INPUT ALLOCATION EFFICIENCY IN THE UNITED STATES RAILROAD INDUSTRY: CHANGING WORK RULES AND MANAGERIAL FLEXIBILITY

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Abstract

Following regulatory reform in the late 20th century, US 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. This study explores the possibility of movement away from railroad input market distortion found in research examining pre-regulatory reform input allocation, and movement toward allocative efficient use of inputs following regulatory reform. Shadow input costs are estimated using Class I railroad cost information from 1983 to 2015 to examine the change in input usage over time. Using labor as the benchmark of comparison, we find that the use of all inputs aligns in a more allocatively efficient way with labor now than in 1983. This comports well with the notion that significant easing of work rule restrictions facilitates a more efficient use of labor relative to non-labor inputs.

Keywords: allocative efficiency, railroad industry, regulatory reform.

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1. Introduction

Regulatory reform enacted in the last quarter of the 20th century facilitated major transformation of the US 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). Reform further promoted profitable and efficient operations of rail firms by easing regulations limiting Class I carriers' ability to abandon non-profitable rail lines (Winston, 1998). Winston (1998) reveals evidence of significant efficiency gains from regulator reform, observing that real operating cost per ton-mile fell 60 percent immediately following regulatory reform.[1] 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 regulatory reform contracts with shippers included provisions making it easier for rail firms to align their cars and equipment with shipper demand and 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) present a direct test of changes in crew size and productivity. Using the translog specification to estimate costs for the railroad industry they investigate the effect of post deregulation innovation on rail freight productivity attributable to the elimination of cabooses and related crew members. Their findings indicate that the elimination of cabooses and the associated crew members decreased costs of Class I carriers by 5-8 percent from 1983 to 1997.

While past work focuses on the effect of more lenient work rules on railroad productivity, there is a dearth of research examining whether these carriers use an allocatively efficient combination of factor inputs following regulatory reform.[2] Such an analysis is significant, because it helps identify a previously unexamined source of post regulatory reform productivity gains and reveals whether there is opportunity for rail carriers to achieve greater productivity

[1]Bereskin (1996) shows that following the 1978 4R act and Staggers act of 1980 railroad productivity grew of 2.72 percent, 6.44 percent and 12.34 percent for 1978-1980, 1978-1982 and 1981-1982 respectively.
[2] In contrast to the amount of research on resource misallocation post regulatory reform, there is notable research examining pre-regulatory reform input allocation inefficiency in the rail industry (Atkinson et al. 2003 and Khumbhakar (1988).

gains by negotiating less rigid work rules. This study estimates a translog cost function to test whether rail firms used an allocatively efficient mix of labor and non-labor inputs shortly after deregulation, and whether this mix has changed in more recent years.

The remainder of the study consists of five additional sections. The succeeding section documents changing work rules following deregulation and the potential for achieving an allocatively efficient mix of factor inputs due to such labor market changes. Section 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 I U.S. rail carriers use an allocatively efficient combination of labor and non-labor inputs. Section 5 presents empirical results and examines whether the combination of inputs is allocatively efficient. Last, concluding remarks are presented in section 6.

2 Changing Work rules and Stepped Up Investment in Rail Infrastructure

Pre-Deregulation Input Market

The U.S. railroad industry has a long history of government oversight of its operations. While regulation of rates, entry, and exit has received substantial attention from past research, much less analysis examines regulatory oversight of this industry's labor market. Major labor legislation was enacted as far back as the turn of the 20th century. For instance, the Railroad Hours of Service Act was passed in 1907, to avoid erosion of employee well-being associated with long hours of work and to enhance safety. Maximum consecutive hours of work with minimum hours of rest were stipulated in the code of federal regulations (CFR).[3] For instance, provision (49 CFR 228) reported below, highlights the emphasis this act placed on working conditions.

> Limitation on Hours: The Act establishes two limitations on hours of service. First, no employee engaged in train or engine service may be required 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.

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

> 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)[4]

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 large rail networks (Cappelli, 1985). Nonetheless, enforcing hours of service regulations introduces unintended consequences by contributing to input market distortions (Kumbhakar, 1992). Such distortions arise if hours of service regulation creates an incentive for railroad employers to hire 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. 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 contributed to the guidelines for determining rail workers' earnings becoming 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 distort 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. Distance traveled to be considered as a work day took less time, making it easier for rail workers to earn overtime wages and leading to an increase in labor

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

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 bedding--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 that 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 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 necessarily commensurate with their productivity.

Post-deregulation Input Market

The last quarter of the twentieth century witnessed a sea change in policy regarding the regulation of business practices in the rail industry and rail companies' investments in cost-saving technology. Economic theory predicts that both of these events should influence the mix of inputs in this industry. Regulatory reform placed downward pressure on rates by increasing rate flexibility 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.

Using rail carrier data from 1961 to 1990, Hsing and Mixon (1995) report findings suggesting that following regulatory reform the labor demand curve for rail workers shifted downward significantly, while the marginal product of labor increased. Wage patterns following regulatory reform are somewhat more complicated. Talley and Schwarz-Miller reveal real weekly earnings increased immediately following passage of the Staggers act, peaking in 1988 and then declining relative to 1983 earnings for the 1989-1993 observation period. They attribute the decline to the absence of increases in nominal contract pay for the 1988-1991 period and moderate increase thereafter. Their 1983-1988 findings are consistent with Hendricks' (1994) findings of an increase in the rail-non-rail wage premium from 1980-1988. More current research by Peoples (2014) reveals real wages of non-management rail workers continued to decline from 1990 to 1995, then stabilized from 1995 to 2011. In sum, as Talley and Schwarz-Miller (1998, p. 151) reveal, "the Staggers Act in particular provided a basis for railroads to press more effectively for work- and pay-rule changes and moderation in wage increase." Consistent with this observation, Hendrick's (1994, p. 228) states that "Regulation did, constrain management's ability to use its work force in the most efficient manner."

Enhanced labor substitutability linked to regulatory reform arises from this policy, facilitating a business environment that places a premium on technology investment as a means to lower costs, in large part by reducing labor content in rail operations. Examples of post regulatory reform labor saving technology include the introduction of electronic switching systems, communications technology, fuel efficient locomotives, and new track technology. Innovation in switching systems constitute grouping of the switch boxes or posts, automation of hump-yard switching, and installation of electronic transponder devices which makes the operating systems of trains easier with less man-handling involved (Schwarz-Miller and Talley, 2002). Indeed, the employment of switchmen and brakemen following the introduction of this system fell from 50,578 in 1983 to 7,238 by 2010.[5] 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. 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[6], hot box[7] and dragging equipment detectors[8] contribute to the elimination of caboose, which in turn eliminated the need for brakemen.[9] 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).

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[5] Source: Unionstats.com

[6] The end-of-train device conveys information to the engineer on the braking systems such as brake pressure and enables him\her to set breaks on the trains. (http://www.up.com/aboutup/history/caboose/technology_overtakes/index.htm)

[7] Hot boxes, which are installed on the track line, monitor the wheel and brake temperature.

[8] Such equipment provides detection of potential train derailment.

[9] A caboose is known as a conductor office, carrying also a brakemen and a flagmen. In early years, the engineer whistled the brakemen in the caboose to maneuver the brake wheels while the flagmen cautioned other train that came closer.

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.[10] 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 that 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 regulatory reform and during the introduction of labor saving technology weakened rail unions' ability to retain rigid work rules that protected worker job security. Evidence of relatively flexible work rules following regulatory reform 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 regulatory reform settlements starting in 1985 changed the stipulation of a standard work day for a rail worker from the previous to100 to 108 miles. Succeeding negotiations led to a more significant increase of 130 miles as the definition of a day's work by 1995. More current railroad union contracts exclude the standard work day based on miles hauled and now provide pay based on hours worked or mileage (mileage-rate) transported given a specific weight of freight hauled. This pay structure change provides managerial flexibility to pay wages close to marginal productivity, especially pay based on miles hauled.[11] Settlements also reduced crew sizes by initially phasing out firemen and hostlers.[12] By 1991 train crew sizes fell from consisting

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[10] Improvements in track technology did not start with deregulation, however, as Schwarz-Miller and Talley (2002) report, deregulation promoted greater use of this technology by increasing traffic density on major routes.

[11] The mileage rate schedule negotiated between the United Transportation Union (UTU) and Class I carriers stipulates mileage rate pay for locomotive engineers starting a low of $1.75 per mile for less than 40,000 pounds hauled to a maximum of $1.79 per mile for 1,000,000 pounds hauled.

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

of an engineer, conductor and two brakemen to consisting of just two workers, typically an engineer and conductor.

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 regulations, however, might create a challenge to rail managers' ability to employ an optimal number of workers. 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).

The preceding presentation of changing work-rule regulations following deregulation in the rail industry suggests rail employers face less limitations in 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 indicate labor market changes in 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 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 with moderation in wage increases (Talley and Schwarz-Miller, 1998). This suggests the possibility of a movement toward allocatively efficient use of labor relative to non-labor inputs.

Past research on input allocation inefficiency in the railroad industry focuses on pre-regulatory reform employment of factor inputs, and does observe a misallocation of resources prior to regulatory reform. For example using rail data covering the years 1951 to 1975, Atkinson, Fare and Primont (2003) find fuel, equipment, and way and structures were overutilized relative to labor. This misallocation of resources relative to labor, though, decreased over time, and labor was actually over utilized relative to equipment by 1966.[13] The authors argue these results are consistent with the notion that regulation limiting Class I carriers' ability to abandon unprofitable routes contributed to a misallocation of equipment (locomotives and cars), fuel, and way and structures relative to labor. However, the shift away from underutilization of labor over time suggests the possibility rigid work rules began to play a more dominant role influencing resource misallocation as the industry neared regulatory reform.

Importantly, while Atkinson, et. al (2003) found that an inability to abandon unprofitable routes contributed to an overutilization of way & structures input relative to labor, our findings should differ from theirs. We examine allocative efficiency between way & structures input and other inputs, holding route miles constant.[14] As highlighted by Bitzan (2000, page 42), route miles define the geographic scope of services provided by the railroad, not the amount of capital employed for a given network size. Thus, excess route miles that existed in the regulatory period do not imply an overuse of capital relative to other inputs, when one controls for network size, as we do in this study.

3 Modeling Work Rules and Allocative Efficiency

Standard economic theory indicates cost minimization arises when companies employ factor inputs efficiently by equating the ratios of marginal productivities and input prices across factor inputs. 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).

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

Where M_{PL} and MP_{NL} are the marginal product of labor and non-labor inputs, respectively, and w_L and w_{NL} are input prices. This same cost minimizing condition can be shown graphically as the point of tangency between a firm's isoquant for producing a particular output level and an isocost line based on input prices (Figure 1). Optimization using observed input prices without restrictive work rules is represented graphically by point *A* in Figure-1, where the combination of X_L units of labor and X_{NL} units of non-labor inputs minimizes the cost of producing $\bar{q}$ units of output at a cost of C (using an isocost line based on observed input prices, $C = w_L x_L + w_{NL:} x_{NL}$).

[13] Atkinson et al.'s (2003) results are consistent with the earlier findings of Kumbhakar (1988), using the same data. Kumbhakar calculates the cost of using an allocative inefficient mix of factor inputs prior to regulatory reform amounted to 12.03, 15.2 16.6 19.1 and 20.4 percent for the five-year intervals used in his analysis.

[14] Thus, firms can adjust their capital stock by adjusting the amount of side-by-side track in place or by making improvements in the roadway.

However, work rules are likely to alter the productivity of inputs and/or the costs of hiring additional units of each input. Restrictive work rules are designed to enhance employment by decreasing the substitutability of nonlabor inputs for labor. Thus, work rules could increase the cost of using non-labor inputs – e.g. by requiring a large number of crew members for every locomotive used, the work rule would increase the cost of using another locomotive. On the other hand, work rules could also increase the cost of using each additional unit of labor through decreased labor productivity.

Because of the potential for work rules to alter the costs of using different inputs, we define the true unit costs of using inputs (taking the impacts of work rules into account) as input shadow prices (w_L* and w_{NL}*). If restrictive work rules increase the shadow costs of using non-labor inputs, then w_{NL}* would exceed w_{NL}, flattening the isocost line representing a cost of C (C= w_L*X_L+ w_{NL}*X_{NL}) in comparison to the isocost line that would exist if the true cost of using nonlabor inputs were reflected in observed input prices (w_{NL}). Moreover, this would reduce the amount of output the firm could produce for a given cost. Thus, the isocost line associated with producing the same amount of output as originally ($\bar{q}$) with the higher cost of non-labor inputs is represented by higher costs (C'), more labor (X_L*), and less non-labor inputs (X_{NL}*) (point B in

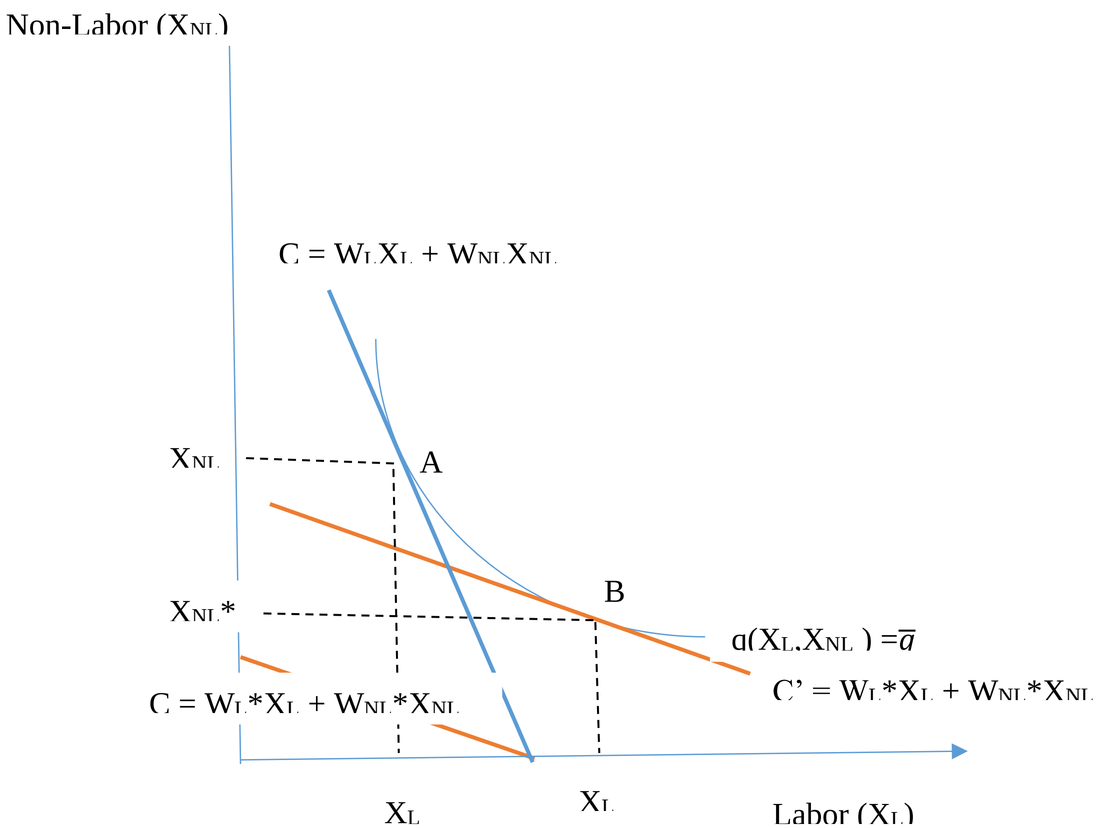

Figure 1: Factor Input Allocation of Actual and Shadow Input Prices

Figure 1).

Going back to the mathematical representation of an optimal input mix, if restrictive work rules alter the true unit costs of using inputs, the ratios of marginal productivities are really set equal to the ratios of shadow prices (rather than observed input prices) as in Equation 2. An alternative way to think about it is that the marginal product of a dollar's worth of labor is equal to the marginal product of a dollar's worth of non-labor input at the true unit costs of each (Equation 3).

$$\frac{MP_L}{MP_{NL}} = \frac{w_L^*}{w_{NL}^*} \qquad (2)$$

$$\frac{MP_L}{w_{L^*}} = \frac{MP_{NL}}{w_{NL^*}} \qquad (3)$$

If the shadow price of using non-labor inputs (w_{NL}*) is higher than the observed price of non-labor inputs (w_{NL}) due to the restrictive work rules, but the shadow price of labor (w_L*) is equal to the observed price of labor (w_L), then the equality in Equation 3 implies that the marginal product of a dollar's worth of labor is less than the marginal product of a dollar's worth of non-labor inputs at observed input prices (Equation 4). This suggests that the firm is using more labor relative to non-labor inputs than it would if it optimized based on observed input prices.

$$\frac{MP_{NL}}{w_{NL^*}} < \frac{MP_{NL}}{w_{NL}}, \frac{MP_L}{w_{L^*}} = \frac{MP_L}{w_L} \;\Rightarrow\; \frac{MP_L}{w_L} < \frac{MP_{NL}}{w_{NL}} \qquad (4)$$

Alternatively, if restrictive work rules increase the cost of using labor inputs, but not non-labor inputs, the firm would use more non-labor inputs relative to labor that it would if it optimized based on observed input prices. The impact that work rules have on input prices and consequently on the mix of inputs used is an empirical question.

The preceding graphical representation on factor input price distortion provides guidance for empirically examining allocative efficiency of factor inputs by highlighting the need to empirically compute the input price distortion index to attain information on the magnitude of the price distortion, and consequently the overutilization or underutilization of various inputs.

4 Data and Empirical Approach

Data

The empirical analysis of allocative efficiency in the US railroad industry uses data from *Class I Annual Reports* (R-I reports) from 1983 to 2015. Information on Class I rail carriers' total costs, prices of factor inputs, outputs, and technological characteristics are taken from these reports. Input prices include those for labor, fuel, equipment, materials & supplies, and way & structures. As highlighted by Bitzan and Keeler (2003), studies using pre-deregulation data often treated track as a quasi-fixed factor based on regulation's limitations on railroads' abilities to adjust capital stock. However, as in that study, we assume that the firm can vary all inputs based on our use of post regulation data. Recent observation has shown railroads heavily investing in double tracking, increased sidings, and centralized train control to alleviate congestion on heavily-trafficked routes, suggesting that railroads do adjust capital stock to traffic levels. Outputs are defined as ton-miles provided in unit train, way train and through train freight services. Technological characteristics include miles of road (or route miles), average train speed, and average length of haul. Table A1 of the appendix describes how these variables are constructed. Descriptive statistics are presented in Table-1, showing that labor accounts for the largest mean share of factor input cost. The next largest input share is materials & supplies, accounting for about 27 percent of costs. Way & structures account for 26 percent of total cost, followed by equipment at 11 percent , and fuel at about 8 percent. Consistent with past research, through train shipments are the largest output provided by railroads, closely followed by unit train services. Way train services are by far the smallest service provided by Class I railroads.

Empirical Approach

Using the conceptual framework presented in section 2 this study employs the cost estimation approach introduced by Atkinson and Halvorsen (1984) that allows for estimating factor input price distortion. When work rules or some other phenomenon alters the cost of using inputs, firms decide how much of various inputs to use based on unobserved shadow prices, rather than on observed input prices. Therefore, they minimize total shadow costs as in Equation 5:

$$C^S = C^S(Q, W^*, T) \qquad (5)$$

where C^S are the firm's total shadow costs, Q is a vector of outputs, W^* is a vector of shadow prices, and T is a vector of technological characteristics. Each shadow price's association with the observed input price is depicted in a multiplicative form as follows[15]:

[15] An additive version of this model can also be used. Results are invariant to the approach used.

$$w_i{}^* = w_i \ x \ g_i \qquad (6)$$

Where $w_i{}^*$ denotes the shadow price of the *ith* input, w_i denotes the actual price of that input, and g_i is the factor of proportionality[16] or the price efficiency parameter that accounts for the deviation of the shadow price from the actual price. If g_i is greater than one, this implies that the shadow price for input *i* is higher than the observed price, and the input is underutilized in comparison to its utilization under a situation where work rules or other phenomena don't affect the cost of inputs. If g_i is less than one, it implies that the shadow price for input *i* is less than the observed input price, and there is higher utilization of the input in comparison to that based on market price.

In the railroad industry, during the time period observed in this study, there is reason to believe that the factor of proportionality has varied over time. Previous research has shown that many of the effects of railroad deregulation have taken a long time to be realized. For example, Bitzan and Keeler (2003) find acceleration in productivity from deregulation occurring through the mid-1990s. This study estimates three different factors of proportionality: one from 1983-1994, one from 1995-2004, and one from 2005-2015. Specifically, g_i's are modeled as follows:

$$g_i = g_i^0 + g_i^{95} x \ d95 + \ g_i^{05} \ x \ d05 \qquad (7)$$

where: $d95 = 0 \ when \ year < 1995, \ d95 = 1 \ when \ year \ \geq 1995$

$d05 = 0 \ when \ year < 2005, d05 = 1 \ when \ year \ \geq 2005$

Shephard's Lemma can be applied to the shadow cost function to get input demands (Equation 8):

$$\frac{\partial C^S}{\partial w_{i^*}} = \ x_i \qquad (8)$$

This implies that total costs can be specified as in Equation 9:

$$C = \sum_i w_i x_i = \sum_i w_i \frac{\partial C^S}{\partial w_{i^*}} \qquad (9)$$

We can show the relationship between input demand, shadow cost, and shadow share of input i (Equation 11) by noting that shadow share of input i is as shown in Equation 10:

$$S_i^S = \frac{g_i w_i x_i}{C^S} \qquad (10)$$

$$\Rightarrow \ x_i = \frac{C^S S_i^S}{g_i w_i} \qquad (11)$$

[16]The symbol g_i is also known as price distortion index.

This implies that the total cost function in levels is as in Equation 12 and in logs is as in Equation 13:

$$C = \sum_i w_i \frac{C^S S_i^S}{g_i w_i} = C^S \sum_i \frac{S_i^S}{g_i} \qquad (12)$$

$$\ln C = \ln C^S + \sum_i \ln\left(\frac{S_i^S}{g_i}\right) \qquad (13)$$

This shows that we can estimate the shadow cost function as an embedded part of the total cost function. If we specify the shadow cost function in the translog form, we get the following:

$$\begin{aligned}
lnC &= \alpha_0 + \\
&+ \sum_i \alpha_i ln\,(w_i g_i) + \sum_k \beta_k ln(y_k) + \sum_m \sigma_m ln(a_m) + \theta t \\
&+ \frac{1}{2}\sum_i \sum_j \alpha_{ij} ln(w_i g_i) ln(w_j g_j) + \sum_i \sum_k \tau_{ik} ln(w_i g_i) ln(y_k) \\
&+ \sum_i \sum_m \vartheta_{im} ln(w_i g_i) ln(a_m) + \sum_i \gamma_i ln(w_i g_i) t + \frac{1}{2}\sum_k \sum_l \beta_{kl} ln(y_k) ln(y_l) \\
&+ \sum_k \sum_m \varphi_{km} ln(y_k) ln(a_m) + \sum_k \pi_k \ln(y_k)\, t + \frac{1}{2}\sum_m \sum_n \sigma_{mn} ln(a_m) ln(a_n) + \sum_m \mu_m ln(a_m) t \\
&+ \frac{1}{2}\gamma t^2 \qquad (14)
\end{aligned}$$

Where y_ks are outputs, a_ms are technological characteristics, and t is a time trend. When symmetry and homogeneity conditions are imposed, the following parameter restrictions apply:

$$\sum_i \alpha_i = 1, \sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0\ , \sum_i \tau_{ik} = \sum_i \vartheta_{im} = \sum_i \gamma_i = 0, \; and \; \alpha_{ij} = \alpha_{ji}. \qquad (15)$$

Shephard's Lemma is used to obtain shadow share equations as follows:

$$\frac{\partial lnC^S}{\partial \ln(g_i w_i)} = \frac{1}{C^S} x_i\,(g_i w_i) = S_i^S \qquad (16)$$

From the translog specification:

$$S_i^S = \alpha_i + \sum_j \alpha_{ij} ln\,(w_i g_i) + \sum_k \tau_{ik} ln(y_k) + \sum_m \vartheta_{im} ln(a_m) + \partial \gamma_i t \qquad (17)$$

Then, from Equations 13, 14, and 17, we get the total cost function:

$$\begin{aligned}
lnC &= \alpha_0 + \\
&+ \sum_i \alpha_i ln\,(w_i + g_i) + \sum_k \beta_k ln(y_k) + \sum_m \sigma_m ln(a_m) + \theta t
\end{aligned}$$

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

$$+\sum_i\sum_m \vartheta_{im} ln(w_i+g_i)ln(a_m)+\sum_i \partial_i ln(w_i+g_i)t+\frac{1}{2}\sum_k\sum_l \beta_{kl} ln(y_k)ln(y_l)$$

$$+\sum_k\sum_m \varphi_{km} ln(y_k)ln(a_m)+\sum_k \pi_k \ln(y_k)\, t+\frac{1}{2}\sum_m\sum_n \sigma_{mn} ln(a_m)ln(a_n)+\sum_m \mu_m ln(a_m)t$$

$$+\frac{1}{2}\gamma t^2 \ +\ln\left\{\sum_i\left(\alpha_i+\sum_j \alpha_{ij}\ln(w_j g_j)+\sum_k \tau_{ik} lny_k+\sum_m \vartheta_{im} lna_m+\gamma_i t\right)/g_i\right\}+\epsilon \qquad (18)$$

We jointly estimate total costs (Equation 18) with factor share equations in a seemingly unrelated system of equations. Since actual cost share of input *i* is (as opposed to shadow share):

$$S_i=\frac{w_i x_i}{C} \qquad (19)$$

Then from Equations 11 and 12, we can put actual cost share in terms of shadow share as follows:

$$S_i=\frac{S_i^S/g_i}{\sum_i(S_i^S/k_i)} \qquad (20)$$

These share equations are put in terms of the translog parameters by substituting Equation 17 into Equation 20 as follows:

$$S_i=\frac{\left(\alpha_i+\sum_j \alpha_{ij} ln\,(w_i\times g_i)+\sum_k \tau_{ik} ln(y_k)+\sum_m \vartheta_{im} ln(a_m)+\partial\gamma_i t\right)/g_i}{\sum_i\left(\alpha_i+\sum_j \alpha_{ij} ln\,(w_i\times g_i)+\sum_k \tau_{ik} ln(y_k)+\sum_m \vartheta_{im} ln(a_m)+\partial\gamma_i t/g_i\right)} \qquad (21)$$

Given this specification of the cost and share equations depicted by equations (18) and (21), a parametric approximation of shadow prices is derived by estimating cost and cost share equations with nonlinearity in parameters such that shadow prices are identified as the product of the price distortion index 'g_i' and the actual price for each observation ($g_i \times p_i$). Assuming firms choose inputs to minimize total cost based on the shadow price, the price distortion index derived from estimating the cost and share equations using the MLE technique captures departures from cost minimization based on the actual price. This approach assumes the disturbance term reflects errors in shadow cost minimizing behavior (Atkinson and Haloverson,1984). Measurement error, then could arise if the disturbance term includes a nonrandom component depicted by technical efficiency. An alternative estimation approach uses the stochastic frontier procedure to estimate cost function as part of a system of equations with the factor cost share equations. This approach includes overall inefficiency in the error of the cost function and allocative inefficiency in the error of the cost share equations (Kumbahakar, 1997). However, Kumbahakar (2015, page 208) explains that econometric estimation of the model is too difficult due to nonlinearities of the input allocative inefficiency term. In that book he constructs the primal system approach as an alternative. That approach requires the estimation of a stochastic frontier production model.

We chose the estimation of the shadow cost system of equations model over the Stochastic Frontier model due to advantages of estimating a cost function over a production function. The Stochastic Frontier model's use of a production function introduces several problems. These include: (1) introduction of measurement error, due to less reliable data on input quantities in comparison to input prices; this is particularly true for materials and supply prices; (2) endogeneity between input quantities and outputs; and (3) collinearity between inputs. In contrast, Shephard (1970) observes that estimating cost functions, which are duel to production functions can easily accommodate multiple outputs and avoid endogeneity issues that characterize production function estimations. Furthermore, in the event that shadow cost estimation results do not indicate input allocative inefficiency by default the disturbance term also excludes the technical efficiency component.

The cost determinants used in this study are the same as those used in past railroad cost research by Bitzan and Keeler (2003). That cost equation specification is depicted by the model below:

$$C = C(w_i, y_k, a_m, t); \qquad (22)$$

$$where\ w_i = (w_L, w_E, w_F, w_M, w_{WS});\ y_k = (y_U, y_W, y_T);$$

$$and\ a_m = \left(a_{miles}, a_{speed}, a_{haul}\right)$$

The symbol C depicts total cost, w_L is the unit price of labor, w_E is the unit price of equipment, w_F is the unit price of fuel, w_M is the unit price of materials and supplies, w_{WS} is the unit price of way and structures , y_U is unit train ton-miles, y_W is way train ton-miles, y_T is through train ton-miles, a_{miles} is miles of road (route miles), a_{speed} is speed in train miles per train hour, a_{haul} is the average length of haul, and *t* is a time trend variable.

The cost equation (18) is jointly estimated with the factor share equations (21) using Zellner's Seemingly Unrelated Regressions. One share equation is dropped to obtain a nonsingular covariance matrix, since factor shares add to 1. Finally, because the cost function is homogeneous of degree zero in factors of proportionality, one of the factors of proportionality is normalized to one. The factor of proportionality normalized to one in this study is labor; thus, all other factors of proportionality are measured relative to the one for labor.

The estimated factors of proportionality (g_is) show the deviations of shadow input prices from actual input prices, and therefore, can be used to assess whether carriers are using different amounts of inputs than they would if input choices were based on actual input prices. As shown above, a factor of proportionality above one implies a shadow price for the input that is higher than the actual input price, implying underutilization of the input, while a factor of proportionality below one implies the opposite.

While this translog shadow cost-share system approach has not been previously applied to the rail sector to test for factor-input allocative inefficiencies, Atkinson and Halvorson (1984), Ekin and Kniesner (1988), Oum and Zhang (1995), Christopoulos and Tsionas (2001), and Ahmad and Burki (2016) used this approach to examine factor-input allocative inefficiency in the electric power generation, hospital, telecommunications, manufacturing, and banking sectors, respectively.

Although not used to assess allocative efficiency, we also estimate a total cost function using the conventional approach (without estimating shadow prices) to compute factor demand elasticities and elasticities of substitution. These elasticities provide supplemental information to our estimation of the embedded shadow cost function, as they show the ability of inputs to be substituted for each other and the ways that input price distortion can alter the mix of inputs used.

The significance of examining elasticities for regulated industries such as rail is highlighted in analysis by Law (2014) who observes that past research examining input misallocation attributable to the A-J-W effect failed to account for the fact that capital assets are complementary to other inputs, which helped explain the lack of over-capitalization due to rate-of-return regulation. In mentioning the A-J-W effect in the context of the study by law, we do not intend to imply that this effect should exist in the railroad industry. At the time of deregulation, the regulatory structure was not leading to the type of monopoly profits one might expect from regulation. Rather, the industry was suffering from bankruptcy. Using pre-1980 data, Keeler (1983) found that very few earned the full opportunity cost of capital, and that firms classified as "unlikely to be viable" or worse accounted for almost half of all railroad freight revenues and route miles.

Own and cross factor price elasticity are calculated using the equations shown below:

$$\varepsilon_{ii} = \frac{\alpha_{ii}}{S_i} + S_i - 1 \qquad for\ all\ i \qquad \text{(Own price elasticity)} \qquad (23)$$

$$\varepsilon_{ij} = \frac{\alpha_{ij}}{S_i} + S_j \qquad for\ all\ i \neq j \qquad \text{(Cross price elasticity)} \qquad (24)$$

Where the symbols $\alpha_{ii}$and α_{ij} are the estimated coefficients on the own and cross second order terms for input prices, and the symbols S_i and S_i are the respective input shares for the *ith* and *jth* factor inputs. In addition, to computing own and cross price elasticities, the Allen-Uzawa partial elasticity of substitution (AES), Miroshima elasticity of substitution (MES) and McFadden shadow elasticity of substitution (SES) are calculated. Those elasticities are derived using the following equations.

$AES_{ij} = \frac{\alpha_{ij}}{S_i S_j} + 1 = \frac{\varepsilon_{ij}}{S_j} \quad for\ all\ i\ \neq j$ (Allen-Uzawa elasticity of substitution) (25)

$MES_{ij} = \varepsilon_{ji} - \varepsilon_{ii} = S_i\left(AES_{ji} - AES_{ii}\right)$ (Miroshima elasticity of substitution) (26a)

$MES_{ji} = \varepsilon_{ij} - \varepsilon_{jj} = S_j\left(AES_{ij} - AES_{jj}\right)$ (Miroshima elasticity of substitution) (26b)

$SES_{ij} = \frac{S_i}{S_i + S_j} MES_{ij} + \frac{S_j}{S_i + S_j} MES_{ji}$ (McFadden elasticity of substitution) (27)

While the Allen-Uzawa elasticity of substitution is a common measure of input substitutability, it may not accurately measure curvature for all cost equation specifications (Blackorby and Russell, 1989). For a subset of cost functions it is not a sufficient statistic for evaluating changes in relative prices and quantities, since relative changes can be derived using the own elasticity of substitution. In addition, it does not allow for taking the log derivative of the input quantity ratio with respect to the input price ratio. The Miorshima elasticity of substitution addresses this issue and provides a two factor, one-price elasticity of substitution compared to the one-factor, one-price elasticity of substitution provided by the Allen-Uzawa elasticity of substitution. The Allen-Uzawa elasticity of substitution classifies a pair of inputs as direct substitutes if an increase in the price of one causes an increase in the quantity of another, whereas the Miroshima concept classifies a pair of inputs as direct substitutes if an increase in the price of one causes the quantity of the other to increase relative to the input whose price changes. For this reason, the Morishima taxonomy leans more toward substitutability.[17] McFadden elasticity of substitution is a weighted average of the Miroshima elasticities and shows a change in input ratio with respect to a change in a pair of input prices. Chambers (1988, p. 97) claims that this elasticity of substitution measure provides a more complete measure of relative price responsibility. This measure is a two factor, two price elasticity of substitution. This study uses all three specifications to allow for a more complete analysis of elasticity of substitution.

[17] Put, differently, if two inputs are direct substitutes according to the Allen-Uzawa criterion, theoretically they must be direct substitutes according to the Miroshima criterion, but if the two inputs are direct complements according to the Allen-Uzawa criterion, they can be either direct complements or direct substitutes according to the Miroshima criterion.

5 Cost Results

Findings derived from estimating the cost function are presented in Table-2.[18] Coefficient estimates presented in column (1) contain cost results when estimating the standard translog specification using the SUR technique to predict observed input price effects on costs, while results in column (3) contain cost findings when using the full information maximum likelihood approach to estimate the cost effect of shadow input prices.[19] A brief analysis of the control variables presented in column (1) of Table-2 reveals the cost shares of labor, equipment, fuel, material and way and structures constitute 31.1, 12.8, 8.1, 23.5 and 24.4 percent of total cost, respectively. These findings closely resemble those of past research (Bitzan and Keeler, 2003)[20] When examining the shadow factor input cost results in column (3), the relative ranking of cost shares change such that the shadow cost share of materials is larger than the shares of the four other inputs, and the shadow cost share of labor is half as large as its predicted observed cost share. The higher shadow shares than observed shares for every factor of production except labor and equipment suggest that the actual cost of using these factors of production are higher than the observed costs based on input prices. This suggests that labor rules have increased the costs of using these other inputs, and therefore have discouraged railroads from substituting these factors of production for labor.

The parameter estimates for the remaining control variables presented in Table-2 are consistent with past findings on railroad costs (Bitzan and Keeler, 2003). The elasticity of costs with respect to through train service is highest of the three types of outputs, reflecting the fact that through train services are provided on lines where more capacity is being utilized. On the other hand, the elasticity of costs with respect to way train service is the lowest, reflecting the fact that way train services are provided on very light density lines. The sum of the parameter estimates on the three output variables suggests increasing returns to density. Focusing on the shadow cost estimates, the parameter estimates for the technological characteristic variables have the expected

[18] Observations with zero values for unit train ton miles were deleted. As stated in Bitzan (1999), there is reason to doubt the validity of these observations.

[19] Results testing regularity conditions are consistent with past findings for the US rail industry using the same data as that used in this study (Bitzan and Keeler, (2013). The conditions for monotinicity in input prices and output are satisfied,for nearly all observations whereas the condition for concavity in input prices is met for 41 percent of the observations. Bitzan and Keeler as well as Pels and Rietveld (2008) note, failure to find global concavity is common in empirical studies. The absence of complete global concavity for this study's analysis is not unexpected, especially if there is distortion in the input market. Concavity in input prices is indicative of cost minimizing behavior based on actual prices. However, as emphasized in this study government mandate hours of service regulations could introduce distortion such that carriers minimize cost based on shadow prices rather the actual prices.

[20] Bitzan and Keeler report findings indicating the share of labor, equipment, fuel, material and way and structures constitute 34.86, 14.61, 6.57, 18.6 and 25.36 percent of total cost, respectively.

signs, although not all are significant. The route miles variable has a positive and significant parameter estimate reflecting the increase in costs that accompanies the obligation to serve a larger network. While transport speed increases costs and average length of haul decreases costs, neither is statistically significant. Last, the parameter estimated on the time trend suggests rail costs decline over time, which is consistent with the notion that Class I rail carriers have experienced productivity gains during the post deregulatory period of greater managerial flexibility over input usage.

The main parameter estimates of interest in this study are the factors of proportionality g_i at the bottom of Table-2. These parameters are standardized by using unit labor costs as the benchmark comparison factor input price. Hence, the factor of proportionality parameter for labor, g_1, equals one for all three observation periods. As the table shows, factors of proportionality are all above one in the initial time period (1983-1994), with that for equipment at 3.49, that for fuel at 16.05, that for materials & supplies at 4.75, and that for way & structures at 3.59. This suggests that the true costs of using all of these inputs were inflated relative to labor as a result of restrictive work rules (though we need to check for statistical significance, which is done subsequently), and that those inputs were underutilized relative to labor. When looking at changes in the factors of proportionality over time, we see that all factors of proportionality are getting closer to one, suggesting an improvement in allocative efficiency over time. As an example, consider equipment; the factor of proportionality in the initial period is 3.49; then, in the 1995-2004 period it is 2.47 (3.49-1.02); finally, in the 2005-2015 period it is 2.14 (3.49-1.02-.33). Similar calculations for the other factors of proportionality show that from the 1983-1994 period to the 2005-2015 period, the factor of proportionality for fuel has declined from 15.05 to 3.62, the factor of proportionality for materials & supplies has declined from 4.75 to 3.85, and the factor of proportionality for way & structures has declined from 3.59 to 0.72. All of these suggest that work rules increased input prices of other factors of production, discouraging substituting those factors of production for labor, and therefore, promoting an overutilization of labor relative to those inputs. The results also suggest that this overutilization of labor relative to other inputs has declined over time. However, it is necessary to examine statistical significance to attach true meaning to these results.

Table-3 presents Wald statistics for each factor of proportionality, g_i, to determine whether each is statistically significantly different than one. Input allocative efficiency is satisfied if the Wald statistic lacks statistical significance. If we use a 10 percent level of significance, the table shows that all factors of production other than equipment were underutilized relative to labor during the 1983-1994 period. By 2005, equipment, materials & supplies, and way & structures were all being used in an allocatively efficient mix relative to labor; fuel was still being underutilized, but only at a 9.86 percent level of significance. If we use a 5 percent level of significance, the table shows that only fuel is underutilized relative to labor in the initial period. However, by 2005, all factors of production are used in an allocatively efficient mix relative to labor. These results support the idea that a relaxation in work rules has facilitated a more efficient mix of inputs over time. Moreover, the recent use of longer trains with multiple locomotives (and train crews on only one locomotive) is consistent with less use of labor relative to fuel, equipment, and other inputs.

As mentioned previously, we also supplement this estimation by examining elasticities of substitution between factors of production. A summary of these elasticites is presented in Table-4. The contents of the first panel in Table-4 report derived own demand elasticity findings for labor, equipment, fuel, materials & supplies, and way & structures. These results show negative own-price elasticity as expected, and demands for all factor inputs that are inelastic. Demand for way & structures is the least elastic of the inputs. Significant for the emphasis of this study are the cross elasticity findings suggesting labor is a substitute for all other inputs. The general finding of factor input substitutability for labor is robust as measures of partial elasticity of substitution present results that are consistent with the cross elasticity of demand findings. For instance, results from computing the Allen-Uzawa, the Miroshima and the McFadden elasticity of substitution suggest labor is a substitute for all other inputs. These findings are consistent with this study's assumption of labor substitutability depicted in Figure-1.

Benefits associated with attaining an allocatively efficient mix of inputs are quantified by simulating costs with the initial factor of proportionalities (in the 1983-1994) period and comparing them to simulated costs with the factor of proportionalities set to the 2005-2015 levels. Changes in quantities of various factors demanded are simulated in a similar manner..[21] Table-5 shows the simulated cost savings and changes in input demands at the mean of all variables for the industry. As the table shows, the average cost savings from the improvement in allocative efficiency is about 6 percent. Moreover, the change resulted in about a 13 percent reduction in the quantity of labor used. The simulations also show reductions of about 9 percent in way & structures and in materials, and an increase in equipment by about 2.5 percent and an increase in the amount of fuel used by about 23 percent.

[21] This is done at the mean of all variables with the time trend set to zero. Atkinson and Halvorsen (1984) also simulate cost savings by changing the factor of proportionality in a similar way.

6 Discussion and Concluding Remarks

For the majority of the 20th century U.S. railroads operated in a regulated business environment that contributed to industry unions' ability to negotiate rigid work rules. These rules were intended to provide workers a safe work environment, as well as facilitate more effective rail operation in the earlier years of U.S. railroad service (Davis and Wilson 2003 and Cappelli 1985). This study shows the imposition of standard crew sizes, and standard work day as stipulated by negotiated work rules actually limited carriers' ability to employ an efficient combination of factor inputs. In the latter quarter of the 20th century significant easing of regulations promoted the movement to a labor market that provides mangers greater flexibility to employ an allocatively efficient combination of workers relative to other inputs. This study also notes that the shift towards such flexibility did not occur immediately, but incrementally over time. Hence, it is possible for some inefficiency to persist immediately following regulatory reform and for a more allocatively efficient use of inputs to arise as railroad companies negotiate less restrictive work rules.

In examining the allocative efficiency of factor inputs in the Class I railroad industry, cost findings suggest that at high levels of statistical significance two out of four non-labor inputs were used allocatively efficiently with labor immediately following regulatory reform. By 1995, all inputs excluding fuel were used in an allocatively efficient manner, and by 2005 all inputs were used allocatively efficiently. Such findings are consistent with the view that less rigidity in work rules presented rail carriers with greater ease in achieving efficient allocation of labor with those inputs. In contrast, pre-deregulation findings by Atkinson et. Al. (2003) and Kumbhakar (1988) that examine the allocative efficiency for Class I railroad for the sample years between 1951 and 1975 find that most railroad companies used an allocatively inefficient mix of nonlabor inputs relative to labor. The input usage pattern uncovered in this study comports well with the notion that relaxation of work-rule constraints following regulatory reform in the US rail industry has provided managers of Class I railroad companies the opportunity to save costs by employing an allocatively efficient mix of factor inputs.

Acknowledgement:

The authors are grateful for the comments and suggestions provided by Kent Curry and participants at the *Economics and Regulation of the Freight Industry*, Second Annual Research Colloquium, Georgetown University, and participants at the Ninety-First Western Economic Association International meetings in Portland, Oregon.

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Table-1: Descriptive Statistics

	Variables	**Mean**
Factor Input Shares	Labor share	0.2926
	Equipment share	0.1074
	Fuel share	0.0759
	Materials & supplies share	0.2655
	Way & structures share	0.2586
Outputs	Adjusted unit train gross ton miles (in thousands)	46,872,332
	Adjusted way train gross ton miles (in thousands)	4,540,349
	Adjusted through train gross ton miles (in thousands)	78,429,277
Movement Characteristics	Miles of road or route miles	12,032
	Train miles per hour	25.99
	Average length of haul[22]	490.39

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

Table-2: Results derived from estimating cost equation (1) using the SUR technique

	Cost Function without Shadow Price		*Cost Function with Shadow Price*	
	(1)	***(2)***	***(3)***	***(4)***
Variables	*Coefficient*	*t-value*	*Coefficient*	*t-value*
Intercept	22.8391***	312.03	22.6861***	229.14
w_L	0.31127***	52.61	0.15461***	3.98
w_E	0.127803***	27.29	0.11725***	6.12
w_F	0.080719***	32.63	0.09923***	5.59
w_M	0.235466***	29.44	0.36816***	13.73
w_{ws}	0.244512***	41.53	0.26076***	12.16
y_u	0.101891***	3.33	0.09555***	2.6
y_w	0.056046**	2.00	0.05978*	1.78
y_t	0.388295***	6.28	0.41721	5.6
a_{haul}	0.033918	0.33	-0.1017	-0.79
$a_{RouteMile}$	0.65488***	6.14	0.65572***	5.11
a_{Speed}	0.028967	0.41	0.09548	1.09
T	-0.03307***	-7.97	-0.0292***	-5.72
$0.5(y_U)^2$	0.037104***	3.32	0.03134**	2.34
$0.5(y_W)^2$	-0.00433	-0.24	-0.0109	-0.5
$0.5(y_T)^2$	0.156209**	2.58	0.18852**	2.59
$0.5(w_L)^2$	0.093317***	9.52	0.04357***	2.99
$0.5(w_E)^2$	0.020429***	5.58	0.0164***	4.04
$0.5(w_F)^2$	0.064483***	27.98	0.14491***	8.1
$0.5(w_M)^2$	0.076061***	4.97	0.09243***	4.51
$0.5(w_{WS})^2$	0.163962***	26.40	0.1325***	6.18
$0.5(a_{haul})^2$	-0.22939	-1.15	-0.2432	-1.01
$0.5(a_{RouteMile})^2$	-0.04128	-0.52	-0.0445	-0.46
$0.5(a_{Speed})^2$	-0.10813	-1.23	-0.0836	-0.77
$0.5(t)^2$	0.000857***	5.27	0.00063***	3.12
w_L*w_E	-0.02233***	-5.83	-0.0088***	-2.62

w_L*w_F	-0.01362***	-4.11	-0.0157**	-2.18
w_L*w_M	0.002407	0.23	0.00512	0.81
w_L*w_{WS}	-0.05977***	-11.55	-0.0243***	-2.61
w_L*y_U	-0.00557***	-2.95	-0.0031**	-2.25
w_L*y_W	-0.00419	-1.40	0.0012	0.9
w_L*y_T	0.009004*	1.69	0.00693**	2.02
w_L*a_{haul}	-0.02397***	-3.36	-0.021**	-2.39
$w_L*a_{RouteMile}$	0.014006*	1.86	0.00284	0.79
w_L*a_{Speed}	-0.02173***	-3.13	-0.0067*	-1.73
w_L*t	-0.00269***	-9.38	-0.0008**	-2.41
w_E*w_F	-0.00551***	-3.38	-0.0148***	-3.06
w_E*w_M	0.023723***	4.35	0.02597***	4.2
w_E*w_{WS}	-0.01631***	-4.75	-0.0188***	-4.06
w_E*y_U	0.003847***	2.41	0.00169	0.99
w_E*y_W	0.007767***	2.99	0.00822***	2.62
w_E*y_T	0.007506*	1.72	0.00887*	1.88
w_E*a_{haul}	-0.01753***	-2.84	-0.03****	-3.83
$w_E*a_{RouteMile}$	-0.02214***	-3.58	-0.0174**	-2.47
w_E*a_{Speed}	-0.00705	-1.17	-0.0051	-0.8
w_E*t	-0.00126***	-5.54	-0.0016***	-3.13
w_F*w_M	-0.02983***	-7.27	-0.0743***	-5.89
w_F*w_{WS}	-0.01552***	-6.66	-0.0402***	-3.94
w_F*y_U	0.005959***	7.77	0.01724***	6.03
w_F*y_W	-0.00033	-0.27	0.009**	2.54
w_F*y_T	0.004947**	2.17	0.0053	0.81
w_F*a_{haul}	0.054806***	19.21	0.13088***	7.47
$w_F*a_{RouteMile}$	-0.02046***	-6.37	-0.0561***	-5.34
w_F*a_{Speed}	-0.01331***	-4.81	-0.0208**	-2.55
w_F*t	0.000521***	4.45	-0.0008**	-2.16
w_M*w_{WS}	-0.07236***	-10.10	-0.0493***	-3.77

w_M*y_U	-0.01052***	-3.97	-0.0184**	-5.52
w_M*y_W	-0.0154***	-3.54	-0.0257**	-4.79
w_M*y_T	0.022033***	2.83	0.01076	1.07
w_M*a_{haul}	-0.01405	-1.40	-0.0634***	-3.9
$w_M*a_{RouteMile}$	0.003862	0.36	0.04637***	3.53
w_M*a_{Speed}	0.0178*	1.79	0.02013	1.58
w_M*t	0.001387***	3.58	0.00266***	3.72
$w_{WS}*y_U$	0.00628***	3.17	0.00257	1.28
$w_{WS}*y_W$	0.012148***	3.83	0.00725**	2.55
$w_{WS}*y_T$	-0.04349***	-7.72	-0.0319***	-4.1
$w_{WS}*a_{haul}$	0.00074	0.10	-0.0165*	-1.87
$w_{WS}*a_{RouteMile}$	0.024732***	3.14	0.02434***	2.77
$w_{WS}*a_{Speed}$	0.024292***	3.24	0.01245**	2.05
$w_{WS}*t$	0.002042***	7.07	0.00057**	1.94
y_U*y_W	-0.00063	-0.06	0.00618	0.47
y_U*y_T	-0.07226***	-3.20	-0.0753***	-2.77
y_U*a_{haul}	0.04318	1.48	0.01188	0.33
$y_U*a_{RouteMile}$	0.026624	0.85	0.05288	1.39
y_U*a_{Speed}	0.003555	0.13	0.02619	0.79
y_U*t	0.000754	0.59	0.00121	0.78
y_W*y_T	-0.03507**	-1.93	-0.0213	-0.96
y_W*a_{haul}	-0.05411	-1.61	-0.0689*	-1.71
$y_W*a_{RouteMile}$	0.097946***	3.19	0.08516**	2.31
y_W*a_{Speed}	0.039519	1.38	0.02681	0.78
y_W*t	-0.00028	-0.23	0.00015	0.1
y_T*a_{haul}	0.084487	0.82	0.11557	0.93
$y_T*a_{RouteMile}$	-0.01397	-0.21	-0.0489	-0.61
y_T*a_{Speed}	0.036776	0.63	-0.0552	-0.79
y_T*t	-0.00591***	-2.19	-0.0062*	-1.9
$a_{haul}*a_{RouteMile}$	0.127711	1.02	0.11015	0.73

$a_{haul}*a_{speed}$	-0.00261	-0.03	0.09274	0.76
$a_{haul}*t$	0.004241	0.90	0.00922	1.57
$a_{RouteMile}*a_{Speed}$	-0.0601	-0.71	0.02305	0.22
$a_{RouteMile}*t$	0.007823**	2.29	0.00539	1.3
$a_{speeds}*t$	-0.00372	-1.21	-0.0079**	-2.04
dg_{equip}			3.48962**	2.02
$dg_{equip95}$			-1.0245*	-1.83
$dg_{equip05}$			-0.3257	-1.22
dg_{fuel}			16.0516**	2.26
dg_{fuel95}			-5.3213*	-1.86
dg_{fuel05}			-7.1054**	-2.19
dg_{mat}			4.75496**	2.2
dg_{mat95}			-0.8647*	-1.79
dg_{mat05}			-0.0427	-0.16
$dg_{w\&s}$			3.58562**	2.28
$dg_{w\&s95}$			-1.8048**	-2.11
$dg_{w\&s05}$			-1.059**	-2.17

Note: dgequip is the factor proportionality index for equipment from 1983-1994. The factor of proportionality for equipment from 1995-2004 is equal to dgequip+dgequip95. The factor of proportionality for equipment from 2005-2015 is equal to dgequip+dgequip95+dgequip05. Factors of proportionality for fuel, materials, and way & structures are determined in a similar way. Labor is the benchmark comparison factor input; hence its factor proportionality is set to one.

The notation *** indicates significance at 1% level, ** indicates significance at 5% level and * indicates significance at 10% level.

Table-3: Tests of Significance of Factors of Proportionality Over Time

Test	**Wald Statistic** *(g_i>1)*	**Pr>ChiSq**
Equipment		
dgequip=1 (1983-1994)	2.08	0.1492
dgequip+dgequip95=1 (1995-2004)	1.45	0.2285
dgequip+dgequip95+dgequip05=1 (2005-2015)	1.15	0.2838
Fuel		
dgfuel=1 (1983-1994)	4.5	0.0339
dgfuel+dgfuel95=1 (1995-2004)	4.21	0.0402
dgfuel+dgfuel95+dgfuel05=1 (2005-2015)	2.73	0.0986
Materials & Supplies		
dgmat=1 (1983-1994)	3.01	0.0828
dgmat+dgmat95=1 (1995-2004)	2.7	0.1002
dgmat+dgmat95+dgmat05=1 (2005-2015)	2.68	0.1015
Way & Structures		
dgway=1 (1983-1994)	2.7	0.1001
dgway+dgway95=1 (1995-2004)	1	0.3168
dgway+dgway95+dgway05=1 (2005-2015)	0.8	0.3713

Table-4: Estimated Elasticities at Mean Values of All Variables

OWN PRICE							
E_{LL}	-0.38894						
E_{EE}	-0.71241						
E_{FF}	-0.12042						
E_{MM}	-0.44151						
E_{WW}	-0.08492						
CROSS PRICE[1]		Allen-Uzawa		Miroshima [2]		McFadden	
E_{LE}	0.056294	AES_{LE}	0.43969	MES_{LE}	0.5258	SES_{LE}	0.59659
E_{EL}	0.13686			MES_{EL}	0.7687		
E_{LF}	0.036959	AES_{LF}	0.45787	MES_{LF}	0.53146	SES_{LF}	0.45443
E_{FL}	0.14252			MES_{FL}	0.15738		
E_{LM}	0.2432	AES_{LM}	1.03284	MES_{LM}	0.71043	SES_{LM}	0.69935
E_{ML}	0.32149			MES_{ML}	0.68471		
E_{LW}	0.052483	AES_{LW}	0.21464	MES_{LW}	0.45575	SES_{LW}	0.31569
E_{WL}	0.066813			MES_{WL}	0.1374		
E_{EF}	0.037646	AES_{EF}	0.46638	MES_{EF}	0.77212	SES_{EF}	0.53468
E_{FE}	0.059711			MES_{FE}	0.15807		
E_{EM}	0.42075	AES_{EM}	1.7869	MES_{EM}	0.94119	SES_{EM}	0.89006
E_{ME}	0.22878			MES_{ME}	0.86227		
E_{EW}	0.11715	AES_{EW}	0.4791	MES_{EW}	0.77375	SES_{EW}	0.39853
E_{WE}	0.061339			MES_{WE}	0.20206		
E_{FM}	-0.13406	AES_{FM}	-0.56933	MES_{FM}	0.07447	SES_{FM}	0.24797
E_{MF}	-0.04596			MES_{MF}	0.30745		
E_{FW}	0.052248	AES_{FW}	0.21368	MES_{FW}	0.13767	SES_{FW}	0.13729
E_{WF}	0.017248			MES_{WF}	0.13717		
E_{MW}	-0.0628	AES_{MW}	-0.25686	MES_{MW}	0.38103	SES_{MW}	0.19819
E_{WM}	-0.06048			MES_{WM}	0.02212		

[1] Negative value for cross price elasticity indicates complements whereas positive values indicates substitutes.
[2]MES is asymmetric.

Table-5: Simulated Cost Savings and Change in Input Demands from the Change in Allocative Efficiency (at means of all variables)

Percent Change in Total Cost	-6.23
Percent Change in Labor	-13.2
Percent Change in Equipment	2.5%
Percent Change in Fuel	23.3%
Percent Change in Materials & Supplies	-9.1%
Percent Change in Way & Structures	-9.0%

Appendix

Table-A1: Construction of variables

Variable Construction

- **Real total cost = (opercost – capexp + roird + roilcm + roicrs)/gdppd**

  opercost = railroad operating cost (schedule 410, line 620, column f)

  capexp = capital expenditures classified as operating in r1 (schedule 410, lines 12-30, 101-9, column f)

  roird = return on investment in road = (roadinv – accdepr) * costkap

    roadinv: road investment (schedule 352b, line 31) + capexp from all previous years

    accdepr: accumulated depreciation in road (schedule. 335, line 30, column g)

    costkap: cost of capital (AAR railroad facts)

  roilcm =return on investment in locomotives = [(iboloco+locinvl) – (acdoloco + locacdl)] * costkap

    iboloco: investment base in owned locomotives (schedule 415, line 5, column g)

    locinvl: investment base in leased locomotives (schedule 415, line 5, column h)

    acdoloco: accumulated depreciation of owned locomotives (schedule 415, line 5, column i)

    locacdl: accumulated depreciation of leased locomotives (schedule 415, line 5, column j)

  roicrs =return on investment in cars = [(ibocars + carinvl) – (acdocars + caracdl)]*costkap

    ibocars: investment base in owned cars (schedule 415, line 24, column g)

    carinvl: investment base in leased cars (schedule 415, line 24, column h)

    acdocars: accumulated depreciation of owned cars (schedule 415, line 24, column i)

    caracdl: accumulated depreciation of leased locomotives (schedule 415, line 24, column j)

  gdppd = gdp price deflator

Price of factor inputs

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

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

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

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

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

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

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

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

Factor input prices are divided by gdp price deflator

Outputs

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

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

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

Movement characteristics

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

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

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

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

- **Average length of haul = rtm/revtons**

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

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