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Three Essays on Railroad Cost

Azrina Abdullah Al-Hadi

University of Wisconsin-Milwaukee

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THREE ESSAYS ON RAILROAD COST

By

Azrina Abdullah Al-Hadi

A Dissertation Submitted in
Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy
in Economics

at
The University of Wisconsin-Milwaukee
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ABSTRACT
THREE ESSAYS ON RAILROAD COST
by
Azrina Abdullah Al-Hadi

The University of Wisconsin-Milwaukee, 2014
Under the Supervision of Professor James H. Peoples

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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Finally, I would like to express my gratitude to the Malaysian government, especially my employer Universiti Kebangsaan Malaysia, Bangi for the financial support. Above all, I thank to Allah, the Most Gracious and Most Merciful. Alhamdulillah.
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. 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. 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.

---

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 1 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 of unit train service (U), way train service (W) and through train service (T)

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<th>car miles (W)</th>
<th>car miles (T)</th>
<th>cars loaded (U)</th>
<th>cars loaded (W)</th>
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1 Average distance is calculated by dividing car miles by number of cars loaded.
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<td>2931717</td>
<td>2587000</td>
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<td>13281662</td>
<td>8245000</td>
<td>6704000</td>
<td>16253000</td>
<td>1.48</td>
<td>0.07</td>
<td>0.82</td>
<td></td>
</tr>
</tbody>
</table>


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:

\[ C(Y_1, 0) + C(0, Y_2) - C(Y_1, Y_2) > 0 \]  

(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):

\[ \text{Degree of economies of scope for } Y_1 \text{ and } Y_2 = \frac{C(Y_1, 0) + C(0, Y_2) - C(Y_1, Y_2)}{C(Y_1, Y_2)} \]  

(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
classified 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-I 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. 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.\(^6\)

\[
C(Y) + C(Y') \geq C(Y + Y')
\]

Where \( Y \) and \( Y' \) are output vectors for \( N \) products \( Y = (y_1, y_2, \ldots, y_n) \) and \( Y' = (y'_1, y'_2, \ldots, y'_n) \) 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:

\[
C(Y_U, 0,0) + C(0, Y_W,0) + C(0,0,Y_T) > C(Y_U, Y_W, Y_T)
\]

---

\(^5\) 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:

\[
\ln C = \alpha_0 + \sum_i \alpha_i \left[ \frac{\left( Y_i^{\lambda_i - 1} \right)}{\lambda} \right] + \sum_k \beta_k \ln W_k + \frac{1}{2} \sum_i \sum_j \partial_{ij} \left[ \left( Y_i^{\lambda_i} - 1 \right) / \lambda_i \right] \left[ \left( Y_j^{\lambda_j} - 1 \right) / \lambda_j \right] + \frac{1}{2} \sum_k \sum_i \gamma_{ki} \ln W_k \ln W_i + \sum_i \sum_k \rho_{ik} \left[ \left( Y_i^{\lambda_i} - 1 \right) / \lambda_i \right] \ln W_k
\]

where \(\partial_{ij} = \partial_{ji}\) and \(\gamma_{ki} = \gamma_{ik}\) and \(\lambda = \text{a power of parameter}^7\).

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 \(Y_i = \frac{\left( Y_i^{\lambda_i - 1} \right)}{\lambda} \) if \(\lambda_i \neq 0\) and \(Y_i = \ln Y_i\) if \(\lambda_i = 0\).
\[ SL(Y, W) = \frac{[C(Y, W)]}{\sum_i Y_i MC_i} = 1/\left[ \sum_i \varepsilon_{CY_i} \right] \]  

(6)

where \( MC_i \) is the marginal cost with respect to the ith output and \( \varepsilon_{CY_i} = \frac{\partial \ln C}{\partial \ln Y_i} \) is the cost elasticity of the ith output. The cost elasticity is later expressed as

\[ \varepsilon_{CY_i} = (\alpha_i) + \sum_j \partial_{ij} \left[ (Y_i^\lambda - 1) / \lambda_j \right] + \sum_k \rho_{ik} \ln W_k Y_i^\lambda \]  

(7)

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

\[ SL = 1/\left[ \sum_i \alpha_i \right] \]  

(8)

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

\[ SC = \frac{[C(Y, W) - C(Y, W)]}{C(Y, W)} \]  

(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:

\[ SC = [C(Y_F, 0, W) + C(0, Y_P, W) - C(Y_F, Y_P, W)]/C(Y_F, Y_P, W) \]  

(10)

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

\[ SC = \left[ e^{\left( \alpha_0 - \frac{\alpha_F}{\lambda_F} + \frac{\delta F F}{2 \lambda_F^2} \right)} + e^{\left( \alpha_0 - \frac{\alpha_P}{\lambda_P} + \frac{\delta P P}{2 \lambda_P^2} \right)} - e^{(\alpha_0)} \right] / e^{(\alpha_0)} \]  

(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.

\[ QC = QC \left( w_l, w_m+s, w_f, w_e, \text{UTGTM, WTM, TTM}, \text{MOR, ALH, TRK, WSCAP, Time} \right) \] (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, \( \text{UTGTM} \) is the adjusted unit train gross ton miles, \( \text{WTGTM} \) is the adjusted way train gross ton miles, \( \text{TTGTM} \) is the adjusted through train gross ton miles, \( \text{MOR} \) is the route miles, \( \text{ALH} \) is the average length of haul, \( \text{TRK} \) is the miles of track per mile of road, \( \text{WSCAP} \) 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 $\varphi, \rho, \gamma = (0.1, 0.2, ..., 0.9); q_1, q_2, q_3 =$ 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 tests 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 $y^i \neq y \text{ s.t. } C(y^S, 0) < \sum C(y^i, 0)$. (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
\[ C = C^C(y_B, y_E, y_I, w_L, w_E, w_F, w_M; H, R, T, U, \theta) + \rho R \]  
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, \( \theta \) is the fixed effect and \( \rho \) 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 significant whereas between \( y_B \) and \( y_I \) is positively significant. Furthermore, they propose a testing method based on definition of cost subadditivity 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 \( \partial C^0 \) 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:

\[
\text{real total cost} = \frac{\text{opercost} - \text{capexp} + \text{roird} + \text{roilcm} + \text{roicrs}}{\text{gdppd}}
\]  

(15)

where \( \text{opercost} = \) railroad operating cost,

\( \text{capexp} = \) capital expenditures,

\( \text{roird} = \) return on investment in road,

\( \text{roilcm} = \) 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.

\[
\text{roird} = (\text{roadinv} - \text{accdepr}) \times \text{costkap} \tag{16}
\]

where \( \text{roadinv} = \) road investment,

\( \text{accdepr} = \) accumulated depreciation

\[
\text{roilcm} = ([\text{iboloco} + \text{locinvl}] - (\text{acdoloco} + \text{locacdl})) \times \text{costkap} \tag{17}
\]

where \( \text{iboloco} = \) investment base in owned locomotives,

\( \text{locinvl} = \) investment base in leased locomotives,

\( \text{acdoloco} = \) accumulated depreciation of owned locomotives,

\( \text{locacdl} = \) accumulated depreciation of leased locomotives

\[
\text{roicrs} = ([\text{ibocars} + \text{carinvl}] - (\text{acdocars} + \text{caracdl})) \times \text{costkap} \tag{18}
\]

where \( \text{ibocars} = \) investment base in owned cars,

\( \text{carinvl} = \) investment base in leased cars

\( \text{acdocars} = \) accumulated depreciation of owned cars

\( \text{caracdl} = \) accumulated depreciation of leased cars

An adjusted factor is multiplied with each of the output variable. The adjusted factor is
given as:
\[ \frac{\text{rtm}}{\text{utgtm} + \text{wtgtm} + \text{ttgtm}} \] (19)

where \( \text{rtm} = \) revenue ton miles,

\( \text{utgtm} = \) unit train gross ton miles,

\( \text{wtgtm} = \) way train gross ton miles and

\( \text{ttgtm} = \) through train gross ton miles

The labor price per hour is calculated by:

\[
\text{labor price per hour} = \frac{\text{swge} + \text{fringe} - \text{caplab}}{\text{lbhrs}}
\] (20)

where \( \text{swge} = \) total salary and wages,

\( \text{fringe} = \) fringe benefits,

\( \text{caplab} = \) labor portion of capital expenditure classification as operation

\( \text{lbhrs} = \) 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:

\[
\text{way and structures price} = \frac{\text{roird} + \text{anneprd}}{\text{mot}}
\] (21)

where \( \text{anneprd} = \) annual depreciation of road and

\( \text{mot} = \) 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:

\[
\text{speed} = \frac{\text{trnmls}}{\text{trnhr} - \text{trnhs}}
\]  

(22)

where \(\text{trnmls} = \text{total train miles}\)

\(\text{trnhr} = \text{train hours in road service includes train switching hours}\)

\(\text{trnhs} = \text{train hours in train switching}\)

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

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<tbody>
<tr>
<td>Burlington Northern (BN) 1983-2008</td>
<td>• Atchison Topeka &amp; Santa Fe (ATSF) 1983-1995, then merged into BN</td>
</tr>
<tr>
<td>Boston &amp; Maine (BM) 1983-1986</td>
<td></td>
</tr>
<tr>
<td>Consolidated Rail Corporation (CR) 1983-1997</td>
<td></td>
</tr>
</tbody>
</table>
| 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 (DTI) 1983, then merged into GTW


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


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.\textsuperscript{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.\textsuperscript{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

\textsuperscript{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.

\textsuperscript{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.
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). The condition for linear homogeneity of this form is said to be satisfied by construction. 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.

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 is specified as

\[ C(w_i, y_k, a_m, t) \]  

(23)

---

10 A function is considered flexible if “there are no restrictions on its free parameters” (Diewert and Wales, 1988, p. 303).
11 Prior to 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 Taylor's expansion is shown in the following equation:

\[
C(w_i, y_k, a_m, t) = C(\bar{w}_i, \bar{y}_k, \bar{a}_m, t) + \frac{C(\bar{w}_i, y_k, a_m, t) - C(\bar{w}_i, \bar{y}_k, a_m, t)}{0!} + \ldots
\]

\(^{15}\) 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 Taylor's series expansion.
\[
+ \sum_i \frac{\partial C}{\partial w_i} (w_i - \bar{w}_i) + \sum_k \frac{\partial C}{\partial y_k} (y_k - \bar{y}_k) + \sum_m \frac{\partial C}{\partial a_m} (a_m - \bar{a}_m) + \frac{\partial C}{\partial t} (t - \bar{t})
\]

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

\[
+ \sum_i \sum_m \frac{\partial^2 C}{\partial w_i \partial a_m} (w_i - \bar{w}_i) (a_m - \bar{a}_m) + \sum_i \frac{\partial^2 C}{\partial w_i \partial t} (w_i - \bar{w}_i) (t - \bar{t})
\]

\[
+ \sum_k \sum_i \frac{\partial^2 C}{\partial y_k \partial w_i} (y_k - \bar{y}_k) (w_i - \bar{w}_i) + \sum_k \sum_i \frac{\partial^2 C}{\partial y_k \partial y_i} (y_k - \bar{y}_k) (y_i - \bar{y}_i)
\]

\[
+ \sum_k \sum_m \frac{\partial^2 C}{\partial y_k \partial a_m} (y_k - \bar{y}_k) (a_m - \bar{a}_m) + \sum_k \frac{\partial^2 C}{\partial y_k \partial t} (y_k - \bar{y}_k) (t - \bar{t})
\]

\[
+ \sum_m \sum_i \frac{\partial^2 C}{\partial a_m \partial w_i} (a_m - \bar{a}_m) (w_i - \bar{w}_i)
\]

\[
+ \sum_m \sum_k \frac{\partial^2 C}{\partial a_m \partial y_k} (a_m - \bar{a}_m) (y_k - \bar{y}_k)
\]

\[
+ \sum_m \sum_n \frac{\partial^2 C}{\partial a_m \partial a_n} (a_m - \bar{a}_m) (a_n - \bar{a}_n) + \sum_m \frac{\partial^2 C}{\partial a_m \partial t} (a_m - \bar{a}_m) (t - \bar{t})
\]

\[
+ \sum_i \frac{\partial^2 C}{\partial t \partial w_i} (t - \bar{t}) (w_i - \bar{w}_i) + \sum_k \frac{\partial^2 C}{\partial t \partial y_k} (t - \bar{t}) (y_k - \bar{y}_k)
\]

\[
+ \sum_m \frac{\partial C}{\partial a_m} (t - \bar{t}) (a_m - \bar{a}_m) + \frac{\partial^2 C}{\partial t^2} (t - \bar{t})^2
\]

(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\(^{18}\):

\[
C = a_0 + \sum_i a_i (w_i - \bar{w}_i) + \sum_k \beta_k (y_k - \bar{y}_k) + \sum_m \sigma_m (a_m - \bar{a}_m) + \theta (t - \bar{t}) \\
+ \frac{1}{2} \sum_i \sum_j a_{ij} (w_i - \bar{w}_i) (w_j - \bar{w}_j) + \frac{1}{2} \sum_k \beta_{kl} (y_k - \bar{y}_k) (y_l - \bar{y}_l) \\
+ \frac{1}{2} \sum_m \sum_n \sigma_{mn} (a_m - \bar{a}_m) (a_n - \bar{a}_n) + \frac{1}{2} \gamma (t - \bar{t})^2 \\
+ \sum_i \sum_k \tau_{ik} (w_i - \bar{w}_i) (y_k - \bar{y}_k) \\
+ \sum_i \sum_m \vartheta_{im} (w_i - \bar{w}_i) (a_m - \bar{a}_m) + \sum_k \sum_m \phi_{km} (a_m - \bar{a}_m) (y_k - \bar{y}_k) \\
+ \sum_i \vartheta_i (t - \bar{t}) (w_i - \bar{w}_i) + \sum_k \pi_k (t - \bar{t}) (y_k - \bar{y}_k) + \sum_m \mu_m (t - \bar{t}) (a_m - \bar{a}_m) + \epsilon \\
\]

(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:\(^{19}\):

\[
C(W, Y, A, T) = \alpha_0 + [\alpha_1 \alpha_2 \alpha_3 \alpha_4] \begin{bmatrix}
w_L \\
w_E \\
w_F \\
w_WS \\
\end{bmatrix} + [\beta_1 \beta_2 \beta_3] \begin{bmatrix}
y_U \\
y_W \\
y_T \\
\end{bmatrix}
+ [\sigma_1 \sigma_2 \sigma_3 \sigma_4] \begin{bmatrix}
d_M \\
d_S \\
d_H \\
d_C \\
\end{bmatrix} + \theta [t]
\]

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

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

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

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

\[
+ [w_L \ w_E \ w_F \ w_WS] \begin{bmatrix}
\vartheta_{11} & \vartheta_{12} & \vartheta_{13} & \vartheta_{14} \\
\vartheta_{21} & \vartheta_{22} & \vartheta_{23} & \vartheta_{24} \\
\vartheta_{31} & \vartheta_{32} & \vartheta_{33} & \vartheta_{34} \\
\vartheta_{41} & \vartheta_{42} & \vartheta_{43} & \vartheta_{44} \\
\end{bmatrix} \begin{bmatrix}
da_M \\
da_S \\
da_H \\
da_C \\
\end{bmatrix}
\]

\(^{19}\)The demeaning process is not shown in the matrix form for simplicity.
\[ C(W, Y, A, t) = \alpha_0 + (A \ast W') + (B \ast Y') + (C \ast Z') + (D \ast t) \]

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

\[ + (W \ast I \ast Y') + (W \ast J \ast Z') + (Z \ast K \ast Y') + (t \ast L \ast W') + (t \ast M \ast Y') + (t \ast N \ast Z') \]

The above equation can also be expressed as

\[ C(W, Y, A, t) = \alpha_0 + (A \ast W') + (B \ast Y') + (C \ast Z') + (D \ast t) \]

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

\[ + (W \ast I \ast Y') + (W \ast J \ast Z') + (Z \ast K \ast Y') + (t \ast L \ast W') + (t \ast M \ast Y') + (t \ast N \ast Z') \]

where

\[ W = [w_L \ w_E \ w_F \ w_{WS}] \]

\[ Y = [y_U \ y_W \ y_T] \]

\[ Z = [a_M \ a_S \ a_H \ a_C] \]

\[ A = [\alpha_1 \ \alpha_2 \ \alpha_3 \ \alpha_4] \]

\[ B = [\beta_1 \ \beta_2 \ \beta_3] \]

\[ C = [\sigma_1 \ \sigma_2 \ \sigma_3 \ \sigma_4] \]

\[ D = [\theta] \]

\[ E = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \alpha_{24} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \alpha_{34} \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} \end{bmatrix} \]

\[ F = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix} \]

\[ G = \begin{bmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} & \sigma_{14} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} & \sigma_{24} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} & \sigma_{34} \\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_{44} \end{bmatrix} \]

\[ H = [t] \]

\[ I = \begin{bmatrix} \tau_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \tau_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \tau_{33} \\ \tau_{41} & \tau_{42} & \tau_{43} \end{bmatrix} \]

\[ J = \begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} \\ \phi_{41} & \phi_{42} & \phi_{43} & \phi_{44} \end{bmatrix} \]

\[ K = \begin{bmatrix} \varphi_{11} & \varphi_{12} & \varphi_{13} \\ \varphi_{21} & \varphi_{22} & \varphi_{23} \\ \varphi_{31} & \varphi_{32} & \varphi_{33} \\ \varphi_{41} & \varphi_{42} & \varphi_{43} \end{bmatrix} \]
\[ L = [\delta_1 \ \delta_2 \ \delta_3 \ \delta_4] ; M = [\pi_1 \ \pi_2 \ \pi_3] ; N = [\mu_1 \ \mu_2 \ \mu_3 \ \mu_4] \]

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.

\[ C(W, Y, A, t) = \alpha_0 + \alpha_1 w_L + \alpha_2 w_E + \alpha_3 w_F + \alpha_4 w_{WS} + \alpha_5 y_U + \alpha_6 y_W + \alpha_7 y_T \]

\[ + \sigma_1 a_M + \sigma_2 a_S + \sigma_3 a_H + \sigma_4 a_C + \theta t \]

\[ + \frac{1}{2} \sigma_{11} a_M^2 + \frac{1}{2} \sigma_{22} a_S^2 + \frac{1}{2} \sigma_{33} a_H^2 + \frac{1}{2} \sigma_{44} a_C^2 + \frac{1}{2} \gamma t^2 \]

\[ + \alpha_8 w_L w_E + \alpha_9 w_L w_F + \alpha_{10} w_L w_{WS} + \alpha_{11} w_E w_F + \alpha_{12} w_E w_{WS} + \alpha_{13} w_F w_{WS} \]

\[ + \beta_{12} y_U y_W + \beta_{13} y_U y_T + \beta_{23} y_W y_T + \sigma_{12} a_M a_S + \sigma_{13} a_M a_H + \sigma_{14} a_M a_C \]

\[ + \sigma_{23} a_S a_H + \sigma_{24} a_S a_C + \sigma_{34} a_H a_C + \tau_{11} w_L y_U + \tau_{12} w_L y_W + \tau_{13} w_L y_T \]

\[ + \tau_{21} w_E y_U + \tau_{22} w_E y_W + \tau_{23} w_E y_T + \tau_{31} w_F y_U + \tau_{32} w_F y_W + \tau_{33} w_F y_T \]

\[ + \tau_{41} w_{WS} y_U + \tau_{42} w_{WS} y_W + \tau_{43} w_{WS} y_T \]

\[ + \theta_{11} w_L a_M + \theta_{12} w_L a_S + \theta_{13} w_L a_H + \theta_{14} w_L a_C \]

\[ + \theta_{21} w_E a_M + \theta_{22} w_E a_S + \theta_{23} w_E a_H + \theta_{24} w_E a_C \]

\[ + \theta_{31} w_F a_M + \theta_{32} w_F a_S + \theta_{33} w_F a_H + \theta_{34} w_F a_C \]

\[ + \theta_{41} w_{WS} a_M + \theta_{42} w_{WS} a_S + \theta_{43} w_{WS} a_H + \theta_{44} w_{WS} a_C \]

\[ + \varphi_{11} a_M y_U + \varphi_{12} a_M y_W + \varphi_{13} a_M y_T + \varphi_{21} a_S y_U + \varphi_{22} a_S y_W + \varphi_{23} a_S y_T \]

\[ + \varphi_{31} a_H y_U + \varphi_{32} a_H y_W + \varphi_{33} a_H y_T + \varphi_{41} a_C y_U + \varphi_{42} a_C y_W + \varphi_{43} a_C y_T \]

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

\[ + \mu_1 a_M t + \mu_2 a_S t + \mu_3 a_H t + \mu_4 a_C t \quad (28) \]

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:
\[
\frac{\partial C}{\partial w_i} = x_i = \alpha_i + \sum_j \alpha_{ij} w_j + \sum_k \tau_{ik} y_k + \sum_m \theta_{im} a_m + \gamma_i t
\] (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. 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. 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 \( \leq 0 \) and every principal with even order is \( \geq 0 \). 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.
\[
\begin{bmatrix}
-k_1^2 & -k_1k_{21} & -k_{11}k_3 & -k_{11}k_4 \\
-k_{11}k_{21} & -(k_{21}^2 + k_{22}^2) & -(k_{21}k_{31} + k_{22}k_{32}) & -(k_{21}k_{41} + k_{22}k_{42}) \\
-k_{11}k_{31} & -(k_{21}k_{31} + k_{22}k_{32}) & -(k_{21}^2 + k_{22}^2 + k_{33}^2) & -(k_{31}k_{41} + k_{32}k_{42} + k_{33}k_{43}) \\
-k_{11}k_{41} & -(k_{21}k_{41} + k_{22}k_{42}) & -(k_{31}k_{41} + k_{32}k_{42} + k_{33}k_{43}) & -(k_{41}^2 + k_{42}^2 + k_{43}^2 + k_{44}^2)
\end{bmatrix}
\]

(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\(^\text{22}\):

\[
SCOPE = C(y_U, 0,0) + C(0,y_W, 0) + C(0,0, y_T) - C(y_U, y_W, y_T)
\]

\[
= 2 * (a_0 + a_1w_L + a_2w_E + a_3w_F + a_4w_{WS} + \sigma_1a_M + \sigma_2a_S + \sigma_3a_H + \sigma_4a_C + \theta t
+ \frac{1}{2} a_{11}w_L^2 + \frac{1}{2} a_{22}w_E^2 + \frac{1}{2} a_{33}w_F^2 + \frac{1}{2} a_{44}w_{WS}^2 + \frac{1}{2} \sigma_{11}a_M^2 + \frac{1}{2} \sigma_{22}a_S^2 + \frac{1}{2} \sigma_{33}a_H^2
+ \frac{1}{2} \sigma_{44}a_C^2 + \frac{1}{2} \gamma t^2 + a_{12}w_Lw_E + a_{13}w_Lw_F + a_{14}w_Lw_{WS} + a_{23}w_Ew_F
+ a_{24}w_Ew_{WS} + a_{34}w_Fw_{WS} + a_{12}a_Ma_S + a_{13}a_Ma_H + a_{14}a_MA_C + a_{23}a_Sa_H
+ a_{24}a_Sa_C + a_{34}a_Ha_C + \theta_{11}w_La_M + \theta_{12}w_La_S + \theta_{13}w_La_H + \theta_{14}w_La_C + \theta_{21}w_Ea_M
+ \theta_{22}w_Ea_S + \theta_{23}w_Ea_H + \theta_{24}w_Ea_C + \theta_{31}w_Fa_M + \theta_{32}w_Fa_S + \theta_{33}w_Fa_H
+ \theta_{34}w_Fa_C + \theta_{41}w_{WS}a_M + \theta_{42}w_{WS}a_S + \theta_{43}w_{WS}a_H + \theta_{44}w_{WS}a_C + \delta_1w_Lt + \delta_2w_Et)
\]

\(^{22}\) Pulley and Humphrey (1991) generalized the calculation for economies of scope in the case of m firms as

\[
SCOPE = [(m - 1)a_0 - \sum_{i=1}^{m} \sum_{j=1}^{m} a_{ij}q_j]/h(q).
\]

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.
\[
+ \delta_3 y_{FT} + \delta_4 y_{WS} t + \mu_1 a_M t + \mu_2 a_S t + \mu_3 a_H t + \mu_4 a_C t 
+ \beta_{12} y_U y_W + \\
\beta_{13} y_U y_T + \beta_{23} y_W y_T
\]

(31)

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

\[
SC_m = \frac{c(y^m) + c(y^{-m}) - c(y)}{c(y)}
\]

(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 prevail 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.

\[
SC_{mn} = \frac{c(y^m) + c(y^n) - c(y^{(m)}, y^{(n)})}{c(y^{(m)}, y^{(n)})}
\]

(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. 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).

\[ \text{SCOPE-U:} \quad C(y_U, 0, 0) + C(0, y_W, y_T) > C(y_U, y_W, y_T) \]  
\[ \text{SCOPE-W:} \quad C(0, y_W, 0) + C(y_U, 0, y_T) > C(y_U, y_W, y_T) \]  
\[ \text{SCOPE-T:} \quad C(0, 0, y_T) + C(y_U, y_W, 0) > C(y_U, y_W, y_T) \]

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:

\[
SCOPE-U-W: \ C(y_u, 0, 0) + C(0, y_w, 0) > C(y_u, y_w, 0) \tag{37}
\]

\[
SCOPE-U-T: \ C(y_u, 0, 0) + C(0, 0, y_T) > C(y_u, 0, y_T) \tag{38}
\]

\[
SCOPE-W-T: \ C(0, y_w, 0) + C(0, 0, y_T) > C(0, y_w, y_T) \tag{39}
\]

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>
<thead>
<tr>
<th>Monotonicity condition</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \partial C / \partial y_U &gt; 0 )</td>
<td>93 percent of observations</td>
</tr>
<tr>
<td>( \partial C / \partial y_W &gt; 0 )</td>
<td>67 percent of observations</td>
</tr>
<tr>
<td>( \partial C / \partial y_T &gt; 0 )</td>
<td>72 percent of observations</td>
</tr>
<tr>
<td>( \partial C / \partial w_L &gt; 0 )</td>
<td>71 percent of observations</td>
</tr>
<tr>
<td>( \partial C / \partial w_E &gt; 0 )</td>
<td>70 percent of observations</td>
</tr>
<tr>
<td>( \partial C / \partial w_F &gt; 0 )</td>
<td>75 percent of observations</td>
</tr>
<tr>
<td>( \partial C / \partial w_WS &gt; 0 )</td>
<td>85 percent of observations</td>
</tr>
</tbody>
</table>

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: 
\[ \frac{ac}{ay_U} = \beta_1 + \beta_{11} y_U + \beta_{12} y_W + \beta_{13} y_T + \tau_{11} w_L + \tau_{12} w_E + \tau_{13} w_F + \tau_{41} w_WS + \varphi_{11} a_M + \varphi_{21} a_S + \varphi_{31} a_H + \varphi_{41} a_C + \pi_1 t \]

\(^{27}\) For example, derivative of cost with respect to price of labor is shown as: 
\[ \frac{ac}{aw_L} = \alpha_1 + \alpha_{11} w_L + \alpha_{12} w_E + \alpha_{13} w_F + \alpha_{14} w_WS + \tau_{11} y_U + \tau_{12} y_W + \tau_{13} y_T + \phi_{11} a_M + \phi_{12} a_S + \phi_{13} a_H + \phi_{14} a_C + \delta_1 t \]
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 \textit{milesroad} and \textit{speed} are negative and statistically significant, the estimated

\(^{28}\) 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**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Without concavity</th>
<th>With concavity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>s.e.</td>
</tr>
<tr>
<td>Intercept</td>
<td>59052.21***</td>
<td>3674.778</td>
</tr>
<tr>
<td><em>w</em>&lt;sub&gt;L&lt;/sub&gt;</td>
<td>19337425***</td>
<td>830899.7</td>
</tr>
<tr>
<td><em>w</em>&lt;sub&gt;E&lt;/sub&gt;</td>
<td>1093.011***</td>
<td>268.007</td>
</tr>
<tr>
<td><em>w</em>&lt;sub&gt;F&lt;/sub&gt;</td>
<td>4.00E+08***</td>
<td>31835309</td>
</tr>
<tr>
<td><em>w</em>&lt;sub&gt;WS&lt;/sub&gt;</td>
<td>12137.46***</td>
<td>199.9104</td>
</tr>
<tr>
<td><em>y</em>&lt;sub&gt;U&lt;/sub&gt;</td>
<td>0.000364***</td>
<td>0.000057</td>
</tr>
<tr>
<td><em>y</em>&lt;sub&gt;W&lt;/sub&gt;</td>
<td>0.003745***</td>
<td>0.000299</td>
</tr>
<tr>
<td><em>y</em>&lt;sub&gt;T&lt;/sub&gt;</td>
<td>0.000546***</td>
<td>0.000049</td>
</tr>
<tr>
<td><em>a</em>&lt;sub&gt;miles&lt;/sub&gt;</td>
<td>-1.65865***</td>
<td>0.237675</td>
</tr>
<tr>
<td><em>a</em>&lt;sub&gt;speed&lt;/sub&gt;</td>
<td>-249.267***</td>
<td>84.19541</td>
</tr>
<tr>
<td><em>a</em>&lt;sub&gt;hauli&lt;/sub&gt;</td>
<td>24.42795***</td>
<td>7.312301</td>
</tr>
<tr>
<td><em>a</em>&lt;sub&gt;caboose&lt;/sub&gt;</td>
<td>522069</td>
<td>2559789</td>
</tr>
<tr>
<td><em>t</em></td>
<td>-2121.99***</td>
<td>178.884</td>
</tr>
<tr>
<td>0.5(<em>y</em>&lt;sub&gt;U&lt;/sub&gt;)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-2.99E-13</td>
<td>5.09E-13</td>
</tr>
<tr>
<td>0.5(<em>y</em>&lt;sub&gt;W&lt;/sub&gt;)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-1.24E-09***</td>
<td>4.65E-11</td>
</tr>
<tr>
<td>0.5(<em>y</em>&lt;sub&gt;T&lt;/sub&gt;)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>7.19E-12***</td>
<td>5.84E-13</td>
</tr>
<tr>
<td>Term</td>
<td>Value 1</td>
<td>Value 2</td>
</tr>
<tr>
<td>---------------------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>$0.5(w_L)^2$</td>
<td>-4.20E+09***</td>
<td>1.94E+08</td>
</tr>
<tr>
<td>$0.5(w_E)^2$</td>
<td>48.54731***</td>
<td>4.279762</td>
</tr>
<tr>
<td>$0.5(w_F)^2$</td>
<td>-6.88E+11***</td>
<td>4.45E+10</td>
</tr>
<tr>
<td>$0.5(w_{WS})^2$</td>
<td>-76.382***</td>
<td>10.1424</td>
</tr>
<tr>
<td>$0.5(a_{miles})^2$</td>
<td>0.000595***</td>
<td>0.000041</td>
</tr>
<tr>
<td>$0.5(a_{speed})^2$</td>
<td>-33.5235***</td>
<td>6.097911</td>
</tr>
<tr>
<td>$0.5(a_{haul})^2$</td>
<td>-0.28017***</td>
<td>0.034789</td>
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<td>$0.5(a_{caboose})^2$</td>
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<td>13.3609</td>
</tr>
<tr>
<td>$w_L \cdot w_E$</td>
<td>798090.7***</td>
<td>46101.71</td>
</tr>
<tr>
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<td>-3.58E+10***</td>
<td>3.19E+09</td>
</tr>
<tr>
<td>$w_L \cdot w_{WS}$</td>
<td>-525085***</td>
<td>39094.04</td>
</tr>
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<td>0.011143</td>
</tr>
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<td>-3.29477***</td>
<td>0.127369</td>
</tr>
<tr>
<td>$w_L \cdot y_T$</td>
<td>0.253375***</td>
<td>0.011565</td>
</tr>
<tr>
<td>$w_L \cdot a_{miles}$</td>
<td>337.9932***</td>
<td>81.88123</td>
</tr>
<tr>
<td>$w_L \cdot a_{speed}$</td>
<td>1000907***</td>
<td>57102.85</td>
</tr>
<tr>
<td>$w_L \cdot a_{haul}$</td>
<td>3009.409</td>
<td>3183.987</td>
</tr>
<tr>
<td>$w_L \cdot a_{caboose}$</td>
<td>9.35E+09***</td>
<td>1.14E+09</td>
</tr>
<tr>
<td>$w_L \cdot t$</td>
<td>-709356***</td>
<td>74962.77</td>
</tr>
<tr>
<td>$w_E \cdot w_F$</td>
<td>4112048***</td>
<td>314702.7</td>
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<td>$w_E \cdot w_{WS}$</td>
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</tr>
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<td>-3.50E-06</td>
<td>3.75E-06</td>
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<tr>
<td>$w_E \cdot y_W$</td>
<td>-0.00037***</td>
<td>0.000045</td>
</tr>
<tr>
<td>$w_E \cdot y_T$</td>
<td>0.000047***</td>
<td>4.11E-06</td>
</tr>
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<td>$w_E \cdot a_{miles}$</td>
<td>-0.08531***</td>
<td>0.023706</td>
</tr>
<tr>
<td>$w_E \cdot a_{speed}$</td>
<td>8.434251</td>
<td>15.43111</td>
</tr>
<tr>
<td>$w_E \cdot a_{haul}$</td>
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<td>0.754206</td>
</tr>
<tr>
<td>$w_E \cdot a_{caboose}$</td>
<td>3394215***</td>
<td>368263.9</td>
</tr>
<tr>
<td>$w_E \cdot t$</td>
<td>70.6142***</td>
<td>23.69644</td>
</tr>
<tr>
<td>$w_F \cdot w_{WS}$</td>
<td>-9282573***</td>
<td>332709.8</td>
</tr>
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<td>$w_F \cdot y_U$</td>
<td>-2.7989***</td>
<td>0.388153</td>
</tr>
<tr>
<td>$w_F * y_W$</td>
<td>-43.2156***</td>
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</tr>
<tr>
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<td>13.57421***</td>
<td>0.396995</td>
</tr>
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<td>-52675.6***</td>
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</tr>
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</tr>
<tr>
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<td>103735.9</td>
</tr>
<tr>
<td>$w_F * a_{caboose}$</td>
<td>1.32E+11***</td>
<td>3.32E+10</td>
</tr>
<tr>
<td>$w_F * t$</td>
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\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{variable} & \text{coefficient} & \text{standard error} & \text{t-value} & \text{p-value} \\
\hline
\text{a}_{\text{miles}} \times \text{a}_{\text{speed}} & -0.01797 & 0.016516 & -25.4535 & ** \\
\text{a}_{\text{miles}} \times \text{a}_{\text{haul}} & -0.00156 & 0.000776 & 0.134324 & 0.6032 \\
\text{a}_{\text{miles}} \times \text{a}_{\text{caboose}} & -430.326 & 260.7547 & -328421 & 204482 \\
\text{a}_{\text{miles}} \times \text{t} & 0.225063 & 0.021707 & -42.1698 & 16.2978 \\
\text{a}_{\text{speed}} \times \text{a}_{\text{haul}} & 6.215739 & 0.386726 & 3.687197 & 354.3 \\
\text{a}_{\text{speed}} \times \text{a}_{\text{caboose}} & 1198683 & 120814.9 & 1.16E+08 & 1.17E+08 \\
\text{a}_{\text{speeds}} \times \text{t} & -15.0218 & 6.626258 & 2568.9 & 6621.7 \\
\text{a}_{\text{haul}} \times \text{a}_{\text{caboose}} & 20183.95 & 5399.54 & -3182217 & 5377594 \\
\text{a}_{\text{haul}} \times \text{t} & -0.70175 & 0.548849 & -651.032 & 433.7 \\
\text{a}_{\text{caboose}} \times \text{t} & -904903 & 197655.3 & 1.04E+08 & 1.85E+08 \\
\hline
\end{array}
\]

**Note.** The variable \( w_L \) is the labor price, \( w_E \) is the equipment price, \( w_F \) is the fuel 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, \( a_{\text{miles}} \) is the miles of road, \( a_{\text{speed}} \) is the train miles per train hour, \( a_{\text{haul}} \) is the average length of haul, \( a_{\text{caboose}} \) 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 between each other. The presence of cost complementarity is one of the contributors for economies of scope. However, the coefficient for interaction

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

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

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\(^{32}\) 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.
Without imposing concavity

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

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38 $SCOPE_{UW} = C(y_U, 0, 0) + C(0, y_W, 0) - C(y_U, y_W, 0)$
39 $SCOPE_{UT} = C(y_U, 0, 0) + C(0, 0, y_T) - C(y_U, 0, y_T)$
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41 $SCOPE = C(y_u, 0, 0) + C(0, y_w, 0) + C(0, 0, y_T)$
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 $SCOPE_WT = C(0, y_w, 0) + C(0, 0, y_T) - C(y_w, 0, y_T)$

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### 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.
References


Appendix A: Construction of variables

Variable Construction

- Real total cost = (opercost – capexp + roird + roilcm + roics)/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)
  - roics = 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

- Utgt: unit train gross ton miles (schedule 755, line 99, column b)
- Wtgt: way train gross ton miles (schedule 755, line 100, column b)
- Ttgm: 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)

**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

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

$$= a_0 + \sum_i \alpha_i \lambda w_i + \sum_k \alpha_k Y_k + \frac{1}{2} \sum_i \sum_j \alpha_{ij} \lambda^2 w_i w_j + \frac{1}{2} \sum_k \sum_i \alpha_{kl} Y_k Y_l$$

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

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

**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 $\tilde{w}_i = \frac{w_i}{\bar{w}}$, $\tilde{C} = \frac{C}{\bar{w}}$ and $\bar{w}$ is the numeraire:

$$\tilde{C} = a_0 + \sum_i^{n-1} \alpha_i \tilde{w}_i + \sum_k \alpha_k Y_k$$

$$+ \frac{1}{2} \sum_i \sum_j^{n-1} \alpha_{ij} \tilde{w}_i \tilde{w}_j + \frac{1}{2} \sum_k \sum_i \alpha_{kl} Y_k Y_l + \sum_i \sum_k^{n-1} \alpha_{ik} \tilde{w}_i Y_k$$

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

$$C(w_i, 1, Y) = a_0 \bar{w} + \sum_i^{n-1} \alpha_i w_i + \sum_k \alpha_k Y \bar{w}_k$$

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

$$C(\lambda w_i, 1, Y) = a_0 \lambda \bar{w} + \sum_i^{n-1} \alpha_i \lambda w_i \sum_k \alpha_k Y \lambda \bar{w}_k$$
\[ + \frac{1}{2} \sum_{i}^{n-1} \sum_{j}^{n-1} \alpha_{ij} \left( \frac{\lambda^2}{\lambda} \right) \left( \frac{w_i w_j}{\bar{w}} \right) + \frac{1}{2} \sum_{k}^{m} \sum_{l}^{l} \alpha_{kl} Y_k Y_l \bar{w} + \sum_{l}^{l} \sum_{k}^{m} \alpha_{lk} \lambda w_i Y_k \bar{w} \]

\[ \therefore C(\lambda w_i, 1, Y) = \lambda^1 C(w_i, 1, Y) \] 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.\footnote{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.} 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
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 indicate 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. 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)  

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

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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
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\textsuperscript{53}, hot box\textsuperscript{54} and dragging equipment detectors\textsuperscript{55} contribute to the elimination of caboose, which in turn eliminated the need for brakemen.\textsuperscript{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.\textsuperscript{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-
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 to 100 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. By 1991 train crew sizes fell from consisting of an engineer, conductor and two brakemen to only consisting of just two workers.

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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):

\[
\frac{MP_L}{w_L} = \frac{MP_{NL}}{w_{NL}}
\]  

(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:

\[
\frac{MP_{NL}}{MP_L} = MRTS_{NL,L} = -\frac{\Delta L}{\Delta NL}
\]  

(2)

where \( \Delta L \) and \( \Delta NL \) 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:

\[
MRTS_{NL,L} = \frac{w_{NL}}{w_L}
\]

(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 \( C = w_Lx_L + w_{NL}x_{NL} \). 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 \( C' = w_Lx_L^* + w_{NL}x_{NL}^* \) 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 \((w_L^* \text{ and } w_{NL}^*)\). 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.

\[
C^* = w_L^*x_L^* + w_{NL}^*x_{NL}^*
\]

When employing at \(x_L^* \text{ and } x_{NL}^* \text{ and } w_L^* \text{ and } w_{NL}^* \) are the shadow input prices for labor and non-labor respectively. It should be noted that for this example the shadow price for

**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

\[
\frac{MP_L^*}{w_L^*} = \frac{MP_{NL}^*}{w_{NL}^*} \tag{4}
\]

Where \(MP_L^*\) and \(MP_{NL}^*\) are the marginal product of labor and non-labor respectively, when employing at \(x_L^* \text{ and } x_{NL}^* \text{ and } w_L^* \text{ and } w_{NL}^* \) are the shadow input prices for labor and non-labor respectively.
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

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

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 between labor and non-labor becomes larger and this is depicted by the isoquant approaching linearity. 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.

\[ \sigma = \frac{\% \text{ change in } \left( \frac{L}{NL} \right) \text{ ratio}}{\% \text{ change in } \text{MRTS}_{NL}} \]

Factor inputs for a linear production function are perfect substitutes where \( \sigma = \infty \).
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>
<thead>
<tr>
<th>Table-8: Construction of variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Construction</td>
</tr>
<tr>
<td>Real total cost = (opercost – capexp + roird + roilcm + roicrs)/gdppd</td>
</tr>
<tr>
<td>opercost = railroad operating cost (schedule 410, line 620, column f)</td>
</tr>
<tr>
<td>capexp = capital expenditures classified as operating in r1 (schedule 410, lines 12-30, 101-9, column f)</td>
</tr>
<tr>
<td>roird = return on investment in road = (roadinv – accdepr) * costkap</td>
</tr>
<tr>
<td>roadinv: road investment (schedule 352b, line 31) + capexp from all previous years</td>
</tr>
<tr>
<td>accdepr: accumulated depreciation in road (schedule. 335, line 30, column g)</td>
</tr>
<tr>
<td>costkap: cost of capital (AAR railroad facts)</td>
</tr>
<tr>
<td>roilcm = return on investment in locomotives = [(iboloco+locinvl) – (acdoloco + locacdl)] * costkap</td>
</tr>
<tr>
<td>iboloco: investment base in owned locomotives (schedule 415, line 5, column g)</td>
</tr>
<tr>
<td>locinvl: investment base in leased locomotives (schedule 415, line 5, column j)</td>
</tr>
<tr>
<td>accoloco: accumulated depreciation of owned locomotives (schedule 415, line 5, column i)</td>
</tr>
<tr>
<td>locacdl: accumulated depreciation of leased locomotives (schedule 415, line 5, column j)</td>
</tr>
<tr>
<td>roicrs = return on investment in cars = [(ibocars + carinvl) – (acdocars + caracdl)]*costkap</td>
</tr>
<tr>
<td>ibocars: investment base in owned cars (schedule 415, line 24, column g)</td>
</tr>
<tr>
<td>carinvl: investment base in leased cars (schedule 415, line 24, column h)</td>
</tr>
<tr>
<td>acdocars: accumulated depreciation of owned cars (schedule 415, line 24, column i)</td>
</tr>
<tr>
<td>caracdl: accumulated depreciation of leased locomotives (schedule 415, line 24, column j)</td>
</tr>
</tbody>
</table>
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. c)
  caplab = labor portion of capital expenditure classification as operating in R1 (schedule 410, lines 12-30, 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 + w tgtm + 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)

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

\[ L = \sum_{h} P_{h}X_{h} - \phi[f(X) - Q] \]  

(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:

\[ L = \sum_{h} P_{h}X_{h} - \phi[f(X) - Q] - \sum_{i} \lambda_{i}R_{i}(P, X) \]  

(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 \( \phi \) and \( \lambda_{i} \) 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:

\[
\frac{\partial f}{\partial x_j} / \frac{\partial f}{\partial x_k} = \frac{p_j + \sum \lambda_i \partial R_i / \partial x_j}{p_k + \sum \lambda_i \partial R_i / \partial x_k} = \frac{p_j^*}{p_k^*}
\]

(10)

where the marginal product of input-\( j \) and input-\( k \) are presented by \( \frac{\partial f}{\partial X_j} \) and \( \frac{\partial f}{\partial X_k} \) respectively and the marginal rate of technical substitution between input-\( j \) and input-\( k \) is presented by \( \frac{\partial f}{\partial x_j} / \frac{\partial f}{\partial x_k} \). 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

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\(^{61}\) 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:

\[
C(\bar{w}_i, \bar{y}_k, \bar{a}_m, t) = \frac{C(\bar{w}_i, \bar{y}_k, \bar{a}_m, t)}{0!} + \sum_i \frac{\partial C}{\partial \bar{w}_i} (\bar{w}_i - \bar{w}_i) + \\
\sum_k \frac{\partial C}{\partial y_k} (y_k - \bar{y}_k) + \sum_m \frac{\partial C}{\partial a_m} (a_m - \bar{a}_m) \\
+ \frac{\partial C}{\partial t} (t - \bar{t}) + \sum_i \sum_j \frac{\partial^2 C}{\partial \bar{w}_i \partial \bar{w}_j} (\bar{w}_i - \bar{w}_i) (w_j - \bar{w}_j) \\
+ \sum_i \sum_k \frac{\partial^2 C}{\partial \bar{w}_i \partial y_k} (\bar{w}_i - \bar{w}_i) (y_k - \bar{y}_k) \\
+ \sum_i \sum_m \frac{\partial^2 C}{\partial \bar{w}_i \partial a_m} (\bar{w}_i - \bar{w}_i) (a_m - \bar{a}_m) + \sum_i \frac{\partial^2 C}{\partial \bar{w}_i \partial t} (\bar{w}_i - \bar{w}_i) (t - \bar{t}) \\
+ \sum_k \sum_i \frac{\partial^2 C}{\partial y_k \partial \bar{w}_i} (y_k - \bar{y}_k) (\bar{w}_i - \bar{w}_i) + \sum_k \sum_l \frac{\partial^2 C}{\partial y_k \partial \bar{y}_l} (y_k - \bar{y}_k) (y_l - \bar{y}_l) \\
+ \sum_k \sum_m \frac{\partial^2 C}{\partial y_k \partial a_m} (y_k - \bar{y}_k) (a_m - \bar{a}_m) + \sum_k \frac{\partial^2 C}{\partial y_k \partial t} (y_k - \bar{y}_k) (t - \bar{t}) \\
+ \sum_m \sum_i \frac{\partial^2 C}{\partial a_m \partial \bar{w}_i} (a_m - \bar{a}_m) (\bar{w}_i - \bar{w}_i) \\
+ \sum_m \sum_k \frac{\partial^2 C}{\partial a_m \partial y_k} (a_m - \bar{a}_m) (y_k - \bar{y}_k) + \sum_m \sum_n \frac{\partial^2 C}{\partial a_m \partial a_n} (a_m - \bar{a}_m) (a_n - \bar{a}_n)
\]
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:

\[
\ln C = \alpha_0 + \\
+ \sum_i \alpha_i \ln \left( \frac{w_i}{\bar{w}_i} \right) + \sum_k \beta_k \ln \left( \frac{y_k}{\bar{y}_k} \right) + \sum_m \sigma_m \ln \left( \frac{a_m}{\bar{a}_m} \right) + \theta t \\
+ \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln \left( \frac{w_i}{\bar{w}_i} \right) \ln \left( \frac{w_j}{\bar{w}_j} \right) + \sum_i \sum_k \tau_{ik} \ln \left( \frac{w_i}{\bar{w}_i} \right) \ln \left( \frac{y_k}{\bar{y}_k} \right) \\
+ \sum_l \sum_m \delta_{lm} \ln \left( \frac{w_l}{\bar{w}_l} \right) \ln \left( \frac{a_m}{\bar{a}_m} \right) \\
+ \sum_i \partial_i \ln \left( \frac{w_i}{\bar{w}_i} \right) t + \frac{1}{2} \sum_k \sum_l \beta_{kl} \ln \left( \frac{y_k}{\bar{y}_k} \right) \ln \left( \frac{y_l}{\bar{y}_l} \right) + \sum_k \sum_m \phi_{km} \ln \left( \frac{y_k}{\bar{y}_k} \right) \ln \left( \frac{a_m}{\bar{a}_m} \right) \\
+ \sum_k \pi_k \ln \left( \frac{y_k}{\bar{y}_k} \right) t + \frac{1}{2} \sum_m \sum_n \sigma_{mn} \ln \left( \frac{a_m}{\bar{a}_m} \right) \ln \left( \frac{a_n}{\bar{a}_n} \right) + \sum_m \mu_m \ln \left( \frac{a_m}{\bar{a}_m} \right) t \\
+ \frac{1}{2} \gamma t^2 + \epsilon
\]
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;

$$\frac{\partial \ln C}{\partial \ln w_i} = \alpha_i + \sum_j \alpha_{ij} \ln w_j + \sum_k \tau_{ik} \ln y_k + \sum_m \vartheta_{im} \ln a_m + \gamma_i t + \epsilon$$  \hspace{1cm} (13)

Since at the industry mean $w_i = \bar{w}_i, y_k = \bar{y}_k, a_m = \bar{a}_m, t = 0$, then $\frac{\partial \ln C}{\partial \ln w_i} = \alpha_i$. Thus $\alpha_L, \alpha_E, \alpha_M \text{ and } \alpha_{WS}$ 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 $\beta_k$ represents economies of scale and the coefficient $\vartheta_i$ 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:

$$\ln C = \alpha_0 +$$

$$+ \sum_i \alpha_i \ln \left(\frac{w_i}{\bar{w}_i}\right) + \sum_k \beta_k \ln \left(\frac{y_k}{\bar{y}_k}\right) + \sum_m \sigma_m \ln \left(\frac{a_m}{\bar{a}_m}\right) + \theta t$$

$$+ \frac{1}{2} \sum_i \sum_j \alpha_{ij} \ln \left(\frac{w_i}{\bar{w}_i}\right) \ln \left(\frac{w_j}{\bar{w}_j}\right) + \sum_i \sum_k \tau_{ik} \ln \left(\frac{w_i}{\bar{w}_i}\right) \ln \left(\frac{y_k}{\bar{y}_k}\right)$$

$$+ \sum_i \sum_m \vartheta_{im} \ln \left(\frac{w_i}{\bar{w}_i}\right) \ln \left(\frac{a_m}{\bar{a}_m}\right)$$

$$+ \sum_i \vartheta_i \ln \left(\frac{w_i}{\bar{w}_i}\right) t + \frac{1}{2} \sum_k \sum_i \beta_{ki} \ln \left(\frac{y_k}{\bar{y}_k}\right) \ln \left(\frac{y_i}{\bar{y}_i}\right) + \sum_k \sum_m \varphi_{km} \ln \left(\frac{y_k}{\bar{y}_k}\right) \ln \left(\frac{a_m}{\bar{a}_m}\right)$$

$$+ \sum_k \varphi_k \ln \left(\frac{y_k}{\bar{y}_k}\right) t + \frac{1}{2} \sum_m \sum_n \sigma_{mn} \ln \left(\frac{a_m}{\bar{a}_m}\right) \ln \left(\frac{a_n}{\bar{a}_n}\right) + \sum_m \mu_m \ln \left(\frac{a_m}{\bar{a}_m}\right) t$$

$$+ \frac{1}{2} \gamma t^2 + \epsilon$$  \hspace{1cm} (12)
\[
\frac{\partial \ln c}{\partial \ln w_i} = \alpha_i + \sum_j \alpha_{ij} \ln w_j + \sum_k \tau_{ik} \ln y_k + \sum_m \theta_{im} \ln a_m + \gamma_i t + \mu
\]  

(13)

In estimating the translog cost function, the variable depicting carrier use of a caboose is computed using a Box-Cox transformation\(^\text{62}\) 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 \(\sum_i \alpha_i = 1, \sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0, \sum_i \tau_{ik} = \sum_i \theta_{im} = \sum_i \gamma_i = 0, \alpha_{ij} = \alpha_{ji}\).

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

\[
\frac{MPl}{MPj} = \frac{w_i}{w_j}
\]

(14)

----

\(^{62}\) Box-Cox transformations is defined as \(y_\omega = \frac{y^\omega}{\omega}\) if \(\omega \neq 0\) and \(y_\omega = \ln y_i\) 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 \( i \)th 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

\[
\frac{MP_i}{MP_j} = \frac{w_i^*}{w_j^*}
\]  

(15)

where \( w_i^* \) is the shadow price for input \( i \)th. The shadow price is in the form of additive version as shown in the following equation.

\[
w_i^* = w_i + g_i
\]  

(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.

\[C^* = C^*(w_i^*, y)
\]  

(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

\[
\frac{\delta C^*(w_i^*, y)}{\delta w_i^*} = x_i
\]  

(18)

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

\[C = \sum_i w_i x_i
\]  

(19)

\[C^* = \sum_i w_i^* x_i
\]  

(20)

The following equations represent the actual cost share and shadow cost share for \( ith \) input respectively.

\[M_i = \frac{w_i x_i}{C}
\]  

(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.
\[ M_i^* = \frac{w_i x_i}{c^*} \]  

(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

\[ \frac{M_i^* c^*}{w_i^*} = x_i \]  

(23)

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

\[ C = \sum_i w_i \frac{M_i^* c^*}{(w_i^*)} = C^* \sum_i M_i^* \frac{w_i}{(w_i^*)} \]  

(24)

In logarithmic term this equation will become

\[ \ln C = \ln C^* + \ln \sum_i M_i^* \frac{w_i}{(w_i^* + g_i)} \]  

(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

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

\[ + \frac{1}{2} \sum_i \sum_j \beta_{ij} \ln (g_i + w_i) \ln (g_j + w_j) \]  

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

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

(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:

\[ M_i = \frac{w_i (M_i^* C^*)}{C^* \sum_i M_i^* w_i} = \frac{M_i^* w_i}{\sum_i M_i^* w_i} = \frac{w_i}{\sum_i (\alpha_i + \beta_{iy} \ln y + \sum_j \beta_{ij} \ln (g_j + w_j))} \]

(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:

\[ \varepsilon_{ii} = \frac{\partial x_i}{\partial w_i} \left( \frac{w_i}{x_i} \right) \]  
\[ (30) \]

\[ \varepsilon_{ij} = \frac{\partial x_i}{\partial w_j} \left( \frac{w_j}{x_i} \right) \]  
\[ (31) \]

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

\[ \varepsilon_{ii} = \frac{\partial (\partial C/\partial w_i)}{\partial w_i} \left( \frac{w_i}{x_i} \right) = \frac{\partial^2 C}{\partial w_i^2} \left( \frac{w_i}{x_i} \right) \quad \text{for all } i \]  
\[ (32) \]

\[ \varepsilon_{ij} = \frac{\partial (\partial C/\partial w_i)}{\partial w_j} \left( \frac{w_j}{x_i} \right) = \frac{\partial^2 C}{\partial w_i \partial w_j} \left( \frac{w_j}{x_i} \right) \quad \text{for all } i \neq j \]  
\[ (33) \]

For the translog cost function, \( \alpha_{ii} \) and \( \alpha_{ij} \) are represented by the following equations

\[ \alpha_{ii} = \frac{w_i w_i}{c} \frac{\partial^2 C}{\partial w_i^2} - S_i^2 + S_i \]  
\[ (34) \]

\[ \alpha_{ij} = \frac{w_i w_j}{c} \frac{\partial^2 C}{\partial w_i \partial w_j} - S_i S_j \]  
\[ (35) \]

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

\[ \frac{\partial^2 C}{\partial w_i^2} = (\alpha_{ii} + S_i^2 - S_i) \frac{c}{w_i} \]  
\[ (36) \]

\[ \frac{\partial^2 C}{\partial w_i \partial w_j} = (\alpha_{ij} + S_i S_j) \frac{c}{w_i w_j} \]  
\[ (37) \]

Therefore the own price elasticity is depicted in following equation:
\[ \varepsilon_{ii} = (\alpha_{ii} + S_i^2 - S_i) \frac{c}{w_i} \left( \frac{w_i}{x_i} \right) = (\alpha_{ii} + S_i^2 - S_i) \frac{1}{S_i} \quad (38) \]

\[ \varepsilon_{ii} = \frac{\alpha_{ii}}{S_i} + S_i - 1 \quad \text{for all } i \quad (39) \]

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

\[ \varepsilon_{ij} = (\alpha_{ij} + S_iS_j) \frac{c}{w_iw_j} \left( \frac{w_j}{x_i} \right) \quad (40) \]

\[ \varepsilon_{ij} = (\alpha_{ij} + S_iS_j) \frac{1}{S_i} \quad (41) \]

\[ \varepsilon_{ij} = \frac{\alpha_{ij}}{S_i} + S_j \quad \text{for all } i \neq j \quad (42) \]

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

\[ AES_{ij} = \frac{c}{x_i x_j} \left( \frac{\partial x_i}{\partial w_j} \right) \quad (43) \]

\[ AES_{ij} = \frac{c}{x_i x_j} \frac{\partial^2 c}{\partial w_i \partial w_j} = \frac{c}{x_i x_j} (\alpha_{ij} + S_iS_j) \frac{c}{w_iw_j} \quad (44) \]

\[ AES_{ij} = \frac{\alpha_{ij}}{S_iS_j} + 1 = \frac{\varepsilon_{ij}}{S_j} \quad \text{for all } i \neq j \quad (45) \]

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:

\[ MES_{ij} = \varepsilon_{ij} - \varepsilon_{ii} = AES_{ji}S_i - AES_{ii}S_i = S_i(AES_{ji} - AES_{ii}) \quad (46) \]

\[ MES_{ji} = \varepsilon_{ij} - \varepsilon_{jj} = AES_{ij}S_j - AES_{jj}S_j = S_j(AES_{ij} - AES_{jj}) \quad (47) \]
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.

$$SES_{ij} = \frac{s_i}{s_i + s_j} MES_{ij} + \frac{s_j}{s_i + s_j} MES_{ji}$$ (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\textsuperscript{64}.

\textsuperscript{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

<table>
<thead>
<tr>
<th>Monotonicity in output</th>
<th>Percentage satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{\partial C}{\partial y_U} &gt; 0$</td>
<td>96 percent of observations</td>
</tr>
<tr>
<td>$\frac{\partial C}{\partial y_W} &gt; 0$</td>
<td>82 percent of observations</td>
</tr>
<tr>
<td>$\frac{\partial C}{\partial y_T} &gt; 0$</td>
<td>93 percent of observations</td>
</tr>
</tbody>
</table>

Monotonicity in input prices

| $\frac{\partial C}{\partial w_L} > 0$ | 100 percent of observations |
| $\frac{\partial C}{\partial w_E} > 0$ | 100 percent of observations |
| $\frac{\partial C}{\partial w_F} > 0$ | 99.6 percent of observations |
| $\frac{\partial C}{\partial w_M} > 0$ | 100 percent of observations |
| $\frac{\partial C}{\partial w_{WS}} > 0$ | 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

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient without Shadow Price</th>
<th>Coefficient with Shadow Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>s.e.</td>
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<td>Intercept</td>
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<td>0.121083</td>
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<tr>
<td>w_L</td>
<td>0.332219***</td>
<td>0.008235</td>
</tr>
<tr>
<td>w_E</td>
<td>0.141867***</td>
<td>0.006931</td>
</tr>
<tr>
<td>w_F</td>
<td>0.062492***</td>
<td>0.015808</td>
</tr>
<tr>
<td>w_M</td>
<td>0.19176***</td>
<td>0.019363</td>
</tr>
<tr>
<td>w_ws</td>
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<td>0.007604</td>
</tr>
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<td>y_u</td>
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</tr>
<tr>
<td>y_w</td>
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<td>0.033108</td>
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<tr>
<td>y_t</td>
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<td>0.068071</td>
</tr>
<tr>
<td>a_miles</td>
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<td>0.11064</td>
</tr>
<tr>
<td>a_speed</td>
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<td>0.124695</td>
</tr>
<tr>
<td>a_haul</td>
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<td>0.11417</td>
</tr>
<tr>
<td>a_caboose</td>
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<td>0.004329</td>
</tr>
<tr>
<td>T</td>
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<td>0.00594</td>
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<tr>
<td>0.5(w_ws)^2</td>
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<td>0.008327</td>
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<td>0.115552</td>
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<tr>
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<tr>
<td>0.5(a_caboose)^2</td>
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<td>8.65E-07</td>
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<td>0.000291</td>
</tr>
<tr>
<td>w_L*w_E</td>
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<td>0.004659</td>
</tr>
<tr>
<td>w_L * w_F</td>
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<td>0.005044</td>
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<tr>
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<td>w_L * w_WS</td>
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<tr>
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<td>0.00209</td>
</tr>
<tr>
<td>w_L * y_W</td>
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<td>0.003361</td>
</tr>
<tr>
<td>w_L * y_T</td>
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<td>w_L * a_haul</td>
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<td>0.008477</td>
</tr>
<tr>
<td>w_L * a_caboose</td>
<td>2.09E-06**</td>
<td>9.91E-07</td>
</tr>
<tr>
<td>w_L * t</td>
<td>-0.00277***</td>
<td>0.000536</td>
</tr>
<tr>
<td>w_E * w_F</td>
<td>0.007701*</td>
<td>0.004551</td>
</tr>
<tr>
<td>w_E * w_M</td>
<td>0.015968**</td>
<td>0.00803</td>
</tr>
<tr>
<td>w_E * w_WS</td>
<td>-0.02348***</td>
<td>0.004246</td>
</tr>
<tr>
<td>w_E * y_U</td>
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<td>0.001987</td>
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<tr>
<td>w_E * y_W</td>
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<td>0.00324</td>
</tr>
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<td>w_E * y_T</td>
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<td>0.00579</td>
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<td>-0.03202***</td>
<td>0.008308</td>
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<td>0.009554</td>
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<td>0.008221</td>
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<td>9.42E-07</td>
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<td>w_F * w_M</td>
<td>0.032329***</td>
<td>0.011354</td>
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<tr>
<td>w_F * w_WS</td>
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<td>0.005023</td>
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<tr>
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<td>0.004678</td>
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<td>w_F * y_W</td>
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<td>0.007986</td>
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<td>0.012745</td>
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<td>0.017417</td>
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<td>Coefficients</td>
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<td>--------------------</td>
<td></td>
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<tr>
<td>( w_F^*a_{caboose} )</td>
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<td>( w_F^*t )</td>
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</tr>
<tr>
<td>( w_M^*w_{WS} )</td>
<td>(-0.01782^*)</td>
<td></td>
</tr>
<tr>
<td>( w_M^*y_{U} )</td>
<td>(-0.0144^*)</td>
<td></td>
</tr>
<tr>
<td>( w_M^*y_{W} )</td>
<td>(-0.0149)</td>
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</tr>
<tr>
<td>( w_M^*y_{T} )</td>
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<tr>
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</tr>
<tr>
<td>( w_M^*a_{speed} )</td>
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<tr>
<td>( w_M^*a_{haul} )</td>
<td>0.000982</td>
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<tr>
<td>( w_M^*a_{caboose} )</td>
<td>(4.20E-07)</td>
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<tr>
<td>( w_M^*t )</td>
<td>0.003085**</td>
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</tr>
<tr>
<td>( w_{WS}^*y_{U} )</td>
<td>(0.0077^***)</td>
<td></td>
</tr>
<tr>
<td>( w_{WS}^*y_{W} )</td>
<td>(0.011009^***)</td>
<td></td>
</tr>
<tr>
<td>( w_{WS}^*y_{T} )</td>
<td>(-0.04209^***)</td>
<td></td>
</tr>
<tr>
<td>( w_{WS}^*a_{miles} )</td>
<td>(0.026211^***)</td>
<td></td>
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<tr>
<td>( w_{WS}^*a_{speed} )</td>
<td>(-0.02474^**)</td>
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</tr>
<tr>
<td>( w_{WS}^*a_{haul} )</td>
<td>(0.029632***)</td>
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</tr>
<tr>
<td>( w_{WS}^*a_{caboose})</td>
<td>(-3.53E-07)</td>
<td></td>
</tr>
<tr>
<td>( w_{WS}^*t )</td>
<td>(0.001346^***)</td>
<td></td>
</tr>
<tr>
<td>( y_{U}^*y_{W} )</td>
<td>(-0.01806)</td>
<td></td>
</tr>
<tr>
<td>( y_{U}^*y_{T} )</td>
<td>(-0.10382^***)</td>
<td></td>
</tr>
<tr>
<td>( y_{U}^*a_{miles} )</td>
<td>(0.081328^**)</td>
<td></td>
</tr>
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<td>( y_{U}^*a_{speed} )</td>
<td>(0.041548)</td>
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<tr>
<td>( y_{U}^*a_{haul} )</td>
<td>(0.063843^*)</td>
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<td>(-8.83E-06)</td>
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<td>( y_{U}^*t )</td>
<td>(0.005097^***)</td>
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<tr>
<td>( y_{W}^*y_{T} )</td>
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<td></td>
</tr>
<tr>
<td>( y_{W}^*a_{miles} )</td>
<td>(0.058338)</td>
<td></td>
</tr>
<tr>
<td>( y_{W}^*a_{speed} )</td>
<td>(-0.02817)</td>
<td></td>
</tr>
<tr>
<td>( y_{W}^*a_{haul} )</td>
<td>(-0.06164)</td>
<td></td>
</tr>
<tr>
<td>( y_w \cdot a_{\text{caboose}} )</td>
<td>6.24E-06</td>
<td>5.43E-06</td>
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<tr>
<td>( y_w \cdot t )</td>
<td>0.001061</td>
<td>0.001983</td>
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<tr>
<td>( y_t \cdot a_{\text{miles}} )</td>
<td>-0.26305***</td>
<td>0.071801</td>
</tr>
<tr>
<td>( y_t \cdot a_{\text{speed}} )</td>
<td>0.268759**</td>
<td>0.102769</td>
</tr>
<tr>
<td>( y_t \cdot a_{\text{haul}} )</td>
<td>-0.24484***</td>
<td>0.127301</td>
</tr>
<tr>
<td>( y_t \cdot a_{\text{caboose}} )</td>
<td>0.000021</td>
<td>0.000014</td>
</tr>
<tr>
<td>( y_t \cdot t )</td>
<td>-0.00919**</td>
<td>0.004073</td>
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<td>( a_{\text{miles}} \cdot a_{\text{speed}} )</td>
<td>-0.19674</td>
<td>0.124143</td>
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<td>( a_{\text{miles}} \cdot a_{\text{haul}} )</td>
<td>0.317286**</td>
<td>0.147259</td>
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<td>( a_{\text{miles}} \cdot a_{\text{caboose}} )</td>
<td>-9.14E-06</td>
<td>0.000015</td>
</tr>
<tr>
<td>( a_{\text{miles}} \cdot t )</td>
<td>0.007011</td>
<td>0.006299</td>
</tr>
<tr>
<td>( a_{\text{speed}} \cdot a_{\text{haul}} )</td>
<td>-0.59909***</td>
<td>0.187301</td>
</tr>
<tr>
<td>( a_{\text{speed}} \cdot a_{\text{caboose}} )</td>
<td>-0.00002</td>
<td>0.000013</td>
</tr>
<tr>
<td>( a_{\text{speed}} \cdot t )</td>
<td>0.001409</td>
<td>0.006531</td>
</tr>
<tr>
<td>( a_{\text{haul}} \cdot a_{\text{caboose}} )</td>
<td>-0.00003</td>
<td>0.000032</td>
</tr>
<tr>
<td>( a_{\text{haul}} \cdot t )</td>
<td>-0.00013</td>
<td>0.006571</td>
</tr>
<tr>
<td>( a_{\text{caboose}} \cdot t )</td>
<td>-6.48E-07</td>
<td>1.26E-06</td>
</tr>
<tr>
<td>( g_2 )</td>
<td>0.149296</td>
<td>0.1157</td>
</tr>
<tr>
<td>( g_3 )</td>
<td>-0.00002***</td>
<td>8.78E-07</td>
</tr>
<tr>
<td>( g_4 )</td>
<td>1.091199</td>
<td>0.9781</td>
</tr>
<tr>
<td>( g_5 )</td>
<td>0.093678</td>
<td>0.0679</td>
</tr>
</tbody>
</table>

*Note.* \( g_2 \) for equipment, \( g_3 \) for fuel, \( g_4 \) for material and \( g_5 \) 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 
\( E_{\text{LW}} \) is positive while the sign of \( E_{\text{WL}} \) 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 \( MES_{\text{WF}} \). 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 
\( MES_{\text{FL}}, MES_{\text{ML}}, MES_{\text{FE}}, MES_{\text{ME}}, MES_{\text{FM}}, MES_{\text{MF}}, MES_{\text{FW}} \) and \( MES_{\text{MW}} \) are found to be 
larger than one. For example, the value of 1.17 for \( MES_{\text{FL}} \) represents the percentage 
change in fuel-labor ratio (F/L), when the relative price (\( w_{\text{L}}/w_{\text{F}} \)) 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 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**

<table>
<thead>
<tr>
<th>OWN PRICE</th>
<th>Average</th>
<th>AES</th>
<th>Average</th>
<th>MES</th>
<th>Average</th>
<th>SES</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELL</td>
<td>-0.34758</td>
<td>AESLL</td>
<td>0.285134</td>
<td>MESLE</td>
<td>0.4462633</td>
<td>SESLE</td>
<td>0.5211549</td>
</tr>
<tr>
<td>EE</td>
<td>-0.67746</td>
<td>AESEE</td>
<td>1.218333</td>
<td>MESLF</td>
<td>0.722101</td>
<td>SESLF</td>
<td>0.8091222</td>
</tr>
<tr>
<td>EFF</td>
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<td>AESFF</td>
<td>0.374722</td>
<td>MESFL</td>
<td>1.1742053</td>
<td>SESLF</td>
<td>0.8505323</td>
</tr>
<tr>
<td>EMM</td>
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<td>AESMM</td>
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<td>MESLM</td>
<td>0.6436961</td>
<td>SESLM</td>
<td>0.2424007</td>
</tr>
<tr>
<td>EWW</td>
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<td>0.296247</td>
<td>MESWL</td>
<td>0.1119124</td>
<td>SESWL</td>
<td>0.1043121</td>
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</tbody>
</table>

**CROSS PRICE**

<table>
<thead>
<tr>
<th>OWN PRICE</th>
<th>AES</th>
<th>Average</th>
<th>Average</th>
<th>MES</th>
<th>Average</th>
<th>SES</th>
<th>Average</th>
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</thead>
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<tr>
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<td>SESLF</td>
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<td>MESLM</td>
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<td>SESLM</td>
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</tr>
<tr>
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<tr>
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<td>MESME</td>
<td>1.2838617</td>
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<td></td>
</tr>
</tbody>
</table>

---

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.
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

| $E_{EW}$ | 0.051119 | AES$_{EW}$ | 0.109427 | MES$_{EW}$ | 0.699452 | SES$_{EW}$ | 0.3310974 |
| $E_{WE}$ | 0.021293 | AES$_{WE}$ | 0.109427 | 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.
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.
Reference


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

For the translog function: \( \frac{\partial \ln c}{\partial w_i \partial w_j} = \frac{\partial (\ln c / \partial w_j)}{\partial \ln w_i} = \gamma_{ij} \)

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

1) \( \frac{\partial \ln c}{\partial w_j} = \frac{\partial c}{c} \frac{w_j}{\partial w_j} = \frac{\partial c}{\partial w_j} \frac{w_j}{c} \)

2) \( \gamma_{ij} = \frac{\partial^2 \ln c}{\partial \ln w_i \partial \ln w_j} = \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \frac{w_i}{c} \frac{w_j}{c} = \frac{w_i}{c} \frac{w_j}{c} \left\{ \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \cdot \frac{c}{w_i} + \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \cdot \frac{c}{w_j} \right\} \)

3) \( \gamma_{ij} = w_i \left\{ \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \cdot \frac{c}{w_i} + \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \cdot \frac{c}{w_j} \right\} \)

4) \( \gamma_{ij} = w_i \left\{ \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \cdot \frac{c}{w_i} + \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} \cdot \frac{c}{w_j} \right\} \)

5) \( \gamma_{ij} = \frac{w_i w_j}{c} \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_j} - S_i S_j \)

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

7) \( \frac{\partial \ln c}{\partial \ln w_i} = \frac{\partial c}{c} \frac{w_i}{\partial w_i} = \frac{\partial c}{\partial w_i} \frac{w_i}{c} \)

8) \( \gamma_{ii} = \frac{\partial^2 \ln c}{\partial \ln w_i \partial \ln w_i} = \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \frac{w_i}{c} \frac{w_i}{c} = \frac{w_i}{c} \frac{w_i}{c} \left\{ \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \cdot \frac{c}{w_i} + \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \cdot \frac{c}{w_i} \right\} \)

9) \( \gamma_{ii} = w_i \left\{ \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \cdot \frac{c}{w_i} + \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \cdot \frac{c}{w_i} \right\} \)

10) \( \gamma_{ii} = w_i \left\{ \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \cdot \frac{c}{w_i} + \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} \cdot \frac{c}{w_i} \right\} \)

11) \( \gamma_{ii} = \frac{w_i w_i}{c} \frac{\partial^2 c}{\partial \ln w_i \partial \ln w_i} - w_i \frac{w_i w_i}{c} \frac{c}{w_i} \)
12) \( \gamma_{ii} = \frac{w_i w_i}{c} \frac{\partial^2 c}{\partial w_i^2} - S_i S_i + S_i = \frac{w_i^2}{c} \frac{\partial^2 c}{\partial w_i^2} - S_i^2 + S_i \\
\quad \frac{\partial^2 c}{\partial w_i^2} = (\gamma_u + S_i^2 - S_i) \frac{c}{w_i^2} \)
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. 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

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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:

\[
\left( \frac{C_P - C_R}{C_R} \right) \times 100
\]  

(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.

\[
PGX = - \frac{\partial \ln C}{\partial t} 
\]

(2)

\[
PGY = - \frac{\partial \ln C / \partial t}{\sum \partial \ln C / \partial \ln Q_i}
\]

(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:

\[
\frac{\partial \ln C}{\partial t}
\]

(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-I 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\textsuperscript{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

\textsuperscript{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 $-\frac{w_N}{w_L}$ to $-\frac{w_N}{w_L'}$. 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 suggest 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.
Freeman et al. (1987) highlight that the relationship between changes in factor prices and its cost share is not straightforward. 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:

\[
\text{RAC} = \frac{C(ty^o)}{t}
\]

\(^{71}\) Baumol et al. (1988) are referring to the average cost of the composite goods.
where RAC represents ray average cost, $y^o$ represents the unit bundle for a specific mixture of outputs and $t$ represents the number of units in the bundle $= ty^o$. 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 $y^o$. 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.
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\textsuperscript{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”

\textsuperscript{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:

\[
\dot{C} - \dot{Q}^c = \sum_i \left( \frac{P_i X_i}{C} \right) \dot{P}_i + \left( \sum_j \varepsilon_{cQ_j} - 1 \right) \dot{Q}^c + \dot{B}
\]

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

\[
\dot{C} = \frac{1}{C} \frac{dC}{dt}; \quad (6)
\]

\[
\dot{Q}^c = \sum_j \left( \frac{\varepsilon_{cQ_j}}{\sum \varepsilon_{cQ_j}} \right) \left( \frac{1}{Q_j} \frac{dQ_j}{dt} \right); \quad (7)
\]

\[
\dot{P}_i = \frac{1}{P_i} \frac{dP_i}{dt}; \quad (8)
\]

\[
\dot{B} = \sum_k \varepsilon_{cT_k} \left( \frac{1}{T_k} \frac{dT_k}{dt} \right); \quad (9)
\]

\(\varepsilon_{cQ_j}\) 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:

\[ C = f(w_i, y_k, a_m, t) \]  
\[ w_i = (w_L, w_E, w_F, w_M, w_{WS}) \]  
\[ y_k = (y_U, y_W, y_T) \]  
\[ a_m = (a_{miles}, a_{speed}, a_{haul}, a_{caboose}) \]

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 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:

\[ \ln C = \alpha_0 + \sum_i \alpha_i \ln \left( \frac{w_i}{\bar{w}_i} \right) + \sum_k \beta_k \ln \left( \frac{y_k}{\bar{y}_k} \right) + \sum_m \sigma_m \ln \left( \frac{a_m}{\bar{a}_m} \right) + \theta t \]

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

\[
\frac{\partial \ln C}{\partial \ln w_i} = \alpha_i + \sum_j \alpha_{ij} \ln w_j + \sum_k \tau_{ik} \ln y_k + \sum_m \theta_{im} \ln a_m + \gamma t + \epsilon
\]  

(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 \( \beta_k \) depicts the effect of economies of scale on the employment of factor inputs and \( \partial_i \) 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. 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 \( \sum_i \alpha_i = 1, \sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0, \sum_i \tau_{ik} = \sum_i \theta_{im} = \sum_i y_i = 0, \alpha_{ij} = \alpha_{ji}. \)

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.

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74 The variable caboose consists of zero values. Box-Cox transformations is applied to this variable where \( y_i^\omega = \frac{y_i}{\omega} \) if \( \omega \neq 0 \) and \( y_i^\omega = \ln y_i \) if \( \omega = 0 \). A very small value of \( \omega (0.0001) \) 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):

\[
\dot{C} = \sum_{i=1}^{I} \frac{x_i w_i}{c} \dot{w}_i + \sum_{k=1}^{K} \frac{\partial f}{\partial y_k} \frac{y_k}{c} \dot{y}_k + \sum_{m=1}^{M} \frac{\partial f}{\partial a_m} \frac{a_m}{c} \dot{a}_m + \tau
\]  

(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

\[
S_i = \frac{x_i w_i}{c}
\]

(17)

The cost elasticity with respect to output \(y_k\) is given as

\[
\mu_{CY_k} = \frac{\partial f}{\partial y_k} \frac{y_k}{c}
\]

(18)

The cost elasticity with respect to technological characteristics is

\[
\mu_{CA_M} = \frac{\partial f}{\partial a_m} \frac{a_m}{c}
\]

(19)

Therefore, equation (16) can be written as:

\[
\dot{C} = \sum_{i=1}^{I} S_i \dot{w}_i + \sum_{k=1}^{K} \mu_{CY_k} \dot{y}_k + \sum_{m=1}^{M} \mu_{CA_M} \dot{a}_m + \tau
\]

(20)

Furthermore, the rate of change in the weighted product mix is represented as
\[ \dot{y} = \frac{\sum_k \mu_{CY_k} y_k}{\sum_k \mu_{CY_k}} \]  

(21)

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

\[ \dot{C} = \sum_{l} S_I \dot{w}_I + \sum_{k} \mu_{CY_k} \dot{y} + \sum_{m} \mu_{CA} \dot{a}_m + \tau \]  

(22)

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

\[ \dot{C} - \dot{y} = \sum_{l} S_I \dot{w}_I + (\sum_k \mu_{CY_k} - 1) \dot{y} + \sum_{m} \mu_{CA} \dot{a}_m + \tau \]  

(23)

where \(\sum_{l} S_I \dot{w}_I\) represents factor price effects, \((\sum_k \mu_{CY_k} - 1) \dot{y}\) represents scale effect, \(\sum_{m} \mu_{CA} \dot{a}_m\) represents movement characteristics effects and \(\tau\) 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

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

\(^{75}\) Price of way and structures is calculated by \(\text{ROIRD} + \text{ANNDEPRD} \) / 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

<table>
<thead>
<tr>
<th>Year</th>
<th>Labor</th>
<th>Equipment</th>
<th>Fuel</th>
<th>Material</th>
<th>Way &amp; structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983-1984</td>
<td>-0.00694</td>
<td>0.000338</td>
<td>-0.11128</td>
<td>-0.00515</td>
<td>0.097579</td>
</tr>
<tr>
<td>1984-1985</td>
<td>-0.01391</td>
<td>0.183298</td>
<td>-0.04033</td>
<td>0.038545</td>
<td>-0.08047</td>
</tr>
<tr>
<td>1985-1986</td>
<td>-0.00586</td>
<td>-0.13545</td>
<td>-0.36455</td>
<td>-0.0114</td>
<td>-0.08689</td>
</tr>
<tr>
<td>1986-1987</td>
<td>0.059382</td>
<td>0.019961</td>
<td>-0.06704</td>
<td>-0.05148</td>
<td>0.035742</td>
</tr>
<tr>
<td>1987-1988</td>
<td>0.040767</td>
<td>0.054636</td>
<td>-0.02771</td>
<td>0.044568</td>
<td>0.005421</td>
</tr>
<tr>
<td>1988-1989</td>
<td>-0.00229</td>
<td>0.093815</td>
<td>0.093809</td>
<td>0.055291</td>
<td>-0.01984</td>
</tr>
<tr>
<td>1989-1990</td>
<td>0.011942</td>
<td>-0.00599</td>
<td>0.18121</td>
<td>0.039987</td>
<td>0.088533</td>
</tr>
<tr>
<td>Period</td>
<td>Labor</td>
<td>Equipment</td>
<td>Fuel</td>
<td>Material</td>
<td>Way &amp; structure</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
<td>----------</td>
<td>-----------------</td>
</tr>
<tr>
<td>1990-1991</td>
<td>-0.02419</td>
<td>0.157129</td>
<td>-0.05312</td>
<td>0.138369</td>
<td>0.05022</td>
</tr>
<tr>
<td>1991-1992</td>
<td>-0.00404</td>
<td>0.009505</td>
<td>-0.08472</td>
<td>0.055334</td>
<td>0.010554</td>
</tr>
<tr>
<td>1992-1993</td>
<td>-0.0245</td>
<td>0.033542</td>
<td>-0.02865</td>
<td>0.035676</td>
<td>0.0766</td>
</tr>
<tr>
<td>1993-1994</td>
<td>0.031052</td>
<td>0.155352</td>
<td>-0.06645</td>
<td>0.017413</td>
<td>0.125922</td>
</tr>
<tr>
<td>1994-1995</td>
<td>-0.00149</td>
<td>0.084085</td>
<td>-0.05361</td>
<td>0.033785</td>
<td>0.253525</td>
</tr>
<tr>
<td>1995-1996</td>
<td>0.341365</td>
<td>0.258941</td>
<td>0.11256</td>
<td>-0.00606</td>
<td>0.091615</td>
</tr>
<tr>
<td>1996-1997</td>
<td>-0.18045</td>
<td>-0.19989</td>
<td>-0.02438</td>
<td>0.016725</td>
<td>-0.1317</td>
</tr>
<tr>
<td>1997-1998</td>
<td>-0.07492</td>
<td>-0.06027</td>
<td>-0.22093</td>
<td>0.00933</td>
<td>-0.0714</td>
</tr>
<tr>
<td>1998-1999</td>
<td>0.025566</td>
<td>0.346894</td>
<td>0.050127</td>
<td>0.023206</td>
<td>0.054978</td>
</tr>
<tr>
<td>1999-2000</td>
<td>-0.02139</td>
<td>-0.12966</td>
<td>0.552941</td>
<td>0.008622</td>
<td>-0.00587</td>
</tr>
<tr>
<td>2000-2001</td>
<td>0.006883</td>
<td>0.033016</td>
<td>-0.05976</td>
<td>0.022784</td>
<td>-0.02569</td>
</tr>
<tr>
<td>2001-2002</td>
<td>0.017849</td>
<td>0.008705</td>
<td>-0.14479</td>
<td>-0.01813</td>
<td>0.007207</td>
</tr>
<tr>
<td>2002-2003</td>
<td>0.013432</td>
<td>-0.00163</td>
<td>0.172662</td>
<td>0.001408</td>
<td>0.013009</td>
</tr>
<tr>
<td>2003-2004</td>
<td>0.027013</td>
<td>0.067565</td>
<td>0.219808</td>
<td>0.069531</td>
<td>0.23569</td>
</tr>
<tr>
<td>2004-2005</td>
<td>-0.00444</td>
<td>0.084689</td>
<td>0.358394</td>
<td>0.097882</td>
<td>0.248533</td>
</tr>
<tr>
<td>2005-2006</td>
<td>-0.00212</td>
<td>-0.12654</td>
<td>0.215591</td>
<td>0.103925</td>
<td>-0.13831</td>
</tr>
<tr>
<td>2006-2007</td>
<td>-0.04822</td>
<td>0.1932</td>
<td>0.068549</td>
<td>0.075579</td>
<td>0.165678</td>
</tr>
<tr>
<td>2007-2008</td>
<td>-0.0209</td>
<td>0.014507</td>
<td>0.420555</td>
<td>0.093915</td>
<td>0.067314</td>
</tr>
</tbody>
</table>

**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**

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

<table>
<thead>
<tr>
<th></th>
<th>Cost Changes</th>
<th>PL effect</th>
<th>PE effect</th>
<th>PF effect</th>
<th>PM effect</th>
<th>PW effect</th>
<th>Price effect</th>
<th>Scale effect</th>
<th>Milered</th>
<th>Speed</th>
<th>Avehaul</th>
<th>Caboose</th>
</tr>
</thead>
<tbody>
<tr>
<td>83-84</td>
<td>-0.2410</td>
<td>0.0026</td>
<td>-0.0129</td>
<td>-0.0103</td>
<td>-0.0007</td>
<td>0.0204</td>
<td>-0.0009</td>
<td>-0.2336</td>
<td>0.0515</td>
<td>0.0042</td>
<td>0.0009</td>
<td>-0.0006</td>
</tr>
<tr>
<td>84-85</td>
<td>-0.0003</td>
<td>-0.0073</td>
<td>0.0180</td>
<td>-0.0027</td>
<td>0.0075</td>
<td>-0.0015</td>
<td>0.0139</td>
<td>-0.0787</td>
<td>0.1041</td>
<td>0.0018</td>
<td>0.0111</td>
<td>-0.0006</td>
</tr>
<tr>
<td>85-86</td>
<td>-0.1139</td>
<td>-0.0010</td>
<td>-0.0148</td>
<td>-0.0293</td>
<td>-0.0026</td>
<td>-0.0187</td>
<td>-0.0663</td>
<td>-0.0833</td>
<td>0.1180</td>
<td>-0.0236</td>
<td>-0.0015</td>
<td>-0.0011</td>
</tr>
<tr>
<td>86-87</td>
<td>-0.0568</td>
<td>0.0203</td>
<td>0.0027</td>
<td>-0.0061</td>
<td>-0.0110</td>
<td>0.0082</td>
<td>0.0141</td>
<td>-0.1396</td>
<td>0.0914</td>
<td>0.0164</td>
<td>0.0039</td>
<td>-0.0008</td>
</tr>
<tr>
<td>87-88</td>
<td>-0.0632</td>
<td>0.0153</td>
<td>0.0047</td>
<td>-0.0015</td>
<td>0.0097</td>
<td>0.0031</td>
<td>0.0313</td>
<td>-0.0540</td>
<td>-0.0032</td>
<td>-0.0076</td>
<td>0.0108</td>
<td>-0.0009</td>
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<tr>
<td>88-89</td>
<td>-0.0791</td>
<td>-0.0008</td>
<td>0.0129</td>
<td>0.0075</td>
<td>0.0117</td>
<td>-0.0043</td>
<td>0.0270</td>
<td>-0.0162</td>
<td>-0.0415</td>
<td>-0.0068</td>
<td>0.0026</td>
<td>-0.0010</td>
</tr>
<tr>
<td>89-90</td>
<td>-0.0168</td>
<td>0.0043</td>
<td>-0.0008</td>
<td>0.0142</td>
<td>0.0088</td>
<td>0.0185</td>
<td>0.0450</td>
<td>-0.0360</td>
<td>0.0190</td>
<td>-0.0026</td>
<td>-0.0018</td>
<td>-0.0009</td>
</tr>
<tr>
<td>90-91</td>
<td>0.0068</td>
<td>-0.0087</td>
<td>0.0207</td>
<td>-0.0042</td>
<td>0.0293</td>
<td>0.0110</td>
<td>0.0482</td>
<td>-0.0190</td>
<td>0.0147</td>
<td>-0.0012</td>
<td>0.0003</td>
<td>-0.0003</td>
</tr>
<tr>
<td>91-92</td>
<td>-0.0057</td>
<td>-0.0015</td>
<td>0.0012</td>
<td>-0.0065</td>
<td>0.0123</td>
<td>0.0023</td>
<td>0.0079</td>
<td>-0.0876</td>
<td>0.0953</td>
<td>-0.0017</td>
<td>0.0078</td>
<td>-0.0006</td>
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<td>92-93</td>
<td>-0.0277</td>
<td>-0.0085</td>
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<td>0.0002</td>
<td>0.0081</td>
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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\textsuperscript{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\textsuperscript{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

\textsuperscript{77} High labor productivity is mainly due to “technological and institutional innovation” (Martland, 2012).

\textsuperscript{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.
References


## Appendix D: Translog cost results

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</table>

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

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