Work Related Accidents and the Level of Market Competition: An Analysis of Worker Injury Rates at United States Steel Corporation, 1907-1939

by

Christopher S. Decker and David T. Flynn

Christopher S. Decker
Department of Economics
College of Business Administration
University of Nebraska at Omaha
Omaha, NE 68164

David T. Flynn
Department of Economics
College of Bus& Pub Administration
University of North Dakota
Grand Forks, ND 58202

Abstract

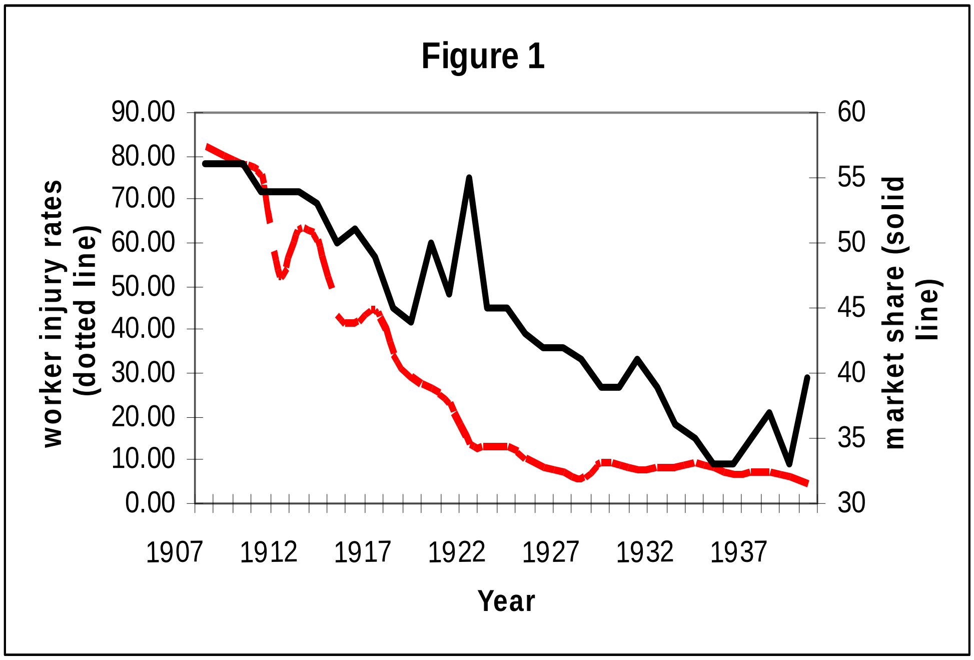
We investigate the relationship between accident rates and industry structure for the U.S. steel industry during the first four decades of the 20th century. We develop a dominant firm theoretical model linking accident rates to number of competitors, showing a positive correlation between accident avoidance and the number of competitors. We then test this theory empirically. When controlling for other influences, we find reductions in the dominant firm's market share reduce worker injury rates substantially.

I. Introduction

During the latter part of the 19th and early 20th centuries manufacturing in the United States experienced substantial changes. There was tremendous growth in large-scale enterprises beginning with business consolidation during the trust movement of the 1880s. Technological advances generating substantial economies of scale and the need for greater capital accumulation tended to favor large firms. Large firms came to dominate markets in industries such as steel and petroleum. As markets continued this trend into the early 20th century, worker safety became an issue of concern for workers, firms, and the country. Aldrich (1997), for instance, has compiled a large amount of information that demonstrates managements' increased concern over the issue of worker safety, motivated in some cases out of a desire for good public relations, and in others as a profit maximizing strategy. In and extensive analysis of the rapid spread of worker compensation laws during the early part of the 20th century, Fishback and Kantor (1998) found that this was the product of coalitions between organized labor, insurers and even employers who anticipated gains from replacing the existing negligence liability institution with more structured and predictable legislative structure.

While a number of studies have looked at the development of worker safety activities by firms and investigated reasons for the development of such regulation, little attention has been given to the potential link between market structure and worker safety incentives. The existence and importance of a link between accidents in general and market structure has surfaced in several venues other than worker safety specifically. Consider, for instance, the airline industry and its deregulation in 1978. Some argued at the time that the benefits of deregulation, primarily lower fares prompted by entry into the industry, would be offset by reductions in safety as increases in the number of flights could lead to increases in air congestion and airplane accidents. Risks would further increase as aggressive competition and tighter profit margins would prompt airlines to cut maintenance and equipment upgrade expenditures to unsafe levels. However, data presented in Kaplan (1986) and Walters (1993) show fatal airline accidents actually decreased after deregulation. Moreover, in an investigation of relationship between various measures of industry structure and the frequency of environmental accidents across a variety of manufacturing industries in the United States, Decker and Wohar (2005) found that higher accident rates are strongly associated with higher levels of industry concentration. Therefore, more competition tends to support fewer industrial accidents.

Focusing on worker safety specifically, this paper explores this relationship from a historical perspective. We investigate the relationship between worker accident rates and the competitive environment in the United States' steel industry between 1907 and 1939. Since this industry was dominated by US Steel Corporation (US Steel) we focus particular attention on it (see below). Indeed, visual observation of the relationship between worker accident rates and firm market share highlight a compelling relationship. Utilizing market share data for US Steel ingot production over time from 1901 to 1939 given by McCraw and Reinhardt (1989) as well as Schroeder (1953), and US Steel injury rates published in Aldrich (1997), Figure 1 shows that there does appear to be a direct positive correlation between the company's market share, and its worker accident rates.



While this is striking there are many other variables which could explain declining worker injury rates. To establish a credible relationship between these two variables what is required is: 1) a theoretical foundation, consistent with profit maximizing behavior, linking accidents with market share, and 2) empirical validation of the relationship. After controlling for other factors such as unionization rates, production levels, number of workers and others, our empirical findings show a lower market share results in lower worker injury rates, leading us to conclude that worker safety benefited from increased competition.[1]

The remainder of this paper is structured as follows: in section II we present a brief discussion of the state of the U.S. steel industry with special attention to worker safety issues. In section III we develop a theoretical model that worker accident rates to

[1] Other measures, such as worker experience would also likely be correlated to accident rates and could explain increases in accidents at times such as the WWI years in the data, as explained in Chaney (1922). The demand for steel at the time increased the number of inexperienced men working in the industry and the accident rate (Chaney, 1922, 277). However, we are not aware of a series that measures worker experience over our time span but do control for the World War I years with a dummy variable discussed below.

industry structure. Sections IV and V present the empirical model and data and related econometric issues. Section VI presents the empirical results and section VII concludes.

II. Steel Industry Structure and History

In 1901 US Steel was chartered, the result of the consolidation of eight substantial steel manufacturers. As the first billion dollar company in the U.S., it commanded a market share of 66 percent of steel ingot production in 1901 (Schroeder, 1953; McCraw and Reinhart, 1989). Given US Steel's leadership position in this industry, it seems reasonable to characterize competition via a dominant firm model, at least over the first four decades of the 20th century. Indeed, Yamawaki (1985) tested pricing in the steel industry from 1907 to 1930 and concluded that the US steel industry was consistent with dominant firm analysis. Furthermore, Scherer (1996) also presents evidence strongly supporting the application of the dominant firm model to the steel industry during the period under consideration here.[2] However, US Steel's market share was not secure, shrinking substantially between 1901 and 1939 due in part to steel producer entry into the market. According to Schroeder's (1953) study, throughout the first four decades of the twentieth century, US Steel faced increased competition from a number of new and growing producers such as Bethlehem Steel Corp., Jones & Laughlin Steel Corp., National Steel Corp., Wheeling Steel Corp., Sharon Steel Corp., and Pittsburgh Steel Company.

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[2] Clearly, with advances in game theory and econometrics, whether or not the dominant firm model still best characterizes the steel market *may* be open to debate and we certainly support such research efforts. However, since our purpose here is to introduce worker accident issues into US Steel's objective function, we are accepting of the existing work supporting the application of the dominant firm model to this industry during the time period covered, and thus build upon that structure. However, while it is clearly our proclivity to build upon Yamawaki (1985) and Scherer (1996), we do point out that at least one other industrial structure, the Cournot modeling framework, also yields theoretical results similar to ones presented here (see Decker and Wohar , 2005).

At the turn of the century US Steel was clearly the major U.S. steel manufacturer, and as Aldrich (1997, 93) points out, the leading firm in accident prevention. In May of 1910 U.S. Steel was the first to implement a worker safety program by introducing its voluntary accident relief program. Indeed their model became the blueprint for other businesses, both in and out of the steel industry. Over the next few years other steel companies, such as Armco, Bethlehem, Commonwealth, Inland, Jones and Laughlin, Lukens, Midvale, and Youngstown introduced similar measures (Aldrich, 129). As early as 1913 Armco attempted to reduce accident rates through adjustments to workday length and other experiments (Schroeder 1953, 70).

Indeed, contemporary commentary re-enforces this. For instance, the Bureau of Labor Statistics noted the industry's leadership role in the implementation of safety measures in a 1929 publication:

> That accidents can be prevented by an intelligent study of the situation, …, is well illustrated by the record of the iron and steel industry. … In 1910, before the accident situation was brought forcibly to the attention of the officials in that great industry through the computing and classification of accident rates, the workers were being killed and injured at the rate of 74.7 for every million man-hours of exposure, and for every thousand hours of exposure 7.2 days were being lost on account of disabling accidents. This was, of course, recognized as a serious economic loss that should be prevented. A definite safety policy was inaugurated and has been consistently maintained and rigorously enforced throughout the years, resulting in material, though intermittent, decrease in accident rates, … (Chaney, 1929).

Perhaps the increased concern over worker safety in this industry during the early part of the 20th century can in part be understood because steel plants had become increasingly dangerous places to work. This was largely as a consequence of significant changes in production and operations that occurred the latter part of the 19th century. Growth in the scale of blast furnaces, a change in final products, increased mechanization, and larger factory scale all contributed to increased worker accident risk (Aldrich 1997, 87-89). The industry, and US Steel in particular, became concerned that injuries would create a negative public perception. Some have argued that the implementation of safety measures at first was motivated by a desire to foster good public relations. They would come to find that this would pay additional dividends as the implementation of such measures resulted in overall reductions in costs for the firm, and increased profits (Aldrich, 91-93). Management developed incentives for safety and pitted plants against each other using safety records as the measurement standard (Aldrich, 140). The result of these efforts was the penetration of safety concerns to new areas of the enterprise such as purchasing of new equipment and the proper layout of the factory (Aldrich, 160-2).

To reiterate, this discussion focused on internal incentives for a firm to promote worker safety, however as we discussed in the Introduction and show later, the external or market environment may very well have contributed to this interest as well.

III. A Simple Dominant Firm Model with Worker Accident Rates

While researchers have made extensive use of dominant firm models in the past they have not typically included a parameter for accidents. In this section we develop a theoretical model that motivates the link between competition and accident rates. Given that the dominant firm model seems appropriate for this industry at this time we adopt a version of the Forchheimer-type dominant firm model, with US Steel as the dominant firm, and add a "worker accident likelihood" measure to the dominant firm's profit maximization function.[3]

We develop the model as follows: let aggregate industry (inverse) demand to be linear: $P = a - bQ$, and assume for simplicity that the marginal production cost of the dominant firm (in this case US Steel) is zero: $c_d = 0$. Further assume, consistent with Forchheimer, a given fringe firm is less efficient in production and that the marginal cost of production for a fringe player is increasing in production: $mc_f = \alpha q_f > 0$. Assuming all N fringe players are identical, the aggregate fringe supply in the industry is: $S_f = Nq_f = \frac{Nmc_f}{\alpha}$.

The dominant firm's demand function is given by:

$$q_d = Q - Nq_f = \frac{a}{b} - \frac{P}{b} - \frac{NP}{\alpha} = \frac{a}{b} - \frac{\alpha + bN}{\alpha b} P .$$

This assumes that the dominant firm sets the price in the market and the fringe players are perfectly competitive and price at their marginal cost.

If we solve the above expression for the dominant firm's inverse demand we get:

$$P = \frac{\alpha(a - bq_d)}{\alpha + bN} > 0. \qquad (1)$$

Note that this demand specification has intuitive appeal from a competitive perspective. As the number of fringe firms increases, thus capturing a larger proportion of the total market, the dominant firm's demand curve becomes more elastic, thus leading to lower price/cost margins, a result one would expect given increased competition.

The following results are helpful for the subsequent comparative statics:

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[3] The basic model can be found in McGee (1988), pp. 71-77. Scherer (1996) also presents a dominant firm model with entry.

$$\frac{\partial P}{\partial q_d} = -\frac{\alpha b}{\alpha + bN} < 0, \quad \frac{\partial^2 P}{\partial q_d^2} = 0,$$
$$\frac{\partial P}{\partial N} = -\frac{\alpha(a - bq_d)b}{(\alpha + bN)^2} < 0, \quad \frac{\partial^2 P}{\partial q_d \partial N} = \frac{\alpha b^2}{(\alpha + bN)^2} > 0. \tag{2}$$

When adding in worker accident likelihood variables, the dominant firm's objective function becomes:

$$\max_{q_d, \theta} \; Pq_d - A(\theta, q_d) - (1-\theta)F \; . \tag{3}$$

The function *A(.)* introduces the cost of worker accidents to the dominant firm. Define $\theta \in [0,1]$ as the probability of *avoiding* a work-related accident.[4]

The function *A(.)* then can be thought of as the (expected) cost of avoiding work-related accidents, which is assumed to have the following properties: $A_\theta > 0, A_{\theta\theta} \geq 0, A_{q_d} > 0, A_{q_d q_d} \geq 0, A_{q_d \theta} > 0.$ Hence, the cost of avoiding an accident increases (at an increasing rate) with the probability of avoiding an accident (i.e. increased avoidance effort). Moreover, it is assumed that the cost of accident avoidance is increasing in q_d suggesting that, *ceteris paribus,* larger scale production operations with greater physical capital find it more difficult to avoid worker accidents. The cross partial effect indicates that the marginal cost of accident avoidance as avoidance effort increases will itself increase with scale of operation. In essence, it becomes increasingly difficult to avoid work-related accidents as scale of operations increase. In fact, as Aldrich (1997) reminds us, one of the reasons why worker accident rates increased in the late 19th and early 20th century was increased production scale.

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4 While we define θ to include 0 and 1, we will restrict our attention to interior solutions for this analysis. We can think of this probability as being a function of work avoidance effort, so $\theta(e)$, where $\theta_e > 0$, which is costly. However, we can avoid the additional mathematical notation by just working with θ.

The remaining piece, $(1-\theta)F$, indicates that in the event of a work-related accident occurring, the firm faces a fine, *F*, perhaps reflecting worker compensation costs, lost worker productivity, or damage to capital. We allow the firm to select an accident avoidance probability (i.e., a level of avoidance effort), and a level of production so as to maximize profits. The following first order conditions obtain:

$$\begin{aligned} P + q_d \frac{\partial P}{\partial q_d} - A_{q_d} &= 0, \\ -A_\theta + F &= 0. \end{aligned} \tag{4}$$

The first condition is standard, indicating the dominant firm will increase production up to the point where the marginal benefit of an additional unit produced and sold equals the expected marginal cost of worker accident avoidance brought about by increased production. The second condition indicates that the dominant firm will invest in worker accident avoidance effort up to the point where the marginal cost of such effort equals the penalty born in the event of a worker accident.

Since our main focus in this paper is the impact of additional entry on the probability of an accident, $(1-\theta)$, we differentiate the two first order conditions from (4) with respect to q_d, θ, and N. In doing so, we obtain the following:

$$\begin{bmatrix} 2\frac{\partial P}{\partial q_d} - A_{q_d q_d} & -A_{q_d \theta} \\ -A_{\theta q_d} & -A_{\theta\theta} \end{bmatrix} \begin{bmatrix} dq_d \\ d\theta \end{bmatrix} = \begin{bmatrix} -\left(\frac{\partial P}{\partial N} + q_d \frac{\partial^2 P}{\partial q_d \partial N} \right) \\ 0 \end{bmatrix} dN \tag{5}$$

The sufficient condition for a maximum require that the 2x2 matrix on the left hand side of the above equation, designated as Π, be negative semi-definite.[5]

By applying Cramer's rule to (5) we find:

$$\frac{d\theta}{dN} > 0, \tag{6}$$

which suggests that more accident avoidance effort on the part of the dominant firm is applied with increased competition from the competitive fringe, that is, the probability of an accident occurring falls with greater competition.[6] The result rests on the impact the costs of such accidents have on the dominant firm's market share and, thus, profits. *Ceteris paribus*, increased production costs reduce profits. Additionally, an increase in the number of competitors reduces the dominant firm's market share and its profits. Therefore, more competition increases the dominant firm's incentive to seek and adopt cost-reducing strategies so as to mitigate profit losses that result from entry. As competition increase the dominant firm places a higher premium on avoiding labor accident costs in an effort to mitigate the effect that lost market share has on profits, illustrated in the model by (6). In a similar fashion, less competition increases the dominant firm's market share and therefore its profits, reducing the firm's incentives to invest as much in accident avoidance effort.

With the model established, the next question to address is whether or not the implications of the model hold up under empirical scrutiny.

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[5] Hence, $2\frac{\partial P}{\partial q_d} - A_{q_d q_d} < 0$, $-A_{\theta\theta} < 0$, and $-\left(2\frac{\partial P}{\partial q_d} - A_{q_d q_d}\right)A_{\theta\theta} - \left(A_{q_d \theta}\right)^2 > 0$. Therefore, $\det \Pi > 0$.

[6] For a complete derivation see the Appendix.

IV. The Empirical Model and Data

There is a paucity of data on worker accident rates across industries limiting extensive empirical analysis, at least from an historical perspective. Fortunately, Aldrich (1997) compiled a substantial amount of data on turn-of-the-century industrial accidents, including the United States steel industry. In this study we use Aldrich's (1997, p. 310) data on injury rates at US Steel, which we label ACC_RATE, from the period 1907-1939 as our dependent variable.[7] The data is measured in injury rates per million worker hours and summary statistics are provided in Table 1.[8] To accurately implement the appropriate econometric technique, we convert this data to injury rates per worker hour.

If more competition results in fewer worker accidents, as theory predicts, then we should see reductions in US Steel's worker injury rate as its market share falls, *ceteris paribus*. This suggests the following general empirical model for US Steel:

$$ACC\_RATE_t = f(MKTSHARE_t, \mathbf{X_t}, \varepsilon_t) \qquad (7)$$

where MKTSHARE, calculated from Schroeder's (1953) data, is US Steel's share of the steel ingot capacity, $\mathbf{X_t}$ is a vector of additional variables believed to influence worker

[7] The data on US Steel covers the period 1913 through 1939 with 1928 and 29 missing. However, industry level data on worker injury rates is available from 1907. With the already limited nature of this historical data, we used the industry level data from 1907-1913 to generate proxies for US Steel's likely injury rates by assuming that the proportional change in industry level rates are the same as that for US Steel (i.e. $ACC\_RATE_{USSteel,t} = ACC\_RATE_{USSteel,t+1}*(ACC\_RATE_{industry,t}/ACC\_RATE_{industry,t+1})$). Since US Steel controlled nearly seventy percent of the steel ingot capacity during the period 1907-1913, and since the industry and US Steel accident rates are highly correlated, this is a reasonable approximation. We used a similar technique for the years 1928 and 1929. While more observations improved the overall regression diagnostics, it should be pointed out that no substantive differences arose regarding the sign, magnitude, and significance of the various independent variables when only the original US Steel data was employed.

[8] Since economists have become accustomed to working with enormous data sets, the fact that our dataset is relatively small may be cause of concern. While this is true to some degree, we would point out that, as is true with a lot of historical datasets, date is limited. Hence, 33 observations does represent a reasonable universe of data on US Steel during this time period. is not unreasonably small. Moreover, one of the main problems with small datasets is that statistical significance is more difficult to attain. As will be clear, we do indeed find statistical significance in a number of key variables even with the limited number of observations.

injury rates, included to isolate the effect MKTSHARE has on ACC_RATE, and ε_t is a normally distributed random error term, $\varepsilon_t \sim N(0,1)$.[9]

While this specification seems reasonable given our theoretical model, it might also be the case that modeling US Steel's worker accident rate relative to the steel industry's overall worker accident rate would offer insights as to how US Steel's rapid loss of market share impacted its accident avoidance efforts. We did, in fact, estimate an equation in which we modeled the US Steel accident rate relative to the industry as a whole as a function of MKTSHARE and other variables. Data from Aldrich (1997) shows that US Steel' worker accident rates declined much faster than the rest of the industry between 1914 and 1939. This might be demonstrating that since US Steel's market share declined much more rapidly than many other steel firms' shares that US Steel experienced proportionally greater pressure to limit worker accidents. It might also be that since US Steel was one of the first to adopt accident avoidance efforts, this first-mover position allowed it to stay ahead of the rest of the industry. The results were similar to the ones presented below.

The variables comprising $\mathbf{X_t}$ and their associated data sources are as follows. WORKERS/CAPACITY, as reported by Schroeder (1953) measures the total number of workers employed by US Steel per ton of US Steel ingot capacity. One might presume as

[9] A possible concern with using market share as our measure of the competitive pressures facing US Steel it that MKTSHARE in period t may be endogenously determined by other contemporaneous factors. This would suggest some other instrument may be preferable to measure competition. One such measure might be the price US Steel sets for its output relative to its competition. While this may very well speak to the competitive pressure facing the company, such data is, to our knowledge, not available at the company level. Moreover, as we referenced above, existing research does not support the notion that the steel industry during this time should be characterized by a Bertrand-type price competing model. However, we did try a Herfendahl index instead of market share and obtained results similar to what we've reported here. We also estimated our models with MKTSHARE lagged one year to in part alleviate some of the endogeneity concerns. These results are available upon request. However, doing so cost of a degree of freedom (which is troubling with our relatively small sample) but yet produced results nearly identical to the ones reported here.

they employ more workers, the likelihood of a worker suffering an injury increases. In addition, we include a measure of (the dollar value of) capital per worker, FIXEDASSETS/WORKER, again taken from Schroeder (1953). The hypothesized effect on ACC_RATE here is less clear. On the one hand, a higher capital to labor ratio may suggest increased automation and superior equipment, thus potentially reducing the likelihood of a work-related injury (or it might suggest improved automation from a worker safety perspective as well). On the other hand, as discussed above, one might expect increased capital intensity as potentially increasing accident rates if the additional capital equipment works at a substantially faster speed, has many moving parts that a worker could get injured by, or is simply more dangerous for a worker to operate. Finally, we include US Steel's inflation-adjusted net income, PROFIT, measured in $ millions, lagged one year.[10] Greater profitability may afford the firm more resources with which to support and adopt worker-safety operations, such as increased research and development funding for safer equipment, and/or worker education activities. We would expect higher profits result in fewer accident rates.

In an effort to capture labor union influence on worker safety during this period, we obtained total union membership (UNION) and total labor force (LABF) for the period 1901 through 1939.[11] Our expectation is higher unionization rates have greater influence on management's behavior towards worker accident prevention.

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[10] Schroeder (1953) provides the data on nominal net income, which we deflate using the United States' GDP deflator as published in Gordon (2000, p. A1). Between 1931 and 1934 US Steel recorded negative net income figures, bottoming out at $30 million (nominal) in 1934. Since ultimately we include this variable in our regression in log form, we adjust the nominal profit figures up by $31 million throughout the data period covered. This preserves the pattern in profits as well as retains four years worth of observations. We lag this variable since there is much higher correlation between US Steel's contemporaneous profits and market share than between market share and lagged profitability.

[11] These data came from the *Historical Statistics of the United States, Colonial Times to 1970, Part 1*. The labor force data came from Series D 1-10, p. 126. and the union membership data came from Series D 946-

In addition, many states, starting in 1911, began to adopt worker compensation laws thereby standardizing the terms and amounts by which companies would have to compensate workers for injuries incurred on the job. As Fishback and Kantor (1998) point out, during this Progressive era in US history, compensation legislation spread very quickly from state to state. Given that this legislation did have the effect of increasing average awards returned to injured workers, we would expect the spread of these laws to have a negative impact on worker accident rates at US Steel plants.[12] To capture this effect, we utilized data from Fishback and Kantor (1998) indicating the year in which various states adopted worker compensation laws and data from Schroeder (1953, p. 114) indicating where US Steel had plants and when they were in operation to construct WORKCOMP. For a given year, WORKCOMP equals the number of states with worker compensation legislation and where US Steel operated at least one plant. For instance, in 1913 and 1914, three states, Illinois, Massachusetts, and Ohio, had worker compensation laws on the books and, at the same time, US Steel plants operated in those states. Therefore, WORKCOMP=3. Between 1915 and 1918, two additional states where US Steel had a presence, Indiana and Pennsylvania, adopted worker compensation laws, hence, WORKCOMP=5. For those years when no worker compensation laws existed, WORKCOMP=0. We expect WORKCOMP to have a negative impact on work injury rates.

With the majority of Americans at this time tending to be rather progressively-minded and wary of monopoly power, it is reasonable to suggest that public pressure to

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951 and Series D 952-969, p. 178. While it would have been desirable to have industry or even company specific data on union membership, such data was not readily available.

[12] By "Increased" we mean in comparison to compensation received under the previous, "negligence liability" institutional arrangement.

the promote workplace safety went beyond only supporting worker compensation laws. Moreover, during this period of American history, information transmission and communication were becoming easier and less time-consuming as a consequence of an ever increasing network of telephone and telegraph lines being constructed across the country. Therefore, news of industrial accidents could now reach a larger and increasingly interested population more quickly. Such news could then spark public outcry, prompting greater regulatory scrutiny on industry. With increased and quicker access to information, management at US Steel recognized the heightened danger, at least from a public relations perspective, of worker accidents being widely reported. As a result, management increased efforts to limit the occurrence of accidents. To capture increased information flow, we collected data from various US Statistical Abstracts of the United States on the total mile of telephone wire strung between 1900 and 1939 (WIRE) as well as data on total US population (POP). We hypothesize that per capita miles of telephone wire strung will proxy for ease and speed of information flow to the public. Therefore WIRE should have a negative effect on worker injury rates at US Steel.

We include the national unemployment rate (UNEMP) taken from Gordon (2000, p. A1) in our regression analysis as well. The idea here is that there may be a cyclical component to worker injury rates. With higher unemployment rates workers seeking jobs may be willing to assume more workplace risk. Companies like US Steel may recognize this and therefore put less effort toward reducing worker injury rates. Finally, we include a dummy variable (WWI) for the years 1914 to 1918, the World War I years, to account for increased workforce injuries resulting from the substantial increases in production and necessary accession of less experienced workers.[13] We earlier hypothesized increased scale of operations would increase worker injury rates. It seems reasonable to assume that war time production could intensify work related hazards. Indeed, Nelson (1995, p 154) documents many instances during World War I where working conditions deteriorated substantially, causing accident rates to rise sharply in many manufacturing industries and severely slowing worker safety advances.[14]

V. Econometric Issues

Before continuing with the full-parametric analysis, it is instructive to investigate in some detail the time-series properties of the data, specifically ACC_RATE and MKTSHARE for at least two reasons. First of all, these two series are the most important series from the perspective of the thesis of this paper. Second, as is evident from Figure 1 above, both series appear to have trend characteristics to them. Hence, testing whether or not each follows a random walk or has a deterministic trend or instance, is of critical importance as the results of such test will have significant implications for estimation.

[13] As Chaney (1922, 277) states, “The huge demand for steel which came with the opening of the war led to taking on any man who offered himself and seemed equal to the physical demands of the task. Such a high accession rate of inexperienced men is always accompanied by increasing accident rates.”

[14] Noticeably absent from our econometric specification is a measure of safety-promoting technological innovations that may have been adopted by US Steel. This it due to a lack of a reliable time series measuring such investments and their associated adoption. However, our regression model does include both a time trend (for reasons given below) and a dollar denominated company-level fixed asset measure; FIXEDASSETS. To the extent that the company adopted any safety-promoting technology, one would reasonably presume such investment expenditures would show up in both the fixed asset series and the trend. While the issue of the diffusion of such technology is deserving of significant attention by scholars in this field, it is principally not the major focus of our study. Therefore, we leave this issue for future research.

Table 2 presents estimation results for a standard Augmented Dickey-Fuller (ADF) test conducted on both ACC_RATE and MKTSHARE.[15] The results suggest that we can safely reject the null hypothesis that either series has a unit root in favor of the alternative hypothesis that there exists a deterministic trend in the data. Hence, with these results allow us to reject that each series follows a random walk and therefore first-differencing the data is not advisable, they do point to the need for including in our regression results a time trend variable to capture the deterministic trend exhibited in the data.[16]

Additionally, while the theory developed above clearly suggests that increased competition "causes" greater accident avoidance effort, one might reasonably ask if there is statistical support for MKTSHARE "causing" ACC_RATE. To address this we also conducted as simple Granger causality test between these two series. The results, presented in Table 3 below, suggest that we cannot reject the null hypothesis that ACC_RATE does not Granger cause MKTSHARE. However, we do reject the null hypothesis that MKTSHARE does not Granger cause ACC_RATE. Therefore, from a purely statistical perspective, which, of course, cannot prove true causality, it appears that these results lend support to the above theory that in fact, we should expect ACC_RATES to be influenced by competition.

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[15] Specifically, the ADF formulation estimated here was $\Delta y_t = \alpha + \beta \text{trend} + (1-\rho) y_{t-1} + \sum_{i=1}^{n} \Delta y_{t-i} + \varepsilon_t$, where y_t is ln(ACC_RATE) and ln(MKTSHARE) respectively. For the results presented in the table, n = 5. However, we estimated the ADF equation using alternative lagged variables and obtained qualitatively similar results.

[16] This result has an ancillary benefit as well. As noted in a footnote above, one variable we were not able to find is a measure of technological innovation in worker safety investment. While FIXEDASSETS will in all likelihood capture some of this innovation, it is not a pure measure of innovation. The time trend will likely pick up some of this trend.

With these preliminary time-series tests complete, we now turn attention to full parametric estimation. When implementing our empirical model, we could have used standard OLS, modeling the natural log of accident rates as a function of the variables discussed above. However, doing so does not take into account that the accident rate is essentially bounded between zero and one.[17] Hence, the unbiasedness and consistency of the resulting estimators cannot be assured.[18] We therefore adopt a modeling procedure with explicitly takes this characteristic into account. Specifically, we assume the injury rate is a conditional probability that follows a logistical distribution. Using the independent variables discussed above, we estimate the following equation:

$$\begin{aligned}\ln\left(\frac{ACC\_RATE_t}{1-ACC\_RATE_t}\right) &= \beta_0+\beta_1\ln(MKTSHARE_t)+\beta_2\ln(WORKERS_t/CAPACITY_t)\\ &+\beta_3\ln(FIXEDASSETS_t/WORKERS_t)+\beta_4\ln(PROFIT_{t-1})\\ &+\beta_5\ln(UNION_t/LABF_t)+\beta_6 WORKCOMP_t\\ &+\beta_7\ln\left((WIRE_t/POP_t)/(WIRE_{t-1}/POP_{t-1})\right)+\beta_8 WWI_t\\ &+\beta_9\ln(UNEMP_t)+TREND+\varepsilon_t\end{aligned} \tag{8}$$

where the dependent variable is the logistical transformation of the worker injury rate. Note that those independent variables that can be treated as continuous are in log-form so that the resulting coefficients can, with some modification, be conveniently interpreted as elasticities.

Since the error term in equation (8) is heteroscedastic, we first estimate (8) using OLS to obtain consistent estimates of the model parameters. The fitted equation is then

[17] Since the data is in worker hours, ACC_RATE attempts to capture the likelihood of the average worker suffering an injury in a given hour of work. It is highly unlikely that a steel worker would suffer more than one injury in an hour's time. Given the dangerous nature of the work involved, any injury suffered (and recorded) would certainly incapacitate a worker longer than one hour. That said, it should be noted that we did estimate (8) using ln(ACC_RATE) as the dependent variable and found similar results. These results are available upon request.

[18] Kmenta (1986, p. 549) offers a complete discussion of the problems encountered when the bounded nature of a dependent variable are not accounted for in the econometric model.

used to construct weights that correct the hetertoscedasticity problem.[19] Equation (8) is then re-estimated via weighted least square and the results are presented in Table 2.[20]

VI. Results

We estimate equation (8) under four different specifications. The first model includes all discussed independent variables. The second and third models drop WORKCOMP and UNION/LABF, respectively. The common sample correlation coefficient for these two series is 65 percent, suggesting the potential for multicollinearity. Indeed, as Fishback and Kantor (1998) find, the degree of unionization in a state was a statistically significant determinant of whether and when a state would adopt worker compensation laws. Finally, in model four we drop both WORKCOMP and UNION/LABF and retain TREND since, again, there is a high degree of correlation between TREND and primarily WORKCOMP.

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[19] For the Logistic model, the error term ε_t is heteroscedastic with a variance equal to $Var(\varepsilon_t) = \frac{1}{n_t \Lambda_t (1 - \Lambda_t)}$ where Λ_t is the injury rate and n_t is the number of "trials" in period t. Hence, the weights used to estimate (8) are $w_t = \sqrt{n_t \Lambda_t (1 - \Lambda_t)}$. Since Λ_t is not known, we adopt the following two step procedure where we first estimate (8) via OLS and then calculate the fitted values of the injury rate: $\hat{\Lambda}_t$, which are used to construct w_t and then used to re-estimate (8). The number of "trials" n_t, which in our case is the total number of worker hours in period t, proved somewhat difficult for us since Aldrich only reported the injury rates. However, using our data on total workers employed at US Steel per year, and assuming a ten hour work day (which is consistent with industry level data reported for this period) a six day work week, and that fifty weeks are worked per year, we estimated total worker hours to be 3,000*$WORKERS_t$. See Greene (1993) for further discussion of the logistic model.

[20] Another issue of importance is the potential for autocorrelation which would bias the standard errors on our estimated coefficients. The Durbin-Watson statistics presented in Table 2 range from 1.3 to 1.6. Unfortunately, with 33 observations and between eight and nine regressors, these statistics prove inconclusive. Other means of testing for autocorrelation, such as certain LM tests (e.g. such as Breusch-Godfrey) require a large number of observations since the distributional properties of the resulting test statistics are only understood asymptotically. However, for each of the models considered, we did analyze the autocorrelation function and partial autocorrelation function at various lag lengths: 2, 10, 15, and 20. We found the autocorrelations and partial autocorrelations were all relatively small, and the associated Ljung-Box Q-statistics were all insignificant with large *p*-values. Therefore, there is little evidence of autocorrelation in our specifications.

Overall, the regressions perform reasonably well. The adjusted R^2 statistics indicate our models capture between 81 and 88 percent of the variation in our dependent variable. Moreover, the F-statistics indicate the models have statistical relevance.

The variable of most interest is the MKTSHARE. In every model, we find that MKTSHARE has a positive and highly significant impact (both economically and statistically) on worker injury rates. Hence, reductions in US Steel's market share result in fewer worker injury rates, as predicted by our dominant firm model. Indeed, focusing on model 3, our preferred specification, a one percent drop in US Steel's market share results in a 2.6 percent reduction in worker injury rates.[21]

The other control variables for the most part yield coefficients consistent with expectation, but only a few had statistical significance. For instance, in model 1 we see that WORKCOMP has a negative and statistically significant impact on injury rates at US Steel. However, the degree of unionization did not prove statistically significant. This is likely due to the fact that the two variables are correlated. Indeed, in model 2 where we drop WORKCOMP, UNION/LABF does have a negative and statistically significant impact on ACC_RATE, indicating that labor unions did exert some, direct or indirect, pressure on US Steel to curb worker injury rates. In model 3 where we retain WORKCOMP but drop UNION/LABF, a similar result obtains. As expected, the spread

[21] While all models report statistical significance on MKTSARE, we view model 3 as our most favored specification for two reasons. First, it generates the highest F-statistic and the highest adjusted R^2. Second, model 3 contains the greatest number of significant variables. Third, the WORKCOMP variable has a closer association with US Steel than does UNION/LABF, since unionization rate is a national number. It is also important to note that the above elasticity is not simply the estimated coefficient. For the logistic model: $\ln\left(\frac{y}{1-y}\right) = \beta \ln x$, the resulting elasticity is $\beta(1-y)$. Following convention and evaluating this elasticity at the mean of *y*. In the case of our ACC_RATE variable, the mean is 0.00002697. Hence, the elasticity between MKTSHARE and ACC_RATE is $2.572(1-0.00002697) \approx 2.6$. Since the mean of ACC_RATE is so small, our estimated coefficients for most of the other variables (such as WORKER/CAPACITY) approximate elasticities as well.

of worker compensation laws into states where US Steel operated plants pushed worker injury rates lower.

The results also strongly suggest that accident rates were indeed higher at US Steel during World War I, likely the result, as suggest by Cheney (1922) and others, of increased production and the employment of new, less experienced workers.

The remaining independent variables are statistically insignificant. For instance, while we find in every specification that more workers per unit capacity has a positive impact on worker injury rates, the effect is never statistically significant. Also, while higher profit levels and greater capital intensity have a negative impact on ACC_RATE they are not statistically significant. In addition, higher unemployment rates have no meaningful impact on ACC_RATE. Finally, the increased telephone wire network included to proxy for increased information transmission, while giving a negative impact on ACC_RATE, also was not statistically meaningful. Some caution may be in order here however. It may be that a more refined measure, currently unavailable, may prove to have a statistically significant on ACC_RATE.[22] This could be a substantial undertaking and is therefore left for future research.

VII. Conclusion

In this paper we explored the relationship between accident rates and industry structure for the U.S. steel industry over the first four decades of the 20th century. We developed a theoretical model linking accident rates to number of competitors. The model shows increased accident avoidance effort is positively related to the number of

[22] For instance, an alternative measure of information transfer may be newspaper circulation. When included in our model we found no statistically meaningful relationship with ACC_RATE, nor did it change the results for the other independent variables.

competitors. We then tested this theory by focusing on the U.S. Steel industry, with specific attention paid to US Steel Corp., the dominant firm in the market, at least during the first four decades of the 20th century. We found, consistent with theory and expectation, reductions in market share, the result in part of increased competition, reduced worker injury rates substantially. While our results don't prove that increased competition was the impetus for worker safety concerns, they strongly imply that increased competition significantly contributed to safer working conditions. It is not clear from our results that such competition would have reduced accident rates had institutional structures like worker compensation regulation not come about, but competition clearly facilitated industry's emphasis on the workplace environment.

This paper presents several avenues for future research. Our focus was on US Steel as the dominant firm in its industry for the first four decades of the 20th century. A useful avenue for future research would be to investigate, both theoretically and empirically, work-related accident rates industry-wide and how they may be influenced by changes in overall industry structure. It may be interesting to test the robustness of our results in the steel industry as it became more global in nature, from the 1950s on. For instance, a parallel study could examine differing safety concerns across countries and the impact of these differing institutions on U.S. safety rates and competitive position. It may be useful also to look at dominant firms in other industries. For instance, DuPont and Ford Motor Co. at the turn of the century were leading competitors in their industries and also early advocates of accident prevention. It would be interesting to see if a similar story manifests itself for these firms.

Finally, there may be benefits to testing these findings to contemporary industries. For instance, over the last few years there have been a number of widely publicized mining accidents both in the United State and elsewhere, with two major tragedies in West Virginia in January 2006. Indeed, the governor of West Virginia ordered the closing of a mine, citing safety concerns. While it is not clear that this industry can best be characterized by a dominant firm model, it is nonetheless interesting in light of the results presented here to note that according to the US Census Bureau, the number of mining establishments fell substantially between 1992 and 2002, from 1,820 to 1,190.[23] At the same time coal demand, according to US Department of Energy data, increased 12 percent over that same period. Could it be that this less competitive environment is having an adverse effect on mining accident rates? Given our results, perhaps this is the case. As another contemporary example, in 1996 the Union Pacific Railroad merged with the Southern Pacific Railroad, a merger trend which has dominated that industry since it was deregulated in 1980. A year later, the new firm experienced 3 major railroad accidents resulting in seven worker fatalities. Could this simply be when companies merge there is sufficient short-term managerial inefficiency resulting increased accidents? Perhaps, however this is now denying that mergers do impact the competitive structure of a market too. Perhaps in light of our results here, the state of competition in the market may have played a role. If true or not is currently uncertain. This and other related issues await further investigation.

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[23] Clearly, establishment counts are not the best measure of competition, but it's really all that is readily available. While concentration ratios serve as better measure of competition, the US Census does not provide such data for the mining industry.

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Table 1. Summary Statistics

	Obs.	Mean	Std. Dev.	Maximum	Minimum
ACC_RATE	33	26.97	25.82	81.75	4.40
MKTSHARE	39	47.27	9.54	66.00	33.00
WORKERS	38	215.97	34.69	269.00	147.00
CAPACITY	38	21.16	5.06	28.90	10.00
FIXEDASSETS	39	2,018,301.00	344,641.30	2,571,617.00	1,508,872.00
PROFITS	37	18.75	12.76	58.86	0.11
UNION	39	3,235.97	1,222.61	6,556.00	1,125.00
LABF	39	42,513.31	7,511.97	55,588.00	29,268.00
WORKCOMP	39	4.03	2.84	7.00	0.00
WIRE	40	38,034,002.00	32,248,450.00	89,595,000.00	1,961,801.00
POP	40	105,924.00	17,155.37	130,880.00	76,094.00
UNEMP	39	8.22	6.82	25.20	1.40

Table 2. Augmented Dickey Fuller Test Results
log(ACC_RATE) and log(MKTSHARE): first differenced dependent variable.

Ln(ACC_RATE):		coefficient	t-statistic	p-value[1]	
ln(ACC_RATE(-1))		-0.334	-2.214	0.464	
Dickey Fuller critical values:	1% level		-4.263		
	5% level		-3.553		
	10% level		-3.210		
Time trend		-0.031	-1.843	0.081	*
Ln(MKTSHARE):		coefficient	t-statistic	p-value[1]	
ln(MKTSHARE(-1))		-1.418	-2.542	0.307	
Dickey Fuller critical values:	1% level		-4.263		
	5% level		-3.553		
	10% level		-3.210		
Time trend		-0.024	-2.458	0.021	**

[1]MacKinnon one-sided p-values.
* - Significant at the 10 percent level.
** - Significant at the 5 percent level.

Table 3: Pair-wise Granger Causality Tests

Null Hypothesis:	F-Statistic	Probability	
Ln(MKTSHARE) does not Granger Cause Ln(ACC_RATE)	1.13897	0.29467	
Ln(ACC_RATE) does not Granger Cause Ln(MKTSHARE)	6.81582	0.01415	**

Table 4. Estimation Output (weighted least squares)

Dep. Var: ACC_RATE; no. of obs. 33

	Model 1		Model 2		Model 3		Model 4	
Constant	-18.822	*	-15.018		-18.730	*	-10.418	
	(-1.737)		(-1.323)		(-1.773)		(-0.782)	
$Ln(MKTSHARE_t)$	2.614	***	3.564	***	2.572	**	3.475	***
	(2.984)		(5.043)		(3.060)		(3.941)	
$Ln(WORKERS_t/CAPACITY_t)$	0.854		-0.066		0.874		-0.416	
	(0.642)		(-0.055)		(0.674)		(-0.362)	
$Ln(FIXEDASSETS_t/WORKERS_t)$	-0.370		-1.158		-0.345		-1.305	
	(-0.373)		(-1.282)		(-0.357)		(-1.187)	
$Ln(PROFIT_{t-1})$	-0.064		0.014		-0.069		-0.005	
	(-0.753)		(0.114)		(-0.924)		(-0.045)	
$Ln(UNION_t/LABF_t)$	-0.065		-0.678		--------		--------	
	(-0.131)		(-1.328)		--------		--------	
$WORKCOMP_t$	-0.137	**	--------		-0.143	**	--------	
	(-2.274)		--------		(-2.677)		--------	
$Ln(WIRE_t/POP_t)/(WIRE_{t-1}/POP_{t-1}))$	-0.001		0.170		0.004		0.396	**
	(-0.005)		(0.961)		(0.024)		(2.122)	
WWI_t	0.601	***	0.434	***	0.612	***	0.505	***
	(4.101)		(3.318)		(5.180)		(4.076)	
$Ln(UNEMP_t)$	0.103		0.064		0.104		0.050	
	(0.558)		(0.338)		(0.579)		(0.306)	
Trend	-0.097		-0.254	*	-0.099		-0.382	**
	(-0.691)		(-1.684)		(-0.741)		(-2.688)	
Durbin-Watson Statistic	1.561		1.379		1.514		1.159	
F-Statistic	37.499	***	34.281	***	43.505	***	34.678	***
Adjusted R^2	0.876		0.856		0.881		0.840	

t-statistics reported in parentheses.

* - Significant at the 10 percent level.

** - Significant at the 5 percent level.

*** - Significant at the 1 percent level.

Appendix

To find $\frac{d\theta}{dN}$, we can apply Cramer's rule and replace the second column in Π with the 2x1 vector that appears on the right hand side of (5). Before doing that we can simplify the following expression by using our results from (2):

$$-\left(\frac{\partial P}{\partial N}+q_d\,\frac{\partial^2 P}{\partial q_d \partial N}\right)=-\left(\frac{-\alpha(a-bq_d)b+\alpha b^2 q_d}{(\alpha+bN)^2}\right)=\frac{\alpha ab}{(\alpha+bN)^2}>0\,. \qquad \text{(A1)}$$

Introduction this into our expression, we have

$$\det\begin{vmatrix} 2\frac{\partial P}{\partial q_d}-A_{q_d q_d} & \frac{\alpha ab}{(\alpha+bN)^2} \\ -A_{\theta q_d} & 0 \end{vmatrix}=\det\Pi'=\frac{\alpha ab}{(\alpha+bN)^2}A_{\theta q_d}>0\,. \qquad \text{(A2)}$$

By Cramer's rule, then, we have $\frac{d\theta}{dN}=\frac{\det\Pi'}{\det\Pi}>0$. Q.E.D.