Strikes, Scabs, and Tread Separations: Labor Strife and the Production of Defective Bridgestone/Firestone Tires

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This paper provides a case study of the effect of labor relations on product quality. We consider whether a long, contentious strike and the hiring of replacement workers at Bridgestone/Firestone's Decatur, Illinois, plant in the mid-1990s contributed to the production of defective tires. Using several independent data sources and looking before and after the strike and across plants, we find that labor strife at the Decatur plant closely coincided with lower product quality. Monthly data suggest that defects were particularly high around the time concessions were demanded and when large numbers of replacement workers and returning strikers worked side by side.

Do workers provide more effort and due diligence if they feel they are treated better? Does the labor relations climate affect the quality of production? Economic models of fairness (e.g., Rabin 1993; Fehr and Gächter 2000) suggest that workers are more cooperative and less prone

to commit sabotage if they feel they are treated well and in good faith. In addition, the dependence of worker effort on pay is an essential feature of efficiency wage models. Yet a relationship between worker treatment and the quality of production has proved difficult to establish. Quality is often unobserved or hard to measure. This paper provides new evidence on the impact of *labor strife* on the quality of production at the plant level by examining the incidence of defective Bridgestone/ Firestone tires.

In August 2000, Firestone and Ford jointly announced the recall of 14.4 million size P235/75R15 ATX, ATX II, and Wilderness AT tires, some 6.5 million of them still on the road, mostly on Ford Explorers.[1] The National Highway Traffic and Safety Administration (NHTSA) issued an advisory concerning several other sizes and models of Firestone tires in September 2000. The NHTSA reported that the Firestone tires under investigation were related to 271 fatalities and more than 800 injuries. The most common source of failure of the recalled tires was tread separation, that is, a sudden detachment of the rubber tread from the steel belts, causing the tire to blow out. One of every 400 tires produced in the Decatur, Illinois, plant in 1995 was returned under warranty because of a tread separation by 2000.[2]

As described in detail in Section I, three of Firestone's 11 North American tire production plants, including its Decatur plant, which manufactured a large number of P235/75R15 tires, underwent a severe strike beginning in July 1994, after Bridgestone/Firestone proposed deviating from the industrywide pattern bargain by moving from an eight- to a 12-hour shift that would rotate between days and nights, as well as cutting pay for new hires by 30 percent. Almost immediately after 4,200 workers walked out on strike, the company hired replacement workers. A final contract, which included provisions to recall all strikers, was not settled until December 1996.

A unique vista into the possible effect of labor relations on product quality is possible in this instance because the recall of Firestone tires, congressional hearings, and scores of liability lawsuits have made confidential, proprietary data publicly available. Tires are still made in large part by hand, so there is scope for human error in producing this

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[1] The recall pertained to size P235/75R15 Firestone ATX and ATX II tires made in *all* Firestone plants from 1991 to 2000 and P235/75R15 Wilderness AT tires produced in the Decatur, Ill., plant from 1996 to 2000. On May 22, 2001, Ford announced plans to replace all Wilderness AT tires on certain Ford vehicles. In October 2001, Firestone recalled additional P235/75R15 tires and P255/70R16 Wilderness AT tires.

[2] This figure is based on our calculations using warranty data provided by Bridgestone/ Firestone to the NHTSA. It is an underestimate of the overall incidence of tread separations because not all tires were covered by the warranty program at the time of a tread separation, and some owners may not have returned covered tires under the warranty program despite having a tread separation.

product. In addition, because millions of tires are produced and are in service each year, failure rates can be calculated for an enormous sample.

Laboratory tests by Firestone and Ford have been unable to identify a single manufacturing or design defect that is responsible for the high incidence of defective tires. A variety of different types of defects were probably at work. Is it possible that the labor dispute affected the safety of the tires? A number of observers—congressmen, plaintiffs' attorneys, and reporters—have hypothesized that undertrained replacement workers or lax supervision during the strike contributed to the tire defects. It is also possible that discord among replacement workers, union members who crossed the picket line, and returning strikers contributed to the production defects. And workers may have been fatigued and more prone to errors because Firestone introduced a 12-hour rotating shift to operate the plant 24 hours a day during the strike.

At least five other hypotheses have been proposed as the source of defective tires. First, Bridgestone/Firestone executives blamed the defects in part on the design of the Ford Explorer, which they argued was prone to roll over. Second, Bridgestone/Firestone also argued that Ford recommended that the air pressure of the tires be set at 26 pounds per square inch (psi), whereas the tire manufacturer recommended 30 psi. At lower pressures, tires become hotter and are more prone to blow out. Third, others have conjectured that features of the manufacturing process in the Decatur plant increased the risk of safety defects, including a shortening of the vulcanization process (time in which tires are cooked to imprint the tread) and plant conditions that may have allowed moisture to seep into the rubber linings. Fourth, some tire experts and workers have conjectured that faulty material inputs, such as outdated rubber, weakened tires manufactured in Decatur. Finally, some have claimed that the design of the tires was responsible for the high rate of tread separations.

Anecdotal evidence is available for all these explanations. In Sections III–V, we try to systematically sort through the possible reasons for the safety-related defects, focusing closely on whether the production of defective tires coincided with the labor dispute. We examine three different data sets and provide five types of evidence. We focus mostly on P235/75R15 tires because they have more data available, but we look at other tires as well. Almost all the P235 tires were produced in three plants: Decatur, Illinois; Joliette, Quebec; and Wilson, North Carolina. For nearly three years—from April 1994 to December 1996—union workers at the Decatur plant either were on strike or were working without a contract; tires were produced by 1,048 replacement workers, union members who crossed the picket line, management, and recalled strikers in this period. The Wilson plant was nonunion, so it did not experience a strike. A Canadian union represents the Joliette plant, but

labor relations there were much less contentious. Joliette had a six-month strike over fringe benefits at the end of 1995, but the plant did not hire replacement workers (which are illegal in Quebec).

The evidence that we have assembled suggests that the strike and associated labor strife in Decatur were major contributing factors to the production of defective tires. First, descriptive analysis and count regression models using data on claims for compensation for property damage or personal injuries show significantly higher defect rates for tires manufactured in Decatur during the labor dispute (defined as 1994–96) than in Decatur at other times or in other plants, conditional on production and other variables. Second, NHTSA data on complaints involving Firestone P235/75R15 tires indicate a similar pattern: a significantly higher incidence of complaints filed concerning tires manufactured in Decatur during the strike period than at other times or at other plants. Third, engineering tests conducted by Firestone—which hold constant conditions such as speed, load, tire pressure, and ambient temperature—indicate a higher failure rate for tires manufactured in Decatur during the strike compared with tires manufactured in Decatur during non–strike years or in other plants.

Fourth, we more closely examine the timing of the production of defective tires using data on the number of claims disaggregated *by the month the tires were produced*. This analysis finds an excess number of claims for tires produced in Decatur in the few months before the contract expired, when Bridgestone/Firestone demanded concessions, and in the period in which many replacement workers and recalled union workers worked side by side. This finding leads us to a somewhat nuanced conclusion on the role of replacement workers: it is not simply that undertrained or poorly supervised replacement workers produced defective tires. Instead, the timing suggests that the concurrence of replacement workers and union members working side by side before the contract was settled, as well as labor strife in the months leading up to the strike, coincided with the production of a high number of defective tires.

Fifth, we examine other models of Firestone tires, which have not been recalled by Firestone. The same workforce produced these tires, so labor strife might have affected their quality. Results for these models also indicate a higher defect rate for tires produced in Decatur during the strike than in Decatur before or after the strike or in other plants.

Although these findings suggest that labor strife contributed to the problems with Bridgestone/Firestone tires, it is unclear whether one can generalize from our results to other settings because tire manufacturing may be different from other industries and because the investigation into the problems with P235 tires made our case study possible in the first place, so "selection bias" may be an issue. Our findings were

not preordained, however, because at the start of our work we were unaware that an excess number of defective tires were produced during the dispute period in the Decatur plant, that the precise timing would indicate a major role for union workers as opposed to replacement workers, or that there was an unusual number of problems with non-P235 tires manufactured in the Decatur plant during the dispute. Still, we would recommend that the reader exercise caution in extending our results to other settings; our paper provides a detailed case study of only one firm in one unique period of its history.

I.   Background and Industrial Relations Environment

In 1988, the Japanese tire manufacturer Bridgestone purchased Firestone, making Bridgestone/Firestone the largest tire manufacturer in the world. Initially, labor relations went smoothly. For example, Bridgestone upheld Firestone's agreement to allow its new plant in Warren County, Tennessee, to organize by means of a card sign-up, forgoing a secret ballot election. In 1991, the three-year contract negotiated between Bridgestone and the United Rubber Workers (URW) became the pattern for the tire industry, and the company and union established a much ballyhooed "Partnership for Involvement" program.[3] When negotiations began in January 1994, however, Bridgestone/Firestone sought to deviate from the industrywide practice of pattern bargaining, asking for what a company negotiator called "a turnaround agreement." Since the 1940s, Firestone plants had adhered to the industrywide pattern bargain. Peter Schofield, Firestone's former director of labor relations, said that the January 1994 bargaining session "certainly didn't make the union happy" (Meyer 2002, p. 337).

Bridgestone/Firestone demanded that the union move from eight-hour to 12-hour shifts that rotated between day and night, that it operate the plant seven days a week, that the pay of new hires be reduced by 30 percent (although the cut would be made up by faster seniority increases over a three-year period), that hourly workers contribute to their health care costs, that the piece rate system be moved to a plant-wide performance pay system, and that vacations be cut by two weeks for senior workers. This request for concessions came at a time of falling national unemployment and just after Bridgestone/Firestone's first profitable year since Bridgestone acquired Firestone (Whitford 1994). The URW proposed that Bridgestone/Firestone follow the master pattern

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[3] The material in this paragraph draws heavily from Franklin (2001) and Meyer (2002).

agreement set with Goodyear, which called for no wage increases other than cost-of-living adjustments.[4]

After the contract expired on April 1, 1994, union members continued working without an agreement. On July 12, 1994, URW locals representing 4,200 workers in three of Bridgestone/Firestone's production plants (Des Moines, Decatur, and Oklahoma City), the Akron, Ohio, research center, and the Noblesville, Indiana, air springs plant went on strike. Bridgestone almost immediately began to hire temporary replacement workers and operate the plants with managerial and supervisory workers. Replacement workers were paid 30 percent less than the union rate (Franklin 2001, p. 140). By January 1995, when the company converted temporary replacement workers to permanent replacement workers, it had hired a total of 2,300 replacement workers (p. 140).

The union set up pickets outside the struck plants. In Decatur, the union posted the names of each member who crossed the picket line under the title "Hall of Shame." The list included a previous president of the local union (Franklin 2001, p. 127). More than 300 of the 1,209 members of Local 713 in Decatur eventually crossed the picket line. By May 1995, the Decatur plant employed 1,048 replacement workers and 371 permanent workers.[5] The company initiated 12-hour rotating shifts and operated the plant 24 hours a day.

On May 7, 1995, members of the URW Local 713 in Decatur voted by a 2–1 margin to officially end their strike against Bridgestone/Firestone. The other plants quickly followed suit.[6] On May 22, the URW unconditionally offered to return to work. According to Local 713 President Roger Gates, the union offered to unconditionally end the strike as a strategy to prevent Bridgestone/Firestone from hiring additional replacement workers and to forestall a union decertification election (Cimini 1996). The strike was the longest in the history of the URW; its strike fund was depleted. Bridgestone/Firestone unilaterally imposed its last offer from July 1994, which cut wages for some job classifications by $5.34 an hour, to about $12 per hour; moved piece rate pay to a flat hourly rate plus plantwide performance pay; paid new hires 30 percent less than before the strike; froze pension benefits; and required workers to contribute a portion of their health care premiums (pp. 26–27). The company also continued operating 12-hour shifts.

Although the strike officially ended in May 1995, the labor dispute continued. The company notified the union that it intended to per-

[4] The previous agreement at Goodyear also expired in April 1994, and the new contract was settled as soon as the old one expired.

[5] Statistics included in a letter submitted by Theodore Hester on behalf of Bridgestone/Firestone, contained in U.S. House (2000, p. 107).

[6] In January 1995 the local representing the research facility in Akron had voted to end the strike.

manently retain the replacement workers and that it would "advise the
URW of the number of employees for whom we have work" (statement
of Bridgestone/Firestone spokesperson Trevor Hoskins [Bureau of Na-
tional Affairs 1995, pp. A6–A7]). In July 1995, the financially bankrupt
URW voted to merge into the United Steel Workers of America (USWA).
The URW ceased to exist. The USWA made the rehiring of all striking
workers a priority for future negotiations, but Bridgestone/Firestone
and the USWA did not reach a new agreement until December 1996.
On July 18, 1995, the USWA announced a worldwide boycott of Bridge-
stone/Firestone and Sears Roebuck, its largest domestic retailer. The
union said it initiated the boycott because the company insisted on
retaining replacement workers instead of recalling some 2,000 strikers
who were willing to return to work (Cimini 1996).[7] The USWA broke
off contract talks in January 1996 because Bridgestone/Firestone would
not agree to a system of pattern bargaining.

A final settlement, which included an agreement to recall all strikers,
was ratified in December 1996. The new contract gave an across-the-
board wage increase of 35 cents compared to the 1994 levels, gave a
$750 bonus, and restored pension benefits. Hourly wages were about
$1.00 below the rate at Goodyear (Sabath 1997). A 12-hour shift re-
mained in place, but it no longer rotated between day and night for
the same worker.

Most strikers had been recalled prior to the final contract agreement.[8]
By early November 1996, all but 40 strikers were recalled. Bridgestone/
Firestone increased the operation of its plants to 24 hours a day, seven
days a week, during the strike, so total employment increased. Because
Bridgestone/Firestone gradually recalled strikers after the union un-
conditionally agreed to return to work, replacement workers and re-
turning strikers worked side by side for several months before a new
contract was reached. From the union's perspective, working conditions
in this period were described as "brutal."

Greenhouse (1996, p. A16) observed that "organized labor made the
dispute one of its crusades largely because it involved one of the largest
uses of permanent replacement workers in the nation's history."[9]

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[7] Among other activities, the USWA staged an anti-Firestone protest at the Indianapolis
500.

[8] John Lampe, Bridgestone/Firestone's executive vice president, testified that "by 1996,
over half of our work force in the Decatur plant was unionized workers that had gone on
strike and come back, and less than half were then replacement or temporary workers"
(U.S. House 2000, p. 1391).

[9] There are many other notable examples in which labor strife has arisen during strikes
in which replacement workers were hired. Examples include the Hormel strike of 1985–
86 in Austin, Minn. (Green 1990); the Iowa Beef Packers strike of 1987 in Dakota City,
Iowa (Craypo 1994); the Phelps Dodge Corp. strike of 1983 in Phelps Dodge, Ariz. (Ro-
senblum 1995); and the International Paper Strike of 1988 in Jay, Maine, which coincided
with toxic gas leaks leading to the evacuation of the town (Bierecree 1991).

TABLE 1
TOTAL PRODUCTION OF SIZE P235/75R15 TIRES, BRIDGESTONE/FIRESTONE PLANTS,
JANUARY 1991–MARCH 2000

Plant	Number of ATX and Wilderness Tires	Percentage of Total	Claims per Million ATX Tires Produced	Notes
Aiken, S.C.	1,442,115	6.9	NA	Plant began operation in 1999
Decatur, Ill.	6,408,584	30.5	356.0	Strike from July 1994 to December 1996; 1,048 replacement workers
Joliette, Que.	5,638,302	26.9	58.9	Strike from August 1995 to February 1996; no replacement workers
La Vergne, Tenn.	455,157	2.2	NA	No strike
Oklahoma City, Okla.	530,515	2.5	44.1	Strike from July 1994 to December 1996
Wilson, N.C.	6,503,642	31.0	142.0	Nonunion; no strike
Total	20,978,315	100.0		

SOURCE.—Production is derived from a Safety Forum spreadsheet. Claims per million are taken from a chart submitted by Firestone to the House Committee on Commerce; they pertain to property damage and personal injury claims for ATX size P235/75R15 tires.
NOTE.—P235/75R15 tires include ATX, ATX II, and Wilderness AT tires. Aiken produced only Wilderness tires.

Tire Production

Column 1 of table 1 reports the number of ATX, ATX II, and Wilderness size P235/75R15 tires produced in each of the six Firestone plants that manufactured such tires from 1991 to 2000. (Henceforth, we use P235 to refer to size P235/75R15 tires and ATX to refer to both ATX and ATX II models.) The Decatur, Joliette, and Wilson plants produced the vast majority of these tires. Wilderness tires were not produced until 1996. A smaller number of ATX tires continued to be produced after Wilderness tires were introduced. Column 4 summarizes the labor relations situation in the 1990s.

Tire manufacturing remains a highly complex, labor-intensive task. According to Firestone's former chief executive officer, Masatoshi Ono, "A typical tire can have more than 26 components, 14 different rubber compounds and require 29 separate steps to manufacture" (quoted in an August 23, 2000, press release [http://www.bridgestone-firestone .com/news/mediacenter/news/000823a.htm]). The Decatur plant is Firestone's oldest manufacturing facility. The plant was originally used by Caterpillar to build large engines for the U.S. military during World War II. It was next used as a U.S. Army signal depot until 1961. In 1962 Firestone purchased the 160-acre site and converted it to produce tires. Local 713 of the URW immediately organized it. Franklin (2001, p. 117) describes the plant as "dark, brooding, and smoky in places, a noisy

monument to the almost unchanging way most tires are still made: with much reaching and lifting and cutting, a lot of human muscle power, and an endless demand for unflinching robot-like concentration." Particularly in the Decatur plant, tire production was not automated. For example, workers had much discretion over the amount of effort exerted to wrap the steel belts, the condition of the rubber used to produce the tread and sidewall, and the implementation of the vulcanization process.

There is much anecdotal evidence that replacement workers were less skilled tire makers and were perhaps more prone to build defective tires. According to William Newton, a retired tire builder from Decatur, "It takes two years to become a good tire builder." When Mr. Newton returned to work after the strike, he said he "saw a lot of people who didn't know how to build tires" (quoted in Barboza [2000, p. C1]). Joe Roundtree, another retired worker from Decatur, reportedly testified in a civil case that he doubted the ability of replacement workers to match the quality of experienced union workers and that he thought moving to 12-hour shifts compromised product quality (Fogarty 2000).

Other employees have testified that they were ordered to remove blisters from tire sidewalls by piercing them with an awl, a small, hand-held pointed instrument, and that production pressures during the labor dispute impaired quality. "I protested it, but I done it," Jan S. Wagoner said. "I didn't like sticking an awl all the way through the sidewall of a tire" (Skertic 2000). The Decatur plant manager, Harry McMillan, testified that the plant "was not producing the volume of tires it was expected to produce [during the dispute], and waste and scrap levels were higher than the company expected them to be" (quoted in Pinkerton [2001b]). Tires are scrapped if a defect is detected. "They preached quality," Lonnie Dart, a retired Decatur worker testified, "but if you didn't make the numbers, you was in trouble" (Skertic 2000). According to one news account, production quotas made thorough inspections nearly impossible (Barboza 2000).

Tire Safety

Tires are more likely to fail if they run at higher speeds or at higher temperatures or carry heavier loads. Older tires are also more likely to suffer a tread separation. A large majority of tread separations occurred in the southwestern part of the United States, almost certainly because of the higher average temperature there. We are not aware of any evidence indicating a change in the regional distribution of Firestone tires produced in different plants, but the location of tires that are installed as original equipment, as opposed to replacement tires, is determined by the auto manufacturer.

One possibly relevant development was that Ford began producing

Explorers at a new plant that opened in St. Louis, Missouri, in 1995, and many of these vehicles were sent to dealers in the Southwest. The other Explorer plant was in Louisville, Kentucky. Firestone's Decatur plant likely supplied tires to both plants because of its proximity. There are several reasons why we doubt that the temporal pattern of defective tires originating from Decatur that we document below was caused by a change in distribution to warmer states during the dispute, however. First, the St. Louis plant began producing in 1995, but there was already an excess number of defective tires produced in Decatur in early 1994. Second, our results are robust if we limit the analysis to replacement tires, which are unaffected by the new Ford plant. Third, the excess number of defects from Decatur abated after 1996, while the St. Louis plant continued to operate. Fourth, and perhaps most important, engineering tests that hold constant temperature and other environmental factors point in the same direction as the field data.

Historically, Firestone has monitored tire safety by running product tests, studying warranty adjustment information, and analyzing failed tires that were returned from the field. Another source of information is claims paid for property damages and personal injuries. According to congressional testimony (U.S. House 2000, p. 137), the company did not closely monitor these data for safety purposes until July 2000, in a joint effort with Ford.[10]

Column 3 of table 1 reports the number of claims for property damages or personal injuries involving Firestone ATX tires. It is clear that the Decatur plant has a much higher rate of claims per million tires produced. A key question is, Was the claims rate elevated for tires made during the labor dispute?

II.   Firestone Claims and NHTSA Complaints Data Sets and Descriptive Analysis

We obtained Firestone's internal claims data from the NHTSA. These data consist of a brief description of claims filed before 2000 for property damage or personal injuries stemming from tire failures. About 70 percent of the claims involved problems related to tread separations. The data we analyze include claims concerning 2,597 P235 tires produced between 1991 and 1999. The data set includes micro data on tire model and size, date of failure, and the 10-digit Department of Transportation (DOT) tire code, from which plant and week of production can be inferred.

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[10] In a deposition for a civil suit in Texas, Allen Rauner, a Ford engineer, testified that he requested claims data in 1999 from Firestone but was told that the company did not have such data (Pinkerton 2001a).

We use these data to construct a cell-level data set, where the cell is a production year by age by plant. We also have added information for each cell on the number of P235 tires produced (by model), the share of tires that were used as original equipment, and the share of tires that are ATX model, which were all provided by Safety Forum, a nonprofit organization that works with trial attorneys involved in lawsuits against Firestone and Ford.

The second set of data on failures was collected by the NHTSA.[11] Briefly, the NHTSA recorded information reported by consumers, police authorities, insurance companies, and other organizations on Firestone tires that failed. The NHTSA data also include information on the tire model and size, date of failure, and DOT tire code. We use these data to construct a cell-level data set on the number of complaints by year of production, plant, and age. One advantage of the NHTSA data set is that it indicates whether the tire failure resulted in a fatality or injury, allowing us to calculate failure rates depending on the severity of the incident. Another advantage is that we can analyze data on P235 and non-P235 tires. And unlike the claims data, the complaints data indicate whether the tire was installed as original equipment or as a replacement tire.

There are three major shortcomings with the NHTSA complaints data, however. First, the records contain many missing values for the variables of interest. Of 5,189 reported complaints (on all tire sizes), only 1,076 have complete data, 3,524 have partial data, and 586 are missing data on the production year, plant, and calendar year of failure of the tire. Second, many complaints were filed after the recall was announced and may involve routine use-related failures, such as running over a nail. Third, there is no financial incentive to report complaints to the NHTSA, as opposed to claims data, so underreporting is probably common. We limited the data to complaints filed before the August 2000 recall to avoid an avalanche of frivolous complaints or complaints that were sparked because the recall singled out Wilderness tires made in Decatur. Before the recall, it was not publicly known that Decatur tires might have a higher defect rate.

To handle the missing values, we multiply imputed missing data using the conditional distribution for the available data using a technique based on Rubin (1987). If, say, a randomly chosen half of all complaints had missing data, we could just double the number of complaints with complete data. But this would not make use of the partially reported data, and we could probably do better filling in the missing data by

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[11] The complaints micro data set is publicly available from the NHTSA. It began compiling the complaints regarding Firestone tires in February 2000 and ceased in June 2001. The data are described in detail in the data appendix to Krueger and Mas (2002).

conditioning on the information that we do have. For example, if a tire's age was missing, we randomly assigned the age from the set of tires with the same year of production and vehicle miles.

Although it is possible to utilize a more sophisticated technique to impute missing values, given the strong likelihood that data are randomly missing (e.g., a tire was so badly damaged that the DOT code was not visible), we implemented a simple, transparent hot-decking technique that relied on a priori expectations of which variables contain information on the missing values. We created 10 micro complaints data sets imputing missing values in this way and then aggregated each micro data set into plant by year of production by age cells. We report summary statistics for the average of the 10 cell-level data sets. The advantage of proceeding in this way (as opposed to assigning conditional expected values to missing data) is that the standard errors that we compute take into account sampling variability introduced by the imputation method.[12] The assumption that is required for the consistency of the estimates using both imputed and nonimputed data is that the missing data are missing at random conditional on the variables used in the imputation. It is reassuring to note that none of our conclusions is qualitatively altered if we use only the nonmissing observations.[13]

Although both the claims and complaints data sets have limitations, they complement each other and have the virtue of being independently collected. For example, while the claims data are more complete and claimants have a financial incentive to file a claim, they lack information on the severity of resulting injuries. Moreover, there is no industrywide standard definition of a claim, so the claims data rely on Firestone's interpretation and recording of claims.

Descriptive Analysis

Figure 1 reports the *cumulative* number of claims against Bridgestone/ Firestone per million ATX tires produced by the year the tires were produced and the age of the tires. The left panel displays data for the Decatur plant and the right panel for Joliette and Wilson, the two other main producers.[14] The three years of the labor dispute—1994, 1995, and 1996—stand out in the figure for Decatur. Four years after pro-

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[12] Specifically, standard errors are calculated by taking the square root of the sum of the average sampling variance of the estimates in each of the data sets and the variance of the estimates across the 10 imputed data sets (to account for variability due to imputation); see the data appendix in Krueger and Mas (2002).

[13] Estimates using the sample of complaints without imputed data are available on request.

[14] Ford submitted a similar graph in congressional testimony, although it pertained just to tread separations and combined all plants other than Decatur (see U.S. House 2000, p. 153).
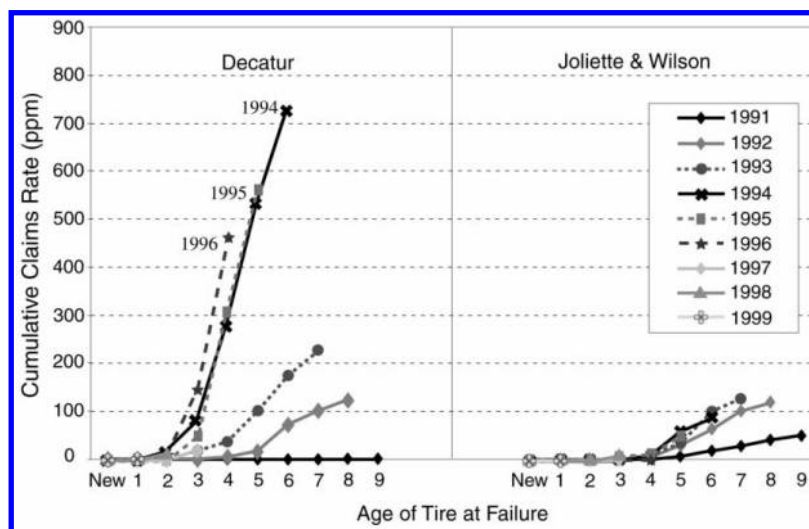
FIG. 1.—Claims per million Firestone ATX tires produced, by age of tire at failure, production year, and plant. Source: Authors' calculations based on Firestone claims data submitted to the NHTSA. Claims pertain to personal injury or property damage involving Firestone ATX tires prior to 2000.

duction, tires that were made in Decatur during the labor dispute were at least 15 times more likely to have resulted in a claim than tires manufactured in other plants. Such a large discrepancy in failure rates is not evident for other production years, although the claims rate for Decatur tires was about double that for other tires for the 1993 production year.

Figures 2 and 3 report similar figures using the *complaints* data for ATX and Wilderness size P235 tires combined. Figure 2 uses only the subsample with complete data for year, plant, and age, and figure 3 uses the average of 10 data sets with allocations for missing data, as described previously. The number of complaints is about half as large as the number of claims, even after imputations are made for missing data. Nonetheless, both figures tell a similar story, and a story similar to the claims data: tires produced during the labor dispute (1994–96) at the Decatur plant have a much higher failure rate than those produced at Joliette or Wilson, although before and after the dispute period the rate of complaints is similar for tires manufactured in Decatur and in the other plants.

Figure 4 displays cumulative incidence rates for cases in the NHTSA database involving at least one fatality.[15] That is, we report the cumulative

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[15] The figure uses imputed data for missing values. The results are quite similar if records with incomplete data are eliminated.
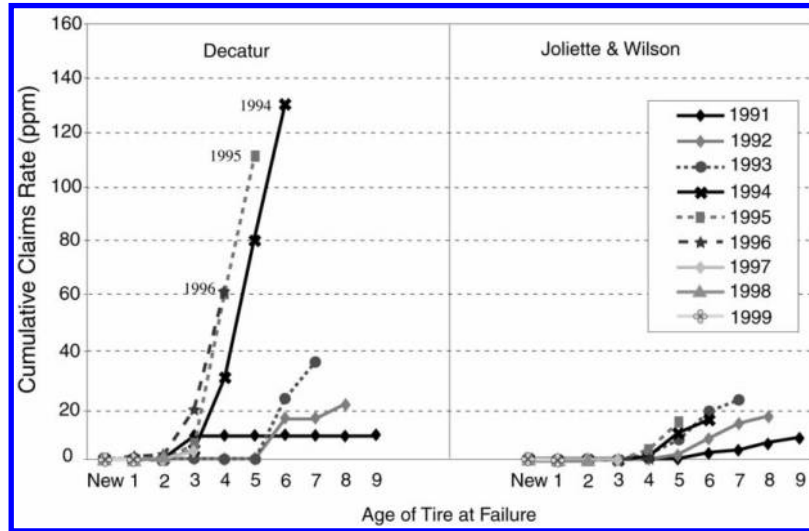
Fig. 2.—Complaints registered by the NHTSA per million P235/75R15 Firestone tires produced, by age of tire, production year, and plant (nonimputed data). Source: Authors' calculations based on NHTSA and Safety Forum data. Complaints concern defects in 1991–99, reported prior to August 2000. Observations with missing data are excluded.
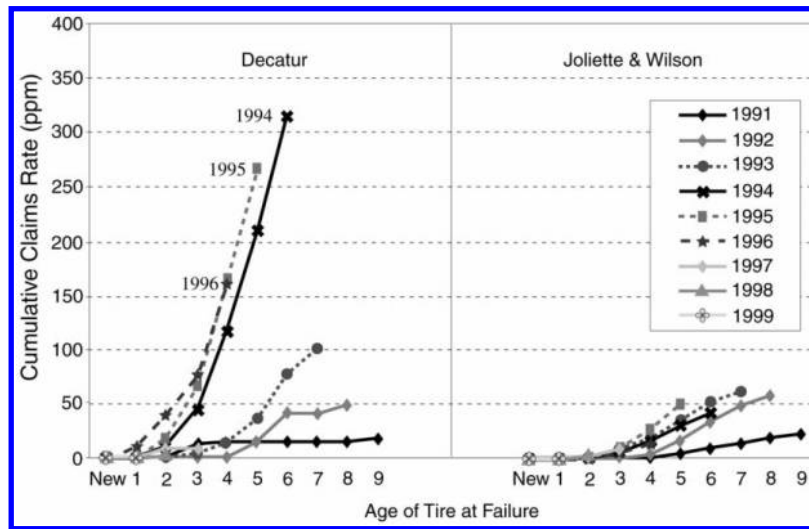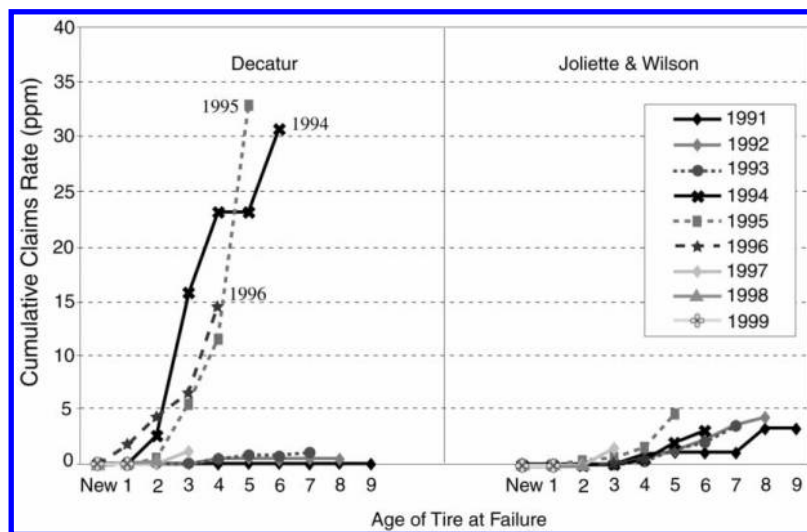

Fig. 3.—Complaints registered by the NHTSA per million P235/75R15 Firestone tires produced, by age of tire, production year, and plant (average of 10 imputed data sets). Source: Authors' calculations based on NHTSA and Safety Forum data. Complaints concern defects in 1991–99, reported prior to August 2000.

Fig. 4.—Number of accidents with fatalities per million Firestone P235/75R15 tires produced, by age of tire, production year, and plant (average of 10 imputed data sets). Source: Authors' calculations based on NHTSA and Safety Forum data. The sample includes ATX and Wilderness P235/75R15 tires. Accidents occurred between 1991 and 1999 and could have been reported at any time after 1991.

number of recorded tire failures linked to a fatality per million tires produced, by year of production, plant, and age of tire. This sample was selected because fatalities are unlikely to be undercounted in the NHTSA data and because records for cases involving fatalities were less likely to have missing data. Even with a small number of counts, these graphs convey a similar message: a higher rate of fatal accidents involving tires produced in Decatur during the labor dispute than tires produced in other plants or tires produced in Decatur during a more tranquil period of labor relations. To put the numbers in perspective, note that before the recall, tires made in Decatur during the labor dispute had a fatal accident rate of 10–30 per million tires produced. As a benchmark, we note that the risk of death from parachuting is estimated at 13 per million jumps (Poynter 1992).[16]

[16] Because tires are driven on frequently over several years, these statistics admittedly compare apples and oranges to dramatize the risk from tire failure. A common but still unsatisfactory alternative is to put both risks per mile traveled. One way to put the figures reported in the text in a comparable context, however, is to note that the risk of a fatal tire blowout is reduced by changing one's tires, and each car has four tires with more or less mutually exclusive risks, so the reduction in risk for a driver from replacing P235 tires manufactured during the labor dispute surely exceeded the risk reduction from refraining from one parachute jump.

III.   Count Data Models

To model tire failures conditional on other variables, we estimate a series of count data regression models. Specifically, we model y_{ijt}, the number of claims (or complaints) for tires produced in plant i in year j that failed in calendar year t, as

$$E(y_{ijt}|\mathbf{x}_{ijt}) = \exp(\mathbf{x}'_{ijt}\boldsymbol{\beta}), \tag{1}$$

where the **x**-vector of explanatory variables includes the logarithm of tires produced in plant i in year j, a dummy variable indicating tires manufactured in Decatur, a dummy indicating tires manufactured during the labor dispute (defined as 1994–96), an interaction between the Decatur dummy and labor dispute dummy, a quadratic in tire age, and possibly other variables such as the fraction of tires in the cell that were installed as original equipment on new vehicles. The vector of parameters is denoted $\boldsymbol{\beta}$.

The "law of rare events" holds that the total number of events of some kind that occur in a time interval will approximately follow a Poisson distribution if a single event may occur in any of a large number of trials, but the probability that the event occurs in any one trial is small. Tire failures would seem a natural to model as a Poisson process because they are rare events and there are a large number of trials, with hundreds of thousands of cars driving on tires made in the same plant and year. A testable restriction of the Poisson model is that the conditional mean, $E(y_{ijt}|\mathbf{x}_{ijt})$, equals the conditional variance, $\mathrm{Var}(y_{ijt}|\mathbf{x}_{ijt})$. Even if this restriction does not hold, however, Poisson maximum likelihood estimates of $\boldsymbol{\beta}$ are still consistent if equation (1) is a correct specification, although the standard errors are inconsistent.

A common feature of count data—and one that we find in our tire failure data—is that the conditional variance exceeds the conditional mean. As a consequence, to avoid understating the standard errors, we compute robust standard errors that are consistent in the presence of overdispersion (see Cameron and Trivedi [1998, pp. 63–65] on robust Poisson). Specifically, we allow

$$\mathrm{Var}(y_i|\mathbf{x}_i) = \alpha \exp(\mathbf{x}'_i\boldsymbol{\beta}), \quad \alpha > 1,$$

where α is an overdispersion parameter. The robust standard errors thus equal the usual Poisson standard errors multiplied by the square root of α. We estimate α by

$$\hat{\alpha} = (n-k)^{-1} \sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{\hat{y}_i}.$$

In addition, we present estimates of negative binomial models for our first set of specifications. The negative binomial model does not impose

TABLE 2
MEANS OF DATA USED IN AGGREGATE ANALYSIS OF ATX AND WILDERNESS AT P235/
75R15 TIRES (*N*=135)

	CLAIMS		COMPLAINTS*	
	Unweighted Means (1)	Weighted Means (2)	Unweighted Means (3)	Weighted Means (4)
Number of claims or complaints	12.10 [29.37]	…	5.81 [10.88]	…
Log production	13.11 [.71]	13.37 [.56]	13.11 [.70]	13.35 [.55]
Proportion ATX	.84 [.32]	.90 [.19]	.84 [.32]	.89 [.21]
Proportion original equipment	.62 [.24]	.52 [.28]	.62 [.24]	.53 [.28]
Age	2.67 [2.22]	3.83 [1.40]	2.67 [2.22]	3.55 [1.54]
Age^2	12 [15.47]	16.63 [12.02]	12 [15.47]	15.24 [12.21]
Decatur dummy (1=yes)	.33 [.47]	.57 [.50]	.33 [.47]	.53 [.50]
Dispute period dummy, defined as 1994–96 (1=yes)	.33 [.47]	.62 [.49]	.33 [.47]	.63 [.49]
Decatur × dispute period	.11 [.32]	.50 [.50]	.11 [.32]	.47 [.50]

SOURCE.—Authors' calculations.

NOTE.—Standard deviations are in brackets. Weighted means are weighted by the number of claims (col. 2) or complaints (col. 4), thus giving the average characteristics of tires that failed. In col. 2 there were 24 cells with a weight of zero (i.e., no claims), and in col. 4 there were 43 cells with a weight of zero (i.e., no complaints).

* Contains imputations for missing values.

the restriction that the mean equal the variance and is also consistent if equation (1) holds.

Table 2 reports means of the two cell-level data sets we use to estimate count models. Columns 1 and 2 present summary statistics for the Firestone claims data set and columns 3 and 4 for the NHTSA complaints data set. In both data sets, we have combined data on ATX and Wilderness tires. The dependent variable (y_{ijt}), shown in the first row, is the total number of failures in either ATX or Wilderness P235 tires in a particular plant by year of production by calendar year. Cells in the claims and complaints data sets pertain to three plants (Decatur, Joliette, and Wilson) by nine production years (1991–99) and nine calendar years (1991–99). Columns 1 and 3 present unweighted means, and columns 2 and 4 use as weights the number of claims or complaints in the cell. Thus columns 2 and 4 provide information on the characteristics of tires that failed.

Complaints are only about half as common per cell as claims. This finding probably reflects underreporting of complaints in the NHTSA

data. Nevertheless, the characteristics of the failed tires are quite similar. In both data sets, for example, more than 90 percent of the failed tires are ATX models, reflecting the fact that ATX tires have a higher failure rate and are older (and therefore more likely to fail) in these samples. The average failed tire is around 3.5 years old at the time of the incident. About half of the failed P235 tires were produced in Decatur during the period of the labor dispute (1994–96); by comparison, only 9 percent of all P235 tires manufactured from 1991 to 1999 were produced in Decatur in this period.

Table 3 presents Poisson models for the Firestone claims data (cols. 1–3) and for the NHTSA complaints data (cols. 4–6). The first model conditions on log production and includes dummy variables indicating tires made in Decatur, tires made during the labor dispute in any plant, and the interaction between the two. The second model also conditions for the age and age squared of the tire. The third model adds controls for the proportion of tires produced in the plant that year that are ATX model and the fraction of tires that were installed as original equipment.

In all the models, tires produced in Decatur during the labor dispute are found to have a statistically significantly higher rate of claims or complaints. First consider the results for claims. In column 3, for example, the Decatur-dispute interaction has a coefficient of 1.48, with a t-ratio of 4.93. This coefficient is a "difference-in-differences" estimate in that it measures the difference in claims between the dispute period and nondispute period in Decatur less the difference over the corresponding time periods in the other plants, conditional on the other variables. To interpret the magnitude of the interaction effect, note that $\exp(1.48) = 4.39$, which implies that the incidence of claims is 339 percent higher for tires produced in Decatur during the labor dispute, other things held constant. The Decatur main effect is on the margin of being significant at the .05 level in column 3, suggesting that, before and after the dispute, the claims rate was somewhat higher for tires manufactured in the Decatur plant than for those manufactured in Joliette and Wilson. This differential is driven by a higher claims rate in Decatur than in the other plants after the dispute, which is possibly a lingering effect of the dispute. The dispute period dummy is insignificant, suggesting that tires from Joliette and Wilson did not result in an increase in claims if they were manufactured during the labor dispute.

The coefficient on the log production variable can be interpreted as a "defect scale" elasticity. Interestingly, in the models in columns 2 and 3, the number of claims rises more than in proportion with the number of tires produced, suggesting that failures exhibit "increasing returns to scale," perhaps because of (accelerating) fatigue in the production process.

TABLE 3
Poisson Regression Models for Number of Defective P235/75R15 Tires by Plant,
Production Year, and Calendar Year: Aggregate Analysis of ATX and
Wilderness AT Tires ($N=135$)

Explanatory Variable	Dependent Variable: Claims			Dependent Variable: Complaints*		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−8.71	−22.45	−18.69	−8.26	−15.60	−12.78
	(2.69)	(1.73)	(2.06)	(2.34)	(1.78)	(2.17)
Log production	.80	1.49	1.27	.72	1.08	.92
	(.20)	(.11)	(.13)	(.18)	(.12)	(.14)
Proportion ATX			.19			.52
			(.48)			(.49)
Proportion original equipment			−1.40			−1.58
			(.56)			(.65)
Age		2.09	2.16		1.17	1.22
		(.17)	(.17)		(.13)	(.13)
Age^2		−.21	−.21		−.11	−.11
		(.02)	(.02)		(.02)	(.02)
Decatur (1=yes)	−.14	1.31	.65	−.36	.43	−.15
	(.45)	(.26)	(.33)	(.43)	(.30)	(.38)
Labor dispute period (1=yes)	−.10	.25	.07	.13	.38	.20
	(.37)	(.19)	(.19)	(.29)	(.19)	(.19)
Decatur × dispute period	2.40	1.39	1.48	2.29	1.73	1.71
	(.57)	(.29)	(.30)	(.50)	(.33)	(.35)
Mean dependent variable	12.10	12.10	12.10	5.81	5.81	5.81
	[29.37]	[29.37]	[29.37]	[10.88]	[10.88]	[10.88]
Pseudo R^2	.40	.81	.82	.42	.68	.69
Log likelihood	−1,417.21	−452.82	−436.66	−559.28	−304.93	−294.43

Note.—Robust standard errors are in parentheses. Standard deviations of the dependent variables are in brackets. The dependent variable corresponds to incidents per year of production, plant of production, and calendar year of failure. Incidents in the NHTSA data set (cols. 4–6) correspond to reporting periods prior to August 2000 for failures occurring between January 1991 and December 1999. Incidents in the Firestone claims data set (cols. 1–3) occurred between January 1991 and December 1999, and claims were made before January 2000. Proportion original equipment denotes the proportion of tires produced in the cell that were original equipment for Ford, Mercury, or Mazda vehicles. Proportion ATX denotes the proportion of tires produced in the cell that were ATX tires. To adjust for incomplete reporting in the NHTSA data set, missing values were imputed by assigning values from other observations with complete data, conditional on available data. Ten imputed data sets were generated. Reported estimates were obtained by averaging the estimates derived from each imputed data set. Standard errors were calculated by taking the square root of the sum of the average sampling variance across data sets and the variance of the estimates across the 10 imputed data sets (to account for variability due to imputation). Other summary statistics reported for cols. 4–6 are the average of the estimates across the imputed data sets.
  * Contains imputations for missing values.

Surprisingly, the proportion of tires in a cell that are ATX models has a small and statistically insignificant, though positive, effect on the incidence of claims. The proportion of tires installed as original equipment has a negative coefficient, which in this case is statistically significant.

Insofar as the labor dispute is concerned, the results for complaints are similar to those for claims. The Decatur-dispute interaction is highly statistically significant, with a t-ratio of 4.89 in column 6. The model in column 6 indicates that tires made in Decatur during the labor dispute were associated with $\exp{(1.71 + .20)} = 6.75$ times more complaints

than tires made in Decatur before or after the dispute. Similarly, tires manufactured in Decatur during the strike were associated with $\exp(1.71 + .20 - .15) = 5.81$ times more complaints than tires manufactured in Wilson or Joliette in nondispute years. The number of complaints concerning tires produced during the dispute in Joliette and Wilson is insignificantly higher than that for tires produced there in other years. And it is worth noting that we cannot reject that the plant main effect and dispute interaction are equal for Wilson and Joliette if we estimate a model that allows their coefficients to differ.

The production variable has close to a unit elasticity in the complaints models in columns 5 and 6. The coefficient on proportion new equipment is negative in the complaints equation and statistically significant.

For both dependent variables, the coefficients on the age variables display an inverted U–shaped pattern, with the number of failures peaking when tires are around five years old. Note that we have made no adjustment to production for tires that are no longer in service. Older tires are more likely to be removed from the road, so the age variables in part reflect obsolescence. We could adjust production by assuming some depreciation rate each year. If we include unrestricted age dummies, however, they would completely absorb any (cross-plant) age-specific obsolescence rate because of the logarithmic specification of production. When we included unrestricted age dummies, the coefficients on production and the Decatur and labor dispute dummies were hardly changed, and the pattern of age effects indicated that the quadratic specification of age fit the data reasonably well. For example, if the model in column 3 of table 3 is estimated with unrestricted age dummies, the coefficient on production is 1.28 (vs. 1.27) and the coefficient on the Decatur-dispute interaction is 1.45 (vs. 1.48). Because the results are so similar if age dummies are included, we have used the more parsimonious quadratic specification.

If we limit the sample of complaints to those involving replacement tires—which are not subject to the regional distribution decisions of the auto manufacturer—the results are very similar. For example, the coefficient on the Decatur-dispute interaction in the model in column 5 of table 3 rises from 1.73 to 2.30 (with a t-ratio of 4.6) if the analysis is limited to spare tires. The other coefficients are also qualitatively similar. This finding suggests that possible changes in Ford's distribution practices are unlikely to account for the results in table 3.

As mentioned previously, the Poisson models impose the constraint $\text{Var}[y|\mathbf{x}] = E[y|\mathbf{x}] = \exp(\mathbf{x}'\boldsymbol{\beta})$. A generalization of the Poisson, the negative binomial II model, specifies the conditional variance as $\text{Var}[y|\mathbf{x}] = (1 + \lambda)\exp(\mathbf{x}'\boldsymbol{\beta})$ while maintaining equation (1). If $\lambda = 0$, the negative binomial is equivalent to a Poisson. A common test for overdispersion is a likelihood ratio test of whether $\lambda > 0$. Table 4 presents

TABLE 4
NEGATIVE BINOMIAL REGRESSION MODELS FOR NUMBER OF DEFECTIVE P235/75R15
TIRES BY PLANT, PRODUCTION YEAR, AND CALENDAR YEAR: AGGREGATE ANALYSIS OF
ATX AND WILDERNESS AT TIRES ($N=135$)

EXPLANATORY VARIABLE	DEPENDENT VARIABLE: CLAIMS			DEPENDENT VARIABLE: COMPLAINTS*		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−2.31	−19.95	−16.55	−6.50	−14.86	−11.62
	(2.40)	(2.11)	(2.19)	(2.24)	(1.83)	(2.12)
Log production	.35	1.34	1.15	.59	1.04	.86
	(.18)	(.14)	(.14)	(.17)	(.13)	(.14)
Proportion ATX			.27			.42
			(.55)			(.51)
Proportion original equipment			−1.71			−1.77
			(.72)			(.72)
Age		1.91	2.01		1.07	1.14
		(.17)	(.18)		(.13)	(.13)
Age^2		−.19	−.19		−.10	−.10
		(.02)	(.02)		(.02)	(.02)
Decatur (1=yes)	−.13	1.12	.37	−.04	.43	−.26
	(.33)	(.31)	(.38)	(.33)	(.30)	(.38)
Labor dispute period (1=yes)	−.17	.24	−.03	.23	.45	.23
	(.29)	(.21)	(.23)	(.26)	(.19)	(.20)
Decatur × dispute period	1.32	1.46	1.60	1.62	1.69	1.74
	(.48)	(.34)	(.36)	(.41)	(.33)	(.36)
Mean dependent variable	12.10	12.10	12.10	5.81	5.81	5.81
	[29.37]	[29.37]	[29.37]	[10.88]	[10.88]	[10.88]
Pseudo R^2	.02	.23	.24	.07	.23	.25
λ	43.49†	6.30†	5.81†	8.07†	1.61†	1.47†
Log likelihood	−391.44	−307.89	−303.40	−335.29	−277.30	−270.45

NOTE.—Standard errors are in parentheses. Standard deviations of the dependent variables are in brackets. The dependent variable corresponds to incidents per year of production, plant of production, and calendar year of failure. Incidents in the NHTSA data set (cols. 4–6) correspond to reporting periods prior to August 2000, for failures occurring between January 1991 and December 1999. Incidents in the Firestone claims data set (cols. 1–3) occurred between January 1991 and December 1999, and claims were made before January 2000. Proportion original equipment denotes the proportion of tires produced in the cell that were original equipment for Ford, Mercury, or Mazda vehicles. Proportion ATX denotes the proportion of tires produced in the cell that were ATX tires. To adjust for incomplete reporting in the NHTSA data set, missing values were imputed by assigning values from other observations with complete data, conditional on available data. Ten imputed data sets were generated. Reported estimates were obtained by averaging the estimates derived from each imputed data set. Standard errors were calculated by taking the square root of the sum of the average sampling variance across data sets and the variance of the estimates across the 10 imputed data sets (to account for variability due to imputation). Other summary statistics reported for cols. 4–6 are the average of the estimates across the imputed data sets. The symbol λ represents the scaling parameter for the conditional variance in the negative binomial model. The conditional variance of the negative binomial model equals the conditional variance of the Poisson model when λ = 0.
* Contains imputations for missing values.
† We can reject the null hypothesis that λ = 0 at the .05 level with the likelihood ratio test.

maximum likelihood estimates of negative binomial regression models corresponding to those in table 3. Both the claims and complaints data exhibit overdispersion. This causes the standard errors on many of the coefficients to roughly double in the negative binomial model compared to a conventional Poisson model. The parameter estimates are fairly similar in the negative binomial regressions, however, as one would expect because both models are consistent if equation (1) holds.

TABLE 5
Poisson Regression Models for Number of Defective P235/75R15 Tires by Tire Model (ATX or Wilderness), Plant, Production Year, and Calendar Year; Pooled Sample ($N=164$)

Explanatory Variable	Dependent Variable: Claims			Dependent Variable: NHTSA Complaints*		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−13.36	−25.57	−21.09	−9.38	−13.61	−11.35
	(3.11)	(2.20)	(2.22)	(2.52)	(2.39)	(2.01)
Log production	1.15	1.72	1.44	.79	.94	.80
	(.23)	(.15)	(.15)	(.19)	(.17)	(.14)
ATX (1=yes)			.57			.60
			(.27)			(.29)
Proportion original equipment			−1.64			−1.48
			(.47)			(.51)
Age		2.07	2.12		1.17	1.22
		(.18)	(.18)		(.16)	(.15)
Age^2		−.20	−.21		−.11	−.11
		(.02)	(.02)		(.02)	(.02)
Decatur (1=yes)	−.01	1.63	.87	−.36	.29	−.26
	(.47)	(.31)	(.36)	(.45)	(.39)	(.39)
Labor dispute period (1=yes)	−.02	.32	.12	.13	.34	.17
	(.39)	(.21)	(.20)	(.31)	(.25)	(.22)
Decatur × dispute period	2.32	1.26	1.25	2.27	1.82	1.81
	(.58)	(.32)	(.30)	(.52)	(.41)	(.37)
Mean dependent variable	9.96	9.96	9.96	4.61	4.61	4.61
	[25.62]	[25.62]	[25.62]	[8.68]	[8.68]	[8.68]
Pseudo R^2	.42	.81	.82	.40	.66	.67
Log likelihood	−1,483.96	−490.20	−461.93	−591.45	−339.36	−323.08

Note.—Robust standard errors are in parentheses. Standard deviations of the dependent variables are in brackets. The dependent variable corresponds to incidents per year of production, plant of production, tire model, and calendar year of failure. Cells corresponding to fewer than 200 units of production were dropped. Incidents in the NHTSA data set (cols. 4–6) correspond to reporting periods prior to August 2000, for failures occurring between January 1991 and December 1999. Incidents in the Firestone claims data set (cols. 1–3) occurred between January 1991 and December 1999, and claims were made before January 2000. Proportion original equipment denotes the proportion of tires produced in the cell that were original equipment for Ford, Mercury, or Mazda vehicles. To adjust for incomplete reporting in the NHTSA data set, missing values were imputed by assigning values from other observations with complete data, conditional on available data. Ten imputed data sets were generated. Reported estimates were obtained by averaging the estimates derived from each imputed data set. Standard errors were calculated by taking the square root of the sum of the average sampling variance across data sets and the variance of the estimates across the 10 imputed data sets (to account for variability due to imputation). Other summary statistics reported for cols. 4–6 are the average of the estimates across the imputed data sets.
    * Contains imputations for missing values.

In table 5 we present additional Poisson models in which the unit of observation is disaggregated into finer cells, delineated by ATX or Wilderness tires as well as year of production, plant, and calendar year of failure. Again we adjust the standard errors for overdispersion. We pool the ATX and Wilderness cells together in the sample and include a dummy variable indicating whether the cell pertains to ATX or Wilderness tires. These models provide a more precise assessment of whether ATX tires have a higher failure rate than Wilderness tires. Indeed, the results for both claims and complaints indicate a substantially higher failure rate for ATX tires, other things equal. The other

results are fairly similar to those for the more aggregate cells in tables 3 and 4.

Incidents with Fatal and Nonfatal Injuries: NHTSA Data

Table 6 presents estimates of Poisson models using the NHTSA complaints database; we provide separate estimates for the number of cases involving at least one fatal accident, number of cases involving a nonfatal injury, and number of cases without a reported injury. The unit of observation is a cell defined by plant by year by age, as in tables 3 and 4. Because we are less concerned about reporting biases in cases involving injuries or fatalities, we use the full reporting period to calculate counts in this table. We continue to limit the sample to tires that failed in 1999 or earlier, however. Results for the unallocated data, which are quite similar, are in Krueger and Mas (2002).

Interestingly, the coefficient on the Decatur–dispute period interaction is positive and statistically significant—and of roughly equal magnitude—in all the models. Likewise, the Decatur and dispute period main effects are statistically insignificant in all the models. To estimate the excess number of fatal incidents involving tires manufactured in Decatur during the labor dispute, denoted Δ, we calculated

$$\Delta = \Sigma_{ijt}[\exp{(\mathbf{x}'_{ijt}\boldsymbol{\beta} + S_j\alpha + D_i\gamma + S_j \times D_{ij}\delta)} - \exp{(\mathbf{x}'_{ijt}\boldsymbol{\beta} + S_j\alpha + D_i\gamma)}],$$

$$(2)$$

where $\mathbf{x}'_{ijt}$ is a vector of explanatory variables such as log production and proportion original equipment, S_j is a dummy variable indicating production during the dispute period (1994–96), D_i is a dummy variable indicating production in Decatur, and $S_j \times D_{ij}$ is the Decatur–dispute period interaction.[17] In our hypothetical calculation, we set the Decatur-dispute interaction to zero but otherwise keep production and the other variables the same. The results suggest that 35.2, or 53 percent, of the 67 fatal accidents linked to P235 tires were due to the excess number of defects occurring on tires manufactured in Decatur during the labor dispute. The number of fatalities is higher because fatal accidents had 1.30 victims, on average. Thus these results suggest that about 46 lives were lost because of the excessive number of defects occurring in P235 tires manufactured in the Decatur plant during the labor dispute.

Using the model in column 2, we can also predict the number of fatalities that were avoided because of the recall of all P235 Firestone

[17] Notice that eq. (2) also equals $\Sigma_{ijt}y_{ijt} - \Sigma_{ijt}\exp{(\mathbf{x}'_{ijt}\boldsymbol{\beta} + S_j\alpha + D_i\gamma)}$ because the exponential of the fitted Poisson values replicates the total count.

TABLE 6
Poisson Regression Models for Number of Incidents with Defective Tires, by Type of Accident, NHTSA Complaints Data (Full Reporting Period): Aggregate Analysis of ATX and Wilderness AT Tires ($N=135$)

	Dependent Variable							
	Accident with Fatality		Nonfatal Injuries		Noninjurious Complaints		All Complaints	
Explanatory Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	−17.33	−13.56	−17.98	−11.02	−13.55	−8.45	−13.61	−8.40
	(4.06)	(4.94)	(3.59)	(3.28)	(2.04)	(1.64)	(2.01)	(1.61)
Log production	1.05	.84	1.15	.76	1.02	.74	1.03	.75
	(.29)	(.33)	(.25)	(.22)	(.14)	(.11)	(.14)	(.11)
Proportion ATX		−.74		−1.31		−.87		−.91
		(1.25)		(1.12)		(.41)		(.40)
Proportion original equipment		−.77		−1.72		−1.58		−1.54
		(1.71)		(1.53)		(.59)		(.58)
Age	.98	1.08	.95	1.21	.89	1.11	.90	1.11
	(.30)	(.32)	(.26)	(.25)	(.14)	(.11)	(.14)	(.11)

Age^2	−.09	−.10	−.09	−.10	−.08	−.10	−.09	−.10
	(.04)	(.04)	(.04)	(.03)	(.02)	(.01)	(.02)	(.01)
Decatur	−.07	−.62	.82	−.22	.31	−.52	.35	−.48
	(1.08)	(1.20)	(.55)	(.60)	(.33)	(.28)	(.32)	(.27)
Labor dispute period	.42	.27	.17	−.13	.26	.02	.26	.02
	(.56)	(.60)	(.55)	(.54)	(.23)	(.19)	(.22)	(.18)
Decatur × dispute	2.39	2.71	1.62	2.22	1.67	2.05	1.68	2.08
	(1.15)	(1.15)	(.73)	(.70)	(.38)	(.31)	(.37)	(.30)
Mean dependent variable	.49	.49	.88	.88	9.35	9.35	10.73	10.73
	[1.21]	[1.21]	[2.08]	[2.08]	[16.57]	[16.57]	[19.39]	[19.39]
Pseudo R^2	.41	.43	.42	.48	.63	.70	.65	.73
Log likelihood	−88.26	−85.89	−135.85	−120.84	−495.21	−392.18	−534.38	−416.42

NOTE.—Robust standard errors are in parentheses. Standard deviations of the dependent variables are in brackets. All specifications correspond to NHTSA complaints data. The dependent variable corresponds to incidents per year of production, plant of production, and calendar year of failure. Incidents correspond to reporting periods prior to June 2001, for failures occurring between January 1991 and December 1999. Proportion original equipment denotes the proportion of tires produced in the cell that were original equipment for Ford, Mercury, or Mazda vehicles. Proportion ATX denotes the proportion of tires produced in the cell that were ATX tires. To adjust for incomplete reporting in the NHTSA data set, missing values were imputed by assigning values from other observations with complete data, conditional on available data. Ten imputed data sets were generated. Reported estimates were obtained by averaging the estimates derived from each imputed data set. Standard errors were calculated by taking the square root of the sum of the average sampling variance across data sets and the variance of the estimates across the 10 imputed data sets (to account for variability due to imputation). Other summary statistics reported are the average of the estimates across the imputed data sets.

tires. Specifically, we predicted the number of fatal accidents that would occur over the period 2000–2004 by

$$\Sigma_{ijq}[\exp{(\mathbf{x}_{ij}'\boldsymbol{\beta} + S_j\alpha + D_i\gamma + S \times D_{ij}\delta)} + (Aj_0 + q)\kappa + (Aj_0 + q)^2\kappa_2]$$

$$\text{for } q = 1, \ldots, 5, \tag{3}$$

where A_0 is tire age in 1999, and κ_1 and κ_2 are the coefficients on age and age squared in the Poisson model. This calculation gives an estimate that 191.4 additional fatal accidents would have occurred on the recalled P235 tires over five years.[18] With the assumption of 1.30 deaths per fatal accident, these results suggest that 249 deaths were avoided as a result of the recall.

IV. Engineering Tests

Firestone performs "advanced aging" tests on tires that are selected off the production line. These stress tests are designed to detect production defects before tires are in the field and are also required for certain tire ratings. We obtained data on 106 high-speed stress tests Firestone performed on size P235 tires and two identical tests on size P255 tires that Firestone submitted to Congress.[19] The high-speed stress test is used by tire manufacturers to obtain a Society of Automotive Engineers "S" speed rating. The test data pertain to tires produced from 1989 to 1998, although most of the data pertain to 1995–98; there are only two tests available for Decatur prior to 1995, both conducted in 1990. Three of the 108 tests either had missing variables or were unreadable and were therefore dropped from the analysis.

According to the protocols, the high-speed test is conducted by over-inflating a tire to 38 psi and running it on a lab machine at specified (accelerating) speeds for prescribed lengths of time, at 100 degrees Fahrenheit (plus or minus 5 degrees), with a load of 80 percent of the maximum load stamped on the tire sidewall. For the first five minutes, the tire is run at 50 miles per hour (mph), then the speed increases to 75 mph for the next five minutes, then to 87 mph for 10 minutes, then to 93 mph for 10 minutes; thereafter the speed increases in increments of 6 mph after each 10-minute period. The tire undergoes this test until it bursts. The most common type of failure was a tread separation. To

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[18] Of course, it is possible that the replacement tires could also contribute to fatalities. We have no way of quantifying this effect and suspect that it is small in any event.

[19] Firestone refers to these tests as "Indoor Test U1." It is possible that more than 108 test results were submitted to the congressional record, but we could obtain only 108 results from the information the committee made publicly available. Results are robust if we exclude the two tests on P255 tires.
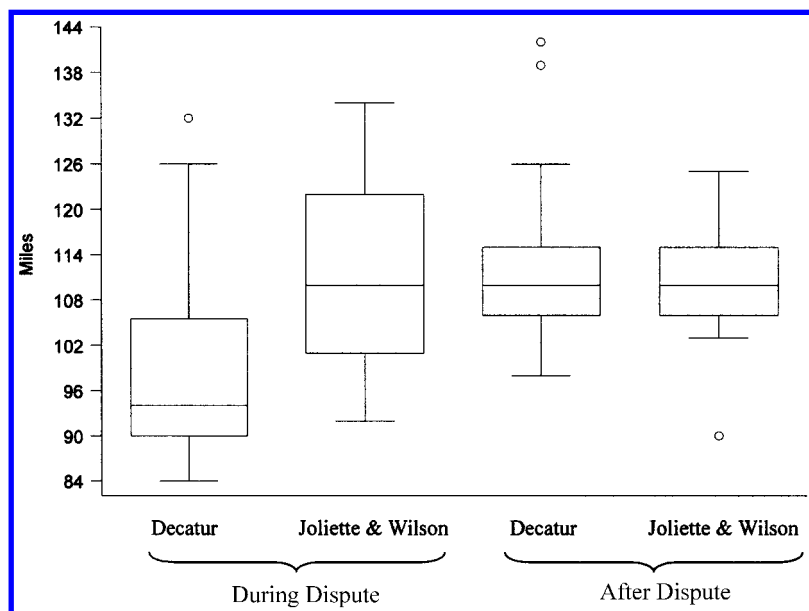
F𝜄𝜄g. 5.—High-speed stress tests: box plots of miles traveled before burst. Source: Authors' calculations from Firestone U1 test data reported to the House Committee on Commerce (U.S. House 2000). Tests in this sample were conducted in 1995–98. The bottom of each box represents the value at the twenty-fifth percentile, and the top represents the value at the seventy-fifth percentile. The middle line indicates the distance traveled before the *median* tire burst. The vertical lines (known as upper and lower adjacent hinges) extend to the first data point encountered within 1.5 times the interquartile range from the edge of the box. Observations that lie beyond the upper and lower adjacent hinges are indicated by a circle.

receive an S speed rating, the tire must exceed 112 mph for 10 minutes before breaking.

   The advantage of analyzing these test results is that they hold many factors constant, including the load, temperature, tire pressure, speed, and driving conditions. A disadvantage of this engineering test (and others) is that it is unclear whether failures caused by the extreme conditions in laboratory settings can be extrapolated to everyday, normal use; the types of conditions (e.g., driving speeds) encountered in practice are different. Nevertheless, the laboratory tests provide another check on the quality of the tires produced during the labor dispute vis-à-vis other tires.

   Figure 5 presents box plots for the high-speed test results. The outcome measure used to summarize test performance is distance traveled before the tire developed a problem, since this reflects both the amount of time the tire ran and its speed. The figure indicates that tires made in Decatur during the labor dispute had lower performance on the

high-speed stress test than tires made in Decatur after the labor dispute or tires made in Joliette or Wilson either during or after the dispute. The median tire produced in Decatur during the dispute traveled less distance before bursting than the tire ranked at the bottom twenty-fifth percentile from the Decatur plant after the dispute or the other plants either during or after the dispute. Indeed, the tire that performed at the top seventy-fifth percentile from Decatur during the dispute performed about as well as the twenty-fifth percentile tire produced at other plants at the same time. Also, tires produced in Decatur during the dispute have a positively skewed distribution, whereas the other tires are more symmetric, which tends to exaggerate the performance of Decatur tires in least-squares compared to median regression models.

Table 7 presents regression estimates in which the dependent variable is the number of miles traveled on the stress test before failing, and the key explanatory variables are a Decatur dummy, dispute period dummy, and Decatur–dispute period interaction. We also control for preproduction model tires; for example, the Wilderness tire was a preproduction tire before it was marketed in 1996. Although one could argue that the preproduction tires should be excluded because they have a different design, they do provide an indication of the skill and care of the employees who built the tires at the various plants. We vary the years covered by the sample, as well as present results in columns 4 and 5 excluding the preproduction tires. In all cases, however, the results are similar to the box plots: tires made in Decatur did not perform as well on the stress tests as tires produced in Decatur after the dispute or tires produced in the other plants. For example, in column 3, the Decatur-dispute interaction has a coefficient of -17 miles, with a t-ratio of 3.18. Interestingly, these tires all passed the standard for an S speed rating, so one could reasonably question whether the standard is set at an appropriately stringent level.

V.   Precise Timing

The NHTSA complaints data set can be used to determine the particular week in which tires that resulted in a claim were produced. Although we do not have weekly production figures, we can examine whether there was an excess number of complaints generated by tires around key dates, such as when replacement workers were hired. In addition, we can make a crude adjustment for scale by interpolating annual production figures. Because the data are noisy, we examine the month in which tires were produced instead of the week, but the weekly data suggest the same patterns.

Figure 6 displays the number of complaints concerning tires produced each month in Decatur. Figure 7 makes an attempt to scale complaints

TABLE 7
HIGH-SPEED STRESS TEST RESULTS: ORDINARY LEAST SQUARES ESTIMATES
Dependent Variable: Miles Traveled to Burst

Explanatory Variable	Means: Full Sample (1)	Full Sample (2)	1994–98 (3)	1995–98 (4)	No Preproduction Tires (5)	No Preproduction Tires, 1995–98 (6)
Constant		108.83	110.16	110.16	108.83	110.16
		(2.30)	(2.65)	(2.66)	(2.37)	(2.86)
Decatur (1=yes)	.47	2.13	1.57	1.99	−.63	−1.41
	[.50]	(3.72)	(4.18)	(4.22)	(4.37)	(5.25)
Dispute period (1=yes)	.61	4.93	3.74	4.61	4.88	5.34
	[.49]	(3.36)	(3.66)	(3.92)	(3.91)	(4.87)
Decatur × dispute period	.30	−16.85	−16.34	−17.29	−12.63	−13.64
	[.46]	(4.80)	(5.22)	(5.43)	(5.96)	(7.13)
Preproduction models	.35	−1.19	−1.43	−2.31		
	[.48]	(2.55)	(2.64)	(2.81)		
Mean dependent variable	107.28	107.28	107.48	107.07	107.28	107.49
	[12.57]	[12.57]	[12.97]	[13.08]	[12.35]	[13.37]
Observations		105	98	90	68	57
R^2		.23	.24	.25	.15	.18
F-statistic		7.40	7.31	7.00	3.90	3.82

NOTE.—Standard errors are in parentheses. Standard deviations are in brackets. Years refer to years of production.
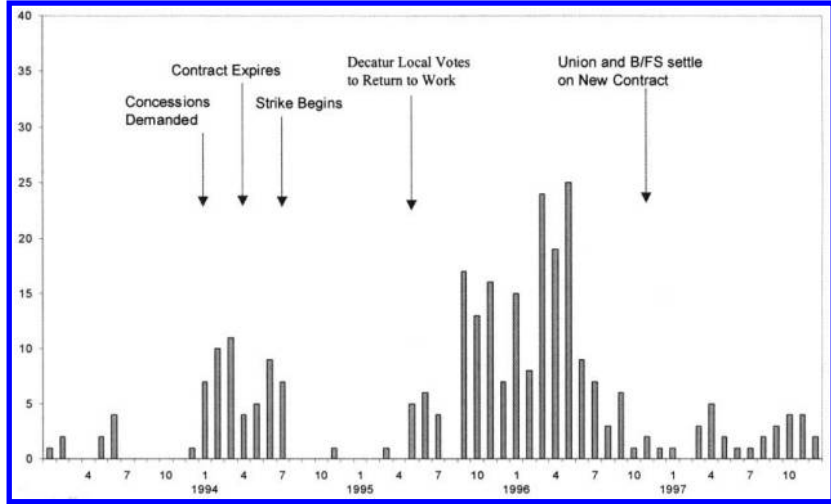
Fig. 6.—Number of complaints concerning P235 tires produced in Decatur, by month. Source: Authors' calculations based on NHTSA complaints data. Records with missing data are excluded.
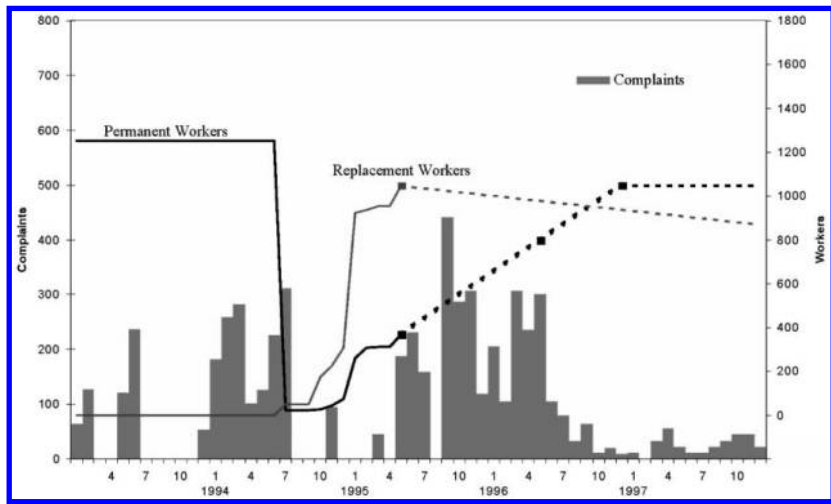
Fig. 7.—Number of permanent workers, replacement workers, and estimated complaints per million tires produced, by month (Decatur plant). Source: Authors' calculations based on NHTSA complaints data, estimated monthly production (see Krueger and Mas 2002, app.), press reports, and Firestone documents submitted to the House Committee on Commerce (U.S. House 2000). Dashed lines indicate estimates of employment; blocks indicate specific data points.

by monthly production.[20] The figure displays the number of complaints relative to estimated monthly production (in millions) as well as our best estimate of the number of replacement workers and permanent workers working in the Decatur plant each month. Interestingly, there was a spike in the number of tires that generated complaints in the first half of 1994, around the time in which concessions were demanded and the old contract expired. Tires produced early in the strike were cited in a relatively small number of complaints, even when we scale by production. Through early 1995, when a large number of replacement workers were building tires, the number of complaints remained relatively low. It was not until the end of 1995, when large numbers of replacement workers and returning strikers worked side by side, that the complaints rate reached its highest level.[21] Complaints remained high for tires made through the first half of 1996.

For figure 8 we constructed monthly production estimates for Joliette and Wilson tires combined and then subtracted their monthly complaints rate from the Decatur rate to net out any temporal companywide effects that may have existed. Figure 8 displays the difference in the complaints rate by month of production between the Decatur plant and Joliette and Wilson plants. This figure displays a pattern similar to that in figure 7.

The monthly complaints data are somewhat noisy and sparse and are possibly affected by retrospective reporting biases. One reason we have confidence that the pattern displayed in figures 6–8 is not spurious, however, is that the *claims* data by production month show a strikingly similar pattern: an excess number of complaints in the first half of 1994 and an even larger peak in the second quarter of 1996. Figure 9, for example, displays the claims rate by month for the Decatur plant minus the Joliette and Wilson plants.

These results suggest that faulty workmanship by novice replacement workers is not the sole source of problem tires. A more complicated dynamic is required to explain the timing of the production of defective tires. It appears likely to us that something about the chemistry between the replacement workers and recalled strikers, or the cumulative impact

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[20] We have annual P235 production by plant, but not monthly data. We used the annual data and other sources to estimate monthly production for the Decatur, Joliette, and Wilson plants. The procedures for estimating monthly production are described in detail in the data appendix of Krueger and Mas (2002).

[21] Roger Gates, former president of the URW local in Decatur, has argued that most workers had not come back to work until December 1996, when a new contract was settled, so there was no period of time in which a significant number of returning strikers worked with replacement workers (Ginsbach 2002). This claim, however, is at odds with press releases from the AFL-CIO, which report that of the 4,200 Firestone workers who went on strike companywide, all but 700–800 had been recalled by March 1996, and all but 150 had been recalled by October 1996 (see Parks 1996*a*, 1996*b*).

Fig. 8.—Difference in the number of complaints per million tires produced, by month (Decatur plant minus Joliette and Wilson plants). Source: Authors' calculations based on NHTSA complaints data. Records with missing data are excluded.
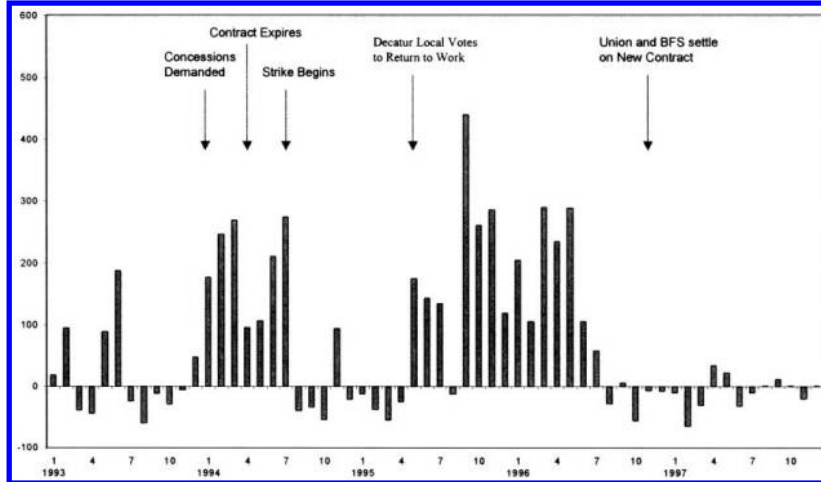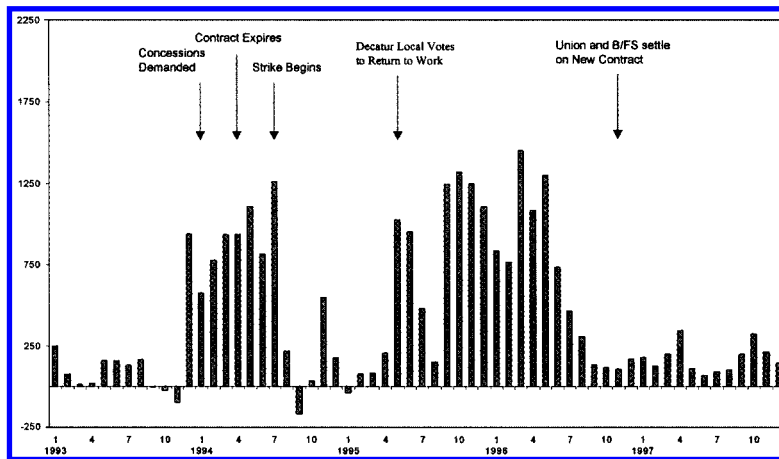

Fig. 9.—Difference in the number of claims per million tires produced, by month (Decatur plant minus Joliette and Wilson plants). Source: Authors' calculations based on Firestone claims data.

of labor strife in general, created the conditions that led to the production of many defective tires. Frictions among production workers, supervisors, and inspectors engendered by the strike and request for labor concessions might also have played a role. It is also possible that the Decatur plant became less vigilant at monitoring and scrapping defective tires in the second half of 1995, which may have contributed to the dissemination of faulty tires. The fact that many different types of defects appear to have been responsible for the tire problems is consistent with our interpretation that the human element was important.

VI.   Other Tire Models and Sizes

If labor strife and ill will among replacement workers, recalled strikers, and management contributed to the production of defective P235/75R15 tires, then one would expect these factors to have compromised the quality of other Firestone tires as well. The NHTSA database includes complaints concerning non-P235 tires covered by their EA00–023 investigation. These data are probably not as complete as the P235 sample but nonetheless provide information as to whether the number of complaints for other tires produced during the labor dispute was elevated.[22]

Table 8 presents estimates of Poisson regression models in which the dependent variable is the number of occurrences of complaints concerning non-P235 Firestone tires. The sample consists of three plants by nine production years by nine calendar year cells. As explained in the data appendix of Krueger and Mas (2002), we use a variety of sources to derive the total number of non-P235 tires produced in each plant each year. This variable is likely to be measured with error, so we constrain the coefficient to one in column 3. In view of the likely impact of measurement error, it is surprising that the unconstrained production elasticity exceeds one (see col. 1). The estimated effect for the Decatur–dispute period interaction is reduced somewhat if we constrain the coefficient on log production to one.

Most important for our purposes, in all the models the coefficient on the Decatur plant–dispute period interaction term indicates that Decatur had an elevated number of complaints involving tires produced during the labor dispute, other things equal. These results suggest that the high incidence of defective tires in the Decatur plant during the labor dispute was not unique to P235, as one would expect if labor strife was an important reason for the production of defective tires.

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[22] To avoid contaminating the sample by including P235 tires because of the allocation of missing values, when we constructed the sample we eliminated all tires that might have been P235 tires and then imputed the missing values for this subsample.

TABLE 8
POISSON REGRESSION MODEL FOR NON-P235/75R15 FIRESTONE TIRES UNDER NHTSA
EA00–023 INVESTIGATION ($N=135$)
Dependent Variable: Number of Complaints (with Imputations for Missing Values)

Explanatory Variable	Means (1)	(2)	(3)
Constant		−38.37	−14.60
		(9.21)	(.31)
Log total non-P235 tires	15.49	2.49	1*
produced	[.45]	(.58)	
Age	2.67	.35	.28
	[2.22]	(.26)	(.26)
Age²	12	−.08	−.08
	[15.47]	(.05)	(.05)
Decatur	.33	−.87	−1.12
	[.47]	(.57)	(.54)
Dispute	.33	−.48	−.19
	[.47]	(.39)	(.35)
Decatur × dispute	.11	1.98	1.34
	[.32]	(.80)	(.74)
Mean dependent variable	2.12	2.12	2.12
	[5.14]	[5.14]	[5.14]
Pseudo R^2		.33	.26
Log likelihood		−339.44	−376.79

NOTE.—Robust standard errors are in parentheses. Standard deviations of the dependent variable are in brackets. All specifications use NHTSA complaints data. The dependent variable corresponds to incidents per year of production, plant of production, and calendar year of failure. Incidents correspond to reporting periods prior to August 2000, for failures occurring between January 1991 and December 1999. To adjust for incomplete reporting in the NHTSA data set, missing values were imputed by assigning values from other observations with complete data, conditional on available data; tire size was not imputed, however. Ten imputed data sets were generated. Reported estimates were obtained by averaging the estimates derived from each imputed data set. Standard errors were calculated by taking the square root of the sum of the average sampling variance across data sets and the variance of the estimates across the 10 imputed data sets (to account for variability due to imputation). Other summary statistics reported are the average of the estimates across the imputed data sets. The specifications in col. 3 constrain the coefficient of log production to one.
  * The coefficient is constrained to one.

VII.   Conclusion

The evidence we have assembled suggesting that the labor dispute contributed to the production of many defective Firestone tires in the 1990s is circumstantial but broad and consistent; we think that the evidence pointing toward the role of labor strife is more persuasive and comprehensive than that in favor of the alternative hypotheses that have been proposed. The temporal patterns in all the data sets we have examined indicate that a higher than expected rate of problems occurred in tires produced in Decatur, the plant with the most contentious labor relations, during the plant's labor dispute. We can also rule out many other explanations—for example, the fact that high-speed stress tests conducted under uniform conditions indicated that tires produced in Decatur during the labor dispute performed less well weighs against the hypothesis that changes in regional distribution patterns or the Ford Explorer was the root cause of the elevated defect rate during the labor dispute—but we cannot be certain that some unobserved factor did not

change, causing defect rates to rise in the struck Decatur plant in the 1994–96 period, and then changed back. This would be a remarkable coincidence; no such factor has yet been identified, but it is a possibility.

Unless another factor can be found that explains the sudden rises in defects in tires produced when Bridgestone/Firestone demanded contract concessions from the union in stalled negotiations and again when replacement workers and recalled strikers worked side by side, we think that the weight of the evidence points to labor strife as being at the root of many of the defective tires.

Our results complement other findings concerning labor-management conflict. Freeman and Medoff (1984, p. 167) cite evidence suggesting that the union productivity effect in the underground bituminous coal industry varies sharply over time with the state of labor relations and management policies. Kleiner, Leonard, and Pilarski (2002) study the impact of the industrial relations climate on productivity at a plant that assembles large aircraft. The evidence they present suggests that industrial relations events had short-term effects on productivity, which dissipated in the longer term. Katz, Kochan, and Gobeille (1983) study the relationship between various plant-level measures of industrial relations and economic performance at General Motors and find strong correlations between the industrial relations climate and productivity. Additionally, they find a strong correlation between some measures of industrial relations performance and the quality of production. Interestingly, the industrial relations measure with the strongest negative correlation with production of automobiles that did not pass inspection is the negotiation time required to reach a new contract agreement.

Ironically, an internal Bridgestone document obtained by the URW reportedly stated that "while it was nice to share a good relationship [with the union], it would no longer be in the company's interest" (see Franklin 2001, p. 122).[23] The stock market valuation of Bridgestone/Firestone fell from $16.7 billion to $7.5 billion in the four months after the recall was announced, and the top management of Bridgestone/Firestone has been replaced. The company also closed the Decatur plant in December 2001 and considered abandoning the Firestone brand name. If antagonistic labor relations were responsible for many of the defects, even indirectly, this episode would serve as a useful reminder that a good relationship between labor and management can be in both the company's and the union's interests.

More speculatively, our results raise the possibility that there may be costs associated with hiring replacement workers and labor strife that

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[23] This document was obtained by the union from an anonymous source, so it is unclear how much stock to put in it.

are not internalized or anticipated by labor or management, especially in industries that affect the public safety. We estimate that more than 40 lives were lost as a result of the excessive number of problem tires produced in Decatur during the labor dispute, and that number probably would have been more than twice as high if it were not for the tire recall. If the external costs were not taken properly into account by labor and management, then public policy could possibly play a valuable role by requiring more safety inspections for products manufactured during a strike or period of labor strife.

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