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Three Essays on Railroad Cost

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THREE ESSAYS ON RAILROAD COST

By

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ABSTRACT
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The railroad industry has traditionally been a major source for transporting bulk products in the United States. Prior to deregulation this industry faced fairly stringent economic regulation and stringent work-rules. However, with passage of the Staggers Act in 1980, railroad carriers now had greater opportunity to legally abandon unprofitable short-haul service. Carriers were also able to negotiate more flexible work-rules as well as take advantage of greater freedom setting competitive shipping rates. These policy changes facilitated significant changes to the cost of providing shipping service in the railroad industry. This dissertation examines three different aspects of railroad cost in the current period of a more market-oriented business environment. Coverage includes analysis of economies of scope, allocative use of factor inputs and determinants of productivity growth.

The first essay examines cost results from estimating a normalized quadratic cost function for the US rail industry to empirically test whether maintenance of short-haul services contributes to economies of scope for Class-1 rail carriers. The analysis examines the existence of economies of scope in the railroad industry with respect to different types of services provided by carriers, namely; unit train, way train and through train services. Special attention is given to the (dis)economies of scope associated with providing way train service, since routes for this service cover small distances and, therefore, depict short-haul shipping that has traditionally been

associated with cost inefficiencies. The parameter estimates obtained from estimating the normalized quadratic cost function are used to simulate hypothetical firms that provide various combinations of outputs, since there is no available data to compare rail firms that provide different combinations of transport service. Findings suggest that the majority of the observations exhibit economies of scope. Without imposing concavity, more than 95 percent of observations display economies of scope, while more than 70 percent of observations display economies of scope when input price concavity is imposed. The findings on diseconomies of scope also suggest that providing way service is not the primary source, rather all three services equally contribute to diseconomies for the non-substantial number of observations when this occurs.

The second essay explores the possibility of railroad input market distortion in the form of allocative inefficiency due to labor market regulation and union work-rules. Rail carriers have consistently negotiated less rigid work-rules which may create a business environment that enhances carriers' ability to employ an allocatively efficient mix of inputs. Using labor as the benchmark of comparison when examining usage of factor inputs suggests that indeed carrier do employ an allocatively efficient combination of equipment and labor, material and labor, and way and structures and labor. Findings suggest carriers over invest in fuel with respect to labor. This latter finding is interpreted as suggesting that relative to shadow fuel prices, low shadow wages due to work-rule restrictions and due to the use of fuel efficient locomotives that facilitate the overuse of fuel relative to labor. Nonetheless, efficient use of labor relative to non-fuel inputs is consistent with the notion that less restrictive work-rules promotes a business environment contributing to allocative efficient use of those inputs.

The third essay examines factor price effects on productivity in the railroad industry. Findings suggest that price effects are not the main source of changes in productivity. Among the price effects, the price of material and price of way and structures show larger and significant magnitudes in explaining the sources of changes in productivity compared to other prices. Interestingly, price of labor and price of fuel are the input prices that contribute the least to changes in unit cost.

Dedicated to my beloved husband and princess,

Hairul Azri Ibrahim & Nur Amirah Hairul Azri

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ESSAY 1: AN EMPIRICAL ANALYSIS OF ECONOMIES OF SCOPE IN THE UNITED STATES RAILROAD INDUSTRY

1.1 Introduction

Railroad service has traditionally been a common modal choice for transporting bulk products in the United States.[1] Products primarily transported by rail include coal, grain, lumber and automobile parts. Given the economic importance of providing consumers' access to these vital products the federal government, since the passage of the 1887 Interstate Commerce Act (ICA), has regulated the operations of class-1 rail carriers. Part of this regulation included requiring these large carriers to provide long-haul and short-haul service.[2] Achieving universal service for customers, especially agricultural firms in rural areas, explained part of the rational for stipulating class-1 carriers provide both freight services. While providing rail service to rural areas was key to agricultural producers having access to the US transportation network, class-1 carriers faced serious challenges making a profit on short-haul lines. Stepped-up competition from trucking starting in the early 20th century and a lack of traffic density on short-haul routes contributed to class-1 carriers difficulties operating profitable short-haul service during the period of regulation by the Interstate Commerce Commission (ICC).These carriers also faced difficulties abandoning short-haul lines in part because abandonment approval from the ICC often meant contending with substantial delays, and high cost associated with labor protection

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[1] The most up to date data of freight hauled in the US indicates that in 2007 39.5 percent of freight was moved by rail compared to 28.6 percent hauled by trucks, the next largest transporter of freight in the US. Source: USDOT Federal Railroad Administration, https://www.fra.dot.gov/Page/P0362.

[2] U.S. Class I Railroads are line haul freight railroads with $250 million or more in revenue adjusted for inflation. Currently there are seven US class-1 rail carriers. Regional and short-line carriers depict the two remaining rail categories. Short-line operators are generally classified as operating less than 250 miles of track, and regional carriers typically operate more than 350 miles of track, or generate more than $40 million in revenue adjusted for inflation since 1991. Often regional carriers are classified as short-haul carriers.

rules (Due, 1987). Furthermore, the ICC often considered the loss of business to shippers over the potential gain to rail carriers when ruling on route abandonment requests (Due, 1987).

Passage of the 1980 Staggers Act addressed the financial challenges facing class-1 carriers by allowing them to abandon or sell costly lines. Following this act the application process for abandonment was streamlined and the burden of proof was transferred from the class-1 carrier to the protestant (Due, 1987). Most of the abandoned lines provided short-haul services and were sold to short-line carriers who were better able to operate a profitable business. Short-line carriers employed a non-union work force compared to the near total unionization of the class-1 non-management workforce. Hence, short-line carriers operated with lower labor costs and less rigid work-rules (Fischer et al., 2001). In addition, the slower speeds used to transport short-haul relative to the speeds used for long distance routes allowed short-line operators to invest less in capital to maintain track and pay for expensive motive power (Due, 1984). Evidence of this change in business ownership is revealed by the increase of 157 short-line rail carriers in the seven years following the passage of the Staggers Act, compared to a total of 93 new short-line carriers for the preceding 50 years (Mielke, 1988). In contrast, the number of class-1 carriers fell from 73 prior to regulatory reform to the current count of seven.

Even though the abandonment of short-haul service by class-1 carriers accelerated following the passage of the Staggers Act, these carriers may still continue to provide the service if the line is economically viable. Given the fact that they provide multiple services such as short-haul and long-haul, an examination of economies of scope during the post Staggers period allows for testing if class-1 carriers have taken advantage of this abandonment provision to achieve cost efficiency by selling or abandoning cost inefficient lines and continuing to service cost efficient profitable short-haul lines. While data is not available that specifically identifies information on class-1 carriers providing short-line service, class-1 annual reports (R1 reports) do present information on the types of train service. These services are classified as unit, way, and through service. Unit train service is dedicated to the transportation of a single commodity for a specific originating-destination location pair (Bitzan 1999; Growitsch and Wetzel 2009). Way train service is characterized by the gathering of cars from differing originating locations and bringing them to a major freight terminal (Bitzan 1999; Growitsch and Wetzel 2009). Through train service transports goods between two or more major freight terminals (Bitzan 1999; Growitsch and Wetzel 2009). Of these three services, the operations of way service most often includes providing short-haul delivery (Bitzan, 1999). Indeed, information on average distance hauled by class-1 carriers presented in Table-1 suggest that way train service is a good proxy for short-hauls. For instance, the average distance of a unit train is between 5 to 30 times longer than the average distance of a way train, and the average distance of a through train is between 5 to 15 times longer than the average distance of a way train. For purposes of this study, the significant observation gleaned form Table-1 is the fact that the share of freight hauled by way train service, based on number of cars loaded, is a non-trivial 29.49 and 21.48 percent of the freight hauled for carriers servicing the eastern and western part of the US, respectively by 2011. This distribution of shares among freight services is fairly constant for the entire observation sample. At issue is whether these carriers continue to provide this service in part because they benefit from economies of scope.

While several studies examine economies of scale, there is a dearth of research examining economies of scope as an approach for analyzing cost efficiency in the post Staggers era. Those that do examine economies scope do not base their analysis exclusively on the type of freight services provided to shippers. For instance, Ivaldi and McCullough (2004) examine joint production between infrastructure companies and competing operating firms as a test of economies of scope. Kim (1987) examines the joint production of passenger and freight service. Rail service considered by these papers represents the type of unit hauled, whereas this essay will be examining the type of services that hauls the unit. Past research that does examine the cost effect of providing different freight services examines whether the condition for subadditivity is satisfied (Bitzan, 2003). While findings from this research do not directly test for economies of scope, the author suggests that the cost conditions of class-1 carriers providing unit, way and through train service satisfy the conditions of a natural monopoly most of the time. From this finding he concludes that economies of scope likely exists in this industry. Since the subadditivity condition is not met for all the observations, there is the possibility that diseconomies of scope exists. Nonetheless, a direct test of economies of scope associated with providing unit, way and through train service has not been provided by past research.

Table-1: Average distance[3] of unit train service (U), way train service (W) and through train service (T)

Carrier	Year	car miles (U)	car miles (W)	car miles (T)	cars loaded (U)	cars loaded (W)	cars loaded (T)	Ave-U	Ave-W	Ave-T
BN	2011	6385717	177053	4828145	4262000	2634000	5935000	1.50	0.07	0.81
CN	2011	229186	141624	875531	1184000	2313000	3180000	0.19	0.06	0.28
CP	2011	165602	33606	615141	258937	601535	1142000	0.64	0.06	0.54
CSXT	2011	1763933	206679	3039401	2469000	3894000	11708000	0.71	0.05	0.26
EAST	2011	3143290	660597	6819335	6128000	11288000	20858000	0.51	0.06	0.33
KCS	2011	188564	26674	416033	229577	362472	740229	0.82	0.07	0.56
NS	2011	1150171	312294	2904403	2474000	5079000	5969000	0.46	0.06	0.49
UP	2011	5284217	178232	7726715	2869000	3098000	9036000	1.84	0.06	0.86
WEST	2011	12024100	415565	13586034	7620000	6697000	16854000	1.58	0.06	0.81
BN	2010	6547019	171298	4580714	4256000	2432000	5589000	1.54	0.07	0.82
CN	2010	220368	131689	853759	1238000	2234000	3069000	0.18	0.06	0.28
CP	2010	139045	30999	607187	274674	568916	1120000	0.51	0.05	0.54
CSXT	2010	1790737	219182	2927003	2618000	3809000	11426000	0.68	0.06	0.26
EAST	2010	3082736	670889	6506212	6215000	11013000	20209000	0.50	0.06	0.32
KCS	2010	185256	42151	385736	613143000	185256000	42151000	0.00	0.00	0.01
NS	2010	1071631	320018	2725450	2358000	4970000	5713000	0.45	0.06	0.48
UP	2010	4970684	173730	7447218	2714000	2800000	8547000	1.83	0.06	0.87
WEST	2010	11842004	418178	13020855	7471000	6190000	15932000	1.59	0.07	0.82
BN	2009	6043229	168589	4125610	3856000	2157000	4914000	1.57	0.08	0.84
CN	2009	168251	90192	791276	969668.1	1511000	2866000	0.17	0.06	0.28
CP	2009	87566	14476	370726	178968	292326	589188	0.49	0.05	0.63
CSXT	2009	1682376	215225	2699019	2584000	3582000	10493000	0.65	0.06	0.26
EAST	2009	2836013	581952	5942109	5566000	9472000	18456000	0.51	0.06	0.32

[3] Average distance is calculated by dividing car miles by number of cars loaded.

KCS	2009	207434	52348	331496	250759	400052	554942	0.83	0.13	0.60
NS	2009	985386	276535	2451814	2012000	4378000	5096000	0.49	0.06	0.48
UP	2009	4609283	156771	6587035	2688000	2626000	7603000	1.71	0.06	0.87
WEST	2009	10947512	392184	11414867	6975000	5476000	13662000	1.57	0.07	0.84
BN	2008	6353259	219554	4599499	4627000	2868000	5795000	1.37	0.08	0.79
CN	2008	201682	88345	1006501	1179000	1543000	3278000	0.17	0.06	0.31
CP	2008	105112	14853	421845	178585	300354	617884	0.59	0.05	0.68
CSXT	2008	1944808	236297	3288920	2851000	4122000	12300000	0.68	0.06	0.27
EAST	2008	3357049	664375	7227138	6618000	11073000	21846000	0.51	0.06	0.33
KCS	2008	182236	60565	392866	238200	498124	633436	0.77	0.12	0.62
NS	2008	1210559	339733	2931717	2587000	5406000	3267000	0.47	0.06	0.90
UP	2008	5579064	181314	7867452	3201000	3037000	9207000	1.74	0.06	0.85
WEST	2008	12219671	476286	13281662	8245000	6704000	16253000	1.48	0.07	0.82

Note. Data retrieved from http://www.stb.dot.gov/stb/industry/urcs.html

Key: In column 1 BN represents Burlington Northern, CN represents Canadian National, CP represents Canadian Pacific, CSXT represent CSX Transportation, EAST represents the east regional Class 1 carriers, KCS represents Kansas City Southern, NS represents Norfolk Southern, UP represent Union Pacific, WEST represents the west regional Class 1 carriers. In column 3, 4, 5 represents the car miles for unit, way and through services respectively, in column 6, 7, 8 represents number of loaded cars for unit, way and through services respectively, and in column 9, 10, 11, the variables ave1, ave2 and ave3 represent the average distance for unit train, way train and through train respectively. The freight service as explanatory variables.

This essay contributes to our understanding of cost efficiencies in the US rail industry by estimating a flexible form cost equation that includes the three types of train transport services. If economies of scope exists, having multi-service railroad carriers would be efficient, whereas, if economies of scope does not exist, divestiture of transport operations would be advantageous (Growitsch and Wetzel, 2009). Results from this study's estimations suggest that 96.7 percent and 70.44 percent of observations display economies of scope before and after imposing input price concavity, respectively. Therefore, it is reasonable to suggest that the majority of observations satisfy the condition for economies of scope except for a small subset of observations for some class-1 carriers.

1.2 Identifying Economies of Scope

Economies of scope is an important concept for use in examining the existence of natural monopoly in an industry with multiple products. In a multiproduct setting, economies of scale are neither necessary nor sufficient for natural monopoly (Baumol et al., 1982; Sharkey, 1982). An industry is considered to be a natural monopoly if it satisfies the conditions of subadditivity. The sufficient conditions for subadditivity are economies of scope and declining average incremental cost (Evans and Heckman, 1984, p. 616). Whereas Sharkey (1982) argues the existence of economies of joint production and economies of scale are conditions necessary to attain subadditivity in a multiproduct setting. For economies of scope, however, it is not enough to only observe economies of joint production as it is also necessary to satisfy the condition of cost complementarity.

Economies of scope is defined as cost savings associated with joint production, such that it is less costly to produce multiple products jointly rather than to produce each product separately (Waldman and Jensen, 2013; Carlton and Perloff, 2005). For the two product case (Y_1 and Y_2) as presented by Baulmol et al. (1982) economies of scope is specified using the following equation:

$$C(Y_1, 0) + C(0, Y_2) - C(Y_1, Y_2) > 0 \qquad (1)$$

where $C(Y_1, 0)$ *and* $C(0, Y_2)$ depict separate firms' cost accrued from specializing in the production of products Y_1 and Y_2 and $C(Y_1, Y_2)$ depicts the joint production cost of producing the same two products. The degree to which cost savings accrue from economies of scope is measured using the following equation suggested by Baumol et al. (1982):

$$Degree\ of\ economies\ of\ scope\ for\ Y_1 and\ Y_2 = \frac{C(Y_1,0)+C(0,Y_2)-C(Y_1,Y_2)}{C(Y_1,Y_2)} \qquad (2)$$

where the degree of cost savings is associated with a positive value for equation (2). This concept of economies of scope for a two good model is depicted geometrically using Figure-1 (Baumol et al., 1982). This graph allows for visually comparing the cost of separately producing a specific amount of goods Y_1^* and Y_2^* at cost $C(Y_1^*, 0)$ *and* $C(0, Y_2^*)$, with the cost of jointly producing the same quantity of these two goods at cost $C(Y_1^*, Y_2^*)$. Graphically, $C(Y_1^*, 0) + C(0, Y_2^*)$ is the sum of the heights of the cost surface over the corresponding coordinates on the axes and $C(Y_1^*, Y_2^*)$ is the height of the cost surface at coordinate (Y_1^*, Y_2^*). The two separate rays that include the cost of producing the two goods separately are used to construct the hyper-plane 0AB, such that the limit of the plane is reached at the production level derived when producing both products at the specified output levels (Y_1^*, Y_2^*). Hence, the cost associated with producing both products separately at these levels is depicted by coordinate D and depicts cost $C(Y_1^*, 0) + C(0, Y_2^*)$. Economies of scope is achieved if the height of the cost surface at the output levels (Y_1^*, Y_2^*) coordinate derived when producing the two goods jointly $C(Y_1^*, Y_2^*)$ lies beneath the hyper-plane.

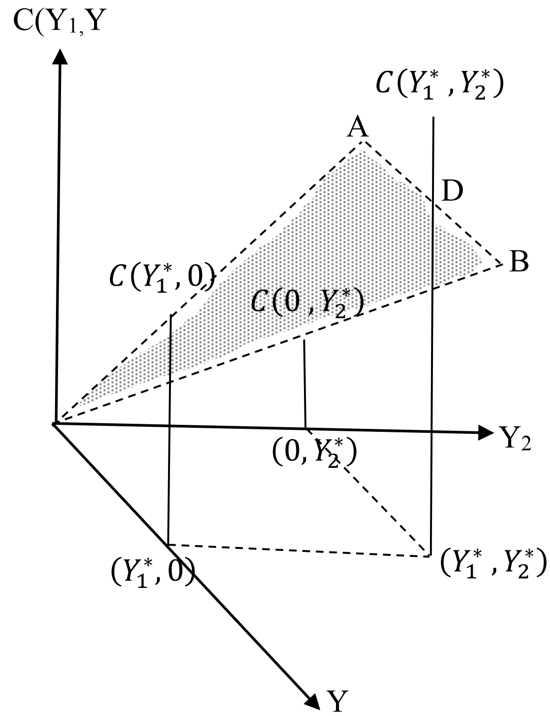

Figure-1: Economies of scope. Adapted from *Contestable Markets and the Theory of Industry Structure* (p.72), Baumol, W. J., Panzar, J. C., & Willig, R. D., 1988, New York, Harcourt, Brace Jovanovich, Inc.

An often cited source of economies of scope is the presence of '*public inputs*' in the production process.[4] Baumol et al. (1982, pp. 75-76) explain that while these public inputs can be used to produce one good, they are available without additional cost for use

[4] The term 'public input' is taken from Marshall (1925), as he identifies these inputs as factors that are readily shared by the processes used to produce several different outputs. He points to the use of sheep for wool and mutton, cows for the production of beef and hides, and grain for the production of wheat and straw.

in the production of other goods. As an example, these authors observe generating capacity of utility companies as a public input that can be used to provide energy services during peak and off-peak period without additional cost from using the capacity of the plant. Indeed, the cost of the plant itself is fixed. This thread of logic can be easily applied to rail, as Pepall et al. (1999, p.93) reveal railroad tracks are fixed cost whose use does not vary if service is provided to haul freight or to haul passengers. In contrast, additional cost is incurred if two separate firms built their own tracks such that one company provided freight service and the other provided passenger service.

For the purposes of this study the relevance of economies of scope as an approach for analyzing cost efficiency associated with rail abandonment is it allows for examining the cost effect of jointly providing unit (U), way (W) and through (T) train service. Consistent with Pepall, Richard and Norman's observation, a contributing reason for economies of scope in unit, way and through train service is sharing the existing railroad tracks. Another reason given by Growitsch and Wetzel (2009, p.5) is the "potential transaction cost savings within an integrated organization since railroad services are characterized by a high level of technological and transactional interdependence between infrastructure and operations". Economies of scope can also arise from sharing "use of headquarters services such as management, marketing or communication services" (Growitsch and Wetzel, 2009, p.2). There is also the possibility that joint production does contribute to higher cost faced when separate companies provide disjointed production of these transportation services. For example, Allen et al. (2002) indicate that following regulatory reform in the rail industry class-1 carriers emphasized operating a wholesale type of business requiring greater use of high speed unit trains and intermodal trains for longer distances. Hence, the retail part of the business that provides service to smaller customers, such as rural farmers, required costly time intensive switching and slow speed operations, especially given the high-wage, highly unionized class-1 work force.[5] In contrast, the work force of shortline carriers is non-union employees. Allen et al. (2002) also observe shortline carriers enjoy a cost advantage focusing on short-haul (way) service because their operation requires less capital investment because of the low speeds associated with this service allows for less investment in track and motive power.

Testing whether economies of scope providing different types of hauling services suggests using a conceptual framework that allows analysis of more than two services, however thus far for simplicity the theoretical description of economies of scope has focused on the two goods model. More generally for *N* products the description of economies of scope can be viewed as mirroring the condition for subadditivity, but applied to a restricted set of output vectors (Sharkey, 1982) as depicted by equation (3) below.[6]

$$C(Y) + C(Y') \geq C(Y + Y') \tag{3}$$

Where Y and Y' are output vectors for N products $Y = (y_{1,} y_2, \dots, y_n)$ and $Y' = (y'_{1,} y'_2, \dots, y'_n)$ and these vectors consist of disjointed outputs such that when $y_{i,} > 0$, then $y'_{j,} = 0$. Within this theoretical framework of economies of scope for unit, way and through train service is depicted as follows:

$$C(Y_U, 0,0) + C(0, Y_W, 0) + C(0,0, Y_T) > C(Y_U, Y_W, Y_T) \tag{4}$$

[5] Peoples (2013) reports unionization rates exceeding 75 percent in the rail industry as late as 2012.

[6] While the condition for economies of scope closely resemble the condition for subaddditivity, Baumol, Panzar, and Willig prove that achieving economies of scope is not sufficient to satisfy the condition of subadditivity. Joint production requires cost complementarity to achieve subadditivity.

where U: unit train service, W: way train service and T: through train service. This essay will refer to equation (4) as the basis for empirically testing the prevalence of economies of scope in the class-1 railroad sector.

1.3 Empirical Tests of Economies of Scope in Rail

Research specifically examining economies of scope for the United States railroad industry is relatively scarce. One such paper by Kim (1987) empirically examines whether the US railroad industry's operations satisfy the conditions for economies of scale and scope. He uses a generalized translog form with two categories of output of railroad firms, which are freight service (Y_f) measured in revenue ton-miles and (Y_p) measured in passenger-miles. The inputs prices used in the model are capital (W_k), labour (W_l) and fuel or energy (W_e). The data used for the study comprised of 56 Class I US railroads in 1963. The generalized translog multiproduct joint cost function used by Kim (1987, p.734) for the railroad industry is specified as follows:

$$lnC = \alpha_0 + \sum_i \alpha_i \left[\frac{(Y_i^{\lambda_i}-1)}{\lambda}\right] + \sum_k \beta_k \, lnW_k + \frac{1}{2}\sum_i \sum_j \partial_{ij} \left[\left(Y_i^{\lambda_i} - 1\right)/\lambda_i\right]\left[\left(Y_j^{\lambda_j} - 1\right)/\lambda_j\right] + \frac{1}{2}\sum_k \sum_l \gamma_{kl} lnW_k lnW_l + \sum_i \sum_k \rho_{ik} \left[\left(Y_i^{\lambda_i} - 1\right)/\lambda_i\right] lnW_k \quad (5)$$

where $\partial_{ij} = \partial_{ji}$ and $\gamma_{kl} = \gamma_{lk}$ and λ = a power of parameter[7].

Kim follows Panzar and Willig's (1977) definition of a local measure of aggregate scale economics for the multiproduct firms presented by the scale elasticity as follows:

[7] In Kim's paper, the two types of outputs, freight services and passenger service, are entered into the cost function using box-cox transformation where $Y_t = \frac{(Y_i^{\lambda_i}-1)}{\lambda}$ if $\lambda_i \neq 0$ and $Y_t = lnY_t$ if $\lambda_i = 0$.

$$SL(Y, W) = \frac{[C(Y,W)]}{[\sum_i Y_i MC_i]} = 1/\left[\sum_i \varepsilon_{CY_i}\right] \tag{6}$$

where MC_i is the marginal cost with respect to the ith output and $\varepsilon_{CY_i} = \frac{\partial lnC}{\partial lnY_i}$ is the cost elasticity of the ith output. The cost elasticity is later expressed as

$$\varepsilon_{CY_i} = (\alpha_i) + \sum_j \partial_{ij}\left[\left(Y_i^{\lambda_i} - 1\right)/\lambda_j\right] + \sum_k \rho_{ik} lnW_k)Y_i^{\lambda} \tag{7}$$

At the approximation point where $Y_i = W_k = 1$, the aggregate scale economies is reduced to

$$SL = 1/[\sum_i \alpha_i] \tag{8}$$

To measure the degree of economies of scope, Kim incorporates Panzar and Willig's (1981) definition which is given by:

$$SC = [\sum_i C(Y_i, W) - C(Y, W)]/C(Y, W) \tag{9}$$

where SC measures the percentage cost savings (increase) resulting from joint production. If economies of scope is present, the term SC will have a positive sign. From here, Kim measures the degree of economies of scope for his railroad model as the following:

$$SC = [C(Y_F, 0, W) + C(0, Y_P, W) - C(Y_F, Y_P, W)]/C(Y_F, Y_P, W) \tag{10}$$

At the point of approximation, Kim (1987, p.736) derives the scope economies as the following:

$$SC = \left[e^{\left(\alpha_0 - \frac{\alpha_F}{\lambda_F} + \frac{\delta_{FF}}{2\lambda_F^2}\right)} + e^{\left(\alpha_0 - \frac{\alpha_P}{\lambda_P} + \frac{\delta_{PP}}{2\lambda_P^2}\right)} - e^{(\alpha_0)}\right]/e^{(\alpha_0)} \tag{11}$$

Kim's analysis on the railroads carriers in the 1963 shows estimated aggregate scale economies is 1.063 implying the existence of mild overall economies of scale for US railroads. Furthermore, the estimated degree of scope economies shows a value of

-0.410 implying the presence of diseconomies of scope. He interprets these results as suggesting that “the cost of providing freight and passenger services separately would be 41% smaller than the cost of producing them jointly” (Kim, 1987, p.738). Kim emphasizes that both of these findings “cast doubt” on the possibility that US railroad industry exhibits the characteristics of a natural monopoly, at least when jointly providing freight and passenger service. Even though these results are somewhat dated, this information is significant to the overall analysis on economies of scope, in part because they indicate cost-savings are far from guaranteed when transporting different types of loads, Even if shared track and terminals would seem to provide cost advantages of a ‘*public inputs*’.

Cost research using more recent data to examine whether the US rail industry exhibits characteristics of a natural monopoly is provided by Bitzan (2003). He empirically test whether the condition for subadditivity is satisfied to class-1 rail carriers, and uses these results to make observations regarding economies of scale and scope for this industry. He uses the following generalized quasi-cost function as the basis for his analysis.

$$QC = QC\begin{pmatrix} w_l, w_{m+s}, w_f, w_e, UTGTM, WTGTM, TTGTM, \\ MOR, ALH, TRK, WSCAP, Time \end{pmatrix} \qquad (12)$$

where QC is the cost excluding way and structure costs, w_l is the price of labor, w_{m+s} is the price of materials and supplies, w_f is the price of fuel, w_e is the price of equipment, $UTGTM$ is the adjusted unit train gross ton miles, $WTGTM$ is the adjusted way train gross ton miles, $TTGTM$ is the adjusted through train gross ton miles, MOR is the route miles, ALH is the average length of haul, TRK is the miles of track per mile of road, $WSCAP$ is the net investment in way and structures per mile of track.

He identifies two basic cost issues addressed in the paper. Firstly, whether efficiency decreases resulting from roadway maintenance separation from transport service. Secondly, whether economies of scale and scope exist in providing transport services. For the first cost issue, he tested the cost function for separability. His estimation results suggest that there are cost savings resulting from jointly producing the roadway and the transport services over it. Thus, multiple firm operations over the rail line will probably produce an increase in costs. To address the second cost issue, the output-cost relationships estimated from this function are then used to test the condition of cost subadditivity by simulating single firm and two firms under various output combinations. He follows Shin and Ying's (1992) simulation approach used to test whether the condition of subadditivity is met. This approach tests whether monopoly cost designated by the term $C(q^M)$ is less than the summation of total cost accrued by smaller hypothetical firms *a* and *b* producing the same aggregate output as the monopoly firm. This subadditivity condition is designated by the following inequality:

$C(q^M) < C(q^a) + C(q^b)$ where $C(q^M) = C(q_1^M, q_2^M, q_3^M)$;

$C(q^a) = C(\varphi q_1^M, \rho q_2^M, \gamma q_3^M)$; $C(q^b) = C((1-\varphi) q_1^M, (1-\rho) q_2^M, (1-\gamma) q_3^M)$ (13)

where $\varphi, \rho, \gamma = (0.1, 0.2, \ldots, 0.9)$; q_1, q_2, q_3 = unit train, way train and through train gross ton miles.

Parameter results derived from estimating quasi-cost function is then used to estimate one-firm and two-firm quasi-costs, where all variables besides outputs, time and miles of road are placed at their sample means. Bitzan (2003, p.218) further mentions that "the single-firm and two-firm costs are estimated by splitting the three outputs into a unique vector combination of 365 for each of the observations that have positive marginal quasi-costs associated with each type of output". From the subadditivity simulations for costs for observations having positive marginal costs, between the years 1983 to 1997, the range of percentage for cost subadditivity condition met is between 1.3 percent and 73.4 percent of the simulations where before the year 1990, less than 50 percent of the simulations in the year met the condition for cost subadditivity. The condition for cost subadditivity is satisfied for more than half the simulations for the observation sample covering the years 1991 onwards. It is important to note, initially, he claimed that if economies of scale and scope are realized in providing transport service over this network, after way and structures costs are eliminated, then "multiple-firm operation over a single network will result in an increase in costs" (Bitzan, 2003, p.204). Testing directly the condition for subadditivity through simulation, he suggests that railroads are natural monopolies in providing transport services over their own network and thus suggesting that "multiple-firm competition over a single rail network would lead to cost increases" (Bitzan, 2003, p.218). While satisfying subadditivity suggests the strong possibility of economies of scope, Baumol et al. (1982) and Sharkey (1982) prove that economies of scope is not a necessary or sufficient condition for subadditivity. Rather, these researchers show trans-ray convexity or cost complementarities are necessary to ensure subadditivity for multiple outputs. Cost complementarity requires that a decline in marginal or incremental costs of any output as the output or any other output increase. Nonetheless, findings using more recent cost data than that used in Kim's study suggests greater possibility of cost-saving through joint production following deregulation in the US railroad industry.

Succeeding research by Ivaldi and McCullough (2004) extends the work of Bitzan by directly testing for economies of scope. They use regulatory reports filed by 22 major US freight railroads for the period 1978-2001 in order to evaluate the technological feasibility of separating vertically integrated firms into an infrastructure company and competing operating firms. Two test**s** are conducted which are an infrastructure separation test and an operational separation test. The first tests whether the cost function is subadditive between network operations and infrastructure, whereas, the second tests whether the cost function is subadditive across types of operations. Ivaldi and McCullough (2004) definition for both separations are as follows:

Definition of infrastructure separation: Let y^S and y^T represent an orthogonal partition of the output vector y into operational activities (y^S) and infrastructure-related activities (y^T). The cost function is subadditive between operations and infrastructure costs if and only if $C(y) < C(y^S, 0) + C(0, y^T)$.
Definition of operational separation: The cost function for operations is subadditive between operations if for any and all vectors $y^i \neq y \;\; s.t\, , C(y^s, 0) < \sum C\left(y^i, 0\right)$. (Ivaldi and McCullough, 2004, p.5-6).

A multiproduct generalized McFadden cost function is estimated that includes both operational and infrastructure outputs. A vertical production process is assumed in which “quasi –fixed land and other inputs (fuel, materials, labor, and equipment) are first transformed into infrastructure outputs and then into differentiated car-miles” (Ivaldi and McCullough, 2004, p.11). The general rail cost model is given by

$$C = C^C(y_B, y_E, y_I, w_L, w_E, w_F, w_M; H, R, T, U, \theta) + \rho R \quad (14)$$

where y_B is the car-miles of bulk traffic (i.e. open hopper, closed hopper, tank), y_E is the car-miles of general traffic (i.e. intermodal, auto-carriers, gondolas and box cars), y_I is the replacement ties installed in a given year, w_L is the index of labor prices, w_E is the index of equipment prices, w_F is the index of fuel prices, w_M is the index of material prices and other input prices, H is the average length of haul, R is the miles of road operated, T is the years, U is the percent car-miles moving in unit trains, θ is the fixed effect and ρ is the opportunity cost of capital. Fixed capital quantity is land which is measured by miles of road (R). Furthermore H and U allow differentiating railroads in terms of their network structures. The variable y_I represents measure of infrastructure department activities. The variables y_B and y_E represent bulk operational output and general freight operational output respectively.

Among major findings from Ivaldi and McCullough's paper is the existence of significant cost complementarities between outputs y_B and y_E, and also between y_I and both of the operational outputs. The second-order output related parameter estimates between y_B and y_E, and between y_E and y_I are negatively siginificant whereas between y_B and y_I is positively significant. Furthermore, they propose a testing method based on definition of cost subaditivity to measure the technical cost of separating network technologies into infrastructure components and operating components. Two simulations are done. Firstly is the infrastructure separation where the subadditivity condition is given by $C^C(y_B, y_E, y_I) \leq \partial C^0 + C^V(y_B, y_E, 0) + C^V(0,0, y_I)$ where ∂C^0 is the degree to which start-up costs are duplicated when production is unbundled. Secondly, is the operational separation where the subadditivity condition is given by $C^C(y_B, y_E, 0) \leq \partial C^0 +$

$C^V(\alpha y_B, \beta y_E, 0) + C^V([1-\alpha]y_B, [1-\beta]y_E, 0)$. A vertical production process is assumed where land, fuel, materials, labor, equipment are first transformed into infrastructure outputs and then into differentiated car- miles. This assumption allows them to examine the technological aspects of vertical and horizontal integration.

The result for infrastructure separation suggests complementarities exist between infrastructure-related activities and train operations and the result from operational separation suggests complementarities exist between types of freight hauled. This essay contributes to the empirical literature on economies of scope in the US rail industry by directly testing whether for economies of scope exist when jointly providing different types of hauling service in contrast to Ivaldi and McCullough (2004) test on the different types of product hauled. As mentioned earlier in the essay the motivation for such an analysis is it allows for examining whether providing short-haul service is cost efficient for those class-1 carriers that continue to offer this service, even when evidence suggests that carriers specializing in short-haul service experience cost saving advantages relative to the class-1 carriers.

1.4 Data

To examine the possibility of short-haul (way) transport services contributing to economies of scope in the post deregulation US rail industry, this essay uses data from Class I Annual Reports (R-I reports) covers the observation period from 1983 until 2008. The overall data are collected in three forms. Firstly, from 1983 to 1995, the data are available in the form of raw file. SAS statistical package is used to extract the needed data. Secondly, from 1996 to 2004, the data are available in the form of EXCEL files uploaded in the Surface Transportation Board (STB) website. However these data are not comprehensive since only selected schedules are available.

To complete the schedule, two trips to the STB library in Washington DC were made and remaining schedules were obtained from taking snapshots on the library microfiche collections and their information saved into a pdf file. Thirdly, from 2005 to 2008, the data collected are in the form of pdf files uploaded in the STB website. For these years, the whole annual reports are uploaded. From these three different forms, the needed data were extracted, gathered and constructed into a common Excel file. The variables' sources and constructions are adapted from Bitzan and Keeler (2003) and summarized in Appendix A.

Data from eight schedules are gathered namely Schedule 335, Schedule 352B, Schedule 410, Schedule 415, Schedule 700, Schedule 720, Schedule 750 and Schedule 755 from all R1 railroad carriers. The cost function is represented by $C = C(w, y, a, T)$ where C is the real total cost, w is the five factor prices (labor, equipment, fuel, material and supply, way and structures), y is the three output variables or three types of train services provided by the railroad carriers (unit train service, way train service, through train service), a is the technological conditions and T is the time trend representing the technology. The real total cost variable is calculated as follows:

$$\text{real total cost} = \frac{(\text{opercost} - \text{capexp} + \text{roird} + \text{roilcm} + \text{roicrs})}{\text{gdppd}} \qquad (15)$$

where opercost = railroad operating cost,

capexp = capital expenditures,

roird = return on investment in road,

roilcm = return on investment in locomotives,

roicrs = return on investment in cars and

gdppd = GDP price deflator

Each of the components in equation (15) are initially constructed using the following equations multiplied with the cost of capital available from Association of American Railroads (AAR) railroad facts.

$$\mathrm{roird} = (\mathrm{roadinv} - \mathrm{accdepr}) * \mathrm{costkap} \tag{16}$$

where $\mathrm{roadinv}$ = road investment ,

$\mathrm{accdepr}$ = accumulated depreciation

$$\mathrm{roilcm} = [(\mathrm{iboloco} + \mathrm{locinvl}) - (\mathrm{acdoloco} + \mathrm{locacdl})] * \mathrm{costkap} \tag{17}$$

where $\mathrm{iboloco}$ = investment base in owned locomotives,

$\mathrm{locinvl}$ = investment base in leased locomotives,

$\mathrm{acdoloco}$ = accumulated depreciation of owned locomotives,

$\mathrm{locacdl}$ = accumulated depreciation of leased locomotives

$$\mathrm{roicrs} = [(\mathrm{ibocars} + \mathrm{carinvl}) - (\mathrm{acdocars} + \mathrm{caracdl})] * \mathrm{costkap} \tag{18}$$

where $\mathrm{ibocars}$ = investment base in owned cars ,

$\mathrm{carinvl}$ = investment base in leased cars

$\mathrm{acdocars}$ = accumulated depreciation of owned cars

$\mathrm{caracdl}$ = accumulated depreciation of leased cars

An adjusted factor is multiplied with each of the output variable. The adjusted factor is given as:

$$\frac{\text{rtm}}{\text{utgtm}+\text{wtgtm}+\text{ttgtm}} \tag{19}$$

where rtm = revenue ton miles,

utgtm = unit train gross ton miles,

wtgtm = way train gross ton miles and

ttgtm = through train gross ton miles

The labor price per hour is calculated by:

$$\text{labor price per hour} = \frac{\text{swge}+\text{fringe}-\text{caplab}}{\text{lbhrs}} \tag{20}$$

where swge = total salary and wages,

fringe = fringe benefits,

caplab = labor portion of capital expenditure classificationas operation

lbhrs = labor hours

Equipment price is the weighted average equipment price. This takes into account the return on investment, annual depreciation, lease/rental payments per car and locomotive weighted by the type of equipment's share in the total equipment cost. Further, the fuel price is measured as price per gallon. The material and supply price is calculated from the AAR material and supply index. The last input price in the cost function is the way and structure price. This is shown by the following equation:

$$\text{way and structures price} = \frac{\text{roird}+\text{anndeprd}}{\text{mot}} \tag{21}$$

where annedeprd = annual depreciation of road and

mot = miles of track

The factor prices are in real term after dividing by the gross domestic product price deflator. For the technological condition, the speed variable measuring train miles per train hour in road service is firstly constructed shown by the following equation:

$$\text{speed} = \frac{\text{trnmls}}{\text{trnhr} - \text{trnhs}} \tag{22}$$

where trnmls = total train miles

trnhr = train hours in road service includes train switching hours

trnhs = train hours in train switching

The average length of haul is constructed by dividing revenue ton miles with revenue tons and caboose variable representing the fraction of train miles with cabooses is constructed by dividing caboose miles with total train miles. Table-2 represents merger information taken from Bitzan and Keeler (2003, p. 240) which allow for appropriately addressing the carrier fixed effects.

Table-2: Merger information on railroad carriers

Railroad
Burlington Northern (BN) 1983-2008
• Atchison Topeka & Santa Fe (ATSF) 1983-1995, then merged into BN
Boston & Maine (BM) 1983-1986
Consolidated Rail Corporation (CR) 1983-1997
CSX Transportation (CSX) 1986-2008
• Baltimore & Ohio (BO) 1983-1985, then merged with CO SCL to form CSX
• Chesapeake & Ohio (CO) 1983-1985, then merged with BO SCL to form CSX
• Seaboard Coast Line (SCL) 1983 – 1985, then merged with BO and CO to form CSX
Delaware & Hudson (DH) 1983-1987
Duluth Missabe & Iron Range (DMIR) 1984
Florida East Coast (FEC) 1985-1991

Grand Trunk & Western (GTW) 1983-1997

- Detroit Toledo & Ironton 1983 (DTI), then merged into GTW

Illinois Central Gulf (ICG) 1983-1998

Kansas City Southern (KCS) 1983-2008

Norfolk Southern (NS) 1985-2008

- Norfolk & Western (NW) 1984, then merged with SRS to form NS
- Southern Railway System (SRS) 1983-1984, then merged with NW to form NS

Pittsburgh Lake Erie (PLE) 1983-1984

SOO Line (SOO) 1984-2008

- Milwaukee Road (MILW) 1983-1984, then merged into SOO

Union Pacific (UP) 1983-2008

- Chicago & Northwestern (CNW) 1983-1994, then merged into UP
- Missouri Pacific (MP) 1983-1985, then merged into UP
- Missouri-Kansas-Texas (MKT) 1983-1987, then merged into UP
- Southern Pacific (SP) 1983-1996, merged into UP
    - Saint Louis Southwestern (SSW) 1983-1989, then merged into SP
    - Denver Rio Grande & Western (DRGW) 1983-1993, then merged into SP
- Western Pacific (WP) 1984-1985, then merged into UP

Note. Adapted from "Productivity growth and some of its determinants in the deregulated US railroad industry." by Bitzan, J. D., & Keeler, T. E., 2003*, Southern Economic Journal*, p.240.

1.5 Empirical Approach

The quadratic cost function is commonly used to analyze economies of scope. Baumol et al. (1982) suggested it as an appropriate specification to examine economies of scope since it allows for zero outputs in the estimation. The popular method of translog specification in estimating multi-product cost function becomes a drawback when the objective is to obtain a direct estimate for economies of scope. Substituting zero outputs will give undefined estimations for log values.[8] Further, the practice of using Box-Cox transformation for zero outputs are seen as inherently non-robust in examining economies of scope (Pulley and Humphrey, 1991). This robustness problem when using translog specification is due to its degenerate limiting behavior (Roller, 1990). To get a direct test for economies of scope, a well-behaved cost function must be chosen and resolve the in-built interpolation problem (Pulley and Humphrey, 1993). To find a well suited cost function in examining economies of scope, Pulley and Braunstein (1992) estimated a set of alternative functional forms.[9] They suggested the composite cost function as the chosen specification but admit that no attempt was done to impose regularity conditions. The composite cost function was selected based on its highest log-likelihood value rather than satisfying regularity conditions, since 45 percent of observations violated concavity in prices. They argued that regularity condition and statistical fit are most unlikely to be well-matched in selecting the right functional form. In addition, due to the non-linear in parameters and meaningless interpretation for the coefficients this form is less commonly used (Triebs et al., 2012).

The quadratic cost function is widely used as direct estimation for economies of scope when firstly introduced by Lau (1974), recommended by Baumol et al. (1982) and further developed by Mayo (1984). However, the quadratic cost function does not necessarily satisfy the condition of homogeneity in input prices. Any parametric constraints to impose homogeneity leads the function to loss its flexibility form (Caves et

[8] Cowing and Holtmann (1983) examined the economies of scope for various groups of hospital outputs. Translog cost function was used where ln e = ln y when y = 0. The values of e were 0.1, 0.01 and 0.001. However they reported the results as instable and should be given limited considerations.

[9] A general specification is developed which nested the translog cost function, generalized translog cost function, separable quadratic cost function and composite cost function. Economies of scope in banking was examined for these five specifications using 205 banks sample of year 1988.

al., 1980).[10] This violation in regulatory condition of any cost function can be overcome by normalizing the cost and factor input variable with one of the factor prices. This essay uses the normalized quadratic cost function introduced by Diewert and Wales (1988).[11] The condition for linear homogeneity of this form is said to be satisfied by construction.[12] Besides being the simplest form of Taylor series expansion of second order, its Hessian matrix contains only constant numbers. Therefore, the normalized quadratic function has a distinctive feature whereby it can impose the desired curvature in a parsimonious way without sacrifice its flexibility (Diewert and Fox, 2009). It is common that most estimated flexible functional forms have a tendency of failing the curvature condition (Diewert and Wales, 1987). Since regularity conditions are important and should be satisfied by all observations in the estimation, this unique characteristic serves as a reason for this essay to use the normalized quadratic cost function as an approximation of the true underlying cost function.[13]

In this essay, the cost structure introduced by Bitzan and Keeler (2003) is used to construct the normalized quadratic cost function. The total cost function[14] is specified as

$$C(w_i, y_k, a_m, t) \tag{23}$$

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[10] A function is considered flexible if "there are no restrictions on its free parameters" (Diewert and Wales, 1988, p. 303).

[11] Prior of using normalized quadratic cost function, this essay has also estimated a generalized translog cost function introduced by Caves et al. (1980) which accommodates zero output values through Box-Cox transformation. However, the results were disappointing when analyzing economies of scope. The values are unreliable which Pulley and Humphrey (1991, p. 12) mentioned that "the difficulties with the translog cost behavior in the neighborhood of zero will remain". Furthermore, even when substituting a very small positive value for zero in a translog cost function, the form will still "badly behaved in a region around zero" (Pulley and Humphrey, 1993, p.440)

[12] Proof for linear homogeneity is shown in Appendix B.

[13] It is common to impose global curvature rather impose monotinicity for normalized quadratic function (Barnett and Usui, 2006).

[14] The total cost function is a long run specification as it is reasonable to assume that the rail carriers are able to optimally adjust their capital stock to output changes.

$w_i = (w_L, w_E, w_F, w_M, w_{WS})$[15]

$y_k = (y_U, y_W, y_T)$

$a_m = (a_{miles}, a_{speed}, a_{haul}, a_{caboose})$

where C is the total cost, w_L is the labor price, w_E is the equipment price, w_F is the fuel price, w_M is the material and supplies price, w_{WS} is the way and structures price, y_U is the adjusted unit train gross ton miles, y_W is the adjusted way train gross ton miles, y_T is the adjusted through train gross ton miles, a_{miles} is the miles of road, a_{speed} is the train miles per train hour, a_{haul} is the average length of haul, $a_{caboose}$ is the fraction of train miles operated with caboose and t represent time trend capturing the changes in technology. The above cost function can be estimated by incorporating the second order Taylor series expansion. Following the usual practice, the mean[16] is used as base point for the approximation. The Taylors expansion is shown in the following equation:

$$C(w_i, y_k, a_m, t) = \frac{C(\bar{w}_i, \bar{y}_k, \bar{a}_m, t)}{0!}$$

[15] The issue of endogeneity may arise when estimation includes input prices as cost determinants. This concern is highlighted by Levinsohn and Petrin (2003) when estimating the production function. They propose the use of intermediate inputs as proxy variables to overcome the endogeneity problem between input levels and unobserved productivity shock. On the other hand, the vast literature on cost functions used to examine the transportation industry does not consider input prices as endogenous (Bitzan and Peoples, 2014; Bitzan and Keeler, 2014; Mizutani and Uranishi, 2013; Bereskin, 2009; Bitzan and Wilson, 2007; Farsi et al., 2007a; Ivaldi and McCullough, 2004; Bitzan and Keeler, 2003; Bitzan, 2003; Bitzan, 2000; Bitzan 1999; Kim, 1987). The absence of such analysis is due in part to the mechanism by which input prices such as labor are determined. Most transportation labor markets are unionized and over 80 percent of rail workers are unionized. Among the major union rail workers are United Transportation Union (UTU), Brotherhood of Locomotive Engineers (BLE), Brotherhood of Maintenance of Way Employees (BMWE) and Transportation Communication Union (TCU). Rail unions have used their negotiation leverage to heavily discount productivity as a determinant of wages. In addition, the concern regarding input price as an exogenous variable has been highlighted by Bitzan and Keeler (2014). They argue that individual railroad firms purchase a relatively small percentage of factor inputs from the supply side, which makes it plausible to conclude that rail carriers might not influence input price movements and therefore these companies are price takers of factor inputs. Handling factor input prices as exogenous when estimating the cost function has been universally accepted as the norm by other transportation research. Nonetheless, addressing the possibility of endogeneity in factor price variables in succeeding work presents a path for future research on cost estimation for the transportation industry.

[16] The median can be another base point of approximation in the Taylors series expansion.

$$+\sum_i \frac{\frac{\partial C}{\partial w_i}}{1!}(w_i-\bar{w}_i)+\sum_k \frac{\frac{\partial C}{\partial y_k}}{1!}(y_k-\bar{y}_k)+\sum_m \frac{\frac{\partial C}{\partial a_m}}{1!}(a_m-\bar{a}_m)+\frac{\frac{\partial C}{\partial t}}{1!}(t-\bar{t})$$

$$+\sum_i\sum_j \frac{\left(\frac{\partial^2 C}{\partial w_i \partial w_j}\right)}{2!}(w_i-\bar{w}_i)\left(w_j-\bar{w}_j\right)+\sum_i\sum_k \frac{\left(\frac{\partial^2 C}{\partial w_i \partial y_k}\right)}{2!}(w_i-\bar{w}_i)(y_k-\bar{y}_k)$$

$$+\sum_i\sum_m \frac{\left(\frac{\partial^2 C}{\partial w_i \partial a_m}\right)}{2!}(w_i-\bar{w}_i)(a_m-\bar{a}_m)+\sum_i \frac{\left(\frac{\partial^2 C}{\partial w_i \partial t}\right)}{2!}(w_i-\bar{w}_i)(t-\bar{t})$$

$$+\sum_k\sum_i \frac{\left(\frac{\partial^2 C}{\partial y_k \partial w_i}\right)}{2!}(y_k-\bar{y}_k)(w_i-\bar{w}_i)+\sum_k\sum_l \frac{\left(\frac{\partial^2 C}{\partial y_k \partial y_l}\right)}{2!}(y_k-\bar{y}_k)(y_l-\bar{y}_l)$$

$$+\sum_k\sum_m \frac{\left(\frac{\partial^2 C}{\partial y_k \partial a_m}\right)}{2!}(y_k-\bar{y}_k)(a_m-\bar{a}_m)+\sum_k \frac{\left(\frac{\partial^2 C}{\partial y_k \partial t}\right)}{2!}(y_k-\bar{y}_k)(t-\bar{t})$$

$$+\sum_m\sum_i \frac{\left(\frac{\partial^2 C}{\partial a_m \partial w_i}\right)}{2!}(a_m-\bar{a}_m)(w_i-\bar{w}_i)$$

$$+\sum_m\sum_k \frac{\left(\frac{\partial^2 C}{\partial a_m \partial y_k}\right)}{2!}(a_m-\bar{a}_m)(y_k-\bar{y}_k)$$

$$+\sum_m\sum_n \frac{\left(\frac{\partial^2 C}{\partial a_m a_n}\right)}{2!}(a_m-\bar{a}_m)(a_n-\bar{a}_n)+\sum_m \frac{\left(\frac{\partial^2 C}{\partial a_m \partial t}\right)}{2!}(a_m-\bar{a}_m)(t-\bar{t})$$

$$+\sum_i \frac{\left(\frac{\partial^2 C}{\partial t \partial w_i}\right)}{2!}(t-\bar{t})(w_i-\bar{w}_i)+\sum_k \frac{\left(\frac{\partial^2 C}{\partial t \partial y_k}\right)}{2!}(t-\bar{t})(y_k-\bar{y}_k)$$

$$+\sum\nolimits_m \frac{\left(\frac{\partial^2 C}{\partial t \partial a_m}\right)}{2!}(t-\bar{t})(a_m-\bar{a}_m)+\frac{\frac{\partial^2 C}{\partial t^2}}{2!}(t-\bar{t})^2 \qquad (24)$$

The partial derivatives in equation (24) are replaced with parameters from the cost estimation as presented in equation (25). Applying the symmetry of second derivatives by Young's theorem[17], simplifying and rearranging the terms, the resulting equation is the quadratic cost function as shown in the following equation[18]:

$$C = \alpha_0 + + \sum_i \alpha_i (w_i - \bar{w}_i) + \sum_k \beta_k (y_k - \bar{y}_k) + \sum_m \sigma_m (a_m - \bar{a}_m) + \theta(t - \bar{t})$$

$$+ \frac{1}{2} \sum_i \sum_j \alpha_{ij} (w_i - \bar{w}_i)(w_j - \bar{w}_j) + \frac{1}{2} \sum_k \sum_l \beta_{kl} (y_k - \bar{y}_k)(y_l - \bar{y}_l)$$

$$+ \frac{1}{2} \sum_m \sum_n \sigma_{mn} (a_m - \bar{a}_m)(a_n - \bar{a}_n) + \frac{1}{2} \gamma (t - \bar{t})^2$$

$$+ \sum_i \sum_k \tau_{ik} (w_i - \bar{w}_i)(y_k - \bar{y}_k)$$

$$+ \sum_i \sum_m \vartheta_{im} (w_i - \bar{w}_i)(a_m - \bar{a}_m) + \sum_k \sum_m \varphi_{km} (a_m - \bar{a}_m)(y_k - \bar{y}_k)$$

$$+ \sum_i \partial_i (t - \bar{t})(w_i - \bar{w}_i) + \sum_k \pi_k (t - \bar{t})(y_k - \bar{y}_k) + \sum_m \mu_m (t - \bar{t})(a_m - \bar{a}_m) + \epsilon \tag{25}$$

Tovar et al. (2007) mentioned two reasons why the variables deviation from the sample mean are commonly applied in research. It gives an immediate estimation of marginal costs and factor demand. Furthermore it increases the variables' variations that avoid multicollinearity between linear, square and cross terms. The properties of any cost function are monotonic in factor prices and outputs, homogenous of degree one in factor

---

[17] For example $\frac{\partial^2 C}{\partial w_i \partial y_k} = \frac{\partial^2 C}{\partial y_k \partial w_i}$

[18] This quadratic cost function with variables deviated from the means has been explained by Jara-Diaz (2000) as analogous with the translog form when the variables are in logs. He mentioned the quadratic and translog forms are flexible because no priori functions are assumed for technology or costs. Furthermore, the quadratic form can directly obtain the marginal costs valued at the sample mean. Farsi et al. (2007b) also used the procedure of demeaning all the explanatory variables from the sample mean in their cost function. They inferred the intercept as the production total cost at the sample mean.

prices and concave in factor prices. Normalization is done by choosing one of the factor prices as the denominator when dividing the cost and all other factor prices. This allows estimation of relative prices and preserves linear homogeneity in factor prices (Diaz-Hernandez et al., 2005). In matrix form, this equation can be illustrated as follow[19]:

$$C(W,Y,A,T) = \alpha_0 + [\alpha_1 \quad \alpha_2 \quad \alpha_3 \quad \alpha_4] \begin{bmatrix} w_L \\ w_E \\ w_F \\ w_{WS} \end{bmatrix} + [\beta_1 \quad \beta_2 \quad \beta_3] \begin{bmatrix} y_U \\ y_W \\ y_T \end{bmatrix}$$

$$+ [\sigma_1 \quad \sigma_2 \quad \sigma_3 \quad \sigma_4] \begin{bmatrix} a_M \\ a_S \\ a_H \\ a_C \end{bmatrix} + \theta[t]$$

$$+\tfrac{1}{2}[w_L \quad w_E \quad w_F \quad w_{WS}] \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \alpha_{24} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \alpha_{34} \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} \end{bmatrix} \begin{bmatrix} w_L \\ w_E \\ w_F \\ w_{WS} \end{bmatrix}$$

$$+\frac{1}{2}[y_U \quad y_W \quad y_T] \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} [y_U \quad y_W \quad y_T]$$

$$+\frac{1}{2}[a_M \quad a_S \quad a_H \quad a_C] \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} & \sigma_{14} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} & \sigma_{24} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} & \sigma_{34} \\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_{44} \end{bmatrix} \begin{bmatrix} a_M \\ a_S \\ a_H \\ a_C \end{bmatrix}$$

$$+\tfrac{1}{2}\gamma[t][t] + [w_L \quad w_E \quad w_F \quad w_{WS}] \begin{bmatrix} \tau_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \tau_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \tau_{33} \\ \tau_{41} & \tau_{42} & \tau_{43} \end{bmatrix} \begin{bmatrix} y_U \\ y_W \\ y_T \end{bmatrix}$$

$$+[w_L \quad w_E \quad w_F \quad w_{WS}] \begin{bmatrix} \vartheta_{11} & \vartheta_{12} & \vartheta_{13} & \vartheta_{14} \\ \vartheta_{21} & \vartheta_{22} & \vartheta_{23} & \vartheta_{24} \\ \vartheta_{31} & \vartheta_{32} & \vartheta_{33} & \vartheta_{34} \\ \vartheta_{41} & \vartheta_{42} & \vartheta_{43} & \vartheta_{44} \end{bmatrix} \begin{bmatrix} a_M \\ a_S \\ a_H \\ a_C \end{bmatrix}$$

[19] The demeaning process is not shown in the matrix form for simplicity.

$$+[a_M \quad a_S \quad a_H \quad a_C]\begin{bmatrix}\varphi_{11} & \varphi_{12} & \varphi_{13}\\ \varphi_{21} & \varphi_{22} & \varphi_{23}\\ \varphi_{31} & \varphi_{32} & \varphi_{33}\\ \varphi_{41} & \varphi_{42} & \varphi_{43}\end{bmatrix}\begin{bmatrix}y_U\\ y_W\\ y_T\end{bmatrix}$$

$$+[t][\delta_1 \quad \delta_2 \quad \delta_3 \quad \delta_4]\begin{bmatrix}w_L\\ w_E\\ w_F\\ w_{WS}\end{bmatrix} + [t][\pi_1 \quad \pi_2 \quad \pi_3]\begin{bmatrix}y_U\\ y_W\\ y_T\end{bmatrix}$$

$$+[t][\mu_1 \quad \mu_2 \quad \mu_3 \quad \mu_4]\begin{bmatrix}a_M\\ a_S\\ a_H\\ a_C\end{bmatrix} \tag{26}$$

The above equation can also be expressed as

$$C(W,Y,A,t) = \alpha_0 + (A * W') + (B * Y') + (C * Z') + (D * t)$$

$$+\left(\frac{1}{2} * W * E * W'\right) + \left(\frac{1}{2} * Y * F * Y'\right) + \left(\frac{1}{2} * Z * G * Z'\right) + \left(\frac{1}{2} * t * H * t\right)$$

$$+(W * I * Y') + (W * J * Z') + (Z * K * Y') + (t * L * W') + (t * M * Y') + (t * N * Z') \tag{27}$$

where

$W = [w_L \quad w_E \quad w_F \quad w_{WS}]$; $Y = [y_U \quad y_W \quad y_T]$; $Z = [a_M \quad a_S \quad a_H \quad a_C]$

$A = [\alpha_1 \quad \alpha_2 \quad \alpha_3 \quad \alpha_4]$; $B = [\beta_1 \quad \beta_2 \quad \beta_3]$; $C = [\sigma_1 \quad \sigma_2 \quad \sigma_3 \quad \sigma_4]$; $D = [\theta]$

$$E = \begin{bmatrix}\alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14}\\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \alpha_{24}\\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \alpha_{34}\\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44}\end{bmatrix} ; F = \begin{bmatrix}\beta_{11} & \beta_{12} & \beta_{13}\\ \beta_{21} & \beta_{22} & \beta_{23}\\ \beta_{31} & \beta_{32} & \beta_{33}\end{bmatrix} ; G = \begin{bmatrix}\sigma_{11} & \sigma_{12} & \sigma_{13} & \sigma_{14}\\ \sigma_{21} & \sigma_{22} & \sigma_{23} & \sigma_{24}\\ \sigma_{31} & \sigma_{32} & \sigma_{33} & \sigma_{34}\\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_{44}\end{bmatrix}$$

$$H = [t] ; I = \begin{bmatrix}\tau_{11} & \tau_{12} & \tau_{13}\\ \tau_{21} & \tau_{22} & \tau_{23}\\ \tau_{31} & \tau_{32} & \tau_{33}\\ \tau_{41} & \tau_{42} & \tau_{43}\end{bmatrix} ; J = \begin{bmatrix}\vartheta_{11} & \vartheta_{12} & \vartheta_{13} & \vartheta_{14}\\ \vartheta_{21} & \vartheta_{22} & \vartheta_{23} & \vartheta_{24}\\ \vartheta_{31} & \vartheta_{32} & \vartheta_{33} & \vartheta_{34}\\ \vartheta_{41} & \vartheta_{42} & \vartheta_{43} & \vartheta_{44}\end{bmatrix} ;$$

$$K = \begin{bmatrix}\varphi_{11} & \varphi_{12} & \varphi_{13}\\ \varphi_{21} & \varphi_{22} & \varphi_{23}\\ \varphi_{31} & \varphi_{32} & \varphi_{33}\\ \varphi_{41} & \varphi_{42} & \varphi_{43}\end{bmatrix}$$

$L = [\delta_1 \quad \delta_2 \quad \delta_3 \quad \delta_4]$; $M = [\pi_1 \quad \pi_2 \quad \pi_3]$; $N = [\mu_1 \quad \mu_2 \quad \mu_3 \quad \mu_4]$

Furthermore, when expanding the brackets with matrices with $\alpha_{ij} = \alpha_{ji}$, $\beta_{kl} = \beta_{lk}$ and $\sigma_{mn} = \sigma_{nm}$, the cost function is illustrated in the following equation.

$$C(W,Y,A,t) = \alpha_0 + \alpha_1 w_L + \alpha_2 w_E + \alpha_3 w_F + \alpha_4 w_{WS} + \beta_1 y_U + \beta_2 y_W + \beta_3 y_T$$
$$+\sigma_1 a_M + \sigma_2 a_S + \sigma_3 a_H + \sigma_4 a_C + \theta t$$
$$+\frac{1}{2}\alpha_{11} w_L^2 + \frac{1}{2}\alpha_{22} w_E^2 + \frac{1}{2}\alpha_{33} w_F^2 + \frac{1}{2}\alpha_{44} w_{WS}^2 + \frac{1}{2}\beta_{11} y_U^2 + \frac{1}{2}\beta_{22} y_W^2 + \frac{1}{2}\beta_{33} y_T^2$$
$$+\frac{1}{2}\sigma_{11} a_M^2 + \frac{1}{2}\sigma_{22} a_S^2 + \frac{1}{2}\sigma_{33} a_H^2 + \frac{1}{2}\sigma_{44} a_C^2 + \frac{1}{2}\gamma t^2$$
$$+\alpha_{12} w_L w_E + \alpha_{13} w_L w_F + \alpha_{14} w_L w_{WS} + \alpha_{23} w_E w_F + \alpha_{24} w_E w_{WS} + \alpha_{34} w_F w_{WS}$$
$$+\beta_{12} y_U y_W + \beta_{13} y_U y_T + \beta_{23} y_W y_T + \sigma_{12} a_M a_S + \sigma_{13} a_M a_H + \sigma_{14} a_M a_C$$
$$+\sigma_{23} a_S a_H + \sigma_{24} a_S a_C + \sigma_{34} a_H a_C + \tau_{11} w_L y_U + \tau_{12} w_L y_W + \tau_{13} w_L y_T$$
$$+\tau_{21} w_E y_U + \tau_{22} w_E y_W + \tau_{23} w_E y_T + \tau_{31} w_F y_U + \tau_{32} w_F y_W + \tau_{33} w_F y_T$$
$$+\tau_{41} w_{WS} y_U + \tau_{42} w_{WS} y_W + \tau_{43} w_{WS} y_T$$
$$+\vartheta_{11} w_L a_M + \vartheta_{12} w_L a_S + \vartheta_{13} w_L a_H + \vartheta_{14} w_L a_C$$
$$+\vartheta_{21} w_E a_M + \vartheta_{22} w_E a_S + \vartheta_{23} w_E a_H + \vartheta_{24} w_E a_C$$
$$+\vartheta_{31} w_F a_M + \vartheta_{32} w_F a_S + \vartheta_{33} w_F a_H + \vartheta_{34} w_F a_C$$
$$+\vartheta_{41} w_{WS} a_M + \vartheta_{42} w_{WS} a_S + \vartheta_{43} w_{WS} a_H + \vartheta_{44} w_{WS} a_C$$
$$+\varphi_{11} a_M y_U + \varphi_{12} a_M y_W + \varphi_{13} a_M y_T + \varphi_{21} a_S y_U + \varphi_{22} a_S y_W + \varphi_{23} a_S y_T$$
$$+\varphi_{31} a_H y_U + \varphi_{32} a_H y_W + \varphi_{33} a_H y_T + \varphi_{41} a_C y_U + \varphi_{42} a_C y_W + \varphi_{43} a_C y_T$$
$$+\delta_1 w_L t + \delta_2 w_E t + \delta_3 w_F t + \delta_4 w_{WS} t + \pi_1 y_U t + \pi_2 y_W t + \pi_3 y_T t$$
$$+\mu_1 a_M t + \mu_2 a_S t + \mu_3 a_H t + \mu_4 a_C t \qquad (28)$$

Applying Shephard's Lemma obtains each factor demand equations. This is done by differentiating the cost function with respect to its price as shown below:

$$\frac{\partial C}{\partial w_i} = x_i = \alpha_i + \sum_j \alpha_{ij} w_j + \sum_k \tau_{ik} y_k + \sum_m \vartheta_{im} a_m + \gamma_i t \qquad (29)$$

The factor demand equations together with the cost function are estimated in a seemingly unrelated regression system. In testing for the concavity, the Hessian matrix is used and since one of the factor prices is used for normalizing, the Hessian matrix consists of only four factor prices. To satisfy the condition of concavity in factor prices, the Hessian matrix which is matrix E should be negative semi definite.[20] For normalized quadratic cost function, its Hessian matrix consists of only scalars. The condition for concavity in input prices represents all observations in the sample in which global concavity is investigated rather than local concavity. This is different compared to translog cost function where each observation has its own calculated Hessian matrix.[21] When global concavity is violated, curvature imposition can be achieved using the Cholesky decomposition technique. Curvature imposition can be carried out by rerun the cost function replacing the matrix of input prices parameters for the cost function. From equation before, to ensure a negative semi-definite Hessian, matrix E can be reparameterized by E$= -KK'$ where K is a lower triangular matrix K such that

$$E = -KK' = -\begin{bmatrix} k_{11} & 0 & 0 & 0 \\ k_{21} & k_{22} & 0 & 0 \\ k_{31} & k_{32} & k_{33} & 0 \\ k_{41} & k_{42} & k_{43} & k_{44} \end{bmatrix} \begin{bmatrix} k_{11} & k_{21} & k_{31} & k_{41} \\ 0 & k_{22} & k_{32} & k_{42} \\ 0 & 0 & k_{33} & k_{43} \\ 0 & 0 & 0 & k_{44} \end{bmatrix}$$

[20] The Hessian matrix is negative semi definite when every principal minor with odd order is ≤ 0 and every principal with even order is ≥ 0. $Hessian = \begin{bmatrix} \frac{\partial^2 c}{\partial w_1^2} & \frac{\partial^2 c}{\partial w_1 \partial w_2} & \frac{\partial^2 c}{\partial w_1 \partial w_3} & \frac{\partial^2 c}{\partial w_1 \partial w_4} \\ \frac{\partial^2 c}{\partial w_2 \partial w_1} & \frac{\partial^2 c}{\partial w_2^2} & \frac{\partial^2 c}{\partial w_2 \partial w_3} & \frac{\partial^2 c}{\partial w_2 \partial w_4} \\ \frac{\partial^2 c}{\partial w_3 \partial w_1} & \frac{\partial^2 c}{\partial w_3 \partial w_2} & \frac{\partial^2 c}{\partial w_3^2} & \frac{\partial^2 c}{\partial w_3 \partial w_4} \\ \frac{\partial^2 c}{\partial w_4 \partial w_1} & \frac{\partial^2 c}{\partial w_4 \partial w_2} & \frac{\partial^2 c}{\partial w_4 \partial w_3} & \frac{\partial^2 c}{\partial w_4^2} \end{bmatrix}$

[21] Local concavity can be imposed when estimating a translog cost function. This imposition ensures that concavity holds at one data point. Chua et al. (2005) imposed local concavity and found a significant increase in the number of observations that satisfies local concavity after the imposition of curvature.

$$
= \begin{bmatrix} -k_{11}^2 & -k_{11}k_{21} & -k_{11}k_{31} & -k_{11}k_{41} \\ -k_{11}k_{21} & -(k_{21}^2 + k_{22}^2) & -(k_{21}k_{31} + k_{22}k_{32}) & -(k_{21}k_{41} + k_{22}k_{42}) \\ -k_{11}k_{31} & -(k_{21}k_{31} + k_{22}k_{32}) & -(k_{31}^2 + k_{32}^2 + k_{33}^2) & -(k_{31}k_{41} + k_{32}k_{42} + k_{33}k_{43}) \\ -k_{11}k_{41} & -(k_{21}k_{41} + k_{22}k_{42}) & -(k_{31}k_{41} + k_{32}k_{42} + k_{33}k_{43}) & -(k_{41}^2 + k_{42}^2 + k_{43}^2 + k_{44}^2) \end{bmatrix} \quad (30)
$$

The elements of matrix above replaces the parameters in the cost function and factor demand equations which represents the curvature imposition. This actually made the system of equations no longer linear in parameters.

The use of normalized quadratic function enables testing the existence of economies of scope for the rail carriers since it allows evaluation at zero outputs. Following Baumol et al. (1982), the global economies of scope for the production of the three train services is shown in the following equation[22]:

$$
SCOPE = \mathrm{C}(\mathrm{y_U}, 0{,}0) + \mathrm{C}(0, \mathrm{y_W}, 0) + \mathrm{C}(0{,}0, \mathrm{y_T}) - \mathrm{C}(\mathrm{y_U}, \mathrm{y_W}, \mathrm{y_T})
$$

$$
= 2 * (\alpha_0 + \alpha_1 w_L + \alpha_2 w_E + \alpha_3 w_F + \alpha_4 w_{WS} + \sigma_1 a_M + \sigma_2 a_S + \sigma_3 a_H + \sigma_4 a_C + \theta t
$$

$$
+ \frac{1}{2}\alpha_{11} w_L^2 + \frac{1}{2}\alpha_{22} w_E^2 + \frac{1}{2}\alpha_{33} w_F^2 + \frac{1}{2}\alpha_{44} w_{WS}^2 + \frac{1}{2}\sigma_{11} a_M^2 + \frac{1}{2}\sigma_{22} a_S^2 + \frac{1}{2}\sigma_{33} a_H^2
$$

$$
+ \frac{1}{2}\sigma_{44} a_C^2 + \frac{1}{2}\gamma t^2 + \alpha_{12} w_L w_E + \alpha_{13} w_L w_F + \alpha_{14} w_L w_{WS} + \alpha_{23} w_E w_F
$$

$$
+ \alpha_{24} w_E w_{WS} + \alpha_{34} w_F w_{WS} + \sigma_{12} a_M a_S + \sigma_{13} a_M a_H + \sigma_{14} a_M a_C + \sigma_{23} a_S a_H
$$

$$
+ \sigma_{24} a_S a_C + \sigma_{34} a_H a_C + \vartheta_{11} w_L a_M + \vartheta_{12} w_L a_S + \vartheta_{13} w_L a_H + \vartheta_{14} w_L a_C + \vartheta_{21} w_E a_M
$$

$$
+ \vartheta_{22} w_E a_S + \vartheta_{23} w_E a_H + \vartheta_{24} w_E a_C + \vartheta_{31} w_F a_M + \vartheta_{32} w_F a_S + \vartheta_{33} w_F a_H
$$

$$
+ \vartheta_{34} w_F a_C + \vartheta_{41} w_{WS} a_M + \vartheta_{42} w_{WS} a_S + \vartheta_{43} w_{WS} a_H + \vartheta_{44} w_{WS} a_C + \delta_1 w_L t + \delta_2 w_E t
$$

[22] Pulley and Humphrey (1991) generalized the calculation for economies of scope in the case of m firms as $SCOPE = [(m-1)\alpha_0 - \sum_{i=1}\sum_{j>i} \alpha_i q_i q_j]/h(q)$. The former term in the right hand side of the equation measures the fixed cost and the latter measures cost complementarity contributions to economies of scope.

$$+\delta_3 w_F t + \delta_4 w_{WS} t \ +\mu_1 a_M t + \mu_2 a_S t + \mu_3 a_H t + \mu_4 a_C t\ ) \ +\beta_{12} y_U y_W + \beta_{13} y_U y_T + \beta_{23} y_W y_T \tag{31}$$

Farsi et al. (2007a) uses the following formula (SC_m) to calculate the degree of product-specific economies of scope.

$$SC_m = \frac{C(y^m)+C(y^{-m})-C(y)}{C(y)} \tag{32}$$

This measures the proportional increase in cost due to production of all outputs excluding the m[th] output. Fraquelli et al. (2004) defines it as cost advantage (disadvantage) of one particular 'stand-alone' output in the production. In other words, it examines whether economies of scope still prevails when separating the production of m[th] output from the rest. Fraquelli et al. (2004) further use another measure for degree of product-specific economies of scope. It examines the proportional increase in cost due to production of certain combination of outputs where the other combinations exhibit zero output. Their measure is showed in the following equation.

$$SC_{mn} = \frac{C(y^m)+C(y^n)-C(y^{(m)},y^{(n)})}{C(y^{(m)},y^{(n)})} \tag{33}$$

Unfortunately, the contribution from research on economies of scope for this area is very limited. There is an absence of data providing information on the stand-alone cost of producing one of the outputs or any combinations of the three outputs. Information is not provided revealing the value of products shipped when class-1 carriers only provide one or two of the freight train service.[23] Observations that have zero outputs for the unit

[23]Gabel and Kennet (1994) examined economies of scope in the local telephone exchange market without having observations producing a stand-alone outputs or combinations of them. Engineering optimization model is used that enable them to estimate the cost of stand-alone telecommunications networks. Simulation is done as such the optimization model chooses combination and placement of facilities that minimizes the production cost.

train service are deleted from the sample as normally practiced by other researchers. Therefore in this essay, a hypothetical output vector is simulated and a direct approach is made by calculating the expected cost of every individual firm if it has produced specialized output or any combination of outputs. For example, one of the outputs is set at its actual value and the other outputs are given values equal to zero.[24] As a result, it permits tractable tests for economies of scope in the railroad industry.

Applying to the three train services, economies of scope can be tested by hypothetically simulating railroad firms producing zero outputs. Equation (4) provides a direct test of test economies of scope for all the three services. It gives the estimated cost of producing all the train services through one network. Specifically, equation (4) examines whether economies of scope exists if there is specialization in producing the train services. This analysis can be further extended in finding out whether economies of scope still exists when separating the production of one of the train services from the rest. This is shown from equation (34) to equation (36).

SCOPE-U: $$C(y_U, 0, 0) + C(0, y_W, y_T) > C(y_U, y_W, y_T) \tag{34}$$

SCOPE-W: $$C(0, y_W, 0) + C(y_U, 0, y_T) > C(y_U, y_W, y_T) \tag{35}$$

SCOPE-T : $$C(0, 0, y_T) + C(y_U, y_W, 0) > C(y_U, y_W, y_T) \tag{36}$$

SCOPE-U measures the proportional increase in cost due to production of all train services except unit train. SCOPE-W and SCOPE-T imply the same definition for way train and through train respectively. Equation (37) to equation (39) is included for completeness in the analysis. These equations are used to test economies of scope for any

[24] Bloch et al. (2001) used simulation for three different output paths in examining the ray-average cost in a given year. The ray-average cost is subject to the variables values and parameters estimated and this cost behavior is observed through the simulation. An output or combination of outputs are scaled down to zero by increment of 0.1 while the remaining output are fixed at the actual level.

combination of pair of train services, which are between unit and way train, between unit and through train and between way and through train. The cost function exhibiting economies of scope for any two train services can be shown in the following:

SCOPE-U-W: $C(y_U, 0, 0) + C(0, y_W, 0) > C(y_U, y_W, 0)$ (37)

SCOPE-U-T: $C(y_U, 0, 0) + C(0, 0, y_T) > C(y_U, 0, y_T)$ (38)

SCOPE-W-T: $C(0, y_W, 0) + C(0,0, y_T) > C(0, y_W, y_T)$ (39)

SCOPE-U-W investigates whether producing a combination of unit train and way train exhibits economies of scope. SCOPE-U-T and SCOPE-W-T examines whether economies of scope prevails when combination of unit-through train and way-through train are produced respectively while zero output for others. Baumol et al. (1982) mentioned that weak cost complementarities are considered as a sufficient condition of presence of economies of scope in contestable market. In the analysis, the economies of scope can be calculated for every firm from the cost function estimation. The predicted value for cost producing all outputs and individually is based on the estimates of the cost function. This is then substituted in the formula for economies of scope.

1.6 Cost Results

The system of equations consisting of the cost function and factor demand equations is estimated using a seemingly unrelated regression technique first introduced by Zellner (1962). The variables in the system are deviations from the sample mean with the price of material as the normalizing factor.[25] The monotonicity condition for output and input

[25] The sample mean is commonly used as the point of approximation. Martinez-Budria et al. (2003) used sample mean as point of approximation for their normalized quadratic cost function when apply to the electric sector in Spain.

prices is validated by looking at whether total cost increases as outputs increase $\left(\frac{\partial C}{\partial y_i} > 0\right)$ [26]and also whether total cost increases as input prices increase $\left(\frac{\partial C}{\partial w_i} > 0\right)$.[27] The test shows that between 67-93 percent of observations fulfill the condition for monotonicity as shown in the following Table-3.

Table-3: Summary of monotonicity condition for outputs and input prices

Monotonicity condition	Percentage
$\partial C/\partial y_U > 0$	93 percent of observations
$\partial C/\partial y_W > 0$	67 percent of observations
$\partial C/\partial y_T > 0$	72 percent of observations
$\partial C/\partial w_L > 0$	71 percent of observations
$\partial C/\partial w_E > 0$	70 percent of observations
$\partial C/\partial w_F > 0$	75 percent of observations
$\partial C/\partial w_{WS} > 0$	85 percent of observations

Another regularity condition to be satisfied by an estimated cost function is the condition for concavity in input prices. For normalized quadratic cost function, the concavity condition is not data dependent and therefore can be tested globally rather than locally. The Hessian matrix is negative semi definite when all principal minors of the Hessian should alternate in signs starting with less than zero. Unfortunately, the estimated cost function fails to satisfy the curvature conditions in input prices. Violation of

[26] For example, derivative of cost with respect to unit train service is shown as: $\frac{\partial C}{\partial y_U} = \beta_1 + \beta_{11}y_U + \beta_{12}y_W + \beta_{13}y_T + \tau_{11}w_L + \tau_{21}w_E + \tau_{31}w_F + \tau_{41}w_{WS} + \varphi_{11}a_M + \varphi_{21}a_S + \varphi_{31}a_H + \varphi_{41}a_C + \pi_1 t$

[27] For example, derivative of cost with respect to price of labor is shown as: $\frac{\partial C}{\partial w_L} = \alpha_1 + \alpha_{11}w_L + \alpha_{12}w_E + \alpha_{13}w_F + \alpha_{14}w_{WS} + \tau_{11}y_U + \tau_{12}y_W + \tau_{13}y_T + \vartheta_{11}a_M + \vartheta_{12}a_S + \vartheta_{13}a_H + \vartheta_{14}a_C + \delta_1 t$

concavity in input prices is often found in past studies and highlighted since it is a firm's rational behavior to minimize cost (Ogawa, 2011). Nonetheless, imposing global curvature can be done relatively easily[28] when estimating the normalized quadratic cost function. If the concavity in input prices is not imposed, the empirical model is not consistent with the economic theory and any linear combination in the price space can further minimize cost. In consideration of this problem this essay imposes concavity in the cost estimation by means of Cholesky decomposition discussed previously. The parameter estimates obtained from estimating the normalized quadratic cost function without imposing concavity becomes the initial values used for the non-linear estimation[29].

Table-4 below shows the estimated coefficients for the equation systems before and after imposing concavity in input prices. The intercept depicts the total fixed cost that occurs at the sample mean. The second column in Table-4 represents the results before imposing concavity in input prices. The first order output coefficients are positive and significant. The coefficients for input prices are also positive and significant. The coefficient for the price of material is not in the results since it is used as the numeraire in the estimation. The negative coefficient of the time trend suggests that cost decreases with technology. Three variables show unexpected result: The estimated coefficient on the variables *milesroad* and *speed* are negative and statistically significant, the estimated

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[28] Featherstone and Moss (1994) carried out estimations with and without imposition of curvature. Comparing the two estimations, the results of economies of scope were opposite between each other.
[29] Initially, non-converging result is greatly expected since convergence highly depends on initial values. The specification consists of a large number of explanatory variables and hence an educated guess for the starting values from the functional form is not feasible. Many trials were made with defaults values and randomly different initial values with varying convergence criterion. Convergence is met when the parameters obtained without imposing concavity is chosen to be the appropriate and plausible initial values. It should also be noted that very few studies impose concavity in transportation research as pursued by this essay.

coefficient on the variable *avehaul* is positive and statistically significant, and caboose shows a positive but not statistically significant coefficient. The third column in Table-4 shows the result after imposing concavity in input prices. The latter results varies where 34 coefficients show changes in signs and 58 coefficients become insignificant after impose concavity. All coefficients for input prices are positive and all of them are significant except fuel. The first order output coefficients are positive with only unit train is significant. The time trend coefficient still suggests that cost decreases with technology. All technological variables are found insignificant except for *milesroad*. However, the sign of *milesroad* is still not as expected.

Table-4: Parameter estimates for the normalized quadratic cost function

	Without concavity		With concavity	
Variables	Coefficient	s.e.	Coefficient	Aprox s.e.
Intercept	59052.21***	3674.778	5209527**	2445709
w_L	19337425***	830899.7	35330212***	2845360
w_E	1093.011***	268.007	9784.998***	1232.1
w_F	4.00E+08***	31835309	2.98E+08	2.73E+09
w_{WS}	12137.46***	199.9104	16557.98***	589.9
y_U	0.000364***	0.000057	0.095018**	0.0416
y_W	0.003745***	0.000299	0.204913	0.2293
y_T	0.000546***	0.000049	0.034689	0.0281
a_{miles}	-1.65865***	0.237675	-432.175**	173.1
a_{speed}	-249.267***	84.19541	-83183.7	84037.5
a_{haul}	24.42795***	7.312301	5454.166	6676
$a_{caboose}$	522069	2559789	-2.82E+08	2.25E+09
t	-2121.99***	178.884	-315368**	154310
$0.5(y_U)^2$	-2.99E-13	5.09E-13	-5.63E-10*	3.07E-10
$0.5(y_W)^2$	-1.24E-09***	4.65E-11	-6.87E-08	4.29E-08
$0.5(y_T)^2$	7.19E-12***	5.84E-13	-2.39E-10	4.11E-10

$0.5(w_L)^2$	-4.20E+09***	1.94E+08	-23914515.1	
$0.5(w_E)^2$	48.54731***	4.279762	-41.5190675	
$0.5(w_F)^2$	-6.88E+11***	4.45E+10	-23991831.7	
$0.5(w_{WS})^2$	-76.382***	10.1424	-81.4304148	
$0.5(a_{miles})^2$	0.000595***	0.000041	0.05656**	0.0244
$0.5(a_{speed})^2$	-33.5235***	6.097911	-2377.71	7423.7
$0.5(a_{haul})^2$	-0.28017***	0.034789	23.27947	33.2802
$0.5(a_{caboose})^2$	-8.44E+09***	3.11E+09	-6.17E+11	3.18E+12
$0.5(t)^2$	68.04709***	13.3609	17465.62	10789.6
$w_L * w_E$	798090.7***	46101.71	-28769.7678	
$w_L * w_F$	-3.58E+10***	3.19E+09	23953114.14	
$w_L * w_{WS}$	-525085***	39094.04	-9829.24964	
$w_L * y_U$	0.139759***	0.011143	-0.14232***	0.0245
$w_L * y_W$	-3.29477***	0.127369	-0.40688	0.3871
$w_L * y_T$	0.253375***	0.011565	0.076465**	0.0341
$w_L * a_{miles}$	337.9932***	81.88123	3486.44***	288.4
$w_L * a_{speed}$	1000907***	57102.85	59734.72	196506
$w_L * a_{haul}$	3009.409	3183.987	-10478.7	8574.9
$w_L * a_{caboose}$	9.35E+09***	1.14E+09	2.11E+09	3.07E+09
$w_L * t$	-709356***	74962.77	-241409	261000
$w_E * w_F$	4112048***	314702.7	28809.09453	
$w_E * w_{WS}$	228.76***	7.244396	2.192292028	
$w_E * y_U$	-3.50E-06	3.75E-06	-0.00004***	0.000014
$w_E * y_W$	-0.00037***	0.000045	-0.0001	0.000211
$w_E * y_T$	0.000047***	4.11E-06	0.000021	0.00002
$w_E * a_{miles}$	-0.08531***	0.023706	0.824577***	0.132
$w_E * a_{speed}$	8.434251	15.43111	-75.8357	72.6614
$w_E * a_{haul}$	8.056295***	0.754206	-11.6018***	4.2458
$w_E * a_{caboose}$	3394215***	368263.9	2399180	1483523
$w_E * t$	70.6142***	23.69644	-106.02	97.1288
$w_F * w_{WS}$	-9282573***	332709.8	9908.487763	
$w_F * y_U$	-2.7989***	0.388153	3.744043	40.6422

$w_F * y_W$	-43.2156***	3.47669	-53.744	568.5
$w_F * y_T$	13.57421***	0.396995	3.088161	40.2762
$w_F * a_{miles}$	-52675.6***	2738.005	25834.21	327255
$w_F * a_{speed}$	-2.01E+07***	1493029	24270326	1.53E+08
$w_F * a_{haul}$	-100275	103735.9	-1712228	7168538
$w_F * a_{caboose}$	1.32E+11***	3.32E+10	3.75E+11	3.15E+12
$w_F * t$	-1.96E+07***	2705368	12578500	2.44E+08
$w_{WS} * y_U$	0.000033***	2.22E-06	-0.00004***	6.75E-06
$w_{WS} * y_W$	-0.00067***	0.00003	-4.92E-06	0.000114
$w_{WS} * y_T$	0.000061***	2.47E-06	8.41E-06	7.11E-06
$w_{WS} * a_{miles}$	0.62076***	0.018547	1.618261***	0.0816
$w_{WS} * a_{speed}$	233.3992***	14.42347	-22.6337	37.212
$w_{WS} * a_{haul}$	7.050127***	0.727568	-2.51739	1.774
$w_{WS} * a_{caboose}$	599798.4**	268094.8	-1550330**	675866
$w_{WS} * t$	-263.895***	17.89458	-109.753**	54.1955
$y_U * y_W$	-3.06E-11***	3.88E-12	-2.98E-09	2.34E-09
$y_U * y_T$	-1.43E-12***	4.43E-13	1.48E-10	2.87E-10
$y_U * a_{miles}$	2.27E-08***	4.67E-09	-5.56E-06*	2.94E-06
$y_U * a_{speed}$	0.000029***	1.86E-06	-0.00021	0.00134
$y_U * a_{haul}$	1.48E-07	1.12E-07	0.000173*	0.000091
$y_U * a_{caboose}$	0.219255***	0.041383	-23.361	31.6284
$y_U * t$	2.00E-06	2.55E-06	0.002668	0.00166
$y_W * y_T$	2.75E-11***	3.14E-12	6.21E-09***	2.22E-09
$y_W * a_{miles}$	4.79E-07***	3.34E-08	2.55E-06	0.000023
$y_W * a_{speed}$	-0.00019***	0.00002	-0.00055	0.0162
$y_W * a_{haul}$	-3.81E-06***	8.01E-07	-0.00078	0.000664
$y_W * a_{caboose}$	2.826311***	0.412587	227.0504	307.3
$y_W * t$	-0.00021***	0.000025	-0.00025	0.0172
$y_T * a_{miles}$	-9.33E-08***	4.29E-09	-3.02E-06	2.53E-06
$y_T * a_{speed}$	-0.00003***	2.13E-06	0.002181	0.00139
$y_T * a_{haul}$	1.01E-06***	1.34E-07	-0.00011	0.000079
$y_T * a_{caboose}$	-0.32476***	0.045829	59.18539**	27.4095
$y_T * t$	-0.00003***	3.02E-06	0.003372**	0.00149

$a_{miles} * a_{speed}$	-0.01797	0.016516	-25.4535**	11.776
$a_{miles} * a_{haul}$	-0.00156**	0.000776	0.134324	0.6032
$a_{miles} * a_{caboose}$	-430.326	260.7547	-328421	204482
$a_{miles} * t$	0.225063***	0.021707	-42.1698**	16.2978
$a_{speed} * a_{haul}$	6.215739***	0.386726	3.687197	354.3
$a_{speed} * a_{caboose}$	1198683***	120814.9	1.16E+08	1.17E+08
$a_{speeds} * t$	-15.0218**	6.626258	2568.9	6621.7
$a_{haul} * a_{caboose}$	20183.95***	5399.54	-3182217	5377594
$a_{haul} * t$	-0.70175	0.548849	-651.032	433.7
$a_{caboose} * t$	-904903***	197655.3	1.04E+08	1.85E+08

Note. The variable w_L is the labor price, w_E is the equipment price, w_F is the fuel pricew_{WS} is the way and structures price, y_U is the unit train gross ton miles, y_W is the way train gross ton miles, y_T is the through train gross ton miles, a_{miles} is the miles of road, a_{speed} is the train miles per train hour, a_{haul} is the average length of haul, $a_{caboose}$ is the fraction of train miles operated with caboose and t for time. The notation *** means significant at 1% level, ** is significant at 5% level and * is significant at 10% level.

A weak test for economies of scope examines the coefficient sign for the interaction variables between outputs. The presence of cost complementarities between outputs may suggest the existence of economies of scope. Before concavity is imposed, the interaction terms between unit train and way train and also between unit train and through train show negative coefficients and significant. The negative sign $\left(\frac{\partial^2 C}{\partial y_U \partial y_W} < 0 \text{ and } \frac{\partial^2 C}{\partial y_U \partial y_T} < 0\right)$ suggest that these outputs are cost complementarities[30]between each other. The presence of cost complementarity is one of the contributors for economies of scope[31]. However, the coefficient for interaction

[30] Any combination of train services are said to be cost complementarities (cost substitutabilities) if the marginal cost of one output decreases (increases) when there is an increase in the production of the other output.

[31] Pulley and Humphrey (1991) mentioned two factors as contribution to economies of scope which are complementarity and fixed cost. The ability to spread the fixed cost over the broader mix of output may as well contribute to economies of scope.

variable between way train and through train is positive and significant implying cost discomplementarities $\left(\frac{\partial^2 C}{\partial y_W \partial y_T} > 0\right)$ between these two train services. After concavity is imposed, the result changes a little bit. Unit train and way train still suggest cost complementarities between each other. However, unit train and through train show cost discomplementarities even though the key parameter estimates are not statistically significant. Only the interaction term between way train and through train is found positive and significant which also suggesting cost discomplementarites. The reason for the presence of cost complementarites between unit and way before and after concavity is imposed may due to the fact that unit train and way train has the same feature, as such most origin-destination switches are done by unit and way trains (Tolliver et al., 2014). This may contribute to the jointly utilized inputs for both train services.[32]Therefore, this essay further examines the economies of scope by simulating hypothetical production of output combinations with and without imposing concavity.

Table-5 presents the percentage of firms exhibiting economies of scope. Table-6 and Table-7 show the simulation results obtained in examining economies of scope for all observations without and with imposing concavity respectively. In Table-6 and Table-7, the expected cost savings when jointly providing the train services rather than by

[32] The level of efficiency for three types of train services are known to be different. Tolliver et al. (2014) suggest that efficiency is mainly influenced by the type of train services. They consider way train and through train as 'non-unit train' since their movements are related and percentage of way train is very small compared to through train. Way train often stops to pick up and drop cars along the route. Through trains moving between yards, therefore perform limited switching activities. Unit train operates in a cycling pattern from origin to destination, least switching activities that suggest the most energy efficient train services. Bitzan (2000) explained the relationship of each train service with respect to efficiency. The unit train service is considered as the most efficient train service since it involves smaller switching requirement with high volume of shipments. The way train service involves high switching requirements, small volume, short distance and slow speed which makes it the most expensive service for railroad carrier. Through train is more efficient than way train but less than unit train even though it comprises the largest service in terms of gross ton mile.

specialized firm are calculated. A positive value suggests a firm's operations exhibits economies of scope and negative value suggests the presence of diseconomies of scope. Without imposing concavity, around 96 percent of the firms exhibit economies of scope except for CR between year 1995 and year 1997, GTW in year 1998, ICG in year 1998, NS in year 1996 and year 1997, and SOO in year 1991. These companies depict diseconomies of scope for all the equations proposed. When concavity is imposed, more than 70 percent of firms exhibit economies of scope. Even though the percentage dropped by more than 20 percent compared before concavity is imposed, it is reasonable to suggest that the percentage of firms exhibiting economies of scope is substantial. The firms that exhibit diseconomies of scope are BN between year 1986 and year 2008, CSX in year 1986 and 1987 and between year 1992 and year 2008, NS between year 1994 and year 2008, SP for year 1995 and year 1996 and UP between 1986 and year 2008. These findings suggested that providing way train service is not the primary source for diseconomies of scope. Even though the number of carriers that exhibit diseconomies of scope are not substantial, all the three services are equally likely to contribute for the rare case when it occurs. The result gives some insight for any future intention to unbundle the multi-service train. Since the way train is not the primary source for diseconomies of scope, any type of train services to be unbundle may also be equally likely to contribute to efficiency due to the market competition.[33]

[33] Unbundling decision on which type of train services need further examination especially way train service incurs the highest cost. Farsi et al. (2007a) emphasized that efficiency gains attained by lowering barriers of market entry is questionable when unbundling a transport mode that has high infrastructure cost.

Table-5: Percentage of firms exhibiting economies of scope

	scope	scopeU	scopeW	scopeT	scopeUW	scopeUT	scopeWT
Without imposing concavity	96.7	96.7	96.7	96.7	96.7	97.1	97.1
With imposing concavity	70.44	72.63	70.8	70.43	72.26	71.5	70.07

Table-6: Analysis on economies of scope at firm level (without concavity imposed)

Yr	Rr	scope[34]	scopeU[35]	scopeW[36]	scopeT[37]	scopeUW[38]	scopeUT[39]	scopeWT[40]
1983	ATSF	159789	80898	79910	79413	80376	79879	78891
1984	ATSF	149271	75287	74989	74157	75114	74282	73984
1985	ATSF	142522	72138	71328	70858	71664	71193	70384
1986	ATSF	140984	71665	70640	69840	71144	70344	69319
1987	ATSF	123149	62387	61864	61051	62098	61285	60762
1988	ATSF	122849	61904	61871	60963	61886	60977	60945
1989	ATSF	127872	64209	64696	63423	64449	63176	63664
1990	ATSF	101830	51563	51603	50250	51580	50228	50267
1991	ATSF	96907	48114	48042	48888	48019	48865	48794
1992	ATSF	95949	47215	47222	48657	47292	48727	48734
1993	ATSF	91931	44966	44778	46685	45247	47154	46965
1994	ATSF	103097	50885	50415	51694	51404	52683	52213
1995	ATSF	132884	67478	66843	64757	68126	66041	65406
1983	BM	163436	88200	76289	79024	84412	87147	75236
1984	BM	130490	71942	60041	62323	68168	70449	58549
1986	BM	172823	92987	80893	83668	89155	91930	79836
1984	BN	232312	118309	117170	114874	117438	115142	114003
1985	BN	232486	116866	116715	115753	116733	115771	115619
1986	BN	192132	97132	97552	94670	97462	94580	95000
1987	BN	181073	92818	93222	87950	93123	87851	88255
1988	BN	179766	92735	92329	87351	92415	87438	87031
1989	BN	185051	94621	93716	91221	93830	91334	90430

[34] $SCOPE = C(y_U,0,0) + C(0,y_W,0) + C(0,0,y_T) - C(y_U,y_W,y_T)$
[35] $SCOPE\ U = C(y_U,0,0) + C(0,y_w,y_T) - C(y_U,y_W,y_T)$
[36] $SCOPE\ W = C(0,y_W,0) + C(y_U,0,y_T) - C(y_U,y_W,y_T)$
[37] $SCOPE\ T = C(0,0,y_T) + C(y_U,y_w,0) - C(y_U,y_W,y_T)$
[38] $SCOPE\ UW = C(y_U,0,0) + C(0,y_W,0) - C(y_U,y_W,0)$
[39] $SCOPE\ UT = C(Y_U,0,0) + C(0,0,Y_T) - C(Y_U,0,Y_T)$
[40] $SCOPE\ WT = C(0,Y_W,0) + C(0,0,Y_T) - C(Y_W,0,Y_T)$

1990	BN	192030	97124	96341	95645	96385	95689	94907
1991	BN	115456	58050	57770	57679	57778	57687	57406
1992	BN	164201	84806	84100	79960	84241	80101	79395
1993	BN	165307	87212	86488	78614	86694	78820	78095
1994	BN	170336	90441	88787	81171	89165	81549	79896
1996	BN	714290	1579424	24425	-403249	1117539	689865	-865134
1997	BN	445752	259256	206479	219563	226189	239273	186496
1998	BN	442621	263420	200408	223070	219552	242214	179201
1999	BN	464948	273648	208916	240170	224778	256032	191300
2000	BN	472268	282276	211678	239458	232810	260589	189992
2001	BN	456478	278630	203802	230276	226203	252676	177848
2002	BN	461280	290017	209430	219513	241767	251851	171263
2003	BN	451500	284746	200821	219945	231555	250679	166754
2004	BN	467735	303461	200851	236437	231298	266884	164275
2005	BN	467156	306688	195325	241176	225980	271831	160468
2006	BN	463892	316701	185959	244104	219788	277933	147191
2007	BN	454096	316901	179986	239648	214448	274110	137194
2008	BN	451992	321221	180030	235961	216031	271962	130771
1983	BO	118209	61537	57448	59566	58643	60760	56672
1984	BO	110945	57437	54075	56177	54768	56871	53509
1985	BO	111336	57785	54179	56281	55056	57157	53552
1983	CNW	119805	62198	58028	60354	59452	61777	57607
1984	CNW	110423	57394	53491	55739	54684	56932	53028
1985	CNW	115780	60547	55861	57900	57880	59919	55233
1986	CNW	135539	70337	65842	67745	67794	69697	65203
1987	CNW	128605	66988	62419	64096	64509	66186	61617
1988	CNW	134683	71350	64581	65526	69157	70102	63333
1989	CNW	129273	68798	61519	62821	66452	67754	60475
1990	CNW	120542	64146	57095	58674	61868	63447	56396
1991	CNW	153309	78819	71731	76704	76605	81578	74490
1992	CNW	127057	67151	60199	62103	64954	66859	59907
1993	CNW	140269	73115	66480	69199	71069	73788	67154
1994	CNW	168460	86888	80810	83386	85074	87650	81572
1983	CO	114825	61265	55975	56048	58776	58849	53560
1984	CO	117057	61867	57539	57444	59614	59519	55190
1985	CO	125079	65928	61463	61426	63654	63616	59151
1983	CR	118812	59643	59241	59553	59259	59571	59169
1984	CR	113463	56770	56585	56893	56571	56878	56694
1985	CR	107933	54288	53955	53924	54009	53977	53644
1986	CR	113344	57066	56797	56484	56860	56547	56278
1987	CR	108284	54124	54191	54094	54190	54093	54160

1988	CR	101642	50656	50898	50731	50911	50744	50985
1990	CR	87331	43783	44009	43366	43965	43322	43548
1991	CR	88425	44315	44419	44021	44405	44007	44110
1992	CR	81611	40783	40991	40634	40977	40620	40829
1993	CR	72171	36439	36908	35395	36776	35263	35732
1994	CR	36884	18571	19369	17626	19257	17514	18313
1995	CR	-4421	-3860	-3497	-1059	-3362	-923	-561
1996	CR	-22218	-14270	-13734	-8561	-13657	-8484	-7948
1997	CR	-129986	-66083	-65345	-64658	-65328	-64641	-63903
1986	CSX	156860	79883	74489	75947	80913	82371	76977
1987	CSX	143775	76310	64935	66651	77125	78841	67466
1988	CSX	163878	82623	80790	79881	83997	83088	81255
1989	CSX	163629	81801	81629	80401	83228	82001	81828
1990	CSX	150566	75210	75056	73758	76808	75510	75356
1991	CSX	165934	82539	83471	81659	84276	82464	83396
1992	CSX	153756	76690	76558	75056	78700	77198	77066
1993	CSX	152206	75344	76620	74782	77424	75586	76862
1994	CSX	129074	66776	63341	62667	66407	65733	62298
1995	CSX	117191	61879	58692	55916	61274	58499	55312
1996	CSX	72877	7771	5300	65647	7230	67577	65106
1997	CSX	30986	6496	2890	25295	5691	28096	24489
1998	CSX	220967	114589	110873	107177	113791	110094	106378
1999	CSX	295921	149044	141368	148389	147532	154553	146876
2000	CSX	215680	112928	102184	105279	110401	113496	102752
2001	CSX	239647	124801	115722	117195	122453	123925	114846
2002	CSX	271654	144726	129690	130470	141184	141964	126928
2003	CSX	248014	134690	117874	117069	130945	130140	113324
2004	CSX	253035	144619	123815	113324	139711	129220	108416
2005	CSX	245476	138519	120568	112095	133381	124908	106957
2006	CSX	216981	121692	104520	101140	115841	112460	95288
2007	CSX	219391	121600	106070	103223	116169	113321	97791
2008	CSX	216245	119634	104691	102296	113949	111554	96611
1983	DH	164882	89216	77693	79404	85478	87189	75667
1984	DH	232022	122801	111317	112929	119093	120705	109222
1985	DH	156620	85436	73744	74909	81711	82876	71183
1986	DH	46290	30491	18598	19571	26718	27692	15799
1984	DMIR	150482	84355	72184	69969	80513	78297	66127
1983	DRGW	172224	92698	83106	82694	89530	89118	79525
1984	DRGW	153513	83895	74331	72716	80796	79182	69617
1985	DRGW	155129	84665	74888	73669	81460	80241	70464
1986	DRGW	173091	93730	83459	82593	90498	89632	79361

1987	DRGW	168719	91552	81166	80436	88283	87552	77167
1988	DRGW	159869	86994	76640	76096	83773	83229	72875
1989	DRGW	157617	85493	75508	75269	82347	82109	72123
1990	DRGW	151252	82195	72270	72169	79082	78982	69057
1991	DRGW	54414	36593	26529	20858	33556	27885	17822
1992	DRGW	101670	58295	48499	46283	55387	53171	43375
1993	DRGW	99511	56849	47251	45434	54078	52260	42662
1983	DTI	141366	78147	66630	67083	74284	74736	63219
1985	FEC	143274	80493	69197	66541	76733	74077	62781
1986	FEC	158921	88248	76688	74399	84522	82233	70673
1987	FEC	161228	89208	77625	75738	85490	83603	72020
1988	FEC	164961	91173	79718	77468	87493	85243	73788
1989	FEC	161162	89458	77965	75371	85791	83197	71703
1990	FEC	142018	80275	68664	65428	76590	73354	61742
1991	FEC	131466	76997	65274	58176	73289	66191	54469
1983	GTW	142032	78256	66739	67507	74525	75293	63776
1984	GTW	128070	71278	60374	60416	67653	67696	56791
1985	GTW	124879	69823	58550	58714	66165	66329	55056
1986	GTW	144328	79064	67851	68910	75418	76477	65264
1987	GTW	164827	89645	78378	78841	85986	86449	75181
1988	GTW	147083	80545	69294	70185	76898	77789	66537
1989	GTW	141890	77695	66408	67833	74057	75482	64195
1990	GTW	128022	70664	59330	61002	67020	68692	57358
1991	GTW	142477	75597	64233	70527	71950	78244	66881
1992	GTW	125945	69106	57804	60464	65481	68141	56838
1993	GTW	138777	75017	63847	67330	71447	74930	63760
1994	GTW	138983	74556	63481	67992	70991	75501	64427
1995	GTW	86479	77547	66457	12490	73989	20022	8932
1996	GTW	625259	274476	263759	354158	271100	361500	350783
1997	GTW	625351	282219	271559	346493	278858	353791	343132
1998	GTW	-204171	-85279	-95976	-115516	-88655	-108195	-118892
1983	ICG	110397	58207	53509	54835	55561	56887	52189
1984	ICG	113966	58879	55568	57608	56358	58398	55087
1985	ICG	127732	66668	62305	63609	64123	65427	61064
1986	ICG	143131	76158	69495	69800	73330	73636	66972
1987	ICG	138561	74418	67116	67144	71418	71445	64143
1988	ICG	136864	73599	66275	66255	70610	70589	63265
1989	ICG	133514	71195	63902	65249	68265	69612	62319
1990	ICG	118783	64010	56431	57705	61078	62352	54773
1991	ICG	179802	93029	85786	89530	90273	94016	86773
1992	ICG	151150	79651	72464	74288	76862	78686	71499

1993	ICG	167323	87739	80824	82303	85019	86498	79584
1994	ICG	172993	91769	84168	83834	89158	88824	81224
1996	ICG	526578	278500	270797	250591	275987	255781	248078
1998	ICG	-146283	-71105	-78879	-72759	-73524	-67404	-75178
1983	KCS	119827	66916	56424	56070	63757	63403	52911
1984	KCS	149907	81600	71527	71423	78484	78379	68306
1985	KCS	158636	85388	75759	76384	82252	82877	73248
1986	KCS	173959	94147	83829	82960	90999	90131	79812
1987	KCS	166830	89872	79736	80099	86731	87094	76958
1988	KCS	166662	89431	79471	80380	86282	87191	77231
1989	KCS	161354	86836	76794	77658	83695	84560	74518
1990	KCS	134471	73252	63306	64344	70127	71165	61220
1991	KCS	64355	41831	31919	25636	38719	32435	22524
1995	KCS	92408	51347	43972	43886	48522	48436	41061
1996	KCS	86462	48157	40977	41181	45282	45485	38305
1997	KCS	85724	47471	40687	41067	44657	45037	38253
1998	KCS	82946	46225	39409	39383	43562	43536	36720
2000	KCS	77984	42800	37064	37981	40003	40920	35184
2001	KCS	66776	37430	31466	32102	34674	35310	29346
2002	KCS	33878	20192	15173	16481	17397	18705	13686
2003	KCS	51640	29118	24074	25327	26313	27566	22522
2004	KCS	51741	28539	24172	25833	25908	27569	23202
2005	KCS	72070	38284	34426	36163	35907	37643	33786
2006	KCS	63504	33573	30435	31994	31510	33069	29931
2007	KCS	50121	27449	23470	24731	25390	26650	22672
2008	KCS	47036	25417	22092	23720	23316	24944	21619
1983	MILW	152152	82973	72965	72514	79638	79187	69179
1984	MILW	145777	79498	70039	69502	76274	75737	66278
1983	MKT	142961	77391	67636	69090	73871	75325	65570
1984	MKT	136822	74183	64829	66124	70699	71994	62640
1985	MKT	147695	79078	69458	72001	75694	78237	68617
1986	MKT	154141	82564	72615	75011	79130	81526	71577
1987	MKT	151158	81169	71441	73284	77875	79718	69989
1983	MP	115739	57980	57430	59242	56498	58310	57760
1984	MP	102204	50904	50748	52623	49581	51456	51299
1985	NS	110796	54752	54815	55640	55157	55981	56045
1987	NS	120333	59464	59464	60305	60027	60869	60868
1988	NS	115931	57093	56249	58191	57741	59683	58839
1989	NS	113288	56221	56756	56333	56955	56532	57067
1991	NS	109110	54165	53905	54375	54735	55205	54945
1992	NS	101834	50236	49740	50927	50908	52094	51598

1993	NS	88799	43314	42271	44741	44059	46528	45485
1994	NS	42006	18822	17730	22238	19768	24276	23184
1995	NS	-273	-4221	-5713	2866	-3139	5440	3948
1996	NS	-207697	-124989	-126731	-83869	-123829	-80967	-82709
1997	NS	-261786	-169448	-172494	-93583	-168203	-89292	-92339
1998	NS	205319	110523	107713	93712	111607	97606	94796
1999	NS	222361	108970	100517	113168	109193	121844	113390
2000	NS	114189	59742	43629	55420	58769	70560	54447
2001	NS	150991	78787	65277	72748	78243	85714	72204
2002	NS	189017	97687	84865	91711	97306	104153	91330
2003	NS	183798	95028	80244	89162	94635	103554	88770
2004	NS	237550	137133	117145	101203	136346	120405	100416
2005	NS	218122	127354	106658	91714	126408	111465	90768
2006	NS	202515	115354	95974	88440	114076	106541	87161
2007	NS	205451	115074	98455	91482	113969	106996	90377
2008	NS	201876	113558	97150	89604	112272	104727	88319
1984	NW	108792	57482	53871	52914	55878	54921	51310
1984	PLE	129067	72009	60254	60930	68137	68813	57058
1984	SOO	179031	94766	85382	87649	91382	93649	84266
1985	SOO	132329	70511	62796	64746	67583	69534	61819
1986	SOO	138133	73411	65824	67582	70550	72308	64722
1987	SOO	133259	66573	65899	69643	63617	67360	66686
1988	SOO	129471	64975	63957	67526	61945	65514	64496
1989	SOO	128064	63916	63914	67188	60876	64150	64148
1990	SOO	128932	64144	64656	67700	61233	64276	64789
1991	SOO	-19041	-11051	-12213	-5127	-13913	-6828	-7990
1992	SOO	52498	27365	24824	27967	24531	27675	25133
1993	SOO	54813	28950	26002	28662	26151	28811	25863
1994	SOO	60623	33540	28694	29921	30702	31928	27082
1995	SOO	61106	36219	29307	27413	33693	31799	24887
1996	SOO	62464	36669	29933	28343	34121	32531	25795
1997	SOO	67852	39448	31690	31085	36767	36162	28404
1998	SOO	47093	29351	21243	20471	26622	25849	17742
1999	SOO	50092	30635	22489	22145	27947	27603	19457
2000	SOO	50138	30460	22414	22272	27866	27724	19678
2001	SOO	41251	26124	18037	17666	23585	23214	15127
2002	SOO	45449	28277	20038	19706	25743	25411	17172
2003	SOO	37608	24283	16176	15828	21780	21432	13325
2004	SOO	42252	26361	18374	18281	23971	23878	15891
2005	SOO	53763	32072	24071	24182	29582	29693	21691
2006	SOO	33830	22466	14359	13834	19996	19471	11364

2007	SOO	42223	26482	18612	18175	24048	23611	15740
2008	SOO	41764	26415	18403	17889	23875	23361	15349
1983	SOU	56120	30348	27554	27533	28587	28566	25772
1984	SOU	63289	33926	31277	30959	32330	32012	29363
1983	SP	140378	69583	69332	71638	68739	71046	70795
1984	SP	120017	58733	58744	61810	58207	61273	61285
1985	SP	136284	67487	67308	69573	66711	68976	68797
1986	SP	132825	65922	65649	67765	65059	67176	66903
1988	SP	117864	60332	59109	58124	59740	58755	57532
1989	SP	112376	57338	56429	55492	56884	55947	55038
1990	SP	87052	43751	44057	43116	43935	42994	43300
1991	SP	129859	65829	66272	63792	66067	63587	64029
1992	SP	93313	46828	48324	45686	47627	44989	46485
1993	SP	89556	44603	46647	43893	45662	42908	44953
1994	SP	97089	47891	49305	47969	49121	47784	49198
1995	SP	104932	51930	53144	52306	52626	51788	53002
1996	SP	98121	48358	49888	49089	49032	48233	49763
1988	SSW	162108	87504	78227	77705	84403	83881	74604
1989	SSW	134679	73378	64465	64304	70376	70214	61302
1983	UP	198782	100602	97627	99069	99714	101155	98180
1984	UP	158870	80558	78096	79008	79862	80774	78312
1985	UP	176062	88437	86388	88098	87964	89674	87625
1986	UP	171235	87722	86113	83572	87663	85122	83513
1987	UP	145841	75321	71953	70899	74942	73888	70521
1988	UP	175340	92585	87006	83837	91502	88334	82755
1989	UP	167081	88329	83328	80257	86823	83752	78752
1990	UP	157315	83684	77784	75405	81910	79531	73631
1991	UP	158642	82845	76766	78251	80391	81877	75797
1992	UP	144727	77497	70176	70107	74620	74551	67230
1993	UP	133539	71859	64536	65447	68092	69004	61680
1994	UP	136735	78121	65325	63345	73390	71411	58614
1995	UP	223963	146327	107636	89574	134389	116327	77635
1996	UP	211542	141303	102123	84511	127031	109419	70239
1997	UP	511433	321641	233678	226971	284461	277754	189791
1998	UP	484599	297759	222378	219803	264796	262221	186840
1999	UP	505583	322865	228303	225120	280462	277280	182718
2000	UP	501551	303793	225236	243835	257716	276314	197757
2001	UP	529852	320254	238195	261577	268275	291657	209598
2002	UP	538424	325178	240103	269204	269220	298321	213246
2003	UP	525148	317705	231609	267766	257382	293539	207443
2004	UP	503446	309184	218078	257784	245662	285368	194263

2005	UP	505417	314361	218738	255200	250218	286679	191056
2006	UP	491224	308208	209127	252892	238332	282097	183016
2007	UP	501109	308898	215339	261796	239313	285770	192211
2008	UP	497112	304956	214234	262780	234332	282877	192156
1984	WP	189337	101146	89984	91819	97519	99354	88191
1985	WP	173149	93510	82304	83247	89902	90846	79639

Note. Observations with zero values for unit train gross ton miles is deleted as usually practiced by those using R-1 data. The missing values for some of the particular years are due to the microfiche that are not found at STB library (BM-1988, BN-1983, 1995, CR-1989, 1998, DH-1987, DMIR-1983, FEC-1983, 1984, ICG-1995, 1997, KCS-1992, 1993, 1994, 1999, MP-1985, NS-1986, 1990, NW-1983, PLE-1983, SCL-1983, 1984, 1985, SOO-1983, SP-1987, SSW-1983,1984,1985, 1986, 1987, WP-1983)

Table-7: Analysis on economies of scope at firm level (with concavity imposed)

yr	Rr	scope[41]	scopeU[42]	scopeW[43]	scopeT[44]	scopeUW[45]	scopeUT[46]	scopeWT[47]
1983	ATSF	9345351	4777969	4726802	4513211	4832140	4618549	4567383
1984	ATSF	9408879	4775152	4764731	4615805	4793073	4644147	4633727
1985	ATSF	8612468	4382770	4356042	4180551	4431916	4256426	4229698
1986	ATSF	8492823	4366119	4306287	4072640	4420183	4186536	4126704
1987	ATSF	7387189	3780459	3757704	3576697	3810492	3629485	3606729
1988	ATSF	6431094	3290103	3288768	3139076	3292018	3142326	3140991
1989	ATSF	8147259	4152153	4182965	4020059	4127201	3964295	3995107
1990	ATSF	7314037	3772690	3775973	3543146	3770891	3538064	3541347
1991	ATSF	8472244	4210056	4225042	4252368	4219875	4247201	4262188
1992	ATSF	9392698	4638162	4614442	4762517	4630181	4778256	4754536
1993	ATSF	9484765	4692799	4557605	4821110	4663656	4927161	4791966
1994	ATSF	9201845	4612692	4335425	4643017	4558827	4866420	4589153
1995	ATSF	5665113	2887077	2529805	2845343	2819770	3135308	2778036
1983	BM	26608818	14274466	12832335	11941171	14667647	13776484	12334352
1984	BM	21433907	11688428	10244224	9353701	12080206	11189682	9745479
1986	BM	19590587	10780789	9311813	8412027	11178560	10278774	8809798
1984	BN	5550159	2902634	2932510	2557084	2993075	2617649	2647525
1985	BN	1353993	720261	730074	619879	734113	623919	633732
1986	BN	-643734	-194779	-208461	-414774	-228960	-435274	-448956
1987	BN	-359445	43531	34449	-371393	11948	-393894	-402976
1988	BN	-28511	212382	226134	-274123	245612	-254645	-240894

[41] $SCOPE = C(y_U,0,0) + C(0,y_W,0) + C(0,0,y_T) - C(y_U,y_W,y_T)$
[42] $SCOPE\ U = C(y_U,0,0) + C(0,y_w,y_T) - C(y_U,y_W,y_T)$
[43] $SCOPE\ W = C(0,y_W,0) + C(y_U,0,y_T) - C(y_U,y_W,y_T)$
[44] $SCOPE\ T = C(0,0,y_T) + C(y_U,y_w,0) - C(y_U,y_W,y_T)$
[45] $SCOPE\ UW = C(y_U,0,0) + C(0,y_W,0) - C(y_U,y_W,0)$
[46] $SCOPE\ UT = C(Y_U,0,0) + C(0,0,Y_T) - C(Y_U,0,Y_T)$
[47] $SCOPE\ WT = C(0,Y_W,0) + C(0,0,Y_T) - C(Y_W,0,Y_T)$

1989	BN	-1166800	-470775	-414311	-778103	-388696	-752488	-696024
1990	BN	-2955310	-1450116	-1383333	-1581850	-1373460	-1571977	-1505194
1991	BN	-4580814	-2273089	-2246579	-2336027	-2244787	-2334235	-2307725
1992	BN	-6345010	-2936397	-2909570	-3467254	-2877756	-3435440	-3408613
1993	BN	-5411144	-2283194	-2275909	-3181740	-2229404	-3135234	-3127949
1994	BN	-5716035	-2446232	-2399122	-3402224	-2313811	-3316913	-3269803
1996	BN	-229900951	19401258	-179622214	-297246811	67345860	-50278736	-249302209
1997	BN	-4087793	-668373	-1689047	-6851827	2764033	-2398746	-3419420
1998	BN	-6847441	-2590791	-2362398	-8810269	1962828	-4485043	-4256650
1999	BN	-11396033	-5662489	-4173310	-10806440	-589592	-7222723	-5733544
2000	BN	-15413106	-6934618	-6574343	-13613123	-1799983	-8838762	-8478488
2001	BN	-16486737	-7269864	-6888726	-14658942	-1827796	-9598011	-9216873
2002	BN	-21152645	-7742155	-10039622	-18418998	-2733646	-11113022	-13410490
2003	BN	-22714972	-9138250	-10560640	-19098050	-3616923	-12154332	-13576722
2004	BN	-25444582	-11382387	-10770755	-21552791	-3891791	-14673827	-14062196
2005	BN	-27134789	-12728727	-11276883	-22783761	-4351028	-15857907	-14406062
2006	BN	-31580793	-15191615	-12774740	-26448982	-5131811	-18806054	-16389178
2007	BN	-34846530	-16861559	-14012518	-28619888	-6226643	-20834012	-17984972
2008	BN	-37244135	-17712258	-14927035	-30450847	-6793288	-22317100	-19531877
1983	BO	16070806	8068320	8098765	7702090	8368716	7972041	8002486
1984	BO	17116024	8528156	8648376	8310883	8805141	8467648	8587868
1985	BO	17783540	8886420	8971656	8613879	9169661	8811884	8897120
1983	CNW	12362111	6252152	6215624	5824844	6537267	6146487	6109959
1984	CNW	13203565	6639975	6651731	6282265	6921300	6551834	6563590
1985	CNW	13584954	6953713	6774162	6354448	7230505	6810791	6631241
1986	CNW	15423799	7871777	7694742	7288087	8135711	7729057	7552022
1987	CNW	14851271	7608740	7393832	6985203	7866068	7457439	7242531
1988	CNW	14819996	7976139	7169889	6616231	8203765	7650107	6843858
1989	CNW	14214817	7717636	6846645	6253655	7961162	7368172	6497181
1990	CNW	14423180	7794956	6953049	6391761	8031419	7470130	6628224
1991	CNW	14463414	7829877	6958390	6403722	8059693	7505024	6633538
1992	CNW	14873946	8026921	7180614	6618989	8254957	7693332	6847025
1993	CNW	15096352	8117505	7293040	6766514	8329838	7803312	6978847
1994	CNW	14338170	7698972	6923860	6450898	7887272	7414310	6639198
1983	CO	16683326	8659939	8285431	7765068	8918258	8397895	8023387
1984	CO	17953762	9201461	8966569	8518399	9435363	8987193	8752301
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1985	WP	17759570	9795785	8453673	7589222	10170349	9305897	7963785

1.7 Discussion and Concluding Remarks

With the passage of the Staggers Act, some railroad Class-1 carriers took advantage of their ability to abandon unprofitable short-haul lines. Despite the post deregulation trend of abandonment, there are many carriers still maintaining their short-haul line service. Way train service resembles the short-haul line; therefore, a question remains whether those carriers are still satisfying the condition of economies of scope in the industry. If carriers are exhibiting economies of scope, then multi-service train operation promotes cost advantages for the railroad carriers, whereas single-service train operation is at a cost disadvantage.

Few studies exam economies of scope in the railroad industry due, in part, to non-availability of data to directly test this concept. Bitzan (2003) directly runs the test of subadditivity proposed by Shin and Ying (1992), and concludes that a natural monopoly exists but generalizes that economies of scope also exist without testing directly for those. His data simulation does not show that the cost subadditivity condition is met for all the observations; therefore, a possibility exists for diseconomies of scope to prevail for some of the carriers. Ivaldi and McCullough (2004) run the test of subadditivity together with economies of scope between infrastructure companies and competing operating firms. These variables represent the type of output produced, whereas the variables used in this essay represent on how the outputs are hauled from one destination to another destination. Kim (1987) did run analysis on economies of scope using a sample from 1963, but again on the type of output produced where the joint production of passenger and freight in 1963 suggested diseconomies of scope. Therefore, this essay contributes to the existing literature because research has not been done yet on economies of scope in the railroad industry regarding how the outputs are hauled. The joint production of unit train service, way train service and through train service is examined to determine whether these three services together depict economies of scope or not.

Due to non-availability of stand-alone cost data, testing directly the condition for economies of scope in the railroad industry for the three train services is not viable. Class-1 carriers are providing all three services for the entire observation period. Therefore, following common practice in subadditivity research, hypothetical firms are simulated to represent the carriers producing a given combination of outputs. Two sets of results are presented depicting the expected cost savings from jointly producing the three train services. The first set does not impose concavity in input prices while the second set does using Cholesky decomposition. When concavity is imposed, the condition for economies of scope is satisfied for over 95 percent of the simulations and when the concavity is imposed, more than 70 percent of simulation exhibit economies of scope. The difference in the results is not unexpected since the cost function may lose its flexibility when imposing concavity and therefore should take caution in interpreting those results. More firms are found to exhibit diseconomies of scope and in general, these firms may still be revenue generating. Even though, before deregulation short-haul lines (way train services) were recognized as unprofitable line and most likely to be abandoned, findings from this study provide interesting evidence on cost-savings attributable to the maintenance of short-haul service. Class-1 freight industry is non-competitive (oligopolistic industry) and it engages in profit maximizing behavior while satisfying the condition of cost minimization. Therefore it is promising that class-1 rail carriers would possible operate in a business environment that experiences economies of scope while simultaneously maximizing profit. On another note, findings on diseconomies of scope for various years when concavity is not imposed; Conrail between year 1995 and year 1997, Grand Trunk and Western in year 1998, Illinois Central Gulf in year 1998, Norfolk Southern in year 1996 and year 1997, and Soo Line in year 1991, and findings on diseconomies of scope for various years when concavity is imposed; Burlington Northern between year 1986 and year 2008, CSX Transportation in year 1986 and 1987 and between year 1992 and year 2008, Norfolk Southern between year 1994 and year 2008, Southern Pacific for year 1995 and year 1996 and Union Pacific between 1986 and year 2008, demonstrate that way train services is not the leading source, but rather all three services are equally contribute to diseconomies of scope. These findings present new information on railroad carrier efficiency in a post deregulation environment and may propose some policy implications. A majority of the class-1 rail carriers observed (more than 70 percent) depicts economies of scope[48]. With the passage of Staggers act, the less regulatory restrictive environment has enabled the class-1 carriers to provide efficient service to their customers. The non-substantial evidence of diseconomies of scope may suggest providing some of the train services or operations

[48] Initially, class-1 rail carriers may seem likely to exhibit economies of scope compared to class-2. However, class-2 rail carriers do not face the cost constraints as with class-1 carriers whereby they employ low wage non-union worker. Hence, it is quite likely that they also experience economies of scope when providing short-haul services.

independently or outsourcing to another party any labor-intensive activities or selling branch lines to short line rail carriers. This may be the answer for the issue whether shippers located in low density areas have access to the efficient rail service. Even though class-1 carriers do not provide the universal access experienced prior to regulatory reform, short-line rail carriers as well as trucking firms have entered this market. As pointed out by Johnson et al. (2004), 46.9 percent of the short-line managers interviewed in the research believed that in future, class-1 carriers will highly specialize in mainline (long-haul) service where branch line operations or switching services are provided by the short-line carriers. Short-line carriers are more customer focused, better in low volume trackage and therefore be the 'customer service arm' (Johnson et al., 2004) for class-1 carriers. Furthermore, if there exist any attempt separating the multi-service train operation, the type of train services chosen to be specialized may also be equally likely to contribute to efficiency gain. Nonetheless, if there is any intention of unbundling the train services, the decision on which of the three train services contributes to efficiency gain due to increase in market competition needs further consideration.

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Appendix A: Construction of variables

Variable Construction
• Real total cost = (opercost – capexp + roird + roilcm + roicrs)/gdppd
opercost = railroad operating cost (schedule 410, line 620, column f)
capexp = capital expenditures classified as operating in r1 (schedule 410, lines 12-30, 101-9, column f)
roird = return on investment in road = (roadinv – accdepr) * costkap
roadinv: road investment (schedule 352b, line 31) + capexp from all previous years
accdepr: accumulated depreciation in road (schedule. 335, line 30, column g)
costkap: cost of capital (AAR railroad facts)
roilcm = return on investment in locomotives = [(iboloco+locinvl) – (acdoloco + locacdl)] * costkap
iboloco: investment base in owned locomotives (schedule 415, line 5, column g)
locinvl: investment base in leased locomotives (schedule 415, line 5, column h)
acdoloco: accumulated depreciation of owned locomotives (schedule 415, line 5, column i)
locacdl: accumulated depreciation of leased locomotives (schedule 415, line 5, column j)
roicrs = return on investment in cars = [(ibocars + carinvl) – (acdocars + caracdl)]*costkap
ibocars: investment base in owned cars (schedule 415, line 24, column g)
carinvl: investment base in leased cars (schedule 415, line 24, column h)
acdocars: accumulated depreciation of owned cars (schedule 415, line 24, column i)
caracdl: accumulated depreciation of leased locomotives (schedule 415, line 24, column j)
gdppd = gdp price deflator
Price of factor inputs
• Price of labor = (swge + fringe – caplab)/lbhrs
swge = total salary and wages (schedule 410, line 620, column b)
fringe = fringe benefits (schedule 410, lines 112-14, 205, 224, 309, 414, 430, 505, 512, 522, 611, col. e)
caplab = labor portion of capital expenditure classification as operating in R1 (schedule 410, lines 12-30, 101-9, column b)
lbhrs = labor hours (Wage form A, line 700, column 4 + 6)
• Price of equipment = weighted average equipment price (schedule 415 and schedule 710)
• Price of fuel (schedule 750)
• Price of material = AAR materials and supply index
• Price of way and structure = (roird + anndeprd) / mot
anndeprd = annual depreciation of road (schedule 335, line 30, column c)
mot = miles of track (schedule 720, line 6, column b)
Factor input prices are divided by gdp price deflator

Outputs

- Utgtm: unit train gross ton miles (schedule 755, line 99, column b)
- Wtgtm: way train gross ton miles (schedule 755, line 100, column b)
- Ttgtm: through train gross ton miles (schedule 755, line 101, column b)

  adjustment factor multiplied by each output variable = rtm/(utgtm + wtgtm + ttgtm)

  rtm: revenue ton miles (schedule 755, line 110, column b)

Movement characteristics

- Miles of road: (schedule 700, line 57, column c)
- Speed = train miles per train hour in road service = trnmls/(trnhr-trnhs)

  trnmls = total train miles (schedule 755, line 5, column b)

  trnhr = train hours in road service – includes train switching hours (schedule 755, line 115, column b)

  trnhs = train hours in train switching (schedule 755, line 116, column b)
- Average length of haul = rtm/revtons

  revtons = revenue tons (schedule 755, line 105, column b)
- Caboose = fraction of train miles with cabooses = cabmiles/trnmls

  cabmiles = caboose miles (schedule 755, line 89, column b)

Note. Adapted from "Productivity growth and some of its determinants in the deregulated US railroad industry." by Bitzan, J. D., & Keeler, T. E., 2003*, Southern Economic Journal*, p.250-251.

Appendix B: Algebra proof of linear homogeneity in input price for normalized quadratic cost function

For illustration, suppose the cost function is represented by $C(w_i, Y)$. Two cases are shown, the quadratic cost function and normalized quadratic cost function.

Case 1: Quadratic cost function

$C(\lambda w_i, Y) \Rightarrow C$

$$= \alpha_0 + \sum_i \alpha_i \lambda w_i + \sum_k \alpha_k Y_k + \frac{1}{2}\sum_i \sum_j \alpha_{ij} \lambda^2 w_i w_j + \frac{1}{2}\sum_k \sum_l \alpha_{kl} Y_k Y_l$$

$$+ \sum_i \sum_k \alpha_{ik} \lambda w_i Y_k$$

$\therefore C(\lambda w_i, Y) \neq \lambda C(w_i, Y)$

Case 2: Normalized quadratic cost function

The quadratic cost function is normalized by dividing factor input prices and cost with one of the factor input prices where $\widetilde{w_i} = \frac{w_i}{\widehat{w}}$, $\tilde{C} = \frac{C}{\widehat{w}}$ and $\widehat{w}$ is the numeraire:

$$\widetilde{C} = \alpha_0 + \sum_i^{n-1} \alpha_i \widetilde{w_i} + \sum_k \alpha_k Y_k$$

$$+ \frac{1}{2}\sum_i^{n-1} \sum_j^{n-1} \alpha_{ij} \widetilde{w_i} \widetilde{w_j} + \frac{1}{2}\sum_k \sum_l \alpha_{kl} Y_k Y_l + \sum_i^{n-1} \sum_k^{m} \alpha_{ik} \widetilde{w_i} Y_k$$

Multiply both sides of equation by $\widehat{w}$:

$$C(w_i, 1, Y) = \alpha_0 \widehat{w} + \sum_i^{n-1} \alpha_i w_i + \sum_k \alpha_k Y \widehat{w}_k$$

$$+ \frac{1}{2}\sum_i^{n-1} \sum_j^{n-1} \alpha_{ij} \left(\frac{w_i w_j}{\widehat{w}}\right) + \frac{1}{2}\sum_k \sum_l \alpha_{kl} Y_k Y_l \widehat{w} + \sum_i^{n-1} \sum_k^{m} \alpha_{ik} w_i Y_k \widehat{w}$$

$$C(\lambda w_i, 1, Y) = \alpha_0 \lambda \widehat{w} + \sum_i^{n-1} \alpha_i \lambda w_i \sum_k \alpha_k Y \lambda \widehat{w}_k$$

$$+\frac{1}{2}\sum_{i}^{n-1}\sum_{j}^{n-1}\alpha_{ij}\left(\frac{\lambda^2}{\lambda}\right)\left(\frac{w_i w_j}{\widehat{w}}\right)+\frac{1}{2}\sum_{k}\sum_{l}\alpha_{kl}\,Y_k\,Y_l\lambda\,\widehat{w}+\sum_{i}^{n-1}\sum_{k}^{m}\alpha_{ik}\,\lambda w_i Y_k\,\widehat{w}$$

$\therefore C(\lambda w_i, 1, Y) = \lambda^1 C(w_i, 1, Y)$ indicating that the normalized cost function is homogeneous of degree 1 in input prices.

ESSAY 2: ALLOCATIVE EFFICIENCY IN THE UNITED STATES RAILROAD INDUSTRY: CHANGING WORK-RULES AND MANAGERIAL FLEXIBILITY

2.1 Introduction

The passage of the Staggers Rail Act of 1980 has brought major transformation to the railroad industry. For instance, easing of rate restrictions presented railroad firms the flexibility to set competitive rates. The ability to better compete with low cost trucking carriers helped contribute to a more profitable rail industry (Grimm and Windle, 1998). The Staggers act further promoted profitable and efficient operations of rail firms by easing regulations limiting class-1 carriers' ability to abandon non-profitable rail lines (Winston, 1998). Winston (1998) reveals evidence of significant efficiency gains as he observes real operating cost per ton-mile fell 60 percent immediately following regulatory reform in this industry.[49] Productivity enhancing managerial decisions, however, were not limited to adjustments of network configurations as railroad companies negotiated efficiency enhancing contracts with shippers and with rail labor. Post deregulation contracts with shippers included provision making it easier for rail firms to align their cars and equipment with shipper demand to avoid the costly practice of operating at over capacity (Winston, 1998). Post deregulation contract negotiations also focused on changing labor practices specified by rigid work-rules. For instance, settlements reduced required crew sizes and increased miles hauled as a measure of a

[49]Bereskin (1996) argues that it is vital to note that deregulation did not begin with the Staggers Act but regulatory reform actually started before the passage due to the 4R Act. His estimation results for the pre-Staggers act passage (1978 4R act) and post Staggers act passage suggest a change in productivity growth of 2.72 percent, 6.44 percent and 12.34 percent for 1978-1980, 1978-1982 and 1981-1982 respectively.

day's work. These changes enhanced rail companies' ability to become more productive by addressing inefficiencies in the industry's input market. Evidence of the efficiency enhancing effect associated with relaxed constraints on crew sizes reported by Bitzan and Keeler (2003) presents a direct test of changes in crew size and productivity. Estimating a translog cost function for the railroad industry, they investigate the effect of post deregulation innovation on the rail freight productivity due to the elimination of cabooses and related crew member. Their findings indicates that without cabooses and the associated crew members rail transport costs of class-1 carriers decreased by 5-8 percent from 1983 to 1987.

While past work focuses on the effect of more lenient work-rules on productivity there is an absence of research examining whether these carriers use an allocatively efficient combination of factor inputs. Such an analysis is significant in part because it helps identify a previously unexamined source of productivity gains and reveals whether there is opportunity for rail carriers to achieve greater productivity gains by negotiating less rigid work-rules. If current work-rules are so rigid that they impede firms' ability to satisfy the condition for allocative efficient use of factor inputs it is not obvious a priori whether these firms over or under-employ workers relative to non-labor inputs. For instance, work-rules that mandate crew sizes might restrict firms' ability to substitute labor saving technology for labor and thus create a work environment that promotes over-employment of labor relative to other factor inputs (Bitzan and Peoples, 2014). Alternatively, work-rules that use miles of freight hauled as a measure of a workday might promote the under-employment of labor relative to other inputs by contributing to wage payments that exceed workers' marginal productivity. This essay estimates a translog cost function to test whether rail firms use an allocatively efficient mix of labor and non-labor inputs for the observation period covering recent years of relatively flexible work-rule in the railroad industry.

The remainder of the essay consists of five additional sections. The next section of the essay documents changing work-rules following deregulation and the potential for achieving allocative efficient use of factor inputs due to such change. Section 2.3 presents a conceptual framework for examining allocative efficiency. This is followed by a description of the data source and empirical approach used to test whether class-1 rail carriers use an allocative efficient combination of labor and non-labor inputs. Section 2.5 presents cost results used to examine whether the combination of inputs satisfies the condition of cost minimization. Last, concluding remarks are presented in section 2.6.

2.2 Changing Work-Rules and Stepped Up Investment in Rail Infrastructure

Rail has a long history of government oversight of its operations. While regulation of rate and entry received substantial attention from past research, much less analysis examines regulatory oversight of this industry's labor market. However, major labor legislation was enacted as far back as the turn of the century. For instance, the Railroad Hours of Service Act was passed in 1907 primarily to avoid erosion of employee wellbeing associated with long hours of work. Maximum consecutive hours of work with minimum hours of rest were set.[50] Provision (49 CFR 228) reported below, highlights the emphasis this act placed on working conditions.

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[50] Key railroad labor legislation following the Hours of Service Act of 1907 include the 1920 Esch-Cummins Act that created the Railroad Labor Board to settle railroad labor disputes. Following this act the

> Limitation on Hours. The Act establishes two limitations on hours of service. First, no employee engages in train or engine service may be require or permitted to work in excess of twelve consecutive hours. After working a full twelve consecutive hours, an employee must be given at least ten consecutive hours off duty before being permitted to return to work.
>
> Second, no employee engaged in train or service engine may be required or permitted to continue on duty or go on duty unless he has had at least eight consecutive hours off duty within the preceding twenty-four hours. (49 CFR Part 228, Appendix A to Part 228) [51]

Previous research suggests restrictions on working conditions were not necessarily opposed by rail companies as Davis and Wilson (2003) report that the imposition of work-rules from the point of view of the employer comports with the objective of creating discipline when bringing together inexperienced and undisciplined railroad workers. Imposing work-rules was also seen as a mechanism to coordinate railroad workers for a large rail networks (Cappelli, 1985). Nonetheless, enforcing hours of service regulations introduces unintended consequences by contributing to input market distortions (Kumbhakar, 1992). Such distortion arises if hours of service regulation

passage of the 1926 Railway Labor Act required rail companies bargain collectively with labor and prohibited discrimination against unions.

[51] Requirement of the Hours of Service Act: Statement of Agency Policy and Interpretation. Retrieved from http://www.law.cornell.edu/cfr/text/49/part-228/appendix-A

creates an incentive for railroad employers hiring additional workers to perform tasks that could be achieved with a smaller work force working longer hours.

The potential for input market distortions seems even more likely when considering that work-rule stipulations are not limited to government mandated hours of service as influential rail unions imposed fairly rigid work-rules pertaining to the stipulation of a standard work day, the practice of deadheading and the standardization of crew sizes. Negotiating the terms of a standard work day allowed rail unions the opportunity to enhance workers' earnings without necessarily negotiating higher hourly wages. Indeed, Talley and Schwarz-Miller (1998, p.139) observe that negotiating a standard work day contributes to the determination of rail workers earnings as possibly the most complex in American industry. The complexity arises from defining a work day based on miles of freight hauled rather than daily hours worked. Prior to 1985, the standard work day for freight crews and all engine crews was set to 100 miles, where any distance over these 100 miles was considered as over-mileage pay. This may eventually distorts the wage productivity relationship when workers take advantage of this provision to increase their hourly wage without markedly increasing their weekly hours worked (Peoples, 1998, p.117). The potential for such wage distortion is exacerbated with the introduction of faster locomotives. For instance, distance traveled to be considered as a work day took less time, therefore making it easier for rail workers to earn overtime wages leading to an increase in labor cost per hour (MacDonald and Cavalluzzo, 1996). Pre-deregulation determination of rail workers wages were further complicated due to rail unions negotiating worker pay without workers performing any rail related service or contributing to company's productivity. The term 'deadheading' is commonly used to describe this type of labor activity. Specifically, according to 49 CFR 228.5, deadheading is defined as "the physical relocation of a train employee from one point to another as a result of a railroad issued verbal or written directive." In other words a crew is transported from one terminal to another or to a train without performing any services. Last, the practice of feather beading--overstaffing or limiting preproduction in compliance with a union contract in order to save or create jobs—further contributed to wage-productivity distortion in the rail industry. Pre-deregulation union contracts generally stipulated crews included firemen even though most locomotives used diesel fuel rather than steam by the middle of the twentieth century. Employing workers in antiquated positions is a clear example of inefficient allocation of crew members relative to non-labor inputs.

In sum, prior to deregulation government mandated and union negotiated work-rules that did not create an incentive to employ an efficient allocation of labor relative to non-labor inputs. Rather, workers were able to receive wage rates that were not commiserate with their productivity. The last quarter of the twentieth century, however, witnessed a sea change in policy regarding the regulation of business practices in the rail industry and rail companies' investment on cost-saving technology. Economic theory predicts that both of these events should influence the employment-mix of inputs in this industry. Deregulation placed downward pressure on costs by relaxing the minimum rate restrictions to allow rail carriers to set competitive rates with trucking. In addition, deregulation allowed rail carriers the opportunity to abandon unprofitable lines and consolidate operations with former rail rivals. These policy changes indirectly influenced labor markets by weakening the negotiation advantage of rail unions and providing substitutes for labor.

Declining demand for rail workers due to abandonment of unprofitable lines, and consolidation of rail service contributed to weakening negotiation leverage of rail unions. For instance, using rail carrier data for the 1961-1990 observation period, Hsing and Mixon (1995) report findings suggesting that following deregulation the labor demand curve for rail workers shifted downward significantly, and became more elastic in wages, while the marginal product of labor increased. These post deregulation labor productivity gains occurred in lockstep with declines in labor wages, as past research find declining wages for rail workers following the passage of the 1980 Staggers act (Talley and Schwarz-Miller, 1998). These trends are consistent with the argument proposing the existence of labor market distortion arising from labor receiving wages that exceed marginal productivity.

Enhanced labor substitutability linked to deregulation arises from this policy facilitating a business environment that places a premium on technology investment as a means to lower cost, in large part by reducing labor content in rail operations. Examples of post deregulation labor saving technology include the introduction of electronic switching systems, communications technology, fuel efficient locomotives, and new track technology. Innovation in switching systems constitute grouping of the switch boxes or posts, automation of hump-yard switching and installation of electronic transponder devices which makes the operating systems of trains easier with less man-handling involved (Schwarz-Miller and Talley, 2002). Indeed, the employment of switchmen and brakemen following the introduction of this system fell from 50,578 in 1983 to 7,238 by

2010.[52] Technological improvement in radio communications further contributed to the loss of jobs for brakemen. The introduction of new communications technology coincides with the passage of the Staggers Act. For instance, in the early 1980's trains were equipped with end-of-train devices which were more dependable in communicating the safety condition of the train. Besides these remote radio devices that monitor trains operations[53], hot box[54] and dragging equipment detectors[55] contribute to the elimination of caboose, which in turn eliminated the need for brakemen.[56] The switch from steam to diesel locomotives affected the crew size by reducing the need for firemen and boilermakers (Schwarz-Miller and Talley, 2002). In addition, the need for diesel locomotive maintenance was low relative to the maintenance needs of steam locomotives (Rich, 1986).

While the introduction of electronic switching systems, communications technology, and fuel efficient locomotives directly affected the demand for train operators, changes in track technology directly affected the demand for maintenance-of-way and structures employees.[57] Improvements in track technology included the use of stronger, low maintenance materials as well as automated improvements in the installation of tracks. Such improvements in track technology reduced the long-term-

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[52] Source: Unionstats.com
[53] The end-of-train device conveys information to the engineer on the braking systems such as brake pressure and enable him to set breaks on the trains. (http://www.up.com/aboutup/history/caboose/technology_overtakes/index.htm)
[54] Hot box, which are installed on the track line, monitor the wheel and brake temperature.
[55] Also provides detection on derailment.
[56] Caboose is known as a conductor office, carrying also a brakemen and a flagmen. In early years, the engineer whistled the brakemen in the caboose to maneuver the brake wheels while the flagmen cautioned other train that came closer.
[57] Improvements in track technology did not start with deregulation, however, as Schwarz-Miller and Talley (2002) report, deregulation promoted greater use of this technology by increasing traffic density on major routes.

demand for maintenance-of-way and structure employees, by reducing the need for their services (Schwarz-Miller and Talley, 2002). In addition, Schwarz-Miller and Talley (2002) report changes in track technology altered the work assignments of maintenance-of-way crews in a way the further reduced the demand for their services. For instance, prior to the widespread use of this technology large numbers of small crews were assigned to repairs in fairly restricted geographic locations. Following enhanced use of track technology rail companies deployed a more optimal approach that relied on a large crew to work periodically across several geographic locations.

Rail labor negotiations settled after deregulation and during the introduction of labor saving technology weakened rail unions' ability to retain rigid work-rules that protected worker job security while possibly introducing inefficiency in the input market. Evidence of relatively flexible work-rules following deregulation is highlighted by changing provisions regarding the practice of deadheading, changes in the codification of a standard work day, and changes in crew sizes. For instance, settlements in 1985 modified the practice of deadheading to allow carriers to limit expenditures to no more than a basic day's pay, and excluded new employees from receiving deadheading pay (Talley and Schwarz-Miller, 1998). Post deregulation settlements starting in 1985 changed the stipulation of a standard work day for a rail worker from the previous to100 to 108 miles. Succeeding negotiations lead to a more significant increase of 130 miles as the definition of a day's work by 1995. Settlements also reduced crew sizes by initially phasing out firemen and hostlers.[58] By 1991 train crew sizes fell from consisting of an engineer, conductor and two brakemen to only consisting of just two workers.

[58] A hostler is a mechanical crew, handling engines in the yards. Definition retrieved from http://home.cogeco.ca/~trains/rrterms.htm

While union negotiations loosened previously rigid work-rules with regards to the practice of deadheading, and with regards to stipulating a standard work day and a standard crew size, federal regulation pertaining to hours of service actually did not change for more than twenty-five years following deregulation. When change did occur it actually strengthened safety regulation by lowering maximum hours of service slightly. For instance, the Rail Safety Improvement Act (RSIA) of 2008 increased the minimum undisturbed rest time of train crews from eight to ten hours, and prohibited railroad employees working for the remainder of a month after spending a total of 276 hours on duty in any month. Imposing these hours of service regulation, however, might create a challenge on rail managers' ability to employ an optimal number of workers as minutes from the October 30, 2003 Committee on Commerce, Science, and Transportation, report " Neither the rail carriers nor the unions have an incentive to reduce the number of hours that employees may work. Limiting hours of service would force the railroads to hire additional workers, and employees would suffer a reduction in earning power" (Senate Report, 108-182, 2003).

In sum, this essay's presentation of changing work-rule regulations following deregulation in the rail industry suggests rail employers face less limitations satisfying the condition of allocative efficiency compared to the limitations faced prior to the passage of legislation enacting regulatory reform. Indeed, empirical findings from past research indicating labor market change employment such that actual wage more closely reflects labor productivity. For instance, empirical analysis by MacDonald and Cavalluzzo (1996) found that ton miles per employee presenting labor productivity more than doubled from 1980 to 1990, and real labor expense per ton mile decreased by almost 60% for the same years. These gains in productivity occurred without increases in real wages (Talley and Schwarz-Miller, 1998). Hence, suggesting the possibility of a movement toward allocative efficient use of labor relative to non-labor inputs. A direct test of efficient input allocation, however, is missing from the literature.

2.3 Modeling Work-rules and Allocative Efficiency

Producer theory identifies two components related to efficiency, which are allocative efficiency and technical efficiency. Technical efficiency is achieved when a firm is operating on the production frontier whereas allocative efficiency occurs when firm is using optimal combination of factor inputs given price and production technology (Farrell, 1957). Shi et al. (2011) examine technical efficiency of Class-1 railroads between 2002 and 2007 and their findings suggest class-1 carriers generally operate on or near the production frontier. Burlington Northern Santa Fe (BNSF) is found to operate on the production frontier for every year in the sample. Other companies such as Soo Line, Union Pacific, Grand Truck Corporation are also found to operate close to the production frontier. Such findings are not surprising since class-1 carriers do not face obvious constraints on their ability to achieve technical efficiency. In contrast, the previous section of this essay presents information on railroad work-rules that might hinder carriers' ability to employ an allocatively efficient mix of inputs and this hindrance should erode following deregulation given the easing of work-rule restrictions. Indeed, this study also observes the possibility that following deregulation, real wages decline jointly with increases in labor productivity. Therefore, under these circumstances, it is possibility that following deregulation railroad carriers are better able to move toward a more allocatively efficiency factor input mix between labor and non-labor inputs. This labor market outcome is an empirical issue whereby without a direct test of allocative efficiency, it is impossible to verify the possibility for improved factor inputs reallocation. What follows in Figure-2 is a graphical depiction of input usage used to provide guidance toward implementing an appropriate empirical approach for testing whether railroad carriers employ an efficient mix of inputs post regulatory reform.

Two scenarios may arise if the labor-non labor combination does not satisfy the cost minimizing condition. As noted in the previous section it is not apparent *a priori* whether the industry is over-utilizing or under-utilizing the labor input respective to the non-labor inputs. If the industry is employing a small quantity of labor relative to non-labor inputs, it may due to the fact that actual price of labor is too high due to rigid work-rules that make the employment of non-labor inputs more cost efficient. Whereas if the industry is employing a large quantity of labor relative to non-labor inputs showing over employment of labor, it may be the case that work-rules are forcing the carriers to use more workers than they would without these constraints, all other inputs remaining constant.

To minimize cost, railroad carriers utilize factor inputs in an efficient proportion when the ratio of marginal product of one input with its price is equal to the ratio of marginal product of other input with its price. For example, assume a hypothetical carrier doesn't face any constraints in the labor market and is thus able to satisfy the condition for cost minimization depicted by equation (1):

$$\frac{MP_L}{w_L} = \frac{MP_{NL}}{w_{NL}} \qquad (1)$$

where MP_L and MP_{NL} are the marginal product of labor and non-labor respectively, and w_L and w_{NL} are the input prices for labor and non-labor respectively. The ratio of marginal product of non-labor to labor represents the marginal rate of technical substitution of non-labor for labor ($MRTS_{NL,L}$) shown in the following equation:

$$\frac{MP_{NL}}{MP_L} = MRTS_{NL,L} = -\frac{\Delta L}{\Delta NL} \qquad (2)$$

where ΔL and ΔNL are the changes in quantity of labor and non-labor respectively, and $-\frac{\Delta L}{\Delta NL}$ represents the negative of the slope of an isoquant. At any given level of output, the least cost combination of factor inputs occurs when the marginal rate of technical substitution is equal to the ratio of factor prices as shown in the following equation:

$$MRTS_{NL,L} = \frac{w_{NL}}{w_L} \qquad (3)$$

Similarly, this means that the least costly combination of factor inputs occurs when the slope of an isoquant equals to the slope of an isocost. This is represented at point A in Figure-2 where at that point, the combination of labor and non-labor minimizes cost when $C = w_L x_L + w_{NL:} x_{NL}$. Now suppose the hypothetical carrier negotiates a labor union contract for rail workers that imposes restrictive work-rules and, the railroad carrier encounters difficulty attaining higher labor productivity matching the negotiated wage. The carrier then has an incentive to invest in more productive alternative inputs per dollar. This labor market outcome is depicted graphically by the factor input combination occurring at point B in Figure-2, where the firm decides to increase in the usage of non-labor input (from x_{NL} to ${x_{NL}}^*$) and decrease in the usage of labor (from x_L to ${x_L}^*$) as a result of restrictive work-rules. Clearly, at point B, cost minimization is not achieved. Here, the isocost is $C' = w_L {x_L}^* + w_{NL} {x_{NL}}^*$ and this isocost is not tangent to the isoquant.

Cost minimization is realized at point B only if the railroad carrier pays the shadow prices (w_L^* and w_F^*). The combination of factor inputs that can be employed if the railroad carrier pays the shadow prices is represented by the isocost $C^* = w_L{}^* x_L{}^* + w_{NL}{}^* x_{NL}{}^*$. When this isocost is tangent to the isoquant, point B becomes the least cost combination of factor inputs.

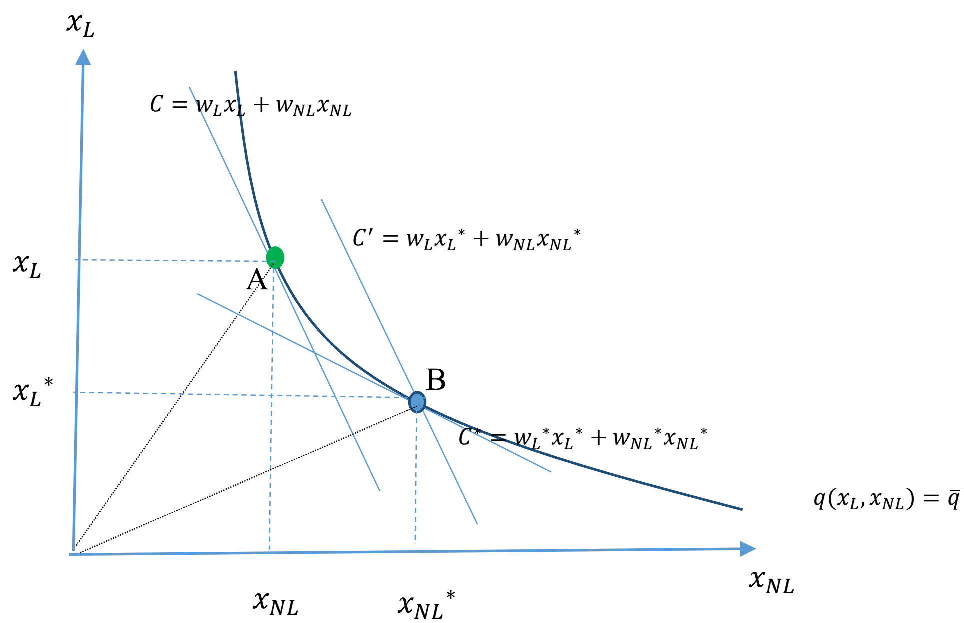

Figure-2: Allocative efficiency between labor (x_L) and non-labor (x_{NL})

Nonetheless at point B, the railroad carrier faces factor inputs decision based on the shadow prices (associated with actual productivity) as a result of the restrictive work-rules. These shadow prices actually capture the price distortion in the factor input market. The mix of factor inputs chosen at point B is the least cost mix when

$$\frac{MP_L^*}{w_L^*} = \frac{MP_{NL}^*}{w_{NL}^*} \qquad (4)$$

Where MP_L^* and MP_{NL}^* are the marginal product of labor and non-labor respectively, when employing at x_L^* and x_{NL}^* and w_L^* and w_{NL}^* are the shadow input prices for labor and non-labor respectively. It should be noted that for this example the shadow price for labor w_L^* is less than the actual price w_L at output level $\bar{q}$. Thus, assuming the price of non-labor inputs matches the marginal productivity of non-labor inputs, then

$$\frac{MP_L^*}{w_L^*} > \frac{MP_L}{w_L} \quad \text{and} \quad \frac{MP_{NL}^*}{w_{NL}^*} = \frac{MP_{NL}}{w_{NL}} \tag{5}$$

The inequality on the left depicts the input price distortion associated with work-rule rigidity. So while the rail carrier is satisfying the condition of cost minimization for shadow input prices, the observed factor input combination is allocatively inefficient for actual prices. The extent of this price distortion can be depicted additively by setting w_L^* $=w_L + g_L$, where g_L is the factor input distortion. It is important to note that the magnitude of this factor input price distortion is influence by the curvature of the isoquant. The greater the curvature of the isoquant, the greater the degree of substitutability of the two inputs. Greater degree of substitutability is portrayed through the isoquant approaching linearity, shown in the following Figure-3.

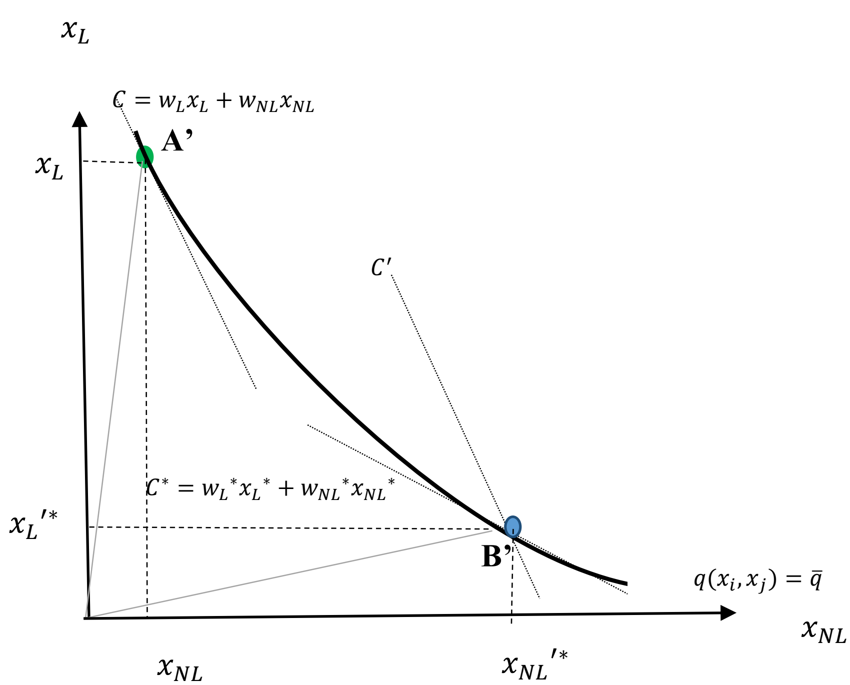

Figure-3: Allocative efficiency between labor (x_L) and equipment (x_{NL}) as elasticity of substitution increases

At point A’, the least cost combination is achieved without restrictive work-rules. With restrictive work-rules, the least cost combination is preserved at point B’ after the firm employs less labor and more non-labor input from point A’. The magnitude of the changes in the factor input is larger than in Figure-3 as the elasticity of substitution[59] between labor and non-labor becomes larger and this is depicted by the isoquant approaching linearity[60]. The elasticity of substitution measures the responsiveness of a firm on changes in relative input prices. The larger the value of elasticity, the easier it is for the firm to substitute between the two factor inputs. Therefore, for a rail carrier to be a cost minimizer, if there is a change in the relative input prices, the carriers will shift to a cheaper factor input. In other words, the greater the substitutability of labor and non-labor inputs, the greater the input market distortion due to the shadow price varying from the actual price. Therefore, this suggests that for the same shadow price, market distortion (inefficient proportion of input mix) is greater since the isoquant is approaching linearity as elasticity of substitution increases.

In sum, the preceding graphical representation on factor input price distortion provides guidance for empirically examining allocative efficiency of factor inputs by using information on input cost to compute the input price distortion index. Additionally, the preceding presentation highlights the importance of computing the elasticity of substitution to attain information on the potential magnitude of the price distortion.

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[59] $\sigma = \dfrac{\%\ change\ in\ \left(\frac{L}{NL}\right) ratio}{\%\ change\ in\ MRTS_{NL,L}}$

[60] Factor inputs for a linear production function are perfect substitutes where $= \infty$.

2.4 Data and Empirical Approach

The empirical analysis of allocative efficiency in the US railroad industry is achieved, in part, by using data from Class I Annual Reports (R-I reports) from 1983 to 2008. The data were not gathered in a same type/format. The data types or formats gathered were from raw data file, micro fiche, excel files and pdf files for the later years. Snapshots from the microfiche were taken and converted into pdf files. All data in the pdf files were extracted manually. The variables sources and construction are taken from a study done by Bitzan and Keeler (2003), which is similar with the first essay. The variable constructions used in their study are presented in Table-8 below. Merger information from Dooley et al. (1991) is used when constructing the fixed effect.

Table-8: Construction of variables

Variable Construction
• Real total cost = (opercost – capexp + roird + roilcm + roicrs)/gdppd
opercost = railroad operating cost (schedule 410, line 620, column f)
capexp = capital expenditures classified as operating in r1 (schedule 410, lines 12-30, 101-9, column f)
roird = return on investment in road = (roadinv – accdepr) * costkap
roadinv: road investment (schedule 352b, line 31) + capexp from all previous years
accdepr: accumulated depreciation in road (schedule. 335, line 30, column g)
costkap: cost of capital (AAR railroad facts)
roilcm = return on investment in locomotives = [(iboloco+locinvl) – (acdoloco + locacdl)] * costkap
iboloco: investment base in owned locomotives (schedule 415, line 5, column g)
locinvl: investment base in leased locomotives (schedule 415, line 5, column h)
acdoloco: accumulated depreciation of owned locomotives (schedule 415, line 5, column i)
locacdl: accumulated depreciation of leased locomotives (schedule 415, line 5, column j)
roicrs = return on investment in cars = [(ibocars + carinvl) – (acdocars + caracdl)]*costkap
ibocars: investment base in owned cars (schedule 415, line 24, column g)
carinvl: investment base in leased cars (schedule 415, line 24, column h)
acdocars: accumulated depreciation of owned cars (schedule 415, line 24, column i)
caracdl: accumulated depreciation of leased locomotives (schedule 415, line 24, column j)

gdppd = gdp price deflator

Price of factor inputs

- Price of labor = (swge + fringe – caplab)/lbhrs

  swge = total salary and wages (schedule 410, line 620, column b)

  fringe = fringe benefits (schedule 410, lines 112-14, 205, 224, 309, 414, 430, 505, 512, 522, 611, col. e)

  caplab = labor portion of capital expenditure classification as operating in R1 (schedule 410, lines 12-30, 101-9, column b)

  lbhrs = labor hours (Wage form A, line 700, column 4 + 6)

- Price of equipment = weighted average equipment price (schedule 415 and schedule 710)
- Price of fuel (schedule 750)
- Price of material = AAR materials and supply index
- Price of way and structure = (roird + anndeprd) / mot

  anndeprd = annual depreciation of road (schedule 335, line 30, column c)

  mot = miles of track (schedule 720, line 6, column b)

Factor input prices are divided by gdp price deflator

Outputs

- Utgtm: unit train gross ton miles (schedule 755, line 99, column b)
- Wtgtm: way train gross ton miles (schedule 755, line 100, column b)
- Ttgtm: through train gross ton miles (schedule 755, line 101, column b)

  adjustment factor multiplied by each output variable = rtm/(utgtm + wtgtm + ttgtm)

  rtm: revenue ton miles (schedule 755, line 110, column b)

Movement characteristics

- Miles of road: (schedule 700, line 57, column c)
- Speed = train miles per train hour in road service = trnmls/(trnhr-trnhs)

  trnmls = total train miles (schedule 755, line 5, column b)

  trnhr = train hours in road service – includes train switching hours (schedule 755, line 115, column b)

  trnhs = train hours in train switching (schedule 755, line 116, column b)

- Average length of haul = rtm/revtons

  revtons = revenue tons (schedule 755, line 105, column b)

- Caboose = fraction of train miles with cabooses = cabmiles/trnmls

  cabmiles = caboose miles (schedule 755, line 89, column b)

Note. Adapted from “Productivity growth and some of its determinants in the deregulated US railroad industry.” by Bitzan, J. D., & Keeler, T. E., 2003*, Southern Economic Journal*, p.250-251.

Atkinson and Halvorsen (1984) suggested a different cost minimization approach than the neoclassical approach. The neoclassical approach assumes cost minimization is subject to output constraint. However Atkinson and Halvorsen propose an additional constraint imposes by the regulatory environment. The neoclassical cost minimization problem is depicted in the following equation

$$L = \sum_h P_h X_h - \phi[f(X) - Q] \tag{8}$$

The solution to the optimization problem provides an input mix that is equivalent to the input combination depict by point A in the previous graph. Nonetheless, with the regulatory environment constraints the cost minimization problem is expressed using the following equation:

$$L = \sum_h P_h X_h - \phi[f(X) - Q] - \sum_i \lambda_i R_i(P, X) \tag{9}$$

$h = 1, \ldots, n\,; i = 1, \ldots, m$

where the price and quantity are represented by P_h and X_h respectively of the input h. The production function is represented by (X) . The symbol Q denotes output and R_i denotes firm's regulatory condition. The symbols $\emptyset$ and λ_i represents the Lagrange multipliers.

Solving this optimization problem provides a conceptual framework that still allows the firm to employ input combinations depicted by combination *A* presented in Figure-2, however costs are not minimized within this framework for the factor input combination associated with the actual input prices. The closer of the value of the input to the level required by the constraint the less binding the constraint, hence, it is assumed that $\frac{\partial W}{\partial X} < 0$. For simplicity, suppose there are two inputs, input-j and input-k. The first order conditions in minimizing cost for input-j and input-k in ratio form is as following:

$$\frac{\partial f/\partial X_j}{\partial f/\partial X_k} = \frac{P_j + \sum_i \lambda_i \, \partial R_i/\partial X_j}{P_k + \sum_i \lambda_i \, \partial R_i/\partial X_k} = \frac{P_j^*}{P_k^*} \tag{10}$$

where the marginal product of input-j and input-k are presented by $\partial f/\partial X_j$ and $\partial f/\partial X_k$ respectively and the marginal rate of technical substitution between input-j and input-k is presented by $\frac{\partial f/\partial X_j}{\partial f/\partial X_k}$. Following deregulation, changing to a more flexible set of work-rules has the potential to affect factor input mixes. The null hypothesis will be that the railroads may find it easier to achieve allocative efficiency after deregulation.

In this essay, the model specification of Bitzan and Keeler (2003) is followed. The total cost function is given by= $C(w_i, y_k, a_m, t)$; $w_i = (w_L, w_E, w_F, w_M, w_{WS})$; $y_k = (y_U, y_W, y_T)$; $and\ a_m = (a_{miles}, a_{speed}, a_{haul}, a_{caboose})$

where C is total cost, w_L is the labor price, w_E is the equipment price, w_F is the fuel price, w_M is the material and supplies price, w_{WS} is the way and structures price, y_U is the unit train gross ton miles, y_W is the way train gross ton miles, y_T is the through train gross ton miles, a_{miles} is the miles of road, a_{speed} is the train miles per train hour, a_{haul} is the average length of haul, $a_{caboose}$ is the fraction of train miles operated with caboose. This cost function is then estimated using the translog cost specification[61]. This specification

[61] Other cost functions specification such as Cobb-Douglas, normalized quadratic and Diewert place a priori restrictions. Cobb-Douglas is very restrictive in terms that it does not have second order term. Diewert restricts the cost function to constant return to scale. Whereas for normalized quadratic, linear homogeneity in input prices in not achieved without sacrificing the flexibility of the functional form.

is derived by using Taylor expansion series to second degree polynomial. This expansion to the second degree is shown in the following equation:

$$C(w_i, y_k, a_m, t) = \frac{C(\bar{w}_i, \bar{y}_k, \bar{a}_m, t)}{0!} + \sum_i \frac{\frac{\partial C}{\partial w_i}}{1!}(w_i - \bar{w}_i) +$$

$$\sum_k \frac{\frac{\partial C}{\partial y_k}}{1!}(y_k - \bar{y}_k) + \sum_m \frac{\frac{\partial C}{\partial a_m}}{1!}(a_m - \bar{a}_m)$$

$$+\frac{\frac{\partial C}{\partial t}}{1!}(t - \bar{t}) + \sum_i \sum_j \frac{\left(\frac{\partial^2 C}{\partial w_i \partial w_j}\right)}{2!}(w_i - \bar{w}_i)\,(w_j - \bar{w}_j)$$

$$+\sum_i \sum_k \frac{\left(\frac{\partial^2 C}{\partial w_i \partial y_k}\right)}{2!}(w_i - \bar{w}_i)\,(y_k - \bar{y}_k)$$

$$+\sum_i \sum_m \frac{\left(\frac{\partial^2 C}{\partial w_i \partial a_m}\right)}{2!}(w_i - \bar{w}_i)\,(a_m - \bar{a}_m) + \sum_i \frac{\left(\frac{\partial^2 C}{\partial w_i \partial t}\right)}{2!}(w_i - \bar{w}_i)(t - \bar{t})$$

$$+\sum_k \sum_i \frac{\left(\frac{\partial^2 C}{\partial y_k \partial w_i}\right)}{2!}(y_k - \bar{y}_k)\,(w_i - \bar{w}_i) + \sum_k \sum_l \frac{\left(\frac{\partial^2 C}{\partial y_k \partial y_l}\right)}{2!}(y_k - \bar{y}_k)\,(y_l - \bar{y}_l)$$

$$+\sum_k \sum_m \frac{\left(\frac{\partial^2 C}{\partial y_k \partial a_m}\right)}{2!}(y_k - \bar{y}_k)\,(a_m - \bar{a}_m) + \sum_k \frac{\left(\frac{\partial^2 C}{\partial y_k \partial t}\right)}{2!}(y_k - \bar{y}_k)(t - \bar{t})$$

$$+\sum_m \sum_i \frac{\left(\frac{\partial^2 C}{\partial a_m \partial w_i}\right)}{2!}(a_m - \bar{a}_m)\,(w_i - \bar{w}_i)$$

$$+\sum_m \sum_k \frac{\left(\frac{\partial^2 C}{\partial a_m \partial y_k}\right)}{2!}(a_m - \bar{a}_m)\,(y_k - \bar{y}_k) + \sum_m \sum_n \frac{\left(\frac{\partial^2 C}{\partial a_m a_n}\right)}{2!}(a_m - \bar{a}_m)\,(a_n - \bar{a}_n)$$

$$+\sum_m \frac{\left(\frac{\partial^2 C}{\partial a_m \partial t}\right)}{2!}(a_m - \bar{a}_m)(t - \bar{t}) + \sum_i \frac{\left(\frac{\partial^2 C}{\partial t \partial w_i}\right)}{2!}(t - \bar{t})(w_i - \bar{w}_i)$$

$$+\sum_k \frac{\left(\frac{\partial^2 C}{\partial t \partial y_k}\right)}{2!}(t - \bar{t})(y_k - \bar{y}_k) + \sum_m \frac{\left(\frac{\partial^2 C}{\partial t \partial a_m}\right)}{2!}(t - \bar{t})(a_m - \bar{a}_m)$$

$$+\frac{\frac{\partial^2 C}{\partial t^2}}{2!}(t - \bar{t})^2 \tag{11}$$

This Taylor series approximation is then transformed by taking the logarithms of the variables and substituting the partial derivatives with parameters. After applying the symmetry of second derivatives (for example,$\frac{\partial^2 C}{\partial w_i \partial y_k} = \frac{\partial^2 C}{\partial y_k \partial w_i}$), simplifying and rearranging the terms, the resulting equation would become the translog cost function as shown in the following equation:

$$lnC = \alpha_0 +$$

$$+\sum_i \alpha_i ln\left(\frac{w_i}{\overline{w_\iota}}\right) + \sum_k \beta_k ln\left(\frac{y_k}{\overline{y_k}}\right) + \sum_m \sigma_m ln\left(\frac{a_m}{\overline{a_m}}\right) + \theta t$$

$$+\frac{1}{2}\sum_i \sum_j \alpha_{ij} ln\left(\frac{w_i}{\overline{w_\iota}}\right) ln\left(\frac{w_j}{\overline{w_J}}\right) + \sum_i \sum_k \tau_{ik} ln\left(\frac{w_i}{\overline{w_\iota}}\right) ln\left(\frac{y_k}{\overline{y_k}}\right)$$

$$+\sum_i \sum_m \vartheta_{im} ln\left(\frac{w_i}{\overline{w_\iota}}\right) ln\left(\frac{a_m}{\overline{a_m}}\right)$$

$$+\sum_i \partial_i ln\left(\frac{w_i}{\overline{w_\iota}}\right) t + \frac{1}{2}\sum_k \sum_l \beta_{kl} ln\left(\frac{y_k}{\overline{y_k}}\right) ln\left(\frac{y_l}{\overline{y_l}}\right) + \sum_k \sum_m \varphi_{km} ln\left(\frac{y_k}{\overline{y_k}}\right) ln\left(\frac{a_m}{\overline{a_m}}\right)$$

$$+\sum_k \pi_k \ln\left(\frac{y_k}{\overline{y_k}}\right) t + \frac{1}{2}\sum_m \sum_n \sigma_{mn} ln\left(\frac{a_m}{\overline{a_m}}\right) ln\left(\frac{a_n}{\overline{a_n}}\right) + \sum_m \mu_m ln\left(\frac{a_m}{\overline{a_m}}\right) t$$

$$+\frac{1}{2}\gamma t^2 + \epsilon \tag{12}$$

Shephard's Lemma can be used in order to obtain each input share equations. This is done by differentiating the translog cost function with respect to the log of factor price as shown below;

$$\frac{\partial lnC}{\partial lnw_i} = \alpha_i + \sum_j \alpha_{ij} lnw_j + \sum_k \tau_{ik} lny_k + \sum_m \vartheta_{im} lna_m + \gamma_i t + \epsilon \quad (13)$$

Since at the industry mean $w_i = \overline{w_i}, y_k = \overline{y_k}, a_m = \overline{a_m}, t = 0$, then $\frac{\partial lnC}{\partial lnw_i} = \alpha_i$. Thus $\alpha_L, \alpha_E, \alpha_F, \alpha_M and\ \alpha_{WS}$ represent labor's share of total cost, equipment's share of total cost, fuel's share of total cost, material's share of total cost and ways and structure's share of total cost respectively. In addition, the coefficient β_k represents economies of scale and the coefficient ∂_i represents the technologies effect on the factor inputs. The input shares equations together with the cost function are estimated using a seemingly unrelated regression method. The whole system of equations estimated is shown as follows:

$$lnC = \alpha_0 +$$

$$+\sum_i \alpha_i ln\left(\frac{w_i}{\overline{w_i}}\right) + \sum_k \beta_k ln\left(\frac{y_k}{\overline{y_k}}\right) + \sum_m \sigma_m ln\left(\frac{a_m}{\overline{a_m}}\right) + \theta t$$

$$+\frac{1}{2}\sum_i \sum_j \alpha_{ij} ln\left(\frac{w_i}{\overline{w_i}}\right) ln\left(\frac{w_j}{\overline{w_j}}\right) + \sum_i \sum_k \tau_{ik} ln\left(\frac{w_i}{\overline{w_i}}\right) ln\left(\frac{y_k}{\overline{y_k}}\right)$$

$$+\sum_i \sum_m \vartheta_{im} ln\left(\frac{w_i}{\overline{w_i}}\right) ln\left(\frac{a_m}{\overline{a_m}}\right)$$

$$+\sum_i \partial_i ln\left(\frac{w_i}{\overline{w_i}}\right) t + \frac{1}{2}\sum_k \sum_l \beta_{kl} ln\left(\frac{y_k}{\overline{y_k}}\right) ln\left(\frac{y_l}{\overline{y_l}}\right) + \sum_k \sum_m \varphi_{km} ln\left(\frac{y_k}{\overline{y_k}}\right) ln\left(\frac{a_m}{\overline{a_m}}\right)$$

$$+\sum_k \pi_k \ln\left(\frac{y_k}{\overline{y_k}}\right) t + \frac{1}{2}\sum_m \sum_n \sigma_{mn} ln\left(\frac{a_m}{\overline{a_m}}\right) ln\left(\frac{a_n}{\overline{a_n}}\right) + \sum_m \mu_m ln\left(\frac{a_m}{\overline{a_m}}\right) t$$

$$+\frac{1}{2}\gamma t^2 + \epsilon \quad (12)$$

$$\frac{\partial lnC}{\partial lnw_i} = \alpha_i + \sum_j \alpha_{ij} lnw_j + \sum_k \tau_{ik} lny_k + \sum_m \vartheta_{im} lna_m + \gamma_i t + \mu \tag{13}$$

In estimating the translog cost function, the variable depicting carrier use of a caboose is computed using a Box-Cox transformation[62] since the data consists null values which will be undefined when using a log transformation. It is also important to note that the share equations are estimated for all the inputs except one in order to avoid singularity in estimated covariance matrix in the errors. The practice of dropping arbitrarily one share equation while keeping the remaining share equations, is common (Takada et al., 1995). Furthermore, in order to correspond to a well-behaved production function, the translog cost function should exhibit certain properties. It needs to be linearly homogeneous, monotonicity and concave in all factor prices. Since the function is continuous and twice differentiable, symmetry of the relevant cross-term parameters are also assumed. The parameter estimated in the share equations also need to be consistent with the cost function. These homogenous and symmetry conditions requires that $\sum_i \alpha_i = 1, \sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0$, $\sum_i \tau_{ik} = \sum_i \vartheta_{im} = \sum_i \gamma_i = 0, \alpha_{ij} = \alpha_{ji}$.

In examining the allocative efficiency in the railroad industry, the following represents the equations used in this study. The cost minimizing decision for the railroad carriers is to satisfies the condition of

$$\frac{MP_i}{MP_j} = \frac{w_i}{w_j} \tag{14}$$

[62] Box-Cox transformations is defined as $y_i^\omega = \frac{y_i^\omega}{\omega}$ if $\omega \neq 0$ and $y_i^\omega = lny_i$ if $\omega = 0$. A value of $\omega =$ 0.0001 is selected since it gives almost same results with log.

where MP_i is the marginal product of i th input and w_i is the price for ith input paid by railroad carriers. However in order to be accurate, there is a need to use shadow prices in the equation which is depicted by

$$\frac{MP_i}{MP_j} = \frac{w_i{}^*}{w_j{}^*} \tag{15}$$

where $w_i{}^*$ is the shadow price for input ith. The shadow price is in the form of additive version as shown in the following equation.

$$w_i{}^* = w_i + g_i \tag{16}$$

where g_i is the factor of proportionality[63] or the price efficiency parameter that accounts for the deviation of the shadow price from the actual price.

$$C^* = C^*(w_i{}^*, y) \tag{17}$$

In equation (17), C^* represents the shadow total cost which is a function of shadow input prices and outputs. Using Sheppard's Lemma from equation (17), the actual demand for the i th input is given as

$$\frac{\delta C^*(w_i{}^*, y)}{\delta w_i{}^*} = x_i \tag{18}$$

The actual total cost and the shadow total cost function are depicted as follows:

$$C = \sum_i w_i x_i \tag{19}$$

$$C^* = \sum_i w_i^* x_i \tag{20}$$

The following equations represent the actual cost share and shadow cost share for *ith* input respectively.

$$M_i = \frac{w_i x_i}{C} \tag{21}$$

[63] The symbol g_i is also known as price distortion index. This parameter estimate is derived by using non-linear in parameter estimation procedure and is not part of the error term.

$$M_i^* = \frac{w_i^* x_i}{C^*} \tag{22}$$

The shadow price cannot be observed from the data set therefore in order to estimate it, the equations used need to have observable values. From equation (22), the actual demand for the ith input is

$$\frac{M_i^* C^*}{w_i^*} = x_i \tag{23}$$

Inserting it into equation (19) and using the additive version for shadow price, the equation will become

$$C = \sum_i w_i \frac{M_i^* C^*}{(w_i^*)} = C^* \sum_i M_i^* \frac{w_i}{(w_i^*)} \tag{24}$$

In logarithmic term this equation will become

$$\ln C = \ln C^* + \ln \sum_i M_i^* \frac{w_i}{(w_i + g_i)} \tag{25}$$

In equation (25) the difference between the actual cost and the shadow cost is depicted by be the second term on the right hand side. This term signifies the bias that exists in cost shares of each input weighted by the ratio between the actual and the shadow respective input prices. It also represents the misallocation in the inputs in giving minimum cost to the railroad carriers. The actual cost function is equivalent to the shadow cost function if $g_i = g_j = 0$ for input $i \neq j$, which suggests cost minimization. It should be noted that the first term of the right hand side of equation (25) is unobservable, hence some mathematical manipulations are used order to estimate this equation. For simplicity, assuming multiple inputs and only one output, the $\ln C^*$ can be re-specify as follows

$$\ln C^* = \alpha_0 + \alpha_y \ln y + \frac{1}{2}\beta_{yy}(\ln y)^2 + \sum_i \beta_{iy} \ln y \ln(g_i + w_i) + \sum_i \alpha_i \ln(g_i + w_i)$$

$$+ \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln(g_i + w_i) \ln(g_j + w_j) \tag{26}$$

By taking differentiation of equation (26) with respect to shadow input prices, the shadow cost share equation can be shown as the following

$$M_i^* = \frac{\delta \ln C^*}{\delta \ln(g_i+w_i)} = \alpha_i + \beta_{iy} \ln y + \sum_j \beta_{ij} \ln(g_j + w_j) \tag{27}$$

In order to get the estimable actual cost share equation, equation (23), (24) and (27) are substituted into equation (21) which gives the following equation:

$$M_i = \frac{w_i\left(\frac{M_i^* C^*}{w_i^*}\right)}{C^* \sum_i M_i^* \frac{w_i}{(w_i^*)}} = \frac{M_i^* \frac{w_i}{(w_i+g_i)}}{\sum_i M_i^* \frac{w_i}{(w_i+g_i)}} = \frac{\{\alpha_i+\beta_{iy}\ln y+\sum_j \beta_{ij}\ln(g_j+w_j)\}\frac{w_i}{(w_i+g_i)}}{\sum_i\{\alpha_i+\beta_{iy}\ln y+\sum_j \beta_{ij}\ln(g_j+w_j)\}\frac{w_i}{(w_i+g_i)}} = \frac{x_i w_i}{C} \tag{28}$$

Finally, equation (11) and (12) are then substituted into equation (10) to derive to the following estimable actual total cost equation.

$$\ln C = \alpha_0 + \alpha_y \ln y + \frac{1}{2}\beta_{yy}(\ln y)^2 + \sum_i \beta_{iy} \ln y \ln(g_i + w_i) + \sum_i \alpha_i \ln(g_i + w_i)$$

$$+\frac{1}{2}\sum_i \sum_j \beta_{ij} \ln(g_i + w_i)(g_j + w_j) + \ln \sum_i\{\alpha_i + \beta_{iy} \ln y + \sum_j \beta_{ij} \ln(g_j + w_j)\} \frac{w_i}{(g_i+w_i)}$$

(29)

In order to create a benchmark for the comparison, one of the parameters for factor proportionality is selected to normalize all of the factor input price distortion measures. For this additive version, the railroad carriers' uses efficient mix of input if the estimated factor for proportionality is found to be not statistically significant from zero. Suppose g_i is found statistically significant from zero. Any values above zero will suggest that there exist underinvestment of input x_i relative to input x_j and any values below zero will suggest that there exist overinvestment of input x_i relative to input x_j.

However, the estimated g_i value does not tell the magnitude of the distortion. An idea, whether the magnitude of under or over investment of input x_i relative to input x_j for the same shadow price, can be drawn from the value of elasticity of substitution between the two factor inputs. For the case of restrictive work-rules in the railroad industry, computing the value of this elasticity provides important information on the choice of non-labor inputs that is most likely to be made in substitution for labor. Comparing between Figure-2 and Figure-3, the market distortion in Figure-3 is larger than in Figure-2. Therefore, the higher the elasticity of substitution may imply greater the market distortion for the same shadow price. The own and cross price elasticity are calculated and shown by the following equations respectively:

$$\varepsilon_{ii} = \frac{\partial x_i}{\partial w_i}\left(\frac{w_i}{x_i}\right) \tag{30}$$

$$\varepsilon_{ij} = \frac{\partial x_i}{\partial w_j}\left(\frac{w_j}{x_i}\right) \tag{31}$$

Using Shephard's Lemma, $x_i = \frac{\partial C}{\partial w_i}$, the own and cross price elasticity becomes

$$\varepsilon_{ii} = \frac{\partial(\partial C/\partial w_i)}{\partial w_i}\left(\frac{w_i}{x_i}\right) = \frac{\partial^2 C}{\partial {w_i}^2}\left(\frac{w_i}{x_i}\right) \qquad for\ all\ i \tag{32}$$

$$\varepsilon_{ij} = \frac{\partial(\partial C/\partial w_i)}{\partial w_j}\left(\frac{w_j}{x_i}\right) = \frac{\partial^2 C}{\partial w_i \partial w_j}\left(\frac{w_j}{x_i}\right) \qquad for\ all\ i\ \neq j \tag{33}$$

For the translog cost function, α_{ii} and α_{ij} are represented by the following equations

$$\alpha_{ii} = \frac{w_i w_i}{C}\frac{\partial^2 C}{\partial {w_i}^2} - S_i^2 + S_i \tag{34}$$

$$\alpha_{ij} = \frac{w_i w_j}{C}\frac{\partial^2 C}{\partial w_i \partial w_j} - S_i S_j \tag{35}$$

Now, the second order derivatives of the cost function with respect to price becomes

$$\frac{\partial^2 C}{\partial {w_i}^2} = (\alpha_{ii} + S_i^2 - S_i)\frac{C}{w_i^2} \tag{36}$$

$$\frac{\partial^2 C}{\partial w_i \partial w_j} = \left(\alpha_{ij} + S_i S_j\right)\frac{C}{w_i w_j} \tag{37}$$

Therefore the own price elasticity is depicted in following equation:

$$\varepsilon_{ii} = (\alpha_{ii} + S_i^2 - S_i)\frac{C}{w_i^2}\left(\frac{w_i}{x_i}\right) = (\alpha_{ii} + S_i^2 - S_i)\frac{1}{S_i} \tag{38}$$

$$\varepsilon_{ii} = \frac{\alpha_{ii}}{S_i} + S_i - 1 \qquad for\ all\ i \tag{39}$$

The following equations further show the derivation for the cross price elasticity:

$$\varepsilon_{ij} = \left(\alpha_{ij} + S_i S_j\right)\frac{C}{w_i w_j}\left(\frac{w_j}{x_i}\right) \tag{40}$$

$$\varepsilon_{ij} = \left(\alpha_{ij} + S_i S_j\right)\frac{1}{S_i} \tag{41}$$

$$\varepsilon_{ij} = \frac{\alpha_{ij}}{S_i} + S_j \qquad for\ all\ i\ \neq j \tag{42}$$

Besides own and cross price elasticity, three other elasticity which can be examined from the estimated cost function are Allen-Uzawa partial elasticity of substitution (AES), Miroshima elasticity of substitution (MES) and McFadden shadow elasticity of substitution (SES). The Allen-Uzawa partial elasticity of substitution is derived from the following equations

$$AES_{ij} = \frac{C}{x_i x_j}\left(\frac{\partial x_i}{\partial w_j}\right) \tag{43}$$

$$AES_{ij} = \frac{C}{x_i x_j}\frac{\partial^2 C}{\partial w_i \partial w_j} = \frac{C}{x_i x_j}\left(\alpha_{ij} + S_i S_j\right)\frac{C}{w_i w_j} \tag{44}$$

$$AES_{ij} = \frac{\alpha_{ij}}{S_i S_j} + 1 = \frac{\varepsilon_{ij}}{S_j} \qquad for\ all\ i\ \neq j \tag{45}$$

The Morishima elasticity of substitution is a two factor, one-price elasticity of substitution. It categorizes a pair of inputs as direct substitutes (complements). Following Blackorby and Russell (1989), the MES formula is expressed as follows:

$$MES_{ij} = \varepsilon_{ji} - \varepsilon_{ii} = AES_{ji}S_i - AES_{ii}S_i = S_i\left(AES_{ji} - AES_{ii}\right) \tag{46}$$

$$MES_{ji} = \varepsilon_{ij} - \varepsilon_{jj} = AES_{ij}S_j - AES_{jj}S_j = S_j\left(AES_{ij} - AES_{jj}\right) \tag{47}$$

The inequality $MES_{ij} > 0$ suggests input j is a Morishima substitute for input i. An increase in j^{th} price will lead to an increase in the i^{th} quantity relative to j^{th} quantity. Whilst, $MES_{ij} < 0$ suggests input j is a Morishima compliment for input i. For example, if price of one input increases, the quantity of the other input increase relative to the quantity of the input whose price has changed. This suggests that MES favors substitutability compared to AES. If two inputs are classified as direct substitutes by AES, they are direct substitutes by MES also. Nonetheless, if two inputs are classified as direct compliments by AES, they may or may not be direct compliments by MES. Sharma (2002, pp. 131) mentioned MES is preferable because it clearly represents 'the adjustment of factor combinations in response to relative price changes.' A more flexible measurement of elasticity is the McFadden's shadow elasticity of substitution (SES). It is a two factor, two-price elasticity of substitution compared to one-price elasticity in AES and MES. SES represents a weighted average of MES that depicts a change in input ratio with respect to a change in a pair of input prices.

$$SES_{ij} = \frac{S_i}{S_i+S_j} MES_{ij} + \frac{S_j}{S_i+S_j} MES_{ji} \quad (48)$$

2.5 Cost Results

The estimated translog cost function met almost all the regularity conditions. If not, the percentage of observations that satisfies the condition is very high. Around 85.5 percent of the observations satisfy the condition for concavity in input prices[64].

[64] Concavity in input prices is met when the sign of the principal minor is alternating in sign starting with negative value. For translog specification, concavity is data dependent. Each observation is tested to know whether it exhibits local concavity in input prices rather than globally concave. The derivation to obtain the elements of the Hessian matrix is shown in Appendix C.

Table-9: Monotonicity condition

Monotonicity in output	Percentage satisfied
$\partial C/\partial y_U > 0$	96 percent of observations
$\partial C/\partial y_W > 0$	82 percent of observations
$\partial C/\partial y_T > 0$	93 percent of observations
Monotonicity in input prices	
$\partial C/\partial w_L > 0$	100 percent of observations
$\partial C/\partial w_E > 0$	100 percent of observations
$\partial C/\partial w_F > 0$	99.6 percent of observations
$\partial C/\partial w_M > 0$	100 percent of observations
$\partial C/\partial w_{WS} > 0$	100 percent of observations

Table-10 presents the parameter estimates from translog cost function. The coefficients in the left column represent the actual cost shares or the cost function estimated without shadow prices. The cost shares of labor, equipment, fuel, material and way and structures are 33.2%, 14.2%, 6.2%, 19.2% and 27.2% respectively. The values for the cost shares of factor inputs resembles with paper by Bitzan and Keeler (2003) where the share of labor, equipment, fuel, material and way and structures are found to be 34.86%, 14.61%, 6.57%, 18.6% and 25.36% respectively. The coefficients in the right column represent the shadow input cost shares. The shadow cost shares of labor, equipment, fuel, material and way and structures are 31.7%, 11.7%, 0.2%, 26.5% and 29.8% respectively. All the shadow cost shares are lower than the actual cost share except for material and way and structures. The shadow cost share for fuel is obviously smaller than the actual and it turns out to be statistically insignificant. The first order term for output consistently shows through train service as the largest shares of cost for both actual and shadow cost functions. The coefficient for time trend variable suggests technological advancements reduce total cost annually by 1.3%.

Table-10: Results of cost function

	Cost Function without Shadow Price			*Cost Function with Shadow Price*		
Variables	*Coefficient*	*s.e.*	*t-value*	*Coefficient*	*s.e.*	*t-value*
Intercept	15.88369***	0.121083	131.18	15.53136***	0.2051	75.74
w_L	0.332219***	0.008235	40.34	0.316937***	0.0284	11.16
w_E	0.141867***	0.006931	20.47	0.117228***	0.0164	7.16
w_F	0.062492***	0.015808	3.95	0.002652	0.0436	0.06
w_M	0.19176***	0.019363	9.9	0.265437***	0.0564	4.7
w_{ws}	0.271662***	0.007604	35.72	0.297746***	0.0268	11.12
y_u	0.021608	0.034249	0.63	0.061128	0.0455	1.34
y_w	0.021277	0.033108	0.64	0.03623	0.0492	0.74
y_t	0.410915***	0.068071	6.04	0.360781***	0.1062	3.4
a_{miles}	0.599511***	0.11064	5.42	0.466281***	0.1648	2.83
a_{speed}	-0.05144	0.124695	-0.41	-0.09982	0.1745	-0.57
a_{haul}	-0.08859	0.11417	-0.78	-0.15178	0.1594	-0.95
$a_{caboose}$	0.00395	0.004329	0.91	0.055662**	0.0225	2.47
T	-0.02819***	0.00594	-4.75	-0.01332	0.011	-1.21
$0.5(y_U)^2$	0.017508	0.011962	1.46	0.02573*	0.0151	1.71
$0.5(y_W)^2$	0.025872	0.023104	1.12	0.035444	0.0315	1.13
$0.5(y_T)^2$	0.405719***	0.069854	5.81	0.325095***	0.0959	3.39
$0.5(w_L)^2$	0.101467***	0.011438	8.87	0.071502***	0.0227	3.16
$0.5(w_E)^2$	0.021605***	0.004741	4.56	0.023075***	0.00738	3.13
$0.5(w_F)^2$	-0.00974	0.008529	-1.14	-0.0281**	0.0117	-2.4
$0.5(w_M)^2$	-0.02792	0.023423	-1.19	-0.08626**	0.0373	-2.31
$0.5(w_{WS})^2$	0.156698***	0.008327	18.82	0.184278***	0.0176	10.45
$0.5(a_{miles})^2$	0.144284	0.115552	1.25	0.248323	0.1826	1.36
$0.5(a_{speed})^2$	0.356505*	0.203614	1.75	0.331681	0.2885	1.15
$0.5(a_{haul})^2$	0.774069***	0.233704	3.31	0.66569**	0.2964	2.25
$0.5(a_{caboose})^2$	7.84E-07	8.65E-07	0.91	0.012527**	0.00592	2.12
$0.5(t)^2$	0.000455	0.000291	1.56	0.000383	0.000876	0.44
w_L*w_E	-0.02179***	0.004659	-4.68	-0.02223**	0.00892	-2.49

w_L*w_F	0.004	0.005044	0.79	-0.01408	0.00902	-1.56
w_L*w_M	-0.00256	0.012578	-0.2	0.037942	0.0247	1.53
w_L*w_{WS}	-0.08111***	0.006785	-11.95	-0.07313***	0.0112	-6.5
w_L*y_U	-0.00458**	0.00209	-2.19	-0.00416	0.00366	-1.14
w_L*y_W	-0.00505	0.003361	-1.5	-0.0111*	0.00611	-1.82
w_L*y_T	0.021262***	0.0064	3.32	0.023041*	0.0117	1.97
w_L*a_{miles}	0.004015	0.009089	0.44	0.005854	0.0178	0.33
w_L*a_{speed}	0.011017	0.00995	1.11	0.012981	0.0178	0.73
w_L*a_{haul}	-0.04281***	0.008477	-5.05	-0.04879***	0.0143	-3.42
$w_L*a_{caboose}$	2.09E-06**	9.91E-07	2.11	0.005442*	0.00298	1.83
w_L*t	-0.00277***	0.000536	-5.18	-0.0021*	0.00109	-1.92
w_E*w_F	0.007701*	0.004551	1.69	0.007783	0.00557	1.4
w_E*w_M	0.015968**	0.00803	1.99	0.022806*	0.0119	1.91
w_E*w_{WS}	-0.02348***	0.004246	-5.53	-0.03143***	0.00633	-4.97
w_E*y_U	0.005456***	0.001987	2.75	0.005707**	0.0022	2.59
w_E*y_W	0.009492***	0.00324	2.93	0.009953***	0.00378	2.63
w_E*y_T	0.012769**	0.00579	2.21	0.017236**	0.00721	2.39
w_E*a_{miles}	-0.03202***	0.008308	-3.85	-0.03768***	0.0106	-3.54
w_E*a_{speed}	0.003568	0.009554	0.37	0.005396	0.0111	0.49
w_E*a_{haul}	-0.02442***	0.008221	-2.97	-0.02243**	0.00902	-2.49
$w_E*a_{caboose}$	1.14E-06	9.42E-07	1.21	0.004082**	0.00183	2.24
w_E*t	-0.00189***	0.000419	-4.51	-0.00033	0.000671	-0.49
w_F*w_M	0.032329***	0.011354	2.85	0.069814***	0.0152	4.59
w_F*w_{WS}	-0.03429***	0.005023	-6.83	-0.03542***	0.00597	-5.93
w_F*y_U	0.005817	0.004678	1.24	0.002171	0.00541	0.4
w_F*y_W	-0.00055	0.007986	-0.07	-0.00745	0.0095	-0.78
w_F*y_T	-0.00699	0.012745	-0.55	0.014308	0.0163	0.88
w_F*a_{miles}	-0.00368	0.019455	-0.19	-0.01268	0.0248	-0.51
w_F*a_{speed}	-0.01883	0.02071	-0.91	-0.00564	0.0258	-0.22
w_F*a_{haul}	0.03661**	0.017417	2.1	0.014014	0.0209	0.67

$w_F*a_{caboose}$	-3.30E-06	2.44E-06	-1.35	0.007623	0.00463	1.65
w_F*t	0.00023	0.000938	0.24	0.002881	0.00175	1.65
w_M*w_{WS}	-0.01782*	0.009987	-1.78	-0.0443***	0.0166	-2.67
w_M*y_U	-0.0144**	0.005507	-2.61	-0.01149**	0.00598	-1.92
w_M*y_W	-0.0149	0.009293	-1.6	-0.00146	0.0103	-0.14
w_M*y_T	0.01505	0.015561	0.97	-0.00606	0.0192	-0.32
w_M*a_{miles}	0.005476	0.023192	0.24	0.009656	0.0286	0.34
w_M*a_{speed}	0.028979	0.025688	1.13	0.001574	0.0293	0.05
w_M*a_{haul}	0.000982	0.021406	0.05	0.032981	0.0237	1.39
$w_M*a_{caboose}$	4.20E-07	2.81E-06	0.15	-0.01169**	0.00503	-2.32
w_M*t	0.003085**	0.001192	2.59	-0.00016	0.00189	-0.09
$w_{WS}*y_U$	0.0077***	0.002115	3.64	0.007774***	0.00227	3.42
$w_{WS}*y_W$	0.011009***	0.003434	3.21	0.01006**	0.00397	2.54
$w_{WS}*y_T$	-0.04209***	0.006903	-6.1	-0.04852***	0.00788	-6.16
$w_{WS}*a_{miles}$	0.026211***	0.009599	2.73	0.034847***	0.0117	2.97
$w_{WS}*a_{speed}$	-0.02474**	0.010068	-2.46	-0.01431	0.0112	-1.27
$w_{WS}*a_{haul}$	0.029632***	0.008562	3.46	0.024225***	0.00926	2.62
$w_{WS}*a_{caboose}$	-3.53E-07	1.00E-06	-0.35	-0.00546***	0.00188	-2.91
$w_{WS}*t$	0.001346***	0.000461	2.92	-0.00029	0.000729	-0.4
y_U*y_W	-0.01806	0.011705	-1.54	-0.00886	0.015	-0.59
y_U*y_T	-0.10382***	0.025561	-4.06	-0.06917**	0.0347	-1.99
y_U*a_{miles}	0.081328**	0.035357	2.3	0.009608	0.0482	0.2
y_U*a_{speed}	0.041548	0.037333	1.11	0.049674	0.0546	0.91
y_U*a_{haul}	0.063843*	0.032744	1.95	0.037896	0.042	0.9
$y_U*a_{caboose}$	-8.83E-06	0.000012	-0.75	0.002011	0.00833	0.24
y_U*t	0.005097***	0.001805	2.82	0.003448	0.00359	0.96
y_W*y_T	-0.03031	0.023499	-1.29	-0.05763*	0.0333	-1.73
y_W*a_{miles}	0.058338	0.044425	1.31	0.047546	0.0607	0.78
y_W*a_{speed}	-0.02817	0.040524	-0.7	-0.07505	0.0628	-1.19
y_W*a_{haul}	-0.06164	0.042601	-1.45	0.052439	0.0597	0.88

y_W*$a_{caboose}$	6.24E-06	5.43E-06	1.15	-0.0031	0.00884	-0.35
y_W*t	0.001061	0.001983	0.54	-0.00107	0.00437	-0.24
y_T*a_{miles}	-0.26305***	0.071801	-3.66	-0.26938***	0.1123	-2.4
y_T*a_{speed}	0.268759**	0.102769	2.62	0.19746	0.1467	1.35
y_T*a_{haul}	-0.24484***	0.127301	-1.92	-0.18536	0.1722	-1.08
y_T*$a_{caboose}$	0.000021	0.000014	1.49	0.045065**	0.019	2.37
y_T*t	-0.00919**	0.004073	-2.26	0.006988	0.0093	0.75
a_{miles}*a_{speed}	-0.19674	0.124143	-1.58	-0.07462	0.1892	-0.39
a_{miles}*a_{haul}	0.317286**	0.147259	2.15	0.096591	0.2111	0.46
a_{miles}*$a_{caboose}$	-9.14E-06	0.000015	-0.62	-0.05825**	0.0247	-2.36
a_{miles}*t	0.007011	0.006299	1.11	-0.00601	0.0139	-0.43
a_{speed}*a_{haul}	-0.59909***	0.187301	-3.2	-0.5527**	0.2622	-2.11
a_{speed}*$a_{caboose}$	-0.00002	0.000013	-1.55	0.005179	0.0248	0.21
a_{speeds}*t	0.001409	0.006531	0.22	0.006258	0.0112	0.56
a_{haul}*$a_{caboose}$	-0.00003	0.000032	-0.94	-0.02126	0.0304	-0.7
a_{haul}*t	-0.00013	0.006571	-0.02	-0.01082	0.0116	-0.94
$a_{caboose}$*t	-6.48E-07	1.26E-06	-0.52	0.000565	0.00204	0.28
g_2				0.149296	0.1157	1.29
g_3				-0.00002***	8.78E-07	-26.12
g_4				1.091199	0.9781	1.12
g_5				0.093678	0.0679	1.38

Note. g2 for equipment, g3 for fuel, g4 for material and g5 for way and structure. The notation *** means significant at 1% level, ** is significant at 5% level and * is significant at 10% level.

Table-11 presents the own-price and cross-price elasticity, Allen-Uzawa partial elasticity of substitution, Miroshima elasticity of substitution and McFadden's shadow elasticity of substitution. The results show negative own-price elasticity as expected. Demands for factor inputs are inelastic except for fuel. Fuel is found to be relatively elastic with respect to their own price. The sign of cross-price elasticity suggests that all pairs of factor inputs indicate substitutability between each other except one. The sign of E_{LW} is positive while the sign of E_{WL} is negative. An increase in the price of way and structure increases the demand for labor implying substitutes. On the other hand, an increase in the price of labor decreases the demand for way and structure suggesting compliments. Fuel and way and structures are found to be compliments between each other. The results from AES suggest equipment, fuel and material are substitutes with labor. Other factor inputs are also substitutes in Allen-Uzawa sense except for labor and fuel are suggest to be compliments to way and structures. The estimates of MES are all positive, implying Miroshima substitutes except for MES_{WF}. Generally, labor and equipment, labor and fuel, labor and material, labor and way and structures, equipment and fuel, equipment and material, equipment and way and structures, fuel and material, material and way and structures are Miroshima substitutes irrespective of which of the two prices increases. Some of the MES estimates have a larger value. The estimates for MES_{FL}, MES_{ML}, MES_{FE}, MES_{ME}, MES_{FM}, MES_{MF}, MES_{FW} and MES_{MW} are found to be larger than one. For example, the value of 1.17 for MES_{FL} represents the percentage change in fuel-labor ratio (F/L), when the relative price (w_L/w_F) changes. A value of greater than one suggests strong substitutability for fuel-labor. One may expect that if price of labor increase, the railroad carriers are highly likely to substitute labor with fuel. As discussed previously, diesel locomotives are proven to be labor saving. Diesel locomotives are more fuel efficient compares to steam locomotives and also promote faster train. Faster trains enable the freights to be transported for longer distance in shorter time. Hence, railroad carriers may be better off when investing more in fuel rather than labor. This confirms with the existing results that there is an over-utilization of fuel[65] relative to labor. Table-11 also provides the value for the symmetric McFadden's shadow elasticity of substitution that allows for the relative prices to change and holds cost constant. All values are positive as expected.

Table-11: Estimated elasticity

OWN PRICE	Average						
E_{LL}	-0.34758						
E_{EE}	-0.67746						
E_{FF}	-1.08897						
E_{MM}	-0.9032						
E_{WW}	-0.11023						
CROSS PRICE[66]	Average	AES	Average	MES[67]	Average	SES	Average
E_{LE}	0.039624	AES_{LE}	0.285134	MES_{LE}	0.4462633	SES_{LE}	0.5211549
E_{EL}	0.098734			MES_{EL}	0.7175421		
E_{LF}	0.087088	AES_{LF}	1.218333	MES_{LF}	0.722101	SES_{LF}	0.8091222
E_{FL}	0.374722			MES_{FL}	1.1742053		
E_{LM}	0.218324	AES_{LM}	0.959517	MES_{LM}	0.6436961	SES_{LM}	0.8505323
E_{ML}	0.296247			MES_{ML}	1.121521		
E_{LW}	0.002533	AES_{LW}	-0.0312	MES_{LW}	0.3384895	SES_{LW}	0.2424007
E_{WL}	-0.00906			MES_{WL}	0.1119124		
E_{EF}	0.14723	AES_{EF}	2.226762	MES_{EF}	0.9193537	SES_{EF}	1.0443121
E_{FE}	0.240822			MES_{FE}	1.2358169		
E_{EM}	0.380665	AES_{EM}	1.694411	MES_{EM}	0.8665868	SES_{EM}	1.1522909
E_{ME}	0.187874			MES_{ME}	1.2838617		

[65] It is important to note that the overutilization of fuel may be argued to change over time. A reasonable examination would be taking annual estimations of the cost function and comparing the value of the price distortion indexes for fuel. Unfortunately, the parameter estimates for factor of proportionality cannot be compared since they do not provide a value of distorting but rather the direction of distortion. In addition, the degrees of freedom fall dramatically when making annual estimations. Note that there are already 104 variables on the right hand side in the cost function.

[66] Negative value for cross price elasticity indicates compliments whereas positive values indicates substitutes.

[67]MES is asymmetric.

E_{EW}	0.051119	AES_{EW}	0.109427	MES_{EW}	0.699452	SES_{EW}	0.3310974
E_{WE}	0.021293			MES_{WE}	0.1623205		
E_{FM}	0.76013	AES_{FM}	3.553453	MES_{FM}	1.3114749	SES_{FM}	1.58165
E_{MF}	0.224194			MES_{MF}	1.6633266		
E_{FW}	-0.29239	AES_{FW}	-1.20392	MES_{FW}	1.0284091	SES_{FW}	0.0582443
E_{WF}	-0.06112			MES_{WF}	-0.1817462		
E_{MW}	0.194881	AES_{MW}	0.69161	MES_{MW}	1.0606356	SES_{MW}	0.6611666
E_{WM}	0.157439			MES_{WM}	0.304974		

Note. L represents labor, E represents equipment, F represents fuel, M represents material and W represents way and structures

Table-10 provides further results for the allocation efficiency testing. Cost results for railroad carriers are interpreted as suggesting railroad carriers using an efficient mix of factor inputs if the estimated factor of proportionality is statistically insignificant from zero. Indeed, cost findings presented in Table-10 suggest that the railroad industry uses an allocatively efficient combination of labor and all non-labor inputs except for fuel. Since the benchmark factor of proportionality is labor, the negative value for fuel indicates the shadow price of fuel relative to its market price is low compared to labor. The restrictive work-rules faced by the railroad carriers induce them to find an alternative factor inputs that contributes better productivity. The lower shadow price of fuel relative to its market price coupled with strong substitutability (E_{FL} = 0.374722, MES_{FL} = 1.17 and AES_{LF} =1.218333) for fuel-labor causes an overutilization of fuel relative to labor. As mentioned previously, the shadow cost share for fuel is smaller than the actual share but is statistically insignificant. It is interesting to note that the shadow cost share for labor and equipment are also smaller and statistically significant. These results may seem to suggest that railroad carriers acknowledge that the actual price of fuel, labor and equipment are low relative to their market price compared to material and way and structures. However, with restrictive work-rules, the productivity realized from utilizing fuel is better off compared to productivity realized from employing labor. As a consequence, the railroad carriers over-utilized fuel resulting allocative inefficiency in the combination of fuel and labor.

2.6 Discussion and Concluding Remarks

This study examines the issue of allocative efficiency in the railroad industry between labor and non-labor inputs. I argue that the possibility of improvement in efficient allocation of input mix seems to be reasonable given easing of work-rules negotiated by the railroad carriers. The rigid work-rules were actually intended to facilitate more effective rail operation in the earlier years of rail service in the US (David and Wilson 2003 and Cappelli 1985). However, this study shows the imposition of standard crew sizes, and standard work day as stipulated by negotiated work-rules actually limits carriers' ability to employ and efficient combination of factor inputs. This study also notes that even though work-rules are more flexible after deregulation, they still remain as constraints for the railroad carriers to minimize cost. Hence, it is possible for some inefficiency to persist even with these less restrictive work-rules.

In examining the allocative efficiency of factor inputs in the class-1 railroad industry, cost findings suggest that three out of four non-labor inputs are found to be used allocatively efficiently with labor. Specifically, the factor input combination between labor and equipment, between labor and material and between labor and way and structure are found to be efficient. Such findings are consistent with the view that less rigidity in work-rules enable rail carriers greater ease achieving efficient allocation of labor with those inputs. In contrast, pre-deregulation findings by Kumbhakar (1988) that examine the allocative efficiency for Class-1 railroad for the sample years between 1951 and 1975 find that most railroad companies used an allocatively inefficient mix of capital relative to labor. In addition to the mentioned scenario, this study's findings suggest an inefficient allocation of labor relative to fuel. This study's findings also suggest that labor and fuel are close substitutes. A possible explanation for the labor-fuel allocative inefficiency results is this input market outcome arises due in part to railroad carriers investing more in fuel efficient locomotives. Compared to less efficient locomotives used in the past, these locomotives travel greater distances for every gallon of gas consumed. This implies that per gallon marginal productivity of fuel has increased over time. Therefore, if work-rules still contribute to actual wages differing from shadow wages then the high opportunity cost associated with employing labor relative to consuming fuel creates an incentive for carriers to over-invest in fuel, especially given this study's finding that these two inputs are reasonable substitutes. Furthermore, the potential for continued over-investment in fuel relative to labor is likely, given the industry's long-term trend of investing in fuel efficient locomotives. For instance, as mentioned by the EPA, since 1980 railroads have increased fuel efficiency by 94 percent. In the future railroad carriers need to comply to the new standards, which are Tier 3 and tier 4 from EPA adopted in 2008. Tier 3 indicates that there is 69% reduction in particulate matter PM and 58% reduction in nitrogen oxide (NOx) from uncontrolled level which take effect in 2012. Tier 4 means there is 90% reduction in PM and NOx from uncontrolled levels which will take effect in 2015. In order to comply with this new standard, railroad carriers likely continue developing and investing in new technologies, which could further exacerbate the inefficient allocation of labor and fuel. However, continued movement toward greater work-rule flexibility could contribute to a business environment promoting a more efficient allocation of labor relative to fuel. Indeed, findings from this study show an efficient allocation of labor and non-fuel inputs for the sample observation period of relatively flexible work-rules.

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Appendix C: Derivation of elements in Hessian matrix for translog cost function

For the translog function : $\frac{\partial lnc}{\partial lnw_i \partial lnw_j} = \frac{\partial(\partial lnc/\partial w_j)}{\partial lnw_i} = \gamma_{ij}$

Need to derive $\frac{\partial^2 c}{\partial w_i \partial w_j}$ from parameters of the translog cost function.

1) $\frac{\partial lnc}{\partial lnw_j} = \frac{\partial c}{c}\frac{w_j}{\partial w_j} = \frac{\partial c}{\partial w_j}\frac{w_j}{c}$

2) $\gamma_{ij} = \frac{\partial^2 lnc}{\partial lnw_i \partial lnw_j} = \frac{\partial\left(\frac{\partial c}{\partial w_j}\frac{w_j}{c}\right)}{\partial lnw_i} = \frac{\partial\left(\frac{\partial c}{\partial w_j}\frac{w_j}{c}\right)}{\frac{\partial w_i}{w_i}} = w_i \frac{\partial\left(\frac{\partial c}{\partial w_j}\frac{w_j}{c}\right)}{\partial w_i} = w_i \left[\left\{\frac{\partial^2 c}{\partial w_i \partial w_j}\frac{w_j}{c}\right\} + \left\{\frac{\partial c}{\partial w_j} w_j (-c^{-2}) \frac{\partial c}{\partial w_i}\right\}\right]$

3) $\gamma_{ij} = w_i \left[\left\{\frac{\partial^2 c}{\partial w_i \partial w_j}\frac{w_j}{c}\right\} - \left\{\frac{\partial c}{\partial w_j}\frac{w_j}{c^2}\frac{\partial c}{\partial w_i}\right\}\right]$; by Sheppard Lemma $x_i = \frac{\partial c}{\partial w_i}$, $x_j = \frac{\partial c}{\partial w_j}$

4) $\gamma_{ij} = w_i \left[\left\{\frac{\partial^2 c}{\partial w_i \partial w_j}\frac{w_j}{c}\right\} - \left\{x_i x_j \frac{w_j}{c^2}\right\}\right]$

5) $\gamma_{ij} = \frac{w_i w_j}{c}\frac{\partial^2 c}{\partial w_i \partial w_j} - \frac{w_i x_i}{c}\frac{w_j x_j}{c}$

6) $\gamma_{ij} = \frac{w_i w_j}{c}\frac{\partial^2 c}{\partial w_i \partial w_j} - S_i S_j$

- $\frac{\partial^2 c}{\partial w_i \partial w_j} = \left(\widehat{\gamma_{ij}} + S_i S_j\right)\frac{c}{w_i w_j}$

Need to derive $\frac{\partial^2 c}{\partial w_i \partial w_i} = \frac{\partial^2 c}{\partial w_i^2}$ from parameters of the translog cost function

7) $\frac{\partial lnc}{\partial lnw_i} = \frac{\partial c}{c}\frac{w_i}{\partial w_i} = \frac{\partial c}{\partial w_i}\frac{w_i}{c}$

8) $\gamma_{ii} = \frac{\partial^2 lnc}{\partial^2 lnw_i} = \frac{\partial\left(\frac{\partial c}{\partial w_i}\frac{w_i}{c}\right)}{\partial lnw_i} = \frac{\partial\left(\frac{\partial c}{\partial w_i}\frac{w_i}{c}\right)}{\frac{\partial w_i}{w_i}} = w_i \frac{\partial\left(\frac{\partial c}{\partial w_i}\frac{w_i}{c}\right)}{\partial w_i} = w_i \left[\left\{\frac{\partial^2 c}{\partial w_i^2}\frac{w_i}{c}\right\} + \left\{\frac{\partial c}{\partial w_i}\left(w_i(-c^{-2})\frac{\partial c}{\partial w_i} + \frac{\partial w_i}{\partial w_i}\frac{1}{c}\right)\right\}\right]$

9) $\gamma_{ii} = w_i \left[\left\{\frac{\partial^2 c}{\partial w_i^2}\frac{w_i}{c}\right\} - \left\{\frac{\partial^2 c}{\partial w_i^2}\frac{w_i}{c^2} + \frac{\partial c}{\partial w_i}\frac{1}{c}\right\}\right]$; by Sheppard Lemma $x_i = \frac{\partial c}{\partial w_i}$

10) $\gamma_{ii} = w_i \left[\left\{\frac{\partial^2 c}{\partial w_i^2}\frac{w_i}{c}\right\} - \left\{x_i x_i \frac{w_i}{c^2} + x_i \frac{1}{c}\right\}\right]$

11) $\gamma_{ii} = \frac{w_i w_i}{c}\frac{\partial^2 c}{\partial w_i^2} - \frac{w_i x_i}{c}\frac{w_i x_i}{c} + \frac{w_i x_i}{c}$

12) $\gamma_{ii} = \frac{w_i w_i}{c} \frac{\partial^2 c}{\partial w_i^2} - S_i S_i + S_i = \frac{w_i^2}{c} \frac{\partial^2 c}{\partial w_i^2} - S_i^2 + S_i$

- $\frac{\partial^2 c}{\partial w_i^2} = (\widehat{\gamma_{\iota\iota}} + S_i^2 - S_i) \frac{c}{w_i^2}$

ESSAY 3: INPUT PRICE EFFECT ON PRODUCTIVITY GAINS IN THE UNITED STATES RAILROAD INDUSTRY

3.1 Introduction

A substantial amount of research examines railroad productivity growth following passage of the Staggers Rail Act of 1980 (See for instance, Berndt et al. (1993), Bereskin (1996), Wilson (1997), Martland (1997, 2010), Bitzan and Keeler 2003, Shi et al. (2011) and Bitzan and Peoples (2014)). Most of the findings from past research suggest that following regulatory reform the railroad industry experienced improvement in productivity (Vellturo et al. (1992), Bereskin (1996) and Bitzan and Keeler (2003)). In this more competitive post deregulation environment understanding factors contributing to enhanced productivity is important, in part to identify sources of cost-savings as well as identifying factors contributing to enhanced costs. Past research by Bitzan and Peoples (2014) examines the influence of changes in density, firm size, movement characteristics and technical change on the Class-1 railroad productivity growth. Density and technical change are found to be the main contributors for the changes in the productivity growth. The density factor contributes to a 47 percent reduction in average cost for the 1983 to 2008 observation period and technical change contributes to an almost 56 percent reduction in average cost for the 1983 to 2008 observation period. While these findings provide new information on the determinants of productivity changes in the railroad industry, the effect of factor input price are not directly tested in their research. However, the examination of input price effects is significant when decomposing the factors influencing productivity growth, in part, because of their direct effect on the ray of average cost. Standard economic theory suggests decreases in input prices lowers the ray of average cost and, increases in input prices raises the ray of average cost (Wilson and Zhou, 1997). The dramatic change in collective bargaining settlements following regulatory reform and the volatility of fuel prices underscore the importance of examining input price effects when examining determinants of productivity growth.

Factor input prices that are commonly examined in most research on railroad costs are the price of labor, price of equipment, price of fuel, price of material and price of way and structure. Past research of productivity growth in the US railroad industry estimates a cost function using a translog specification to obtain information on factor input prices. When using this estimation approach factor price coefficients represent the factor input share of total cost. Recent research by Bitzan and Keeler (2003) that uses this approach find that labor accounts for 34.86 percent of total cost, followed by ways and structure at 25.36 percent, materials at 18.6 percent, equipment at 14.62 percent and fuel at 6.57 percent[68]. This findings comports well with the results from essay-2 of this dissertation where I find labor's share of total cost is 33.22 percent, followed by way and structure at 27.17 percent, materials at 19.18 percent, equipment at 14.19 percent and fuel at 6.25 percent. These results provide some insight on the importance of input price changes as determinants of productivity in the railroad industry, when noting that changes in average costs depict changes in productivity. Evidence of non-trivial changes in input prices in the railroad industry reported by Waters and William (2007) suggest the importance of examining the productivity effect of input price changes in this industry. Therefore, at issue is whether changes in input prices significantly affect costs. *A priori*, it is not obvious that cost would change appreciably with changes in input costs. For instance, increase in fuel prices might not

[68] The cost function specification for essay-2 follows Bitzan and Keeler (2003), however, it is estimated using information from a population sample that includes more years of information. Essay-2 covers the period between 1983–2008 whereas Bitzan and Keeler's (2003) sample population covers years 1983 – 1997.

contribute significantly to higher total cost due to the introduction of fuel efficient locomotives which lowers fuel consumption, all else equal.

Incorporating the empirical approach used by Wilson and Zhou (1997) to decompose productivity effects in telecommunications, this essay isolates the effect of changes in factor price, scale, and investment in technology on productivity growth in the US railroad industry. Past research by Bitzan and Peoples (2014) is the only other study to decompose productivity effects for this industry. However, they use the empirical approach developed by Gollop and Roberts (1981), which differs slightly from the approach used in this study. Their approach does not allow for analysis of the productivity effect of input prices. This study's approach does allow for analysis of factor input price effect on productivity gains and therefore, contributes to existing railroad literature by focusing on the significance of input price effects on railroad productivity. The factor price effects consist of labor price, equipment price, fuel price, material price and way and structures price. The price effect for each input on the ray of average cost is directly examined. This study uses information derived from estimating the translog cost specification used by Bitzan and Peoples (2014) to examine railroad costs. The findings from the translog estimation (given in Appendix D) are used to calculate cost elasticities which is used to capture the price effect on productivity. Hence, I am able to compare decomposition results from this study with past results derived using a different technique developed by Gollop and Roberts (1981). Since Gollop and Roberts' (1981) approach does not allow for the isolation of price effects, using the approach used by Wilson and Zhou (1997) reveals distortions in productivity effects arising from confounding the effects of factor input prices.

This essay consists of six sections. The preceding section provides reviews on research that examine production gains in the railroad industry. This follows with section 3.3 that comprises the presentation of conceptual framework. Section 3.4 represents the empirical approach used and followed by section 3.5 which explains the results in examining the factors that affect productivity growth in the railroad industry. Last, Section 3.6 elaborates on the concluding remarks.

3.2 Literature Review

Passage of the Staggers act created a business environment that promotes productivity gains in the railroad industry. The growth in railroad productivity is a result, in part, of flexible regulatory rules such as the freedom to set rates and abandon unprofitable lines. Berndt et al. (1993) mentioned that these freedoms in rate setting, abandonment of profitable lines and mergers act as catalysts opening the door for the railroad carriers to reduce cost and increase revenue. They examine the contribution of deregulation and stepped-up merger activity to cost savings for the Class-1 railroads from 1974 to 1986. Their findings suggest that by 1986, 91 percent of the cost savings was attributable to deregulation and the 9 percent was attributable to mergers and acquisition. Another paper by Wilson (1997) examined empirically the effects of deregulation on costs and productivity growth in railroad industry. He finds that "pricing innovations" for factor inputs (p. 22) in the non-regulated period promotes cost savings. Examples of the pricing innovations mentioned are contract rates and multi-car rates. The direct and indirect effects of deregulation on cost are calculated as:

$$\left(\frac{C_P - C_R}{C_R}\right) * 100 \qquad (1)$$

where C_P depicts the cost under partially[69] deregulated setting and C_R depicts the cost under regulated setting. Wilson further examined the effect of deregulation on productivity gains adapting Caves et al. (1981) approach with the following productivity measures, PGX and PGY.

$$PGX = -\frac{\partial lnC}{\partial t} \tag{2}$$

$$PGY = -\frac{\partial lnC/\partial t}{\sum_i \partial lnC/\partial lnQ_i} \tag{3}$$

Caves et al. (1981, p.995) defined PGX as “the common rate at which all inputs can be decreased over time with outputs held fixed.” PGY is defined as “the common rate at which all outputs can grow over time with inputs held fixed”. The measurement for productivity used by Wilson (1997) is the yearly percentage change in costs which is calculated as follows:

$$\frac{\partial \ln C}{\partial t} \tag{4}$$

He suggested from the findings that deregulation has caused a “dramatic downward shift” (p.39) in cost function where by 1989, the cost reduction reached 44 percent. Productivity rose with an average of six to seven percent decrease in cost.

Another crucial aspect regarding railroad productivity gains is the components of the productivity growth. Decomposing productivity gains and analyzing the magnitude and significance for each source is important. Shi and Lim (2011) examine the decomposition of productivity growth of Class-1 railroad companies individually rather than using industry averages. The sources for changes in productivity are technical efficiency change, technical change and scale efficiency change. The data covers the period between 2002 and 2007. Sequential data envelopment analysis is used and Malmquist productivity indexes are calculated

[69] The Staggers Rail Act is considered as partially deregulation. All regulatory rules were not totally terminated for this industry.

using sequential frontiers[70]. The decomposition method distinguishes the cause for changes in productivity. Results suggest that CSX, NS and KCS seemed to be the least efficient railroad carriers. BNSF and UP productivity growth are found to be primarily determined by technological advancement. Technological advancement in CSX and NS are not evident.

Research by Bitzan and Peoples (2014) also identify the underlying sources of productivity gains and cost savings in the railroad industry. The main sources of productivity gains considered are scale/density, firm size, movement characteristics and technological changes. In contrast to Shi and Lin, their analysis is based on the estimation of a long-run cost function. They specify the cost function such that total cost is dependents on factor input prices (price of labor, price of fuel, price of equipment, price of materials and supplies and price of way and structures), revenue ton-miles (density), technological characteristics and time variable (technical change). The technological characteristics consist of route miles (firm size), average length of haul (movement characteristic), percent of tons originated, loss/damage expense per ton-mile and speed. A system of seemingly unrelated equations is estimated and the decomposition of productivity gains developed by Gollop and Roberts (1981) is attained by estimating the reduction in average costs while holding factor prices constant. The results suggest that over the 15 year observation period average cost savings is reduced by 47 percent due to density, reduced by 9 percent due to movement characteristics and reduced by almost 56 percent due to changes in technical changes. Average cost increased around 23 percent due to

[70] Data envelopment analysis (DEA) is a non-parametric estimation approach that examines technical efficiency. It does not rely on any production or cost function, therefore does not need to specify any functional form. A linear programming is conducted and sample data representing firms are observed whether it lies on a production frontier. Sample points that lie on the production frontier depict efficient firms (Oum et al., 1999). The Malmquist productivity index is a measurement of productivity change over time and is calculated based on distance functions.

increase in route miles. Overall for the observation years 1983 to 2008, the results suggest in total, around 90 percent of productivity growth is due to factors chosen in that study.

While the model of decomposing productivity growth in previous railroad studies does not consider input price effects directly, these studies do examine the contribution of input price effects on productivity growth by interpreting information gleaned from the interaction variables between time and input prices (Bitzan and Peoples, 2014). Their results from estimating a translog cost function showed a negative coefficient for time input price interaction labor and equipment and positive coefficient for time input price interaction for fuel, material and way and structures. These findings suggest that in the sample period, the unexplained technological advancement are labor saving, equipment saving, fuel using, material using, and way and structure using. For instance, over time an increase in labor price, or equipment price, or way and structure price increases the usage of technology that use less labor, or less equipment, or more way and structure. Evidence of such technology- factor input effects on costs is depicted by the elimination of caboose which is labor saving (Bitzan and Keeler, 2003), double-stack cars which is equipment saving (Schwarz-Miller and Talley, 2002) and improvement of tracks for higher capacity cars which are way and structure using (Schwarz-Miller and Talley, 2002). In other words, an increase in input price that creates an incentive for investing in input-saving technologies decreases cost whereas increases in input prices that lead to input-using technologies increases cost. Realizing the importance of input price effect as one of the sources affecting the changes in productivity gain, this essay adopts the approach by Wilson and Zhou (1997) that decomposes explicitly the price effects and the non-price effects when examining the telecommunication industry. This essay contributes to literature by applying Wilson and Zhou's approach to the railroad industry.

3.3 Theoretical Framework

In order to develop a framework for empirically testing the effects of changes of factor input prices on cost, I firstly consider the analysis for one output setting. The "economic environment" of an industry can be influenced by various factors such as technological advancement, market conditions, government regulations and also changes in the factor input prices (Freeman et al., 1987). An increase in factor input price can be initially thought as a cost past-through to customers, where any changes in factor input is transferred to customer in order to maintain the same profit margin. However, what only matters is the change in relative factor input prices. In the long run, changes in relative factor input prices stimulate changes in the "relative input utilization" (Freeman et al., 1987).

A change in an input price effects the firms in two ways; through the substitution effect and scale effect. The substitution effect measures the change in the combination of inputs used with output held constant whereas the scale effect measures the change in output produced with input price held constant. The following Figure-4 illustrates these two effects resulting from changes in an input price. Suppose there is an increase in price of labor from w_L to $w_{L'}$. The slope of isocost becomes flatter as the ratio on input prices changes from $-\frac{w_{NL}}{w_L}$ to $-\frac{w_{NL}}{w_{L'}}$. With substitution effect, the optimal point now moves from point A to A′. At point A′, there is a reduction in the usage of input (labor) that experiences a price increase (wage) and an increase in the usage of substitute input (non-labor). The magnitude of the substitution effect depends on the level of substitutability between the two inputs. If the isoquant is more linear, an increase in wage will result a greater reduction in the labor usage. In addition, moving from point from A to

A′ influences average cost by changing the expense paid to labor with higher price and also by changing the expense paid for the increase usage of non-labor inputs. However, the effect of a change in the price of labor is not purely substitution. Scale effects suggests that an increase in an input price will reduce the scale of operation. As wages increases from w_L to $w_{L'}$ the production cost and the output price will also increase. Less output will be demanded which then reduces the amount of production and therefore reduce the inputs usage. In Figure-4, the optimal point will again move from point $A' to\ A''$. At point A'' the firm experiences a reduction in output with lower labor usage and lower non-labor usage. At the new production level, the isocost curve shifts inwards. The shift magnitude may be influenced by the marginal productivity of the input that experiences the price change (labor). If marginal productivity increases with the increase in its price, average cost should not increase substantially. For example, paying labor a higher wage may promote greater productivity and eventually offset the effect of increase in wage.

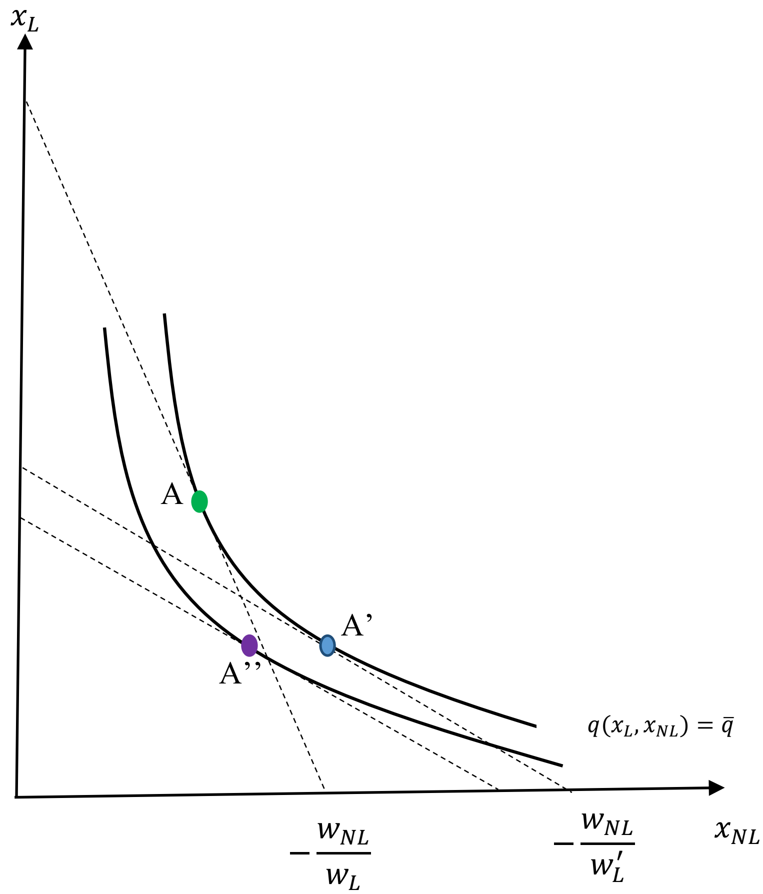

Figure-4: Substitution effect and scale effect

Freeman et al. (1987) highlight that the relationship between changes in factor prices and its cost share is not straight forward. Input substitution, "productivity-enhancing technological change" and combined changes in cost share of other inputs are the three elements that are considered when examining the relationship. Similar to declining average cost for single product, the concept of ray average cost can be used to analyze the effect of changes in factor prices in a multi-product setting. Baumol et al. (1988) define ray average cost[71] as:

$RAC = C(ty°)/t$

[71] Baumal et al. (1988) are referring to the average cost of the composite goods.

where RAC represents ray average cost, $y°$ represents the unit bundle for a specific mixture of outputs and t represents the number of units in the bundle $= ty°$. In other words, a bundle of outputs is chosen arbitrarily as a reference point where its quantity is assigned with the value of unity. From here, this reference point is used to measure the size of the composite commodity by a fixed proportion analysis. According to Baumol et al. (1988, p.49), the ray average cost is declining when "a small proportional change in output leads to a less than proportional change in total cost". The graphical presentation of the ray average cost is further illustrated in the following Figure-5. The ray average cost and total cost intersect at unit output level $y°$. The ray average cost is minimum at output level y^m. At this point, the total cost curve is tangent to ray OT in the hyper plane of ray OR. Ray OR depicts the composite commodity. The cost behavior for the ray average cost is "analytically equivalent" to the cost behavior in a single product setting (Baumol et al. 1988, p. 58). This is shown in Figure-5 where the ray average curve is U-shaped which represents the composite commodity.

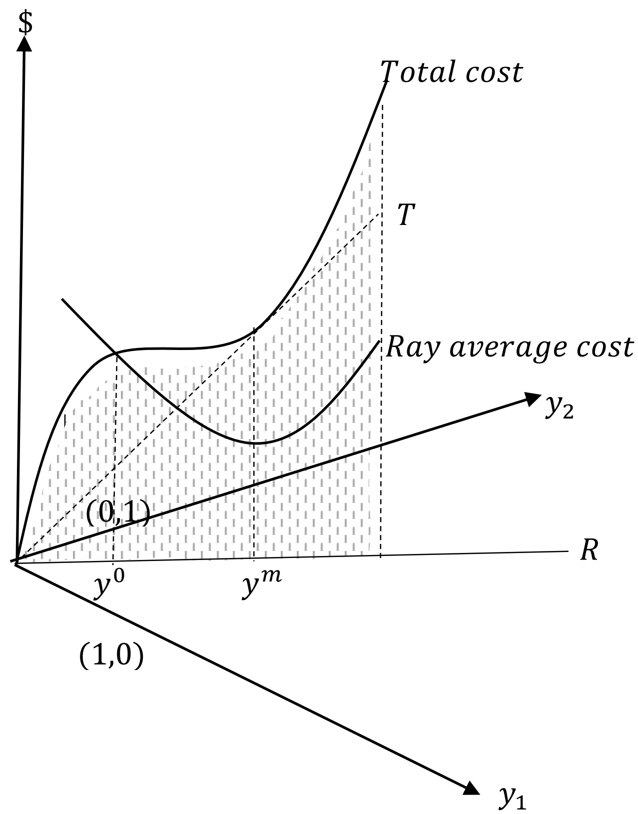

Figure-5: Ray average cost
Adapted from *Contestable Markets and the Theory of Industry Structure* (p.50), Baumol, W. J., Panzar, J. C., & Willig, R. D., 1988, New York, Harcourt, Brace Jovanovich, Inc.

Examining factors that contribute to a reduction in average cost over time is similar to examining the sources of productivity growth. A general construct for productivity measurement is the index number procedures. Oum et al. (1999) discussed the index number procedures and one of the categories is total factor productivity[72]. The total factor productivity index is defined as "the ratio of a total (aggregate) output quantity index to a total (aggregate) input quantity index" (pp. 16). Oum et al. (1999) further emphasizes the requirement to decompose total factor productivity index in several components. They argue that changes in "operating environments"

[72] The two other categories are partial factor productivities and data envelopment analysis method (Oum et al., 1999)

and scale economies may mislead any inferences made on productive efficiency. Two procedures are discussed by Oum et al. (1999) in decomposing total factor productivity. The first procedure is a formula derived by Denny et al. (1981) and the second procedure is by using regression techniques. In their paper, Denny et al. (1981) examine the sources of changes in the unit production costs for Bell Canada for the years 1952-1976. The cost function is differentiated with respect to time, and the expression of changes in the unit production cost is shown as the following:

$$\dot{C} - \dot{Q}^C = \sum_i \left(\frac{P_i X_i}{C}\right) \dot{P_i} + \left(\sum_j \varepsilon_{CQ_j} - 1\right) \dot{Q}^C + \dot{B} \qquad (5)$$

where X are inputs, Q are outputs, T are technical change indicators.

$$\dot{C} = \frac{1}{C}\frac{dC}{dt}; \qquad (6)$$

$$\dot{Q}^C = \sum_j \left(\frac{\varepsilon_{CQ_j}}{\sum \varepsilon_{CQ_j}}\right)\left(\frac{1}{Q_j}\frac{dQ_j}{dt}\right); \qquad (7)$$

$$\dot{P_i} = \frac{1}{P_i}\frac{dP_i}{dt}; \qquad (8)$$

$$\dot{B} = \sum_k \varepsilon_{CT_k}\left(\frac{1}{T_k}\frac{dT_k}{dt}\right); \qquad (9)$$

$\varepsilon_{CQ_j}$the cost elasticity with respect to Q_j

$\varepsilon_{CT_k}$the cost elasticity with respect to T_k

The left hand side of the equation depicts the change in the unit production costs. The first term in right hand side represents the effect of change in factor prices, the second term represents the scale effect and the third term represents the technical change effect. The task of decomposing productivity growth into various sources can be accomplished when using the translog specification when estimating cost. Past research on rail productivity using results derived from estimating the translog specification of the cost function presents mixed findings.

These finding may differ extensively due to estimation procedure, sample period and therefore comparisons among research may not be reliable (Oum et al., 1999). For example, Bitzan and Peoples (2014) find the total productivity gains is estimated at an average of 3.6 percent yearly for the period 1983-2008. Whereas Bereskin (1996) finds the average rate of productivity growth is 1.62 percent yearly for the period 1983-1993.

The objective of this essay is to provide some insight on the influence of input prices as one of the sources of productivity growth in railroad industry. Productivity growth is related to reduction in unit cost of production. In a multi-output setting, this is equivalent to examine the sources of reduction in the ray average cost. Earlier in this section, a change in the relative input price is shown to induce substitution effect and scale effect. In essence, the magnitude of the impact of input price change to average cost is influenced by the marginal productivity of the input. If the marginal productivity of the factor input increases as its price increases, the changes in average cost due to price changes may not be substantial. The most recent research on decomposition of productivity growth in the transportation industry is done by Bitzan and Peoples (2014). However in their paper, the decomposition of productivity growth does not include factor input price effects. Therefore, examining the sources of productivity growth in the railroad industry with explicit contribution of factor input price effect is a natural extension to previous work presented in railroad productivity literature. I follow the method used by Wilson and Zhou (1997) where input price effect is considered as one of components affecting the changes in ray average cost.

3.4 Empirical Approach and Data

This essay examines the decomposition of productivity gains in the railroad industry considering price effects as one of the factors. Other factors taken into account are scale and technical change. As discussed before, there are various approaches used to decompose the effects of determinants on productivity gains. Duality theory that links the production function and cost function is applied in this essay where a cost function is firstly estimated and later used in decomposing the productivity gains. Transcendental logarithmic (translog) is the specific functional form of cost function applied in this essay. The specification cost function is adapted from Bitzan and Keeler (2003) and shown in the following equation:

$$C = f(w_i, y_k, a_m, t) \tag{10}$$

$$w_i = (w_L, w_E, w_F, w_M, w_{WS}) \tag{11}$$

$$y_k = (y_U, y_W, y_T) \tag{12}$$

$$a_m = \left(a_{miles}, a_{speed}, a_{haul}, a_{caboose}\right) \tag{13}$$

where C is the total cost, w_L is the labor price, w_E is the equipment price, w_F is the fuel price, w_M is the material and supplies price, w_{WS} is the way and structures price, y_U is the adjusted unit train gross ton miles, y_W is the adjusted way train gross ton miles, y_T is the adjusted through train gross ton miles, a_{miles} is the miles of road, a_{speed} is the train miles per train hour, a_{haul} is the average length of haul, $a_{caboose}$ is the fraction of train miles operated with caboose[73] and t represent time trend capturing the technological change. The above cost function is then specified using second order Taylors approximation around the mean. The expansion is simplified by taking the natural logarithms on both sides of the equations and replacing partial derivative with parameters shown in the following equation:

$$lnC = \alpha_0 + + \sum_i \alpha_i ln\left(\frac{w_i}{w_i}\right) + \sum_k \beta_k ln\left(\frac{y_k}{y_k}\right) + \sum_m \sigma_m ln\left(\frac{a_m}{a_m}\right) + \theta t$$

[73] Bitzan and Keeler (2003) considered eliminating caboose as a technological innovation in post-deregulation period for two reasons. Automated and electronic safety and controls eradicate the role of caboose. Diesel locomotive replacing steam locomotives eliminates the need for firemen and therefore reduced crew size and caboose space.

$$+\frac{1}{2}\sum_i\sum_j \alpha_{ij} ln\left(\frac{w_i}{\overline{w_i}}\right) ln\left(\frac{w_j}{\overline{w_j}}\right) + \sum_i\sum_k \tau_{ik} ln\left(\frac{w_i}{\overline{w_i}}\right) ln\left(\frac{y_k}{\overline{y_k}}\right) + \sum_i\sum_m \vartheta_{im} ln\left(\frac{w_i}{\overline{w_i}}\right) ln\left(\frac{a_m}{\overline{a_m}}\right)$$

$$+\sum_i \partial_i ln\left(\frac{w_i}{\overline{w_i}}\right) t + \frac{1}{2}\sum_k\sum_l \beta_{kl} ln\left(\frac{y_k}{\overline{y_k}}\right) ln\left(\frac{y_l}{\overline{y_l}}\right) + \sum_k\sum_m \varphi_{km} ln\left(\frac{y_k}{\overline{y_k}}\right) ln\left(\frac{a_m}{\overline{a_m}}\right)$$

$$+\sum_k \pi_k \ln\left(\frac{y_k}{\overline{y_k}}\right) t + \frac{1}{2}\sum_m\sum_n \sigma_{mn} ln\left(\frac{a_m}{\overline{a_m}}\right) ln\left(\frac{a_n}{\overline{a_n}}\right) + \sum_m \mu_m ln\left(\frac{a_m}{\overline{a_m}}\right) t + \frac{1}{2}\gamma t^2 + \epsilon \quad (14)$$

By applying Shephard's Lemma, the input share equations are obtained shown in the following equation.

$$\frac{\partial lnC}{\partial lnw_i} = \alpha_i + \sum_j \alpha_{ij} lnw_j + \sum_k \tau_{ik} lny_k + \sum_m \vartheta_{im} lna_m + \gamma_i t + \epsilon \quad (15)$$

where $\alpha_L, \alpha_E, \alpha_F, \alpha_M and\ \alpha_{WS}$ represent labor's share of total cost, equipment's share of total cost, fuel's share of total cost, material's share of total cost and ways and structure's share of total cost respectively. In addition β_k depicts the effect of of economies of scale on the employment of factor inputs and ∂_i depicts the effect of unexplained technological change on the employment of factor inputs. This system of equations (the cost function and input share functions) is estimated within a seemingly unrelated system[74]. One of the input share equations is left out to avoid perfect collinearity. Linear homogeneity with respect to factor input prices is imposed where holding output constants, any proportional increase in all factor input prices raises the cost by the same proportion. The homogeneity and symmetry restrictions on the parameters require that $\sum_i \alpha_i = 1, \sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0$, $\sum_i \tau_{ik} = \sum_i \vartheta_{im} = \sum_i \gamma_i = 0, \alpha_{ij} = \alpha_{ji}$. The estimation of the system of equation, which gives the values of cost elasticity enables me to further adapt the approach by Wilson and Zhou (1997) in decomposing productivity gains.

[74] The variable caboose consists of zero values. Box-Cox transformations is applied to this variable where $y_i^{\omega} = \frac{y_i^{\omega}}{\omega}$ if $\omega \neq 0$ and $y_i^{\omega} = lny_i$ if $\omega = 0$. A very small value of ω (0.0001) is selected since it gives almost same results with log.

Assuming cost minimizing behavior, the cost function in equation (10) is differentiated with respect to time. Dividing both sides with total cost and applying Sheppard's Lemma, the rate of change in the minimum cost function is given in the following equation (Wilson and Zhou, 1997, pp. 294):

$$\dot{C} = \sum_{i=1}^{I} \frac{x_i w_i}{C} \dot{w_i} + \sum_{k=1}^{K} \frac{\partial f}{\partial y_k} \frac{y_k}{C} \dot{y_k} + \sum_{m=1}^{M} \frac{\partial f}{\partial a_m} \frac{a_m}{C} \dot{a_m} + \tau \qquad (16)$$

where

$$\dot{C} = \frac{1}{C} \frac{\partial C}{\partial t}$$

$$\dot{w_i} = \frac{1}{w_i} \frac{\partial w_i}{\partial t}$$

$$\dot{y_k} = \frac{1}{y_k} \frac{\partial y_k}{\partial t}$$

$$\dot{a_m} = \frac{1}{a_m} \frac{\partial a_m}{\partial t}$$

$$\tau = \frac{1}{C} \frac{\partial f}{\partial t}$$

The cost share of factor input i-th is given as

$$S_i = \frac{x_i w_i}{C} \qquad (17)$$

The cost elasticity with respect to output y_k is given as

$$\mu_{CY_k} = \frac{\partial f}{\partial y_k} \frac{y_k}{C} \qquad (18)$$

The cost elasticity with respect to technological characteristics is

$$\mu_{CA_M} = \frac{\partial f}{\partial a_m} \frac{a_m}{C} \qquad (19)$$

Therefore, equation (16) can be written as:

$$\dot{C} = \sum_{i=1}^{I} S_i \, \dot{w_i} + \sum_{k=1}^{K} \mu_{CY_K} \, \dot{y_k} + \sum_{m=1}^{M} \mu_{CA_M} \, \dot{a_m} + \tau \qquad (20)$$

Furthermore, the rate of change in the weighted product mix is represented as

$$\dot{y^C} = \frac{\sum_k \mu_{CY_k} \dot{y_k}}{\sum_k \mu_{CY_k}} \quad (21)$$

This equation then replaces the second term in equation (20) and therefore,

$$\dot{C} = \sum_{i=1}^{I} S_i \dot{w_i} + \sum_{k=1}^{K} \mu_{CY_K} \dot{y^C} + \sum_{m=1}^{M} \mu_{CA_M} \dot{a_m} + \tau \quad (22)$$

Subtracting equation (21) from both sides of equation (22), the rate of change in ray average cost ($\dot{C} - \dot{Y^C}$) is shown in the following equation

$$\dot{C} - \dot{y^C} = \sum_{i=1}^{I} S_i \dot{w_i} + \left(\sum_k \mu_{CY_k} - 1\right)\dot{Y^C} + \sum_{m=1}^{M} \mu_{CA_M} \dot{a_m} + \tau \quad (23)$$

where $\sum_{i=1}^{I} S_i \dot{w_i}$ represents factor price effects, $\left(\sum_k \mu_{CY_k} - 1\right)\dot{Y^C}$ represents scale effect, $\sum_{m=1}^{M} \mu_{CA_M} \dot{a_m}$ represents movement characteristics effects and τ represents the unexplained technological change. Wilson and Zhou (1997) mentioned that the factor price effect may be negative or positive depending on its effect on the ray average cost. The scale effect also may be negative or positive. The sign for coefficient estimates on movement characteristics may be negative or positive but the sign for the coefficient estimates on technological change is expected to be negative on the ray average cost.

The data used in this essay is gathered from Class-1 Annual Report (R1 reports) from 1983 to 2008. Three types of data are collected during the process and most of the data are re-entered manually due to its availability in micro fiche and pdf forms. The variable sources are taken from Bitzan and Keeler (2003) and the merger information from Dooley et al. (1991) is used in constructing the fixed effects. The descriptive statistics of data are summarized in Table-12. The findings suggest on average, the largest mean share of factor input cost is attributable to labor. Labor cost represents more than one-third of the factor input cost. The next largest is input expense from way and structure (27.8 percent), follows by material (22.7 percent) and equipment (11.28 percent). The smallest mean share of factor input cost is fuel which constitutes around 7 percent. Freeman et al. (1987) highlighted that changes in any cost share is not only attributable to its own price and quantity, but also other input prices and quantities. However, with nearly two-third of the input cost is attributable to labor and way and structure, any increase in these input prices could have non-trivial cost effects.

Table-12: Descriptive statistics for variables used in the analysis

Variables	Mean	Standard deviation
Adjusted unit train gross ton miles (in thousands)	38923011	72505151
Adjusted way train gross ton miles (in thousands)	4388682	4995210
Adjusted through train gross ton miles (in thousands)	70752648	91492490
Labor price per hour	34.195	8.104
Weighted average equipment price	43838.86	28286.15
Price per gallon	1.0619	0.44
AAR materials and supply index	176.4059	47.4997
Price of way and structures[75] (in thousands)	69.96603	31.84221
Miles of road or route miles	10869.67	9901.63
Train miles per train hour	25.9824	6.467284
Average length of haul[76]	465.5535	218.2851
Fraction of train miles with caboose	0.000353	0.000418
Labor share	0.3093	0.06495
Equipment share	0.1128	0.03446
Fuel share	0.0729	0.08201
Material share	0.2270	0.09992
Ways and structure share	0.2779	0.06881

[75] Price of way and structures is calculated by (ROIRD + ANNDEPRD) / MOT where ROIRD is the return of investment in road, ANNDEPRD is annual depreciation in road and MOT is miles of track

[76] Average length of haul is calculated by dividing revenue ton miles with revenue tons.

3.5 Presentation of Result

The results derived when estimating the cost equation are presented in the Appendix D, rather than presented in the text, since the emphasis of this study is the examination of productivity results derived from using the parameter estimates to compute the elements of productivity. Before presenting the productivity results, a brief interpretation of the results of the parameter estimates on the time-factor input price interactions is reported. These estimates are analyzed to specify whether unexplained technology change is input saving or input using. Findings of a negative estimated coefficient on the interaction terms between time and labor and between time and equipment suggest that technology is labor saving and equipment saving. Whereas the interaction term between time and fuel, between time and materials and between time and way and structures suggest technology is fuel using, materials using and way and structures using. Findings for the estimated coefficient on these interaction terms are consistent with findings from railroad cost research by Bitzan and Peoples (2014) and Bitzan and Keeler (2003). Table-13 and Figure-6 further reports the rate of change of the input price for the sample period. In the early years of this observation period the rate of change in the input price does not exhibit regular pattern. For the year 2000 onwards, most of the input prices show increasing trend except for the price of labor.

Table-13: Annual rate of change for factor input price

Year	Labor	Equipment	Fuel	Material	Way & structure
1983-1984	-0.00694	0.000338	-0.11128	-0.00515	0.097579
1984-1985	-0.01391	0.183298	-0.04033	0.038545	-0.08047
1985-1986	-0.00586	-0.13545	-0.36455	-0.0114	-0.08689
1986-1987	0.059382	0.019961	-0.06704	-0.05148	0.035742
1987-1988	0.040767	0.054636	-0.02771	0.044568	0.005421
1988-1989	-0.00229	0.093815	0.093809	0.055291	-0.01984
1989-1990	0.011942	-0.00599	0.18121	0.039987	0.088533

1990-1991	-0.02419	0.157129	-0.05312	0.138369	0.05022
1991-1992	-0.00404	0.009505	-0.08472	0.055334	0.010554
1992-1993	-0.0245	0.033542	0.002865	0.035676	0.0766
1993-1994	0.031052	0.155352	-0.06645	0.017413	0.125922
1994-1995	-0.00149	0.084085	-0.05361	0.033785	0.253525
1995-1996	0.341365	0.258941	0.11256	-0.00606	0.091615
1996-1997	-0.18045	-0.19989	-0.02438	0.016725	-0.1317
1997-1998	-0.07492	-0.06027	-0.22093	0.00933	-0.0714
1998-1999	0.025566	0.346894	0.050127	0.023206	0.054978
1999-2000	-0.02139	-0.12966	0.552941	0.008622	-0.00587
2000-2001	0.006883	0.033016	-0.05976	0.022784	-0.02569
2001-2002	0.017849	0.008705	-0.14479	-0.01813	0.007207
2002-2003	0.013432	-0.00163	0.172662	0.001408	0.013009
2003-2004	0.027013	0.067565	0.219808	0.069531	0.23569
2004-2005	-0.00444	0.084689	0.358394	0.097882	0.248533
2005-2006	-0.00212	-0.12654	0.215591	0.103925	-0.13831
2006-2007	-0.04822	0.1932	0.068549	0.075579	0.165678
2007-2008	-0.0209	0.014507	0.420555	0.093915	0.067314

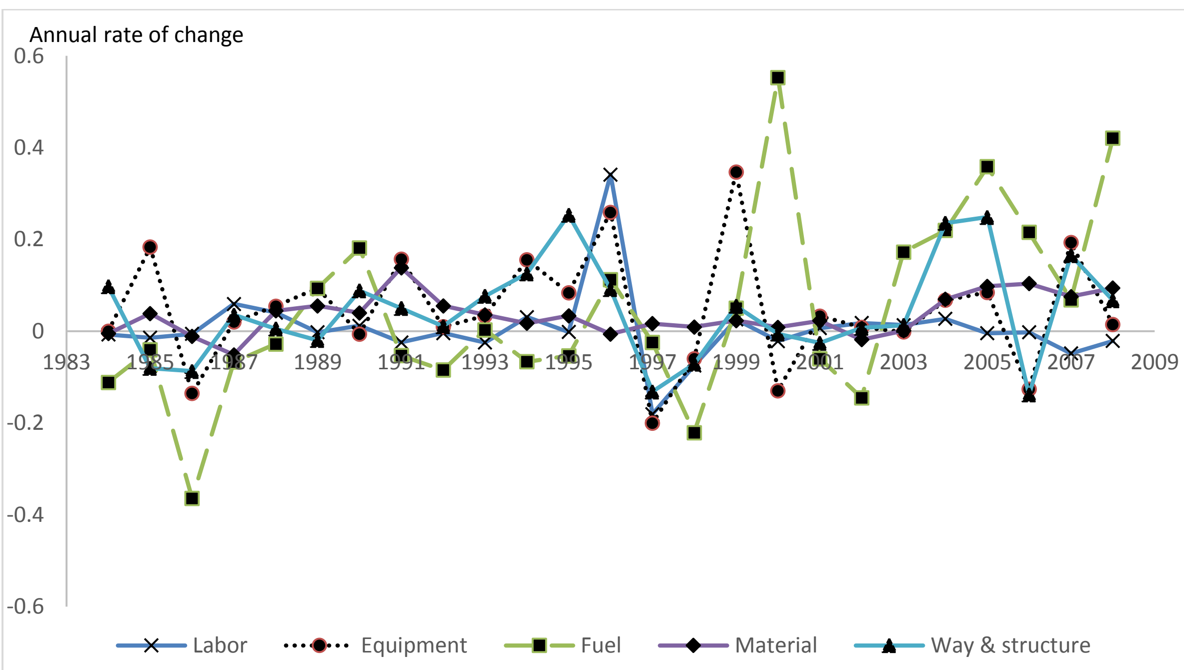

Figure-6: Annual rate of change for factor input price

Table-14 displays the annual rate of change for non-price factor; miles of road, speed, average length of haul and caboose. The annual rate of change for miles of road, speed, and average length of haul do not show neither a consistent pattern nor trend within the sample period. However, almost all annual rate of change for caboose is negative implying that the fraction of trains using caboose is becoming lesser and lesser. “The emergence of the caboose-less train” as mentioned by Duke et al. (1992) eliminates the cost of fuel usage, maintenance and service associated with caboose operations.

Table-14: Annual rate of change for non-price factors

Year	Milesroad	Speed	Avehaul	Caboose
1983-1984	0.014617	0.002081	0.015467	-0.13291
1984-1985	0.192904	0.047171	0.094769	-0.13879
1985-1986	0.183598	0.078261	-0.01028	-0.25078
1986-1987	-0.05193	0.003898	0.041247	-0.20153
1987-1988	0.0834	-0.05687	0.022065	-0.24328
1988-1989	0.033162	0.047979	0.064201	-0.27723
1989-1990	0.037807	0.00396	-0.01819	-0.16254
1990-1991	-0.02515	0.010668	0.012486	-0.12928
1991-1992	0.047048	0.000964	0.034171	-0.15967
1992-1993	-0.0198	-0.04885	0.020188	-0.18124
1993-1994	0.079805	-0.03275	-0.00055	-0.28484
1994-1995	0.104495	0.001042	0.033389	-0.52795
1995-1996	0.115953	-0.08176	-0.05457	-0.50318
1996-1997	0.067152	-0.06795	0.046368	-0.37298
1997-1998	-0.01526	0.015393	-0.0017	-0.51375
1998-1999	0.474384	0.059774	0.18675	0.279924
1999-2000	-0.0029	0.062055	0.013209	-0.01299
2000-2001	0.003542	-0.00038	-0.00941	-0.31884
2001-2002	-0.00986	0.063269	0.014444	-0.22705
2002-2003	-0.00754	-0.06006	0.010899	-0.26739

2003-2004	-0.01055	-0.03846	0.014367	-0.23226
2004-2005	-0.00654	-0.06307	0.011775	-0.23667
2005-2006	-0.00775	0.029654	0.016884	0.036434
2006-2007	-0.00056	0.03119	0.039673	0.161531
2007-2008	-0.00212	-0.00196	-0.0012	-0.14494

Contents in Table-15 depict the results of decomposing productivity growth into price effects and non-price effects. From 1983 to 2008, the unit cost has changed in total by 22.09 percent. The component that most affects productivity growth is the scale effect, followed by changes in miles of road, input prices and unexplained technology. Summary results presented in the second to last row of Table-15 suggest the factor input prices are associated with an increase in average cost (decrease in productivity). However, the magnitude of the average annual factor input price effect on productivity is relatively small. Indeed, productivity decline due to changing input prices declines less than a half of a percent annually for three out of five factor inputs. Only price changes of materials and way structures contribute to a decrease in annual productivity growth exceeding a half of a percent. For instance, annual changes in the price of way and structure reduce productivity by an annual average of 0.97 percent. Changes in the price of materials reduce productivity by an average of 0.8 percent annually. In contrast, changes in the price of equipment are found to reduce productivity by only 0.4 percent annually. The smallest productivity effect occurs from changes in labor and fuel prices. For the non-price effects, the results suggest that scale effects are apparently the dominant factor contributes to the unit cost changes. Scale effects have reduced the ray average cost by an average of 6.29 percent and have become the major source of changes. The yearly findings for average length of haul, speed and caboose suggest that these variables have a relatively small productivity effect. The average length of haul is expected to have negative relationship with cost. When the average length of haul is longer, the fixed costs are likely to spread over more miles and therefore reduce the cost (Wilson, 1997). On the other hand, results in Table-15 suggest in total the changes in average length of haul increase the ray average cost by 18.43 percent with an average of 0.74 percent. It is important to note that the annual rate of change for average length of haul is not necessarily positive. As depicted in Table-14, the annual rate of change is positive consistently between the year 2001 and 2007. Similarly, the speed and caboose are predicted to have positive relationship with cost. As the train increases the speed, the more cost incurs and as more caboose are used in train operation, the more cost needed to operate. Results in Table-15 suggest that in total speed decreases ray average cost by 1.43 percent with an average of 0.06 percent and caboose decreases ray average cost by almost 2 percent in total with an average of 0.08 percent. Table-14 shows that for some years speed experience positive annual rate of change but some are negative. However, the annual rate of change for the usage of caboose is negative except for very a few years. Therefore, result for caboose is expected since with lesser fraction of train operated by caboose every year, the lesser the cost will be. However, these three technological and movement characteristics are initially found not statistically significant in translog estimation results.

Changes in miles of road is the second pronounced source affecting the changes in ray average cost. In total, miles of road has increased the unit cost by almost 108 percent. Miles of road is expected to increase cost since it is associated with firm size or as a degree of network size (Bitzan and Peoples, 2014). Furthermore since 1983, changes in unobserved technology affects the change in ray average cost by 57.14 percent with an average of approximately 2.29 percent yearly. This technological effect, which is proxied by time trend, is consistently decreasing the unit cost every year.

Table-15: Decomposition of productivity growth due to factor price effects, scale effects, movement characteristic effects and unexplained technology effect.

									Movement Characteristic Effects				Unexplained Technology Effect
	Cost Changes	**PL effect**	**PE effect**	**PF effect**	**PM effect**	**PW effect**	**Price effect**	**Scale effect**	**Mileroad**	**Speed**	**Avehaul**	**Caboose**	
83-84	-0.2410	0.0026	-0.0129	-0.0103	-0.0007	0.0204	-0.0009	-0.2336	0.0515	0.0042	0.0009	-0.0006	-0.0626
84-85	-0.0003	-0.0073	0.0180	-0.0027	0.0075	-0.0015	0.0139	-0.0787	0.1041	0.0018	0.0111	-0.0006	-0.0519
85-86	-0.1139	-0.0010	-0.0148	-0.0293	-0.0026	-0.0187	-0.0663	-0.0833	0.1180	-0.0236	-0.0015	-0.0011	-0.0560
86-87	-0.0568	0.0203	0.0027	-0.0061	-0.0110	0.0082	0.0141	-0.1396	0.0914	0.0164	0.0039	-0.0008	-0.0422
87-88	-0.0632	0.0153	0.0047	-0.0015	0.0097	0.0031	0.0313	-0.0540	-0.0032	-0.0076	0.0108	-0.0009	-0.0397
88-89	-0.0791	-0.0008	0.0129	0.0075	0.0117	-0.0043	0.0270	-0.0162	-0.0415	-0.0068	0.0026	-0.0010	-0.0432
89-90	-0.0168	0.0043	-0.0008	0.0142	0.0088	0.0185	0.0450	-0.0360	0.0190	-0.0026	-0.0018	-0.0009	-0.0394
90-91	0.0068	-0.0087	0.0207	-0.0042	0.0293	0.0110	0.0482	-0.0190	0.0147	-0.0012	0.0003	-0.0003	-0.0358
91-92	-0.0057	-0.0015	0.0012	-0.0065	0.0123	0.0023	0.0079	-0.0876	0.0953	-0.0017	0.0078	-0.0006	-0.0268
92-93	-0.0277	-0.0085	0.0042	0.0002	0.0081	0.0169	0.0210	-0.0224	-0.0167	0.0124	0.0041	-0.0005	-0.0256
93-94	0.0058	0.0110	0.0195	-0.0052	0.0038	0.0277	0.0569	-0.1014	0.0652	0.0039	0.0019	-0.0011	-0.0197
94-95	0.0422	-0.0005	0.0104	-0.0041	0.0076	0.0554	0.0687	-0.0104	0.0122	-0.0005	-0.0054	-0.0021	-0.0202
95-96	-0.1418	0.1216	0.0326	0.0088	-0.0013	0.0200	0.1816	-0.4043	0.1057	-0.0029	0.0004	-0.0021	-0.0202
96-97	0.2164	-0.0640	-0.0246	-0.0019	0.0038	-0.0289	-0.1156	0.1490	0.1557	0.0155	0.0282	-0.0012	-0.0152

97-98	-0.1569	-0.0267	-0.0072	-0.0171	0.0021	-0.0157	-0.0646	0.0153	-0.0759	-0.0029	-0.0088	-0.0020	-0.0180
98-99	0.2755	0.0093	0.0250	0.0028	0.0089	0.0052	0.0512	-0.2564	0.4230	-0.0142	0.0773	0.0006	-0.0060
99-00	-0.0116	-0.0078	-0.0039	0.0452	-0.0017	0.0054	0.0372	-0.0313	-0.0027	-0.0119	0.0054	-0.0001	-0.0083
00-01	-0.0169	0.0025	0.0039	-0.0045	0.0053	-0.0054	0.0019	-0.0099	0.0034	0.0001	-0.0040	-0.0012	-0.0071
01-02	-0.0336	0.0065	0.0010	-0.0107	-0.0042	0.0015	-0.0058	-0.0048	-0.0095	-0.0106	0.0054	-0.0009	-0.0073
02-03	0.0007	0.0049	-0.0002	0.0123	0.0003	0.0026	0.0199	-0.0185	-0.0073	0.0104	0.0044	-0.0011	-0.0073
03-04	0.0470	0.0098	0.0087	0.0154	0.0165	0.0478	0.0981	-0.0463	-0.0103	0.0061	0.0062	-0.0009	-0.0059
04-05	0.0974	-0.0016	0.0113	0.0260	0.0225	0.0499	0.1080	-0.0155	-0.0065	0.0114	0.0057	-0.0009	-0.0049
05-06	-0.0533	-0.0008	-0.0172	0.0154	0.0236	-0.0287	-0.0077	-0.0377	-0.0077	-0.0045	0.0084	0.0001	-0.0042
06-07	0.0703	-0.0171	0.0259	0.0050	0.0172	0.0347	0.0658	-0.0088	-0.0006	-0.0057	0.0219	0.0006	-0.0029
07-08	0.0357	-0.0074	0.0019	0.0316	0.0217	0.0140	0.0618	-0.0218	-0.0023	0.0004	-0.0007	-0.0006	-0.0011
Average	-0.0088	0.0022	0.0049	0.0032	0.0080	0.0097	0.0279	-0.0629	0.0430	-0.0006	0.0074	-0.0008	-0.0229
Total	-0.2209	0.0545	0.1231	0.0801	0.1993	0.2415	0.6984	-1.5733	1.0752	-0.0143	0.1843	-0.0199	-0.5714

3.6 Concluding Remarks

A substantial amount of research has examined productivity growth in the US railroad industry following passage of the 1980 Staggers Act. This literature includes research that decomposes productivity growth by determinants of cost. Recent research on decomposition of productivity growth by Bitzan and Peoples (2014) adopts Gollop and Roberts (1981) approach for their analysis. In their paper, the annual rate productivity growth is decomposed into density, firm size, movement characteristics and technical change. Technological advancement generally is believed as the most important factor in reducing the ray average cost. However, factor price effect should not be excluded in discussing the sources of changes in ray average cost. Grifell-Tatjé and Lovell (2000) highlight an important benefit decomposing productivity is it acts as an industry cost benchmark for the producers. It also gives an insight on the sources that contribute to cost variation that are within managerial control. Moreover Tatjé and Lovell (2000, p.29) mention the analysis on input price effect are useful when "long term contracts with relatively efficient suppliers are under management control". Therefore, following the approach used by Wilson and Zhou (1997), this essay highlights the price effects as one of the sources in productivity gains.

Findings from this essay reveal the magnitude as well as the direction of the sources of productivity effects. A negative (positive) sign indicates the source that contributes to productivity growth (loss). The non-price determinants include scale effect, miles of road, average length of haul, speed, caboose and unexplained technological effect. In total within the sample period, four of them contribute to productivity growth; scale, speed, caboose and unexplained technology with the largest source of changes in productivity gains comes scale effects. In total, the scale effect contributes around 157 percent with a yearly average of 6.29 percent to the changes in ray average cost, followed by unexplained technology by 57.1 percent with a yearly average of 2.29 percent. The other two non-price sources; miles of road and average length of haul contributes to productivity loss. In total, miles of road increases the ray average cost by approximately 107 percent with an average of 4.30 percent and average length of haul by 18.43 percent with an average of 0.74 percent. From the overall productivity change attributable to non-price determinants, Table-15 suggests two factors; scale and miles of road, contribute in a large magnitude to the changes of the ray average cost. The unobserved technological change is also found to be consistently reducing the ray average cost every year. In other words, a continual investment in technology is still expected to boost productivity growth in the railroad industry.

Furthermore, Table-15 depicts factor input price contribution in cost variation. In total, changes in the factor input price increase the ray average cost by almost 70 percent with a yearly average of approximately 3 percent. The average price effect for each factor input is not the same. Among the price effects, the price of way and structures and the price of material show larger and significant magnitudes in explaining the sources of changes in unit cost compared to other prices. On average, the changes in price of way and structure contributes to a 0.97 percent decline in productivity growth. This is followed by the changes in price of material with an average of 0.8 percent. The changes in price of labor, price of equipment and price of fuel contributes on average of less than 0.5 percent in productivity loss. Interestingly, the changes in price of labor and price of fuel are the factor input prices that contribute the least to changes in unit cost. These input price effect on productivity is consistent with the notion that high marginal productivity of labor[77] and fuel contribute to relatively low increases in average cost due to increases in labor and fuel prices. In examining productivity growth, the inclusion of price effects highlights several significant revelations on the determinants of such growth in the railroad industry. For instance, while labor's share of total cost is non-trivial, findings suggest that fairly stagnant changes in real wages have helped carriers to avoid relatively large productivity losses[78]. Input price findings also reveal that despite increasingly higher fuel prices for the 2003-2008 sample observation period, the productivity loss was relatively small.

Changes in the price of equipment, price of material and price of way and structure resemble the pattern of increasing fuel prices for the period 2003-2008. Yet, unlike productivity trends for fuel, productivity trends for these inputs suggest relatively large declines in productivity compared to losses due to changes in labor and fuel prices for the 2003-2008 observation period. Such productivity losses may be attributable to a business environment that requires huge expenditure and investment in infrastructure, especially compared to the trucking industry. For instance, railroad companies generally need to set-up their own building structures and lay their own tracks whilst trucking industry use roads that are constructed by the government. At the same time, the expense of renewal and maintenance of track ties and locomotives ties is proportional to traffic volume as mentioned by Martland (2010). Nonetheless findings from this essay suggest that annual productivity loss due to changes in these prices have been limited to an average of less than one percent for

[77] High labor productivity is mainly due to "technological and institutional innovation" (Martland, 2012).

[78] The productivity loss comports with Martland (2010) findings that suggest the increasing fuel price is "more than offset all the fuel economy gains" for the period 1995-2004. Prior to 1995, he finds net benefit for the rail industry due to the combination of decreasing fuel price and fuel efficiency.

the entire observation period. An explanation for such constrained productivity loss is offered by Duke et al. (1992) who highlight the contribution of technology improvement to the construction and maintenance of rail infrastructure. For example, advancement in rail and yard design, computerized and automatic system in operation and highly mechanized equipment have eventually increased the efficiency and productivity of equipment, material and way and structure.

In sum, findings from this essay underscore the importance of including factor prices in the decomposition exercise in part because doing so reveals the key role these cost determinants play in rail companies' ability to attain rates of productivity growth that allow them to compete with low cost competitors in the trucking industry. Notable among these findings is uncovering evidence suggesting that it is the price of materials and way and structures, not wages and fuel prices that are the main input price impediments to productivity growth.

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Appendix D: Translog cost results

Variables	*Coefficient*	*s.e.*	*t-value*
Intercept	15.88369***	0.121083	131.18
w_L	0.332219***	0.008235	40.34
w_E	0.141867***	0.006931	20.47
w_F	0.062492***	0.015808	3.95
w_M	0.19176***	0.019363	9.9
w_{ws}	0.271662***	0.007604	35.72
y_u	0.021608	0.034249	0.63
y_w	0.021277	0.033108	0.64
y_t	0.410915***	0.068071	6.04
a_{miles}	0.599511***	0.11064	5.42
a_{speed}	-0.05144	0.124695	-0.41
a_{haul}	-0.08859	0.11417	-0.78
$a_{caboose}$	0.00395	0.004329	0.91
T	-0.02819***	0.00594	-4.75
$0.5(y_U)^2$	0.017508	0.011962	1.46
$0.5(y_W)^2$	0.025872	0.023104	1.12
$0.5(y_T)^2$	0.405719***	0.069854	5.81
$0.5(w_L)^2$	0.101467***	0.011438	8.87
$0.5(w_E)^2$	0.021605***	0.004741	4.56
$0.5(w_F)^2$	-0.00974	0.008529	-1.14
$0.5(w_M)^2$	-0.02792	0.023423	-1.19
$0.5(w_{WS})^2$	0.156698***	0.008327	18.82
$0.5(a_{miles})^2$	0.144284	0.115552	1.25
$0.5(a_{speed})^2$	0.356505*	0.203614	1.75
$0.5(a_{haul})^2$	0.774069***	0.233704	3.31
$0.5(a_{caboose})^2$	7.84E-07	8.65E-07	0.91
$0.5(t)^2$	0.000455	0.000291	1.56
w_L*w_E	-0.02179***	0.004659	-4.68
w_L*w_F	0.004	0.005044	0.79
w_L*w_M	-0.00256	0.012578	-0.2
w_L*w_{WS}	-0.08111***	0.006785	-11.95
w_L*y_U	-0.00458**	0.00209	-2.19
w_L*y_W	-0.00505	0.003361	-1.5
w_L*y_T	0.021262***	0.0064	3.32
w_L*a_{miles}	0.004015	0.009089	0.44
w_L*a_{speed}	0.011017	0.00995	1.11
w_L*a_{haul}	-0.04281***	0.008477	-5.05
$w_L*a_{caboose}$	2.09E-06**	9.91E-07	2.11
w_L*t	-0.00277***	0.000536	-5.18
w_E*w_F	0.007701*	0.004551	1.69
w_E*w_M	0.015968**	0.00803	1.99

w_E*w_{WS}	-0.02348***	0.004246	-5.53
w_E*y_U	0.005456***	0.001987	2.75
w_E*y_W	0.009492***	0.00324	2.93
w_E*y_T	0.012769**	0.00579	2.21
w_E*a_{miles}	-0.03202***	0.008308	-3.85
w_E*a_{speed}	0.003568	0.009554	0.37
w_E*a_{haul}	-0.02442***	0.008221	-2.97
$w_E*a_{caboose}$	1.14E-06	9.42E-07	1.21
w_E*t	-0.00189***	0.000419	-4.51
w_F*w_M	0.032329***	0.011354	2.85
w_F*w_{WS}	-0.03429***	0.005023	-6.83
w_F*y_U	0.005817	0.004678	1.24
w_F*y_W	-0.00055	0.007986	-0.07
w_F*y_T	-0.00699	0.012745	-0.55
w_F*a_{miles}	-0.00368	0.019455	-0.19
w_F*a_{speed}	-0.01883	0.02071	-0.91
w_F*a_{haul}	0.03661**	0.017417	2.1
$w_F*a_{caboose}$	-3.30E-06	2.44E-06	-1.35
w_F*t	0.00023	0.000938	0.24
w_M*w_{WS}	-0.01782*	0.009987	-1.78
w_M*y_U	-0.0144**	0.005507	-2.61
w_M*y_W	-0.0149	0.009293	-1.6
w_M*y_T	0.01505	0.015561	0.97
w_M*a_{miles}	0.005476	0.023192	0.24
w_M*a_{speed}	0.028979	0.025688	1.13
w_M*a_{haul}	0.000982	0.021406	0.05
$w_M*a_{caboose}$	4.20E-07	2.81E-06	0.15
w_M*t	0.003085**	0.001192	2.59
$w_{WS}*y_U$	0.0077***	0.002115	3.64
$w_{WS}*y_W$	0.011009***	0.003434	3.21
$w_{WS}*y_T$	-0.04209***	0.006903	-6.1
$w_{WS}*a_{miles}$	0.026211***	0.009599	2.73
$w_{WS}*a_{speed}$	-0.02474**	0.010068	-2.46
$w_{WS}*a_{haul}$	0.029632***	0.008562	3.46
$w_{WS}*a_{caboose}$	-3.53E-07	1.00E-06	-0.35
$w_{WS}*t$	0.001346***	0.000461	2.92
y_U*y_W	-0.01806	0.011705	-1.54
y_U*y_T	-0.10382***	0.025561	-4.06
y_U*a_{miles}	0.081328**	0.035357	2.3
y_U*a_{speed}	0.041548	0.037333	1.11
y_U*a_{haul}	0.063843*	0.032744	1.95
$y_U*a_{caboose}$	-8.83E-06	0.000012	-0.75
y_U*t	0.005097***	0.001805	2.82
y_W*y_T	-0.03031	0.023499	-1.29
y_W*a_{miles}	0.058338	0.044425	1.31

y_W*a_{speed}	-0.02817	0.040524	-0.7
y_W*a_{haul}	-0.06164	0.042601	-1.45
$y_W*a_{caboose}$	6.24E-06	5.43E-06	1.15
y_W*t	0.001061	0.001983	0.54
y_T*a_{miles}	-0.26305***	0.071801	-3.66
y_T*a_{speed}	0.268759**	0.102769	2.62
y_T*a_{haul}	-0.24484***	0.127301	-1.92
$y_T*a_{caboose}$	0.000021	0.000014	1.49
y_T*t	-0.00919**	0.004073	-2.26
$a_{miles}*a_{speed}$	-0.19674	0.124143	-1.58
$a_{miles}*a_{haul}$	0.317286**	0.147259	2.15
$a_{miles}*a_{caboose}$	-9.14E-06	0.000015	-0.62
$a_{miles}*t$	0.007011	0.006299	1.11
$a_{speed}*a_{haul}$	-0.59909***	0.187301	-3.2
$a_{speed}*a_{caboose}$	-0.00002	0.000013	-1.55
$a_{speeds}*t$	0.001409	0.006531	0.22
$a_{haul}*a_{caboose}$	-0.00003	0.000032	-0.94
$a_{haul}*t$	-0.00013	0.006571	-0.02
$a_{caboose}*t$	-6.48E-07	1.26E-06	-0.52

Note. The notation *** means significant at 1% level, ** is significant at 5% level and * is significant at 10% level.

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