THE EFFECT OF FIRM CHARACTERISTICS ON TRUCK ACCIDENTS

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ABSTRACT

This paper expands an earlier analysis of the effect of firm characteristics and safety practices on truck accident rates. The sample size has been increased from 13,000 to 75,500. Negative binomial regressions are used in preference to the Poisson technique used previously. The current analysis confirms previous results, but provides important new insights into the safety implications of being a private carrier, hauling hazardous materials, and the effect of having been in business for many years.

In an earlier paper in this journal we reported on the use of Poisson regressions to analyze the effect of truck firm characteristics, such as size, cargo carried, and compliance with safety regulations on accident rates (Moses and Savage 1992). As a result of the interest generated by the paper, the authors approached the Federal Highway Administration (FHWA) to obtain a larger database. The FHWA made available their entire motor carrier safety audit record. Consequently the number of observations in the analysis has been expanded from 13,000 firms to 75,500. Using the new dataset we concluded that the Poisson regression was not appropriate because conditional variances of the dependent variable exceeded conditional means. Therefore negative binomial techniques have been adopted in the present paper. This paper indicates where the new analysis confirms previous findings, and describes new insights that were revealed by the larger dataset.

1. DATA

The data for the investigation are derived from the initial "Safety Review" (SR) audits of U.S. interstate motor carriers conducted by inspectors from the FHWA. In the course of these audits, mandated by the 1984 Motor Carrier Safety Act, data are collected on firms' physical characteristics, goods carried, accident record, and compliance with federal motor carrier safety regulations. The data are kept in the FHWA's Motor Carrier Management Information System (MCMIS). We obtained the entire database for 92,529 firms that were audited between October 1986 and November 1991. Canadian and Mexican firms, bus companies, and firms that did not operate any vehicles were removed from the dataset, as were firms for which there were obvious data entry errors. As a result we had a useable dataset of 75,577 firms.

The most radical change from our previous analysis is the measure of accidents. In the earlier paper the measures used were the total accident experience of firms in the previous 365 days, and the total number of fatalities and injuries in these accidents. The FHWA ceased collecting these data in audits conducted after November 1, 1990, and concentrated on a measure called "reportable accidents". They are defined as accidents that involve a fatality, an injury, or more than $4,400 in property damage. A correlation was carried out between reportable accidents, total accidents and fatalities and injuries, using inspections prior to November 1, 1990. We found a high level of relationship. The correlation between reportable and total accidents was 0.82, while that between reportable accidents and fatalities and injuries was 0.86. Analyses based on reportable accidents exclude a large number of minor damage-only accidents. Therefore the results discussed in this paper should most properly be compared with the results from the fatalities and total injuries measure in the earlier paper.

2. ANALYTICAL TECHNIQUE

The Poisson regression technique was employed in the earlier paper. This technique has been found to be very useful when dealing with count variables, such as the number of accidents in a given time period. However, the Poisson distribution does involve the assumption that for a given set of explanatory variables, the mean of the dependent variable (i.e., the number of accidents) is equal to its variance. The implication for cross-sectional data is that the distribution of the annual accidents of similar firms should follow a Poisson distribution. In reality, the distribution of accidents may be more dispersed because even among ostensively similar firms there may be "safe" firms and "not-so-safe" firms. If the factors that distinguish safe from not-so-safe operation are not totally quantified by explanatory variables then the assumptions of the Poisson distribution are not met.

An example of this problem can be found in the literature on automobile accidents. Dionne and Vanasse (1992), and other authors cited in that paper, have found that drivers of similar age, sex, vehicle use and geographic location, have inherent accident probabilities that differ considerably. To overcome the problem of heterogeneous observations, the negative binomial family of distributions was adopted in preference to the Poisson. The negative binomial distributions allow conditional variances to be larger than conditional means, and introduce a random, unexplained, factor which permits some heterogeneity across observations. Negative binomial distributions assume that the unexplained portion of accidents follows a gamma distribution.

However, one should not assume that the Poisson distribution is never appropriate to the analysis of accidents. There are standard statistical tests available which analyze the dispersion of the error terms in a negative binomial to determine whether the conditional variances are statistically significantly larger than the conditional means. Dionne, Gagné and Vanasse (1992) found by using such tests that Canadian aviation accident data did conform to the assumptions of the Poisson distribution.

It seems reasonable to assume that truck accidents are more like automobile than aviation accidents and thus a negative binomial distribution should be used. Negative binomial models can take many different forms depending on the precise relationship assumed between conditional variances and conditional means. In the present analysis we used the so-called "Negbin II" model which assumes that:

$$\mathrm{Var}(y_i) = E(y_i)\ (\ 1 + \alpha\ E(y_i)\ ).$$

Where y is the dependent variable, Var(·) is the conditional variance and E(·) the conditional mean for a group of similar firms in group i. The statistical package we used (LIMDEP) reports the estimated α coefficient which should be statistically significantly different from zero if the errors are over-dispersed and thus the Poisson assumption would be inappropriate. For our data $\alpha = 0.72$ with a standard error of 0.02. The Poisson distribution is soundly rejected with a t statistic of 42. With our estimated value of $\alpha = 0.72$ there is the implication that firms whose expected number of accidents is one per year, have a variance 1.7 times the mean. Firms that expect ten accidents a year, have a variance that is eight times the mean. Further evidence that the negative binomial model is superior to the Poisson is given by a likelihood ratio test. The log-likelihood of our equation estimated using the "Negbin II" model was -28,763 compared with -34,250 for the same equation estimated with the Poisson technique, an extremely significant change.

3. USE OF EXPOSURE MEASURES

The Poisson and negative binomial regressions have a count of accidents as the dependent variable and measures of exposure on the right hand side. In our earlier analysis our exposure variable was the natural logarithm of fleet miles, which is to say the estimated equation was of the form:

$$\text{Count of Accidents} = e^{(ß\ln(\text{Miles}) + \text{other characteristics})}.$$

Some commentators have asserted that this formulation is too restrictive, since it implies that:

$$\text{Count of Accidents} = \text{Miles}^{B} \text{ x other characteristics.}$$

This formulation means that the elasticity of accidents with respect to exposure is a constant ß, and that:

$$\text{Accident Rate} = \text{Miles}^{ß-1} \text{ x other characteristics.}$$

The great advantage of this form is that it permits a clear and unambiguous statistical test of whether accident rates are invariant with firm size (ß = 1), or else either increase with firm size (ß > 1) or decline with firm size (ß < 1). The disadvantage is that there is an assumption of constant elasticity between accidents and miles. This implies, among other things, that the relationship between accident rate and firm size can only slope in one direction and cannot assume a `U' shape. The latter would permit economies of size with respect to accidents to accrue for small and medium size firms and diseconomies of size for larger firms.

The use of miles, rather than the logarithm of miles, as an explanatory variable does permit such a `U' shape because it implies a variable elasticity between accidents and miles with a value of ß multiplied by the number of fleet miles. A positive ß means that this elasticity must exceed 1 at some level of miles and allows diseconomies of size with respect to accidents for firms over a certain size. It is an empirical issue as to whether the turning point is within the range of miles that comprise the dataset. A drawback of this formulation is that it does not permit the null hypothesis that accident rates are invariant with firm size to be tested, which one might feel is an important issue that should be investigated.

Resolution of the this problem can only be made by observing which form best explains the data. In table 1 we show accident rates of each size decile defined by annual fleet miles. We have split firms into three types to correspond to significant differences in accident experience revealed by the analysis: (1) for-hire general freight firms; (2) for-hire specialized commodity firms; and (3) private carriers. Private carriers are those trucking firms which are owned by manufacturing or service companies and primarily carry the goods of their parent organization. We have also split the top decile into two, treating separating the 72 firms that are extremely large and operate in the range of 50 to 700 million miles a year. This was done because test regressions using miles as the measure of exposure implied that the decline in accident rates might bottom out and start increasing at about 150 million miles a year. Support for this turning-up in accident rates could be found among the specialized for-hire carriers. The eleven very large specialized for-hire carriers have a 30% higher accident rate than the 2,800 other firms in the tenth decile. However this is probably explained by the fact that the eleven large firms are primarily household goods carriers who may have more reportable accidents because of the nature of their cargo. Over 60% of the firms in the dataset are private carriers. For these firms accident rate falls with firm size, and there is no evidence that it falls at a diminishing rate.

Use of the logarithm of miles as the exposure variable was continued for two reasons. First, it allows a test of an important null hypothesis that accident rates are invariant with respect to firm size. Second, the estimated equation using the logarithm of miles fitted the data well. We did experiment with an equation that would permit a `U' shaped relationship by using both the logarithm of miles and the logarithm of miles squared. However, the results were unsatisfactory. There was no improvement in log-likelihood compared to the equation that only had the logarithm of miles. In addition, the estimated coefficients suggested an unreasonably swift and large fall in accident rates for smaller carriers. The accident rate of decile 10A was predicted to be only 10% of that in decile 1. In contrast the formulation with the logarithm of miles predicts that the accident rate of decile 10A is about a third of that of decile 1, a more reasonable result. The equation with the squared term also predicts a very marked increase in accident rates for the very largest firms; the accident rate of decile 10B was predicted to be three times that of decile 10A. Reference to table 1 suggests that such an increase is not reflected in reality.

4. EXPLANATORY VARIABLES EMPLOYED

In addition to the logarithm of fleet miles, we have a number of explanatory variables that represent characteristics of the firms and the safety management practices adopted. They are the same as in the earlier paper except that two dummy variables have been added. One is for private carriers, the other for firms that haul hazardous materials. Thus, there are five variables that represent firm characteristics. The first is the proportion of drivers employed on trips over 100 miles, which is a measure of the mix of short distance and long distance operations by the firm. The second is a dummy variable that indicates whether the firm is a private carrier rather than a for-hire carrier. The final three dummy variables indicate the type of goods hauled: general freight; agricultural goods defined as forest products, livestock, fresh produce, and grain, feed and hay; and hazardous materials. The latter category includes all carriers that transport any quantity of any cargo defined as "hazardous" by the government.

The safety practice dummy variables are obtained from the standard list of 57 questions asked of all carriers during their safety audit. The inspector marks a "yes" or "no" answer to each question, but can append comments and supporting documentation. The inspectors ask 13 general questions. The following is a sample question in this category: "does the individual in charge of safety have authority to terminate drivers?" There is then 1 question on whether the firm has been certified by the government as having a minimum level of financial responsibility; 5 on reporting of accidents ("can the carrier explain the definition of a reportable accident?"); 13 on driver qualifications ("can the carrier list the documents required to be in a driver qualification file?"); 5 on driving ("does the carrier have a policy for monitoring speed?"); 8 on maintenance ("can the carrier produce the prior three months inspection reports on a vehicle selected at random?"); and 12 on hours of service ("can the carrier produce the prior 6 months records of duty status for a driver selected at random?").

A priori, one would expect that there would be considerable collinearity between the answers to the questions, and that techniques such as factor analysis would have to be deployed. In fact, much to our surprise, of the 1596 possible correlation coefficients only 21 (1.3%) are over 0.5. Only 7 are in excess of 0.7. All of the correlations over 0.5 occur between questions on the same section of the audit. In the few cases that involved high collinearity, variables were combined. Details of these combinations are contained in the earlier paper. The remaining audit variables were entered directly into the regressions. Consequently, performance on audits is represented by 45 dummy variables. All questions are worded so that a "no" implies negative safety behavior. The data are coded such that a no equals 1 and a yes equals 0.

5. REGRESSION RESULTS

The coefficients of the estimated negative binomial equation are shown in table 2. This section contains brief comments that highlight where the results confirm those of the earlier paper, and where new insights have been gained.

5.1 Effect of Firm Characteristics on Accident Rates

As in our original analysis we find that accident rates decline with firm size. The coefficient of 0.80 should be compared with 0.86 found in our original analysis for fatalities and serious injuries. As discussed above, this coefficient implies that firms that operate ½ million miles a year, which is to say firms in the ninth decile, have an accident rate about half of that of the smallest firms. The very largest firms have an accident rate about a third of the smallest firms.

The analysis carried out with the new dataset provides additional insight into the safety performance of firms involved in general freight operations. In the earlier paper we found that these firms had a higher rate of total accidents than firms that specialize in particular commodities. When we restrict ourselves to the more serious reportable accidents we still find that general freight firms have a 10% higher rate. The earlier paper established that the increased accident rate was associated with the very small and the very large general freight firms. Reference to table 1 suggests that there continues to be a safety problem associated with the 900 for-hire general freight firms who operate less than 73,000 miles a year. However, there is no longer a difference in accident rates between general freight and specialized firms in the largest two deciles. This finding is consistent with the hypothesis advanced in the earlier paper; namely that most of the total accidents of the large, predominant less-than-truckload, general freight firms are minor in nature and incurred in the urban pick-up and delivery operations that characterize this business. These accidents are not included in the definition of a "reportable" accident.

New insights are gained by the inclusion of dummy variables for hazardous materials haulage and private carrier status. Accident rates of private carriers appear to be about 20% lower than those of comparable for-hire carriers. It may be that these firms have strong incentives for safe operation since it is the company's own cargo that would be damaged in an accident. Private Carriers also have the advantage of relatively repetitious operations, which means that drivers are more familiar with specific routes and local hazards.

Carriers of hazardous materials have accident rates that are 22% higher than the rates of carriers that do not transport these goods. In a separate analysis of these carriers (Moses and Savage 1993) it was found that haulers of hazardous materials have higher accident rates whether they specialize in carrying these materials, or do so as part of a general freight business. However, firms that carry hazardous materials as part of a general freight business have worse accidents than firms which specialize in particular hazardous commodities. More detailed analysis revealed that packaged gases and liquids in tank-trailers are the most accident prone commodities (Moses and Savage 1993). Industry contacts have suggested that poor packaging standards for gases, and the instability of partially filled tank-trailers are the probable explanations.

The current finding on the long distance operation variable is supportive of the earlier analysis. In the earlier paper we found that long distance firms have a 65% lower level of total accidents but only a 10% lower incidence of fatalities and injuries. The implication is that congested urban areas have the largest number of accidents of all kinds, but most of the accidents are minor in nature. This implies that the rate of serious injuries and deaths on short and long distance operations is relatively similar. The present analysis reveals no statistical difference in reportable, which is to say serious, accident rates between firms involved in short as against long distance operations.

In the earlier paper we ran a regression on the subset of firms who were incorporated with a variable representing the logarithm of the number of years since incorporation. We found the counter-intuitive result that older firms had a higher accident rate than newly established firms. We repeated this analysis on the 73% of the firms in new dataset who are incorporated, and found the coefficient on the logarithm of firm age is -0.002 with a statistically insignificant t-statistic of 0.30. (The full regression results are not included for the sake of space, and because the inclusion of this variable does not have a noticeable effect on other coefficients.) Thus we now find that firm age does not influence accident rates.

5.2 The Effect of Safety Practices on Accident Rates

In general, the current results confirm those of the earlier analysis. The most important indicators of safety performance is the filing of accident reports with the government and disciplining drivers involved in "preventable" accidents. The highly significant coefficient on the question that deals with the reporting of accidents suggests that the 11% of firms who are deficient in reporting accidents have a worse accident rate even on the records of accidents found by the inspector during the audit! The magnitude of this effect is large. Firms that are deficient have an accident rate that is nine times higher than that of firms who do report. Clearly the safest trucking firms are those who are concerned about accidents and who take steps to investigate them to determine if disciplinary or educational action is required for the drivers involved.

There is also evidence that compliance with hours-of-service regulations is related to accident performance. These are the federal rules that specify the maximum time that a driver can be on duty and the minimum amount of rest between duties. The 30% of firms that are unfamiliar with the drivers' hours- of-service rules, and do not keep records of duty status of individual drivers have accident rates 30% above those of firms who do comply. These results give some indirect support to the concept that driver fatigue is a major cause of truck accidents.

As in the earlier paper, a startling finding is that many of the safety practices investigated by federal inspectors have little bearing on the safety performance of the firm. This is especially true of those safety practices that deal with driver-hiring qualifications and vehicle maintenance. As analysts we were very concerned that sixteen of the 47 safety practice dummy variables have statistically significant counterintuitive signs, meaning that "better" safety practices give rise to higher accident rates. These safety practices include obtaining outside references on drivers applying for employment, taking disciplinary action against drivers who violate hours-of-service rules, and routinely monitoring speed. It would be difficult to argue convincingly that safety policies such as these actually cause more accidents. In the earlier paper we commented that some firms may not have the actual safety policies in place but arranged their paperwork so as to convince the inspector otherwise. We would also observe that 11 of 16 questions with significant counter-intuitive signs are "failed" by 40-60% of all trucking firms, implying that these safety practices are far from universal in the industry. With only about half of the firms adopting these policies it is much more plausible that some perverse relationships may be found.

6. SUMMARY OF FINDINGS

Our findings can be separated into two groups. The first deals with those characteristics of firms that appear to be reliable predictors of accident risk. We find that: accident rates decline with firm size but not with firm age; the accident rates of private carriers are 20% lower than those of for-hire carriers; and hazardous materials and/or general freight carriers have higher accident rates.

The second group of findings deals with those safety practices, investigated in federal safety audits that are strongly related to accident experience. The keeping of records on accidents, and using this data to take disciplinary against or educational action for the drivers involved, appears to be a safety practice that is effective in reducing accident rates. Such actions may be a clear signal from management to drivers that the company takes accidents very seriously. There also appears to be a strong link between compliance with hours-of-service rules and accident rates. Firms that monitor and keep records of hour-of-service of drivers and use this information in dispatching have lower accident rates. When compared with the poor showing of questions on maintenance procedures, these findings are consistent with the well-documented fact that the vast majority of truck accidents are caused by driver error rather than mechanical failures.

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TABLE 1: ACCIDENT RATE BY FIRM SIZE DECILES

Decile	Miles Range (thousands)	Reportable Accidents per Million Miles		
		For-Hire General Freight	For-Hire Specialized	Private Carrier
1	5-20	3.66	1.89	0.97
2	20-35	0.95	1.42	1.16
3	35-50	1.11	1.03	0.87
4	50-73	1.54	1.02	0.83
5	73-100	1.05	0.83	0.75
6	100-140	1.05	0.76	0.78
7	140-210	1.04	0.92	0.64
8	210-370	0.79	0.78	0.63
9	370-850	0.70	0.66	0.60
10A	850-50000	0.68	0.63	0.49
10B	50000+	0.69	0.81	0.16

TABLE 2: REGRESSION OF FIRM CHARACTERISTICS AND COMPLIANCE WITH SAFETY REGULATIONS ON REPORTABLE ACCIDENTS

Observations	75,577
Log-Likelihood	-28,763
Log-likelihood (log of miles and a constant)	-34,223
α (Over-dispersion parameter with t-statistic)	0.721 (41.88)
Explanatory variables (with t statistics in parentheses)	
Constant	-11.764 (114.47)
Log of Total Fleet Miles+	0.801 (29.27)
Percent of Drivers Employed on Trips over 100 Miles	0.015 (0.55)
Dummy Variable - Private Carrier	-0.243 (10.13)
Dummy Variable - General Freight Hauled	0.090 (3.80)
Dummy Variable - Agricultural Goods Hauled	-0.043 (1.89)
Dummy Variable - Hazardous Materials Hauled	0.196 (8.58)
Dummy Variables - Safety Audit Questions	
Section 387 - Financial Responsibility	
Has minimum level of financial responsibility?	-0.164 (6.17)
Section 390 - General Questions	
Has a copy of federal regulations?	0.026 (0.71)
Has a copy of hazardous materials rules?	-0.241 (5.57)
Is somebody familiar with the federal regulations?	0.208 (4.82)
Is there a director of safety?	-0.105 (2.86)
Safety director hires / fires drivers?	-0.081 (2.64)
Somebody responsible for compliance with hazardous materials rules?	-0.073 (1.32)
Is there a driver safety program?	0.031 (1.14)
Is there safety incentive program?	-0.128 (5.02)

Is familiar with fines/penalties?	-0.066 (2.08)
Does carrier review its safety compliance regularly?	-0.035 (1.26)
Have any employees attended outside safety seminars in past two years?	-0.093 (3.54)
Is carrier profitable?	0.021 (0.48)
Section 391 - Qualifications of Drivers	
Does carrier have written hiring policies?	-0.109 (4.01)
Are oral interviews conducted?	0.034 (0.78)
Are hiring standards stricter than federal requirements?	-0.004 (0.17)
Medical regulations followed?	-0.046 (1.51)
Does carrier have system to keep drivers' licenses current?	0.057 (1.73)
Hiring documentation in order?	-0.108 (3.45)
Does carrier use outside sources to verify drivers' background?	-0.106 (4.43)
Section 392 - Driving of Motor Vehicles	
Does carrier have established rules concerning drugs and alcohol?	-0.102 (1.50)
Has a policy on passengers?	-0.025 (0.40)
Drivers instructed on load securement?	0.106 (1.27)
Has a policy on monitoring speed?	-0.057 (2.37)
Procedure to ensure long trips not timed to break speed limit?	-0.032 (1.20)
Section 394 - Notification and Reporting of Accidents	
Knowledge of Accident Definition?	-0.518 (16.15)
Files accident reports (MCS 50(T))?	2.315 (79.06)
Does carrier determine preventability of accidents?	0.066 (1.50)
Action taken against drivers involved in preventable accidents?	0.331 (7.86)
Section 395 - Hours of Service (HOS) of Drivers	
Can carrier explain rules?	0.163 (4.34)
Drivers required to provide recaps of duty status?	-0.131 (5.94)
Monitors HOS of trip lease drivers?	-0.084 (1.46)

Dispatchers aware of HOS?	0.019 (0.66)
Drivers required to phone in daily?	0.004 (0.11)
Are drivers' records of duty status independently checked?	-0.068 (2.72)
Records kept of duty status?	0.099 (3.23)
Monitors HOS of local drivers?	0.006 (0.14)
Has system to monitor drivers HOS?	0.042 (1.54)
Disciplinary action taken against drivers who violate HOS rules?	-0.102 (3.79)
Section 396 - Inspection, Repair and Maintenance	
Reviews maintenance records of leased equipment?	-0.170 (5.12)
Complies with inspection rules?	0.000 (0.00)
Drivers perform pretrip inspection?	0.033 (0.60)
Can produce prior 3 months inspection records on randomly chosen vehicle?	-0.008 (0.26)
Are all vehicles inspected at home on a periodic basis?	0.015 (0.36)
Maintenance records kept?	0.015 (0.55)

[+] The coefficient on miles is compared against 1 so as determine the effect of fleet miles on accident rate.