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Long-Run Diversion Effects of Changes in Truck Size and Weight (TS&W) Restrictions: An Update of the 1980 Friedlaender Spady Analysis

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Introduction

The purpose of this analysis is to estimate the effect that revised truck size and weight (TS&W) restrictions would have on competitive rail-truck markets in the United States. The analysis is based on a classic study of the intercity freight markets that Ann Friedlaender and Richard Spady (FS) published in the *Review of Economics and Statistics* in 1980.[1] The FS study provided a macro-level perspective on the freight markets by focusing on transportation decisions in key industrial sectors—food, wood products, paper, chemicals, automobiles, and so on. The FS analysis and the current update of that analysis complement the short-run estimates of rail-truck competition levels that are commonly obtained using logit-based models of freight demand. For example, a logit model was a central component of the Intermodal Transportation and Inventory Cost (ITIC) Model used by the U.S. Department of Transportation (DOT) in the 2000 *Comprehensive Truck Size and Weight Study*.

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 FS analysis is based on a more generalized economic framework in which shippers have the flexibility to choose a range of productive inputs that includes truck and rail freight transportation along with labor, materials and capital. The FS framework thus provides a broader and longer term perspective on the potential effect that changes in TS&W regulations would have on the freight markets. The logit estimates can be viewed as identifying the shorter term, lower bounds of the cross-price elasticities between truck and rail while the FS estimates identify long term, upper bounds.

[1] Ann Friedlaender and Richard Spady, "A Derived Demand Function for Freight Transportation, " *Review of Economics and Statistics*, 62:3, 1980, pp. 432-441.

The diversion effects analyzed in the current study are based on a hypothetical ten percent decrease in truck prices. This assumption is based in turn on the TS&W cost effects projected by the DOT in its 2000 *Comprehensive Truck Size and Weight Study*. Though the projected reduction in truck costs is fairly conservative, the losses of rail market share are significant—on the order of 15 to 20 percent in several key competitive rail-truck markets. The impacts on highway users and on railroad shippers who remain on the rail network are also significant. The projected increase in heavy truck traffic is 3.05 billion vehicle miles per year and the projected loss in base year railroad net income is $750 million per year. Total railroad net income in the base year was just $3.2 billion.

1. Description of the FS Model

The underlying assumption of the FS analysis is that freight shippers are business firms whose decisions can be modeled using statistical cost analysis. The elements of the cost analysis are industry output levels, freight movements and expenditures, firm levels of capital and materials, labor prices, truck prices, and rail prices. From their cost analysis, FS derive equations which specify how the shares of freight carried by each mode will respond to changes in truck and rail prices and other producer prices as well. From the near perfectly competitive nature of truckload service it is reasonable to assume that, over the long term, competitive prices will equal marginal cost and that any transportation production factor which lowers real costs will also, in turn, lower market prices.

Movement data for the FS study was from a cross-section of 96 three-digit Standard Transportation Commodity Code (STCC) manufacturing industries reported in the *1972 Census of Transportation*. Non-transportation data on the 96 industries was from the *Economic Census (Annual Survey of Manufactures)* for 1972. The STCC categories used by FS corresponded directly to the Standard Industrial Classification (SIC) categories used in the *Economic Census* at that time.

The mathematical model that FS used to represent shipper costs was the translog (TL) cost function, a generalization of the Cobb-Douglas cost function widely used in economics. The TL function is often used in applied economic analysis because of it “flexibility”, i.e. its ability to represent the cost characteristics of industries whose technologies are more complex than those that can be represented by the Cobb-Douglas. A formal analysis of the TL function and of other technical elements in this report is provided in an Appendix.

FS used results from the TL cost function to calculate a set of industry-specific demand elasticities for railroad and truck freight services. These are summarized in Table 1**.**

The *own-price elasticities* for rail and truck are estimates of the direct effect that a percent increase (or decrease) in a mode's price would have on the amount of traffic (in ton-miles) shipped by that mode. The expected sign of these elasticities is negative and the FS own elasticities meet this basic test.

The *cross price elasticities* for rail and truck are estimates of the direct effect that a percent increase in the competing mode's generalized price would have on the amount of traffic shipped by rail or truck. The expected sign for these elasticities is positive since an increase in rail (or truck) prices should increase the amount of freight shipped by the alternative mode. The FS cross-price elasticities are quite small and some have the wrong sign.

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

2. Description of the Current Model

The updated analysis combines shipment data from the *Commodity Flow Survey* (CFS) and industry-level economic data from the *Economic Census* into a cost-based demand model for freight transportation. The 1972 data that FS used is replaced by a multi-year set of sector-level observations for 1997, 2002 and 2007, the years in which both the *Economic Census* the *Commodity Flow Survey* have been conducted. The TL cost function is replaced by a Generalized McFadden (GM) cost function. The GM cost function is also derived from the Cobb Douglas and has the same flexible characteristics as the TL. As explained below, however, it better accommodates the data available in recent *Economic Surveys*. The function itself is discussed in more detail in the Appendix.

The elasticity results derived using the GM cost function and recent, multi-year data are described below in Section 4. The own price elasticity results for truck and rail are consistent with those in FS but smaller in absolute value. The cross price elasticity results for both modes are uniformly positive (as they should be) but significantly larger than the FS cross price elasticities.

The GM cost function solves a technical problem that FS did not face. The 1997, 2002 and 2007 *Economic Census* reports provide details on output levels, expenditures for labor and other intermediate inputs, and capital stock values for industry sectors. However, the public reports no longer identify the expenditures which industries make on freight transportation either in the aggregate or by mode. For reasons described in the Appendix, the TL model cannot be estimated without data on expenditure shares. The solution to this problem is the GM cost function which can be estimated using information on the quantity of rail or truck freight service used by each industry sector. These data are available in the *CFS*.

The full GM model (like the FS model) includes four equations--demand equations for rail and truck transportation, and pricing equations for rail and truck. The pricing equations in the current model follow FS in using average length of haul for each industry sector and each mode to incorporate quality of service into the price measure.

3. Freight Demand Database

The variables used in the current analysis along with their sources in the *Economic Census,* the *CFS, the* Bureau of Labor Statistics *Producer Price Indices and Occupational Employment Statistics*, and the *Economic Report of the President* are listed in Appendix Table A1.

NAICS was adopted by the Federal Government in 1997 to replace the Standard Industrial Classification (SIC) system that FS used and is now the standard classification system used in collecting and publishing data on business activity. The basic units of observation in the current study are industry sectors identified at the three digit level of NAICS. NAICS classifications extend to six digits but in order to relate NAICS economic data to shipment data in the *Commodity Flow Survey*, 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. Variables taken from NAICS include employment levels, payrolls, capital and material stocks and values of shipments for each industry sector.

The NAICS sectors used in the current analysis are listed in Table 2. The financial and operating data are combined with corresponding shipment data from the *CFS* using Standard Transportation Commodity Group (SCTG) classifications. These were adopted by the federal government in 1997 to replace the STCC codes that FS used. The link between the NAICS data and *CFS* data is *CFS* Table CF0700A15 *Shipment Characteristics by Origin Geography by NAICS by Mode: 2007*. [2] This table provides shipment data by mode for each of the three-digit NAICS industry sectors.

The final data elements in the current analysis are price series for rail, truck and industrial labor for 1997, 2002, and 2007. Rail and truck rates are taken 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. As in FS, sector-specific labor prices were calculated by dividing annual payroll for each sector by the reported number of employees (multiplied by 2,000 to approximate hours worked). Monetary values are converted to real terms in the econometric analysis using the aggregate Producer Price Index.

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

Table 2

NAICS Industries included in Database

(With SCTG Source)

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 FS analysis was restricted to the manufacturing industries listed in Table 1. This list was expanded in the current analysis but a number of SCTG categories were not included because production data on the commodities whose movements were described in the *CFS* could not be precisely identified in the NAICS data. These included SCTG 04 Animal Feed, SCTG 05 Meat, Fish and Seafood, SCTG 10-12 Stone and

Sand, SCTG 13 Other Minerals (Salt), SCTG 16 Crude petroleum, SCTG 25 Logs, and SCTG 37 Railroad Equipment and Aircraft.

4. Results of Current Econometric Model

The focus of both the FS analysis and the current analysis is on industry sectors where railroads and trucks compete 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 current model presents several econometric issues discussed in the Appendix. The system was estimated using Full Information Likelihood Procedure in SAS© Version 9.2. The parameter results are presented in Appendix Table A2. All of the parameters have the expected signs and all of the key parameters are statistically significant.

Of particular importance for this analysis, the own price parameters for rail (β_{RR}) and truck (β_{TT}) are negative as expected and significant. The cross-price parameter between rail and truck (β_{TR}) is positive as expected and also significant. This shows that there is effective competition between truck and rail—especially when intermodal movements are taken into account.

The own price elasticities of truck and rail and the cross price elasticities of truck-for-rail and rail-for-truck can be calculated for each observation in the data set. The elasticity estimates reported in Table 3 are calculated at the midpoint of the *CFS* data. The estimates are generally consistent with the FS estimates but all have the expected signs.

Table 3
U. S. Freight Markets – NAICS Basis
Rail-Truck Price Elasticities

NAICS	Description	Rail-Truck	Own Truck	Own Rail	Truck-Rail
111	Agricultural Prod	1.234	-0.786	-1.624	0.839
311	Food and Kindred	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	0.690	-0.652	-0.907	0.736
325	Chemicals	0.388	-0.419	-0.509	0.473
326	Plastics and Rubber	1.541	-0.92	-2.026	1.038
327	Nonmetallic Mineral	1.56	-0.951	-2.05	1.073
331	Primary Metal Mfr	1.043	-0.822	-1.371	0.928
332	Fabricated Metal	1.255	-0.726	-1.65	0.819
333	Machinery,non-Elec.	1.117	-0.641	-1.468	0.723
336	Transportation Equip	0.560	-0.407	-0.737	0.459

The area where the newer elasticities are significantly larger in absolute terms are the cross price elasticities between truck and rail. These indicate a higher degree of price and service competition between the two modes than FS found using 1972 data. The difference can be explained in two ways.

First, the FS results are based on a one-year *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 1972 data that FS analyzed would not reflect the crucial role that intermodal containers now play 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.

5. Analysis of TS&W Diversion Effects

The primary aim of this analysis is to predict the longer-term effects that that revised truck size and weight (TS&W) restrictions would have on the market for intercity freight movements. The question is: What effect would significant decreases in truck costs—leading presumably to reductions in truck rates--have on railroad and truck shares? The answer has two parts.

First, a significant decrease in truck prices would have a *direct effect* on railroad freight traffic by diverting shipments off the rail system and onto the highway network. Second, a significant decrease in truck prices could have an *indirect effect* on freight traffic by reducing rail revenues and investment and raising the unit costs of shipments which remain on the rail network.

The direct effects of a decrease in truck prices are presented in Table 4 and Table 5. The increase in truck traffic is calculated by multiplying the own-price elasticity of truck from Table 3 by a stipulated decrease in truck price. The decrease in rail traffic is calculated by multiplying the rail-truck cross-price elasticity from Table 3 multiplied by the same stipulated decrease in truck price.

The impacts are based on a hypothetical ten percent decrease in truck prices. This is consistent with the truck cost impacts projected by the U.S. Department of Transportation (DOT) Federal Highway Administration's *Comprehensive Truck Size & Weight Study* (2000). The study projected an 11.4 percent reduction in shipper costs for an "LCV Nationwide Scenario". [*CTS&W Summary Report*, Table 13, p. 38.] The base ton-miles for truck and rail (with rail including both rail and intermodal) are from the 2002 *CFS*.

Table 4
Effect on Market Shares
Base versus 10 % TSW Effect
2002 CFS Data

NAICS	Description	Base Shares Truck	Base Shares Rail	TSW Effect Truck	TSW Effect Rail	**Loss of Rail Market**[3]
111	Agricultural Products	0.27	0.73	0.44	0.56	0.15
311	Food & Kindred	0.69	0.31	0.74	0.26	0.15
312	Beverage & Tobacco	0.69	0.31	0.77	0.23	0.22
321	Wood Products	0.54	0.46	0.68	0.32	0.35
322	Paper	0.64	0.36	0.68	0.32	0.08
324	Petroleum & Coal Products	0.58	0.42	0.61	0.39	0.06
325	Chemicals	0.54	0.46	0.56	0.44	0.04
326	Plastics & Rubber	0.66	0.34	0.73	0.27	0.18
327	Nonmetallic Mineral Products	0.78	0.22	0.83	0.17	0.18
331	Primary Metal Manufactures	0.67	0.33	0.72	0.28	0.11
332	Fabricated Metal Products	0.84	0.16	0.87	0.13	0.16
333	Machinery Except Electrical	0.87	0.13	0.89	0.11	0.14
334	Computers & Electronics	0.85	0.15	0.86	0.14	0.09
336	Transportation Equipment	0.70	0.30	0.72	0.28	0.05

Though the projected 10 percent reduction in truck costs used in the current analysis is fairly small, the losses of rail market share are significant. In several key markets—agriculture, food products, wood products, plastics, non-metallic mineral products, and fabricated metal products--the loss is greater than or equal to 15 percent.[3]

Table 5 restates the direct diversion effects in physical terms. The percent rail diversions are converted into billions of lost rail ton-miles for each NAICS industry. These are then converted into lost movements of rail cars (based on car capacities), and into added truck movements based on truckload equivalents. The assumption is that trucks have an approximate capacity of 57,000 pounds**.** Truck mileage is calculated using known rail mileage and an estimate that railroad circuitry is 10 percent greater than truck circuitry.

[3] The final column of Table 4 lists the change in the own-market for rail. These effects are generally larger than the change in rail share of the total market because in most markets railroads start with a smaller share of the total market.

Table 5
U. S. Freight Markets - NAICS Basis
Nationwide Heavy Vehicle and LCV Impact
2002 Rail and Truck Operations

NAICS	Description	Billions of Lost Rail Ton-Miles	Rail Units Diverted	Additional Truck Trips Required	Additional Truck-miles (millions)
111	Agricultural Products	27.81	327,092	1,155,724	938.2
311	Food and Kindred Products	9.21	140,025	402,388	340.4
312	Beverage and Tobacco	1.73	26,321	75,639	64.0
321	Wood Products	19.24	246,390	767,700	713.0
322	Paper	2.99	49,313	133,579	119.9
324	Petroleum and Coal Products	3.13	56,703	183,041	116.1
325	Chemicals	4.61	64,120	206,984	158.0
326	Plastics and Rubber	4.83	67,272	217,160	165.7
327	Non-Metallic Mineral Products	5.24	204,455	741,060	175.4
331	Primary Metal	3.90	68,322	234,211	141.9
332	Fabricated Metal	1.07	18,728	64,201	38.9
334	Computers and Electronics	0.39	17,308	13,664	18.1
336	Transportation Equipment	0.92	51,110	80,162	60.1
Total	All Measured Commodities	85.1	1,337,160	4,275,513	3,050

The bottom-line result in Table 5 is that TS&W-induced diversion of freight from the rail system would generate about 4.3 million additional trips by large trucks each year and would impose an extra 3.05 billion heavy vehicle-miles on the highways annually. This translates into about 130 billion gross ton-miles a year. The FHWA's *Highway Statistics 2002* report estimates that combination trucks logged a total of 138.7 billion vehicle miles that year. About 30 percent of these were in the 200-mile plus range that characterizes rail-competitive traffic.[4] The 3.05 billion additional vehicle-miles thus represent a seven percent increase in long-haul truck traffic.

Some indirect effects of TS&W-related diversion are presented in Table 6. These are based on revenue-to-variable cost ratios reported by the Surface Transportation Board (STB) in its *2002 Commodity Stratification Report*. The results suggest that TS&W-related diversions would have resulted in a loss of

[4] See the U.S. Census Bureau (2002) *Vehicle Inventory and Use Survey* , Table 7 Truck Miles by Truck Type.

$2.6 billion in rail revenue each year and a reduction in railroad net income of $750 million annually. In 2002, the year upon which the projections are based, total railroad net income was just $3.2 billion.

Table 6
U. S. Freight Markets - NAICS Basis
Nationwide Heavy Vehicle and LCV Impact
2002 Rail Financial Impact

NAICS	Description	Billions of Lost Rail Ton-Miles	Revenue per Revenue Ton-Mile[1]	Cost per Revenue Ton-Mile[2]	Lost Rail Revenue (millions)	Lost Rail Net Income (millions)
111	Agricultural Products	27.81	$0.022	$0.015	$622.9	$209.6
311	Food and Kindred Products	9.21	$0.030	$0.024	$277.1	$52.4
312	Beverage and Tobacco[3]	1.73	$0.030	$0.024	$52.1	$9.9
321	Wood Products	19.24	$0.033	$0.027	$638.8	$127.1
322	Paper	2.99	$0.041	$0.032	$123.1	$26.1
324	Petroleum and Coal Products	3.13	$0.037	$0.023	$114.4	$41.7
325	Chemicals	4.61	$0.039	$0.021	$181.5	$83.1
326	Plastics and Rubber[4]	4.83	$0.039	$0.021	$190.4	$87.2
327	Non-Metallic Mineral Products	5.24	$0.031	$0.023	$160.9	$42.6
331	Primary Metal Manufactures	3.90	$0.035	$0.027	$137.9	$34.3
332	Fabricated Metal Products[5]	1.07	$0.035	$0.027	$37.8	$9.4
334	Computers and Electronics[6]	0.39	$0.033	$0.038	$12.6	-$2.0
336	Transportation Equipment	0.92	$0.119	$0.087	$108.6	$29.2
Total	All Measured Commodities	85.1			$2,658.0	$750.6

1. Source-*Railroad Ten-Year Trends, 1993-2002*, Association of American Railroads, p.40.
2. (Cost per Revenue Ton-Mile) = (Revenue per Revenue Ton-Mile)/(Revenue-Variable Cost Ratio)
3. Included in Food and Kindred Products under STCC system.
4. Included in Chemicals under STCC system.
5. Included in Primary Metal Products under STCC system
6. Handled in Intermodal Transportation.

The results presented in Tables 4, Table 5, and Table 6 use 2002 data that are at the midpoint of the *CFS* sample. The *within-sample* data are statistically the most reliable points from which to make such projections. Nevertheless, though there is some loss of precision, the elasticity results developed using the FS approach can be applied to present markets. Railroad traffic grew from 27.9 million carloads in 2002 to 32.1 million carloads in 2006. The recession slowed rail traffic but it is growing again. It is not unreasonable to assume that the potential effects of changes in TS&W regulation will continue to be significant.

Table 7 projects the results of the updated diversion analysis using commodity-specific data from the STB's 2010 Waybill Sample and revenue-to-variable cost ratios reported by the STB in its *2010 Commodity Stratification Report*.[5] The current model projects that TS&W-related diversions (based again on a 10 percent reduction in truck rates) would have resulted in a loss of $2.9 billion in rail revenue and a reduction in railroad net income of $776.2 million in 2010. (Total railroad net income in 2010 was $9.2 billion.) Also, the diversion of 102 billion ton-miles of freight onto the highway system would have generated more than four million additional trips by heavy trucks.

Table 7
U. S. Freight Markets - NAICS Basis
Nationwide Heavy Vehicle and LCV Impact
2010 Rail Financial Impact

NAICS	Description	Billions of Lost Rail Ton-Miles	Revenue per Revenue Ton-Mile	Cost per Revenue Ton-Mile	Lost Rail Revenue (millions)	Lost Rail Net Income (millions)
111	Agricultural Products	29.1	0.0207	0.0138	$601.6	$200.5
311	Food and Kindred Products	25.7	0.0268	0.0214	$687.6	$138.5
321	Wood Products	14.8	0.0243	0.0234	$359.8	$13.3
322	Paper	5.5	0.0294	0.0287	$161.0	$3.8
324	Petroleum and Coal Products	2.7	0.0345	0.0206	$94.4	$38.0
325	Chemicals	8.2	0.0401	0.0183	$330.3	$179.6
327	Non-Metallic Mineral Products	7.5	0.029	0.0203	$216.9	$65.1
331	Primary Metal Manufactures	4.8	0.0296	0.0238	$142.4	$27.9
334	Computers and Electronics	1.0	0.0869	0.0493	$89.0	$38.5
336	Transportation Equipment	2.8	0.0927	0.0675	$260.7	$70.9
Total	All Measured Commodities	102.1			$2,943.6	$776.2

[5] The Waybill Sample includes some but not all intermodal ton-miles in its report of commodity-by-commodity output levels. About 60 percent of intermodal ton-mileage is reported as Miscellaneous Mixed Shipments (STCC 46) and this can be any commodity. The assumption made in constructing Table 7 was that the proportion of Miscellaneous Mixed Shipments for each major truck-competitive commodity (e.g. Food and Kindred Products) was equal to its share of intermodal shipments not classified as Miscellaneous Mixed Shipments. For example, Food and Kindred Products accounted for 18.2 percent of intermodal ton-miles in 2010 excluding Miscellaneous Mixed Shipments. The assumption was that 18.2 percent of Miscellaneous Mixed Shipments ton-miles were for Food and Kindred Products. These ton-miles were added to the reported Waybill ton-mileage for Food and Kindred Products. (See AAR *Ten-Year Trends*, 2012 Edition, p. 61)

6. Conclusion

The TS&W-related diversion effects analyzed above would be consequential for railroads, shippers and general highway users. The diversions would generate millions of additional trips by heavy trucks and would have reduced railroad net income by as much as 25 percent in 2002 and about 8.5 percent in 2010. This, in turn, could put significant downward pressure on railroad maintenance spending and on new investment in the rail system. It might also put upward pressure on rates paid by bulk and intermodal shippers who remain on the rail system.

The estimates provided here do not take into account the significant external affects that TS&W changes could have on the environment and on highway users. The DOT's *Comprehensive Truck Size & Weight Study* (2000) was an important policy document because it analyzed the effects of TS&W changes in comprehensive economic terms, taking into account the effects on pavement costs, bridge costs, highway capital costs (geometry), congestion costs, energy costs, shipper costs, and railroad costs. Full analysis of these effects is beyond the scope of the present study, but these are all important elements of a complete TS&W policy evaluation.

Appendix

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

The basic assumption of the FS analysis is that rail and truck freight services are inputs shippers' production processes along with capital, labor, and materials. Shipper decisions are modeled using an economic cost function whose arguments include aggregate output levels for key industrial sectors, quasi-fixed stocks of capital and materials, labor prices (wages), and generalized prices for truck and rail freight services. The 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 predict how freight expenditures will change as input prices change.

FS then 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.

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

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

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

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

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

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

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* (*CFS*).

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

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

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:

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

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 *CFS*.

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.

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

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

$$w_R = \theta_{R0} + \theta_{R1} LOH_R + \varepsilon_3 \quad (8)$$

$$w_T = \theta_{T0} + \theta_{T1} LOH_T + \varepsilon_4 \quad (9)$$

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 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.

Model Estimation

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

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 disturbance terms in equations (6) and (7) are contemporaneously correlated and thus 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.

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

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 9.2. 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 from the FIML estimation are presented in Table A2. All of the parameters have the expected signs and the key parameters are significant.

Table A2

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.

As stated above, 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 establishes that there is effective overall competition between truck and rail in the sectors that are analyzed—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.

Diversion Effects

A significant decrease in truck prices will have both a *direct effect* and an *indirect effect* on the levels of railroad freight traffic. The direct effect would be to divert shipments off the rail network. The indirect effect would be to decrease railroad net income and investment levels and increase the unit costs of remaining rail shipments. The direct effects in Table 4 and Table 5 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 change 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 based on the DOT's 2000 *Comprehensive Truck Size and Weight Study*. The indirect effects in Table 6 are also derived from the percent change in rail ton-miles for each NAICS category.

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