 30 to 40 percent during the study period, it is reasonable to assume that a 10 percent increase in the normalized truck price would require a 45–55 percent increase in the actual truck price.

The truck shares shown in Table 7 project what would happen, for example, if per-mile dry van rates to increase from a $2.00 level to $3.00, $3.67, or $4.00 levels and if other prices including rail rates and labor prices were unchanged. In NAICS 322 (Paper) the truck share of the market would respond to an increase from $2.00 to $3.00 (non-normalized) by dropping from 67.6 percent to 62.5 percent.

Comparison of these results with those in Table 6 suggests that there is a significant amount of additional traffic for railroads to gain. In the NAICS 322 (Paper) example that we have been using (assuming a truck rate increase from $2 to $3), trucks would lose 19.9 billion ton-miles of traffic directly to railroads and they would also face an additional loss of revenue in this market equal to the value of 17.1 billion ton-miles. This is because the market demand represented here is based on a generalized cost function which allows manufacturers to make tradeoffs between the amount of freight transportation that they use and the level of other resources employed—labor, materials and capital. Manufacturers could respond to a significant non-transitory increase in truck prices, for example, by making capital investments in better placed production and distribution facilities. In the limit, they might even decide to curtail the production of certain goods.

Table 7

Friedlaender Spady Model

U. S. Freight Markets - NAICS Basis

Projected Truck Shares

(Truck Price Effects)

NAICS	Description	Base Truck Share	50% Rate Increase[1]	75% Rate Increase[2]	100% Rate Increase[3]
311	Food and Kindred Products	0.743	0.694	0.620	0.496
312	Beverages & Tobacco	0.746	0.692	0.612	0.478
321	Wood Products	0.575	0.510	0.412	0.250
322	Paper	0.676	0.625	0.548	0.420
324	Petroleum and Coal Products	0.671	0.633	0.577	0.482
325	Chemicals	0.573	0.551	0.517	0.461
326	Plastics and Rubber Products	0.695	0.634	0.542	0.389
327	Nonmetallic Mineral Products	0.804	0.730	0.619	0.433
331	Primary Metal Manufacturing	0.721	0.666	0.584	0.446
332	Fabricated Metal Products	0.867	0.806	0.715	0.564
333	Machinery, Except Electrical	0.947	0.891	0.808	0.668
336	Transportation Equipment	0.786	0.758	0.715	0.644

[1] Example: Non-transitory increase in 2007 dry van rates (300-750 mile haul) from $2 to $3 per mile.

[2] Example: Non-transitory increase in 2007 dry van rates (300-750 mile haul) from $2 to $3.66 per mile.

[3] Example: Non-transitory increase in 2007 dry van rates (300-750 mile haul) from $2 to $4 per mile.

The results in Table 7 could be interpreted as an “optimum scenario” for railroads since the table projects the total amount of traffic that railroads could expect to gain if they were able to perfectly match the quality of service that trucks provide without increasing their own prices. One would not want to overstate these results, of course. Though the model estimated here incorporates distance (average length of haul) into the generalized pricing equations (8) and (9) as a means of controlling for quality, the model does assume that all shippers have equal access to the rail and highway networks. This is not a reasonable assumption for manufacturers whose goods move only short distances. The optimum scenario also assumes that railroads will be able to invest sufficiently to provide truck-equivalent service levels.

7. Conclusion

Baseline traffic for trucks is projected to grow from 1.66 trillion ton-miles in 2008 to 2.60 trillion ton-miles in 2035-- solely as a result of growth in the U.S. economy and without a change in mode share. Baseline traffic on the Class I U.S. rail network is projected to grow from 1.01 trillion ton-miles in 2008 to 1.69 trillion ton-miles in 2035. The diversion effects detailed above and summarized in Table 8 have important implications for railroads, truckers and general highway users.

Table 8

Summary of Diversion Effects

2035 Baseline Case (billions of ton-miles)

	50 Percent Truck Rate increase	**75 Percent Truck Rate increase**	**100 Percent Truck Rate increase**
Truck Ton-miles	2,602	2,602	2,602
Direct Rail Diversion	204.1	510.4	989.7
Indirect Rail Diversion	170.7	426.7	853.5
Total Diversion	374.8	937.1	1,842
Percent Diverted	14.4 %	36.0%	70.0%

The direct effect of a 50 percent increase in truck prices would be to divert 204 billion ton-miles off the highway network and onto the rail network. More dramatic increases in energy prices, congestion or user fees that increased truck prices by 75 or 100 percent could divert 500 billion to nearly one trillion ton-miles directly onto the rail network.

The “optimum scenario” is even more dramatic. The projections show that optimum rail operations, combined with direct diversion, could reduce truck traffic by 15-70 percent depending on the rate at which truck prices increase. The most aggressive scenario would reduce 2035 truck ton-miles almost down to their 2008 level of 1.66 trillion.

The optimum scenario is admittedly optimistic because it assumes high levels of railroad investment in service quality and unconstrained rail movements at short distances. Nevertheless, this scenario does highlight an important economic aspect of the freight market. If the losses of truck market share in Table 7 were *not* covered by high quality rail services, then the projected reduction in expenditures on truck ton-miles could take the form of reduced production. This would mean a significant loss of economic welfare for consumers of the products listed there—food, beverages, paper products, chemicals, plastics and rubber goods, transportation equipment, and all of the other NAICS products.

References

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Table A1 Data and Sources

Name	Explanation	Source
commodity	NAICS industry	Standard NAICS Classification
year	Calendar Year	
trucktm	Truck Ton-miles	CFS (1997,2002,2007) - Column G
Truckp	Truck Price	BLS PPI Series PCU4841212
Railtm	Rail Ton-miles	CFS (1997,2002,2007) - Column G
Railp	RailPrice	BLS PPI Series PCU4821111
IM_TM	Inter_Model Ton-Miles	CFS (1997,2002,2007) - Column G
Employ	Number Of Employees	Economic Census (1997,2002,2007) American Fact Finder Spreadsheet
Payroll	Annual Payroll	Economic Census (1997,2002,2007) American Fact Finder Spreadsheet
Mat	Materials	Economic Census (1997,2002,2007) American Fact Finder Spreadsheet
ASM_VOS	Value of Shipments	Economic Census (1997,2002,2007) American Fact Finder Spreadsheet
Cap_s	Capital Stock	Economic Census (1997,2002,2007) American Fact Finder Spreadsheet
PPI82	1982 Producer Price Index	Economic Rpt of President B-67